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REVIEWS

Managing Marine Biodiversity: The Rising Diversity and Prevalence of Marine Conservation Translocations

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Abstract

Translocations, the human-mediated movement and free-release of living organisms, are increasingly used as conservation tools in imperiled terrestrial ecosystems. Marine ecosystems, too, are increasingly threatened, and marine restoration efforts are escalating. But the methods and motivations for marine restoration are varied, so the extent to which they involve conservation-motivated translocations is unclear. Because translocations involve considerable risks, building on previous experience to establish and implement best practice guidelines for policy application is imperative. We conducted a global literature review to determine what marine conservation translocation experience exists. Our review indicates marine conservation translocations are widespread and increasingly common. Reinforcements and reintroductions predominate, but precedent for assisted colonizations and ecological replacements also exists. In 39 years, 487 translocation projects were conducted to conserve over 242 marine species or their ecosystems. Most projects involved coastal invertebrates (44%) or plants (30%). Few species were of conservation concern according to the IUCN Red List, likely reflecting the leading objective for most (60%) marine conservation translocations, which was ecosystem rather than species recovery. With currently no standard metrics for evaluating translocation success or ecosystem function, we recommend future projects follow the relevant IUCN guidelines and identify specific targets to measure the efficacy of translocations.

Introduction

For decades, the world's oceans have borne the impact of widespread overfishing (Hilborn *et al.* 2003), carbon dioxide pollution (Hoegh-Guldberg & Bruno 2010), shoreline development (Crain *et al.* 2009), and habitat degradation (Lotze *et al.* 2006). Often synergistic, these threats have substantially degraded marine biodiversity, with greater impacts predicted for the future (Sala & Knowlton 2006, Cheung *et al.* 2009). More than 130 local to global marine extinctions have been documented (Dulvy *et al.* 2003), and although only a fraction of marine taxa have been assessed, 1,206 marine species are currently classified as Critically Endangered, Endangered or Vulnerable on the IUCN Red List (Webb & Mindel 2015). These include 39% of assessed marine mammals, 33% of assessed Anthozoans (corals, sea anemones, sea fans, and sea pens), 20% of assessed marine birds, 19% of assessed mangroves, and 17% of assessed seagrasses (Webb & Mindel 2015). Additional taxa are expected to become threatened in the near future as habitat suitability models predict that climate change will cause an overall perturbation of 60% of global marine biodiversity by 2050 (Cheung *et al.* 2009).

Recommendations to address these threats include: establishment of more marine protected areas (Briggs 2011), closure of ports and markets to illegal, unreported, and unregulated fisheries (Global Ocean Commission 2014), and immediate reduction in carbon dioxide emissions (Rogers & Laffoley 2011). However, global implementation of these measures might be too slow for species facing imminent extinction; immediate conservation interventions are likely to be required to ensure their survival in the interim.

One such intervention is a conservation translocation, which is a translocation "intended to yield a measurable conservation benefit at the levels of a population, species or ecosystem, and not only provide benefit to translocated individuals" (IUCN 2013). Conservation translocations are further classified by their primary objective, be it the restoration of declining or extirpated populations (*population restoration*), or the introduction of species to areas outside their indigenous range (*conservation introduction*). Population restorations can occur where the species is still present (*reinforcement*) or extirpated (*reintroduction*). Conservation introductions are conducted when few alternatives remain to prevent the extinction of the focal species (*assisted colonization*) or to replace the ecological function of a different, extinct species (*ecological replacement*; IUCN 2013).

Conservation translocations have seen increasing use (Seddon *et al.* 2007, 2014), but highly publicized examples typically involve terrestrial species, such as gray wolf (*Canis lupus*) reintroductions in the United States (Ripple & Beschta 2012) and brown kiwi (*Apteryx mantelli*) reinforcements in New Zealand (Robertson *et al.* 2011). Marine species are scarcely mentioned in conservation translocation literature reviews (e.g., Griffith *et al.* 1989; Wolf *et al.* 1996, 1998; Fischer & Lindenmayer 2000; Seddon *et al.* 2007). In contrast, there is a substantial body of literature pertaining to commercial stocking of marine species (Born *et al.* 2004; Bell *et al.* 2006) and coastal restoration/mitigation (e.g., Thayer & Kentula 2005; Elliott *et al.* 2007). Both activities involve translocations, but often these are motivated by catch augmentation, prevention of coastal erosion, protection against storm surges, or restoration of historical landscapes, rather than by concerns over the conservation status of the focal species or ecosystem. It is therefore unclear what marine experience with conservation translocations exists.

Conservation translocations involve a variety of risks related to disease, genetics, population dynamics, species interactions, and welfare, so building on previous experience is important (Harrington *et al.* 2013; Moehrenschlager *et al.* 2013). Lessons learned in terrestrial settings might not reliably inform marine conservation translocations, given the inherent physical differences between terrestrial and marine environments and the diversity of marine taxa for which there are no comparable terrestrial counterparts. Understanding which marine taxa are being translocated, where, why, how, and by whom is therefore critical to developing, disseminating and implementing appropriate policy guidelines and associated legislation. We consequently conducted a global review of the indexed scientific literature, summarizing temporal, geographic, and taxonomic patterns in marine conservation translocations, as well as the objectives, habitats, and organizations involved. We refrained from assessing the success of marine conservation translocations because wide variation in translocation effort, evaluation, success criteria, and reporting make general conclusions about the efficacy of conservation translocations difficult at best (Fischer & Lindenmayer 2000; Moehrenschlager *et al.* 2013; Robert *et al.* 2015).

To our knowledge, we present the first global review of marine conservation translocations. The information compiled emphasizes the need for national policy to parameterize, advise, and optimize the growing practice of translocating marine species for conservation purposes.

Methods

We conducted a comprehensive search for marine translocation publications (gray and primary) within all literature indexed between January 1883 and June 2013 within two major scientific databases: Thomson Reuters Web of Science and Academic Search Complete. The latter indexes a large quantity of gray literature in addition to scientific publications. Although our objectives did not suit a traditional systematic review sensu Pullin & Stewart (2006), we applied the same basic methodology to ensure that our methods are repeatable and our results can be compared to future literature reviews on this topic. Our search terms (Figure 1) were designed to be inclusive, maximizing sensitivity at the expense of specificity to avoid missing relevant publications (Pullin & Stewart 2006). After importing search results into EndNote X6, we manually screened them by title, abstract, and/or full text to determine which publications were truly relevant, that is, which described the intentional translocation of marine species for conservation purposes. Any species dependent on marine habitat or resources anytime within its life-cycle was included. Hence, sea birds and anadromous fish were included, regardless of their release environment. If the purpose of translocation was ambiguous, we conservatively excluded the publication. For example, species with a history of exploitation may be translocated to address extinction/extirpation risk, ecosystem recovery goals, and/or future economic gains. If the latter purpose seemed to predominate, we removed the publication from further analysis, but acknowledge that some subjectivity was unavoidable in our categorization.

We extracted the following data from all relevant publications: author(s), year of publication, type of conservation translocation, species translocated, location

(marine OR ocean OR sea OR gulf OR tidal OR intertidal OR coast OR shore OR reef OR anadromous OR diadromous OR catadromous OR oceanodromous)

AND (restor* OR restock* OR *stocking OR *stocked OR *seeding OR re-seed* OR reseed* OR transloc* OR reintroduc* OR re-introduc* OR augment* OR reinforce* OR re-inforce* OR reenforce* OR re-enforce* OR "captive-bred" OR "captive breeding" OR "assisted migration" OR "conservation introduction" OR "assisted colonization" OR "assisted colonisation" OR "ecological replacement" OR "ecological engineering")

AND (release* OR conserv* OR sustain* OR yield* OR recover*)

Figure 1 Search terms used to retrieve published literature from two online databases (Web of Science and Academic Search Complete).

of release, organization(s) responsible, and terms used by authors to describe what we deemed to be reintroductions, reinforcements, assisted colonizations, or ecological replacements, according to the intention and location of each release. Extracting these data in most cases involved reading the full text, especially introductions and methods. In cases where we had no access to the full text, but could unambiguously tell from the abstract that the article pertained to a conservation translocation, available data were included and missing data scored as ‘unknown’. Because conservation translocations are intended to benefit species and/or ecosystems, we also classified each publication according to its “conservation target”—that is, was the translocation primarily targeted at recovery of the focal species, or at restoring ecosystem function in the release area? We used the IUCN Red List of Threatened Species (IUCN 2014) to obtain conservation status and habitat classifications for all translocated species. For species not yet assessed by the IUCN Red List, we collected habitat information from reputable online databases such as FishBase (Froese & Pauly 2014) and the Marine Species Identification Portal (2014).

Because multiple publications might pertain to the same translocation effort, we grouped translocations into projects, with each unique combination of species and release location considered a separate project. Species’ inferred dispersal ability helped delineate “unique” locations. In the few instances where the ability of individuals to move independently between release sites was uncertain, we conservatively grouped release efforts under one project.

To document temporal trends in conservation translocation activities, we relied on publication dates rather than release dates, because the literature often lacked relevant details. Although there is inevitably a lag between a translocation and any associated publication, we believe publication dates suffice for identifying major temporal patterns. We examined the number of conservation translocation publications released per year and the annual number of unique species represented in these publications. To assess whether observed temporal trends merely reflect a general increase in ecological publications, we also looked at the number of marine translocation publications relative to all ecology publications indexed annually in Web of Science.

Results

Our database searches yielded 12,501 unique references, but the majority were eliminated on the basis of clearly irrelevant titles ($n = 6{,}639$) or abstracts ($n = 3{,}507$). Additionally, 385 publications with ambiguous titles and abstracts were not available for full text analysis and were therefore excluded. Of the remaining 1,970 references, 427 described conservation-motivated translocations, and within these a total of 487 distinguishable projects were identified.

Surprisingly few authors used terminology that distinguished between reintroductions, reinforcements, assisted colonizations, or ecological replacements. Just 9% of projects were described using these terms. Most (58%) were ambiguously labeled as “restoration.” The remainder were described using other, sometimes taxon-specific, terms that do not distinguish the different types of conservation translocations (e.g., “restocking,” “transplantation,” “reseeding,” “afforestation,” or “head-starting”).

The earliest identified record of a marine conservation translocation was from 1947 and described eelgrass (*Zostera* spp.) being planted following its decline in Atlantic North America (Cottam & Addy 1947). A publication gap followed, spanning to the mid 1970s, after which the number of relevant publications grew rapidly (Figure 2a). While marine conservation translocation articles comprised a tiny proportion of all ecology

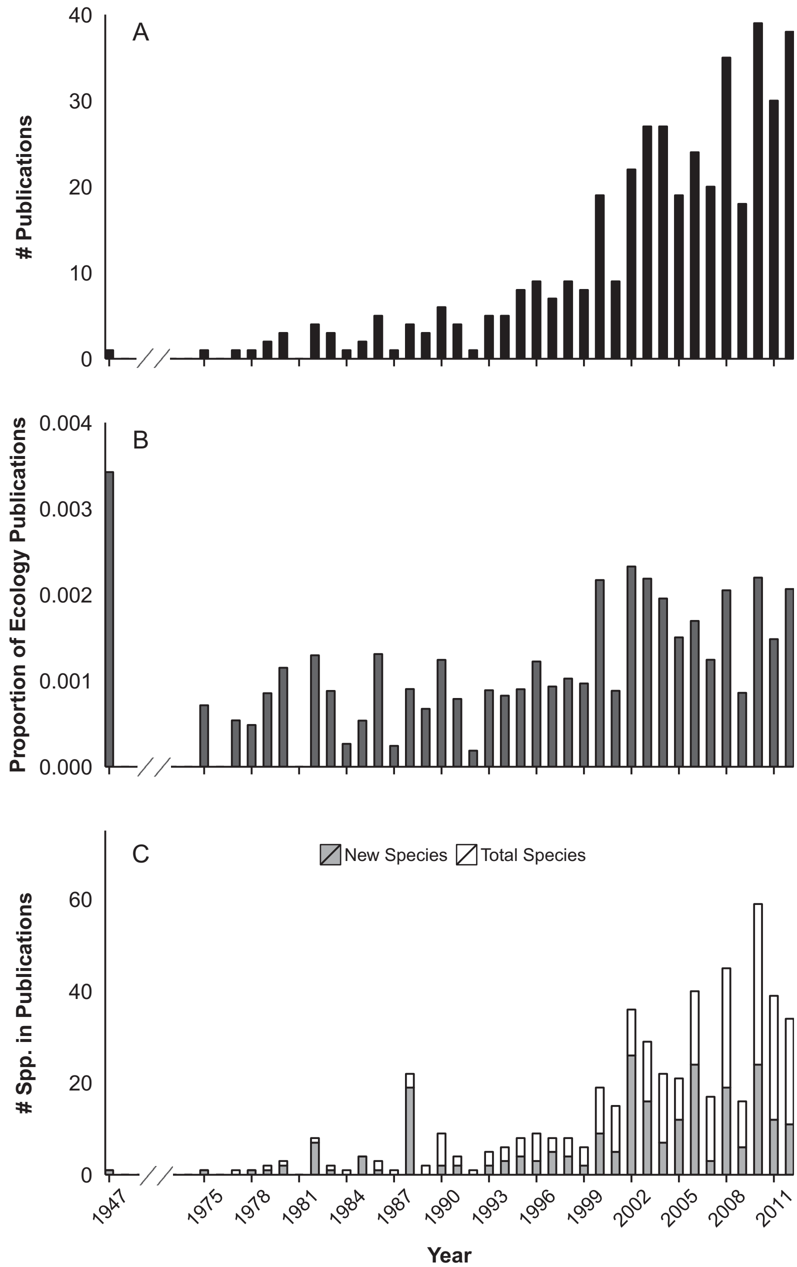

Figure 2 (a) Annual number of marine conservation translocation publications indexed in Web of Science and/or Academic Search Complete and dated between 1888 and 2012. (b) The proportion of all ecology publications in the Web of Science database (dated between 1888 and 2012) that pertain to marine conservation translocations. The large bar in 1947 results from a single reinforcement publication in a year when ecology publications were still relatively few ($n = 292$). (c) The number of species appearing in conservation translocation publications indexed in Web of Science and/or Academic Search Complete and dated between 1888 and 2012. Height of white bars indicates the total number of marine species appearing in conservation translocation publications in a given year. Dark bars indicate the number of marine species appearing in the conservation translocation literature for the first time in a given year.

publications, this proportion has gradually increased (Figure 2b). The diversity of species represented in the translocation literature also increased over this time period (Figure 2c).

At least 242 marine species have been part of conservation translocations worldwide (see Table S1 for full list of species); this is a conservative estimate, as not all translocated taxa were identified to species. Invertebrate and plant species were translocated most commonly (44% and 30% of projects, respectively), followed by vertebrates (23% of projects), and distantly by algae (3% of projects).

Within the invertebrates, 71% of translocated species were Anthozoa (corals and sea fans), 15% Bivalvia (mussels, oysters, scallops and clams), 5% Gastropoda (abalone, limpets, and other sea snails), 2% Malacostraca (lobster and crabs), 2% Porifera (sponges), 2% Echinoidea (urchins), 2% Hydrozoa (fire corals), and 1% Polychaeta (tube worms). All translocated plants were vascular, flowering species (Magnoliopsida or Liliopsida) that fell into one of four general categories: mangroves (36%), salt-marsh plants (34%), sea grasses (28%), or palm (2%). Within the vertebrates, 51% of translocated species were fish, 31% birds, 10% reptiles, and 8% mammals.

Few conservation translocation projects involved species considered at risk of extinction on the IUCN Red List: only 23% of projects involved species listed as Near Threatened or higher. The majority are classified as Least Concern (41%) or Not Evaluated (27%). However, just 36% of published projects clearly targeted species recovery objectives, whereas 60% targeted ecosystem recovery (four percent of projects could not be categorized into one or the other category; inset Figure 3a). Ecosystem-focused projects, most frequently conducted as part of reef, mangrove, or seagrass restoration efforts, almost exclusively involved invertebrate and plant species (54% and 42%, respectively), of which 17% were listed as Near Threatened or higher on the IUCN Red List (Figure 3b). Species recovery-focused projects were largely split among fish (41%), invertebrate (27%), and bird species (10%), including a larger proportion (34%) of species listed as Near Threatened or higher (Figure 3a).

Population reinforcement was the predominant type of marine conservation translocation ($n = 341$ projects), followed by reintroduction ($n = 127$ projects), assisted colonization ($n = 18$ projects) and ecological replacement ($n = 1$ project). Reinforcement projects primarily targeted invertebrates (52%) and plants (28%), whereas reintroduction projects focused more evenly on plants, invertebrates, and fish, with relatively few projects involving birds, mammals, and reptiles (Figure 4). Overall, however, vertebrates appeared more frequently in reintroduction projects (39%) than did invertebrates (30%) or plants (26%). Assisted colonization projects were limited to 17 plant species (mostly involving the creation of mangrove forests) and one fish species (European eel, *Anguilla anguilla*). The sole ecological replacement project we detected involved birds: the yellow crowned night heron (*Nyctanassa violacea*), a coastal predator of marine and freshwater invertebrates, was introduced to Bermuda to replace the extinct Bermuda night heron (*Nyctanassa carcinocatactes*), which previously controlled crab populations on the island (Wingate 2006).

Virtually all projects were conducted in coastal areas (i.e., between the shoreline and continental shelf edge). Their geographic distribution was broad, but not even: most projects were located in North America and Asia, whereas Africa was relatively underrepresented (Figure 5). The United States (U.S.) alone housed 34% of projects, with reinforcement and reintroduction of seagrasses ($n = 21$ projects), corals ($n = 21$ projects), and Atlantic oysters (*Crassostrea virginica*; $n = 9$ projects)

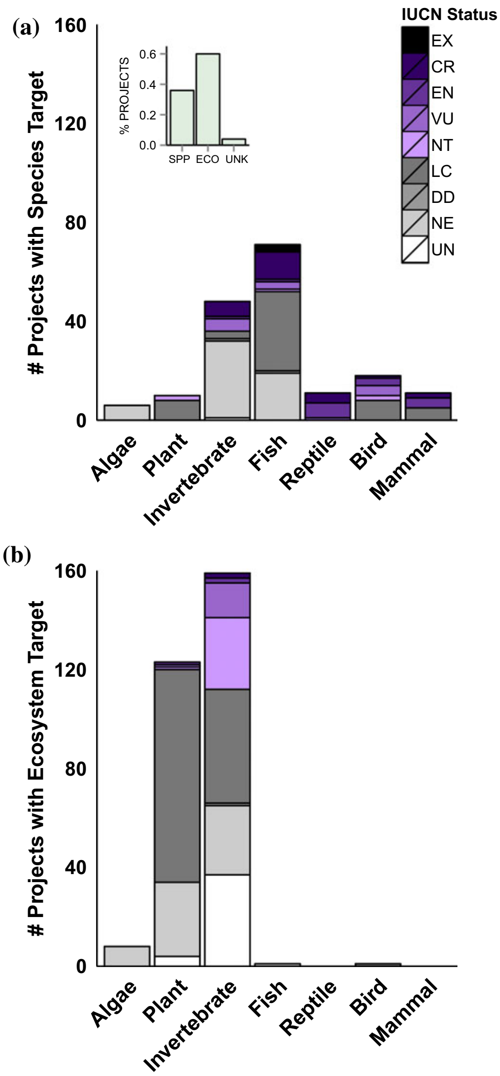

Figure 3 (a) Conservation status (IUCN Red List of Threatened Species) of all marine species translocated for projects with species recovery focus. Inset: Proportion of conservation translocation projects with a species recovery focus (SPP), ecosystem recovery focus (ECO), and unknown/ambiguous focus (UNK). (b) Conservation status (IUCN Red List of Threatened Species) of all marine species translocated for projects with ecosystem recovery focus. UN = "Unknown" (taxa were not identified to the species level by authors), NE = "Not Evaluated," DD = "Data Deficient," LC = "Least Concern," NT = "Near Threatened," VU = "Vulnerable," EN = "Endangered," CR = "Critically Endangered," EX = "Extinct." Projects were published between 1888 and June 2013 and indexed in Web of Science and/or Academic Search Complete.

predominating on the Atlantic coast. Trout and salmon reinforcement and reintroduction projects (*Oncorhynchus* spp., $n = 18$ projects) and reintroduction, reinforcement, and assisted colonization of salt marsh plants ($n = 10$ projects) prevailed on the U.S. Pacific coast. The country with the second-highest number of marine conservation

Figure 4 Number of reinforcement ($n = 341$), reintroduction ($n = 127$), assisted colonization ($n = 18$) and ecological replacement ($n = 1$) projects involving mammal, bird, reptile, fish, invertebrate, plant, and algae species. Projects were published between 1888 and June 2013 and indexed in Web of Science and/or Academic Search Complete.

translocations, the Philippines, was home to 8% of projects. These primarily comprised reinforcements of coral ($n = 29$ projects) and mangrove ($n = 4$ projects), but also some reintroductions (e.g., giant clams, $n = 6$ projects).

Organizational involvement was often mixed, but government played a role in the majority of assisted colonizations (56%) and reintroductions (54%; Figure 6). Reinforcements, in contrast, involved academia (56%) more often than government (44%) and also had greater involvement from nonprofit and industrial organizations (12% and 11% of projects, respectively) than did reintroductions (8% and 2%, respectively).

Discussion

Our comprehensive review affirmed that conservation translocations are not solely relevant to terrestrial and freshwater species, but also of increasing significance to marine species. Over 242 marine species were translocated for conservation purposes, with increasing frequency over 39 years. Most projects reinforced existing populations, many reintroduced species into areas of former extirpation, and some involved assisted colonizations or ecological replacements outside species' indigenous ranges. One third of all projects were conducted in the United States and 74% involved marine plants or invertebrates.

The prevalence of marine plants and invertebrates in our review likely reflects the large proportion of projects focusing on the conservation of whole ecosystems rather than individual species. Ecosystem engineer species, such as corals, bivalves and mangroves, were common subjects of marine conservation translocations. For example, *Montipora digitata*, a Scleractinean coral abundant in shallow reef areas of Bolinao, Philippines, was transplanted to nearby denuded reefs to restore reef habitat (Gomez *et al.* 2011). *M. digitata* was chosen not because of any conservation concern for the species, but because it withstands wave-induced breakage and thus is well-suited for rebuilding reefs. Similarly, well-known efforts to reinforce Atlantic oyster (*Crassostrea virginica*) populations in Chesapeake Bay, U.S., were intended not only to reverse

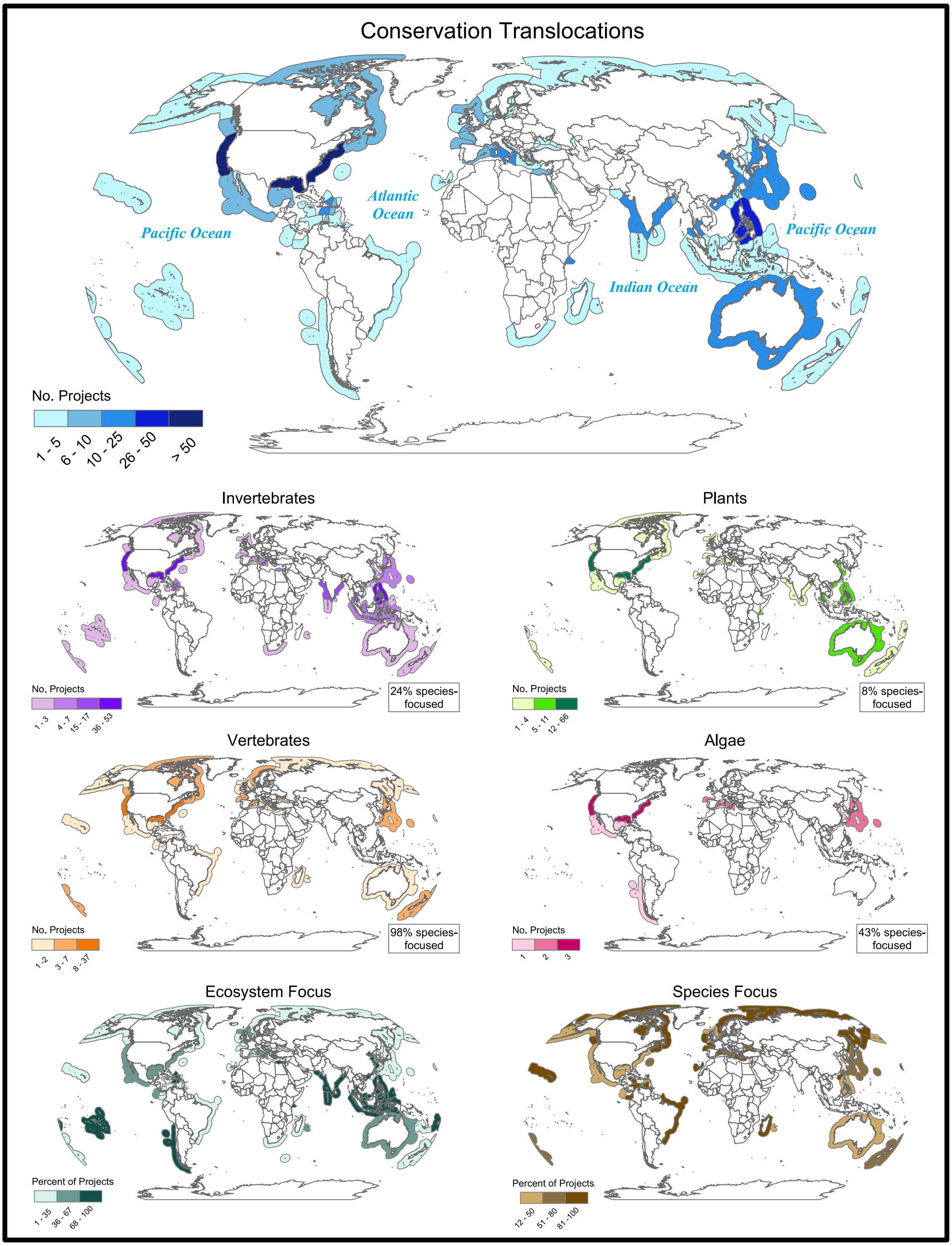

Figure 5 Top: the number of marine conservation translocation projects conducted around the world, by Exclusive Economic Zone (EEZ shapefile obtained from VLIZ, 2014). Rows 2 and 3: The number and global distribution of Invertebrate, Plant, Vertebrate, and Algae translocation projects, by Exclusive Economic Zone. Text boxes display the proportion of species-focused projects within each taxonomic group (e.g., of the 196 invertebrate projects we detected, 24% were motivated by species-recovery objectives, thus ~76%* were motivated by ecosystem-recovery objectives). Row 4: The proportion of all conservation translocation projects motivated by ecosystem ("Ecosystem focus") or species-recovery objectives ("Species focus"). *Four percent of conservation translocation projects could not be categorized into either of these categories and are not shown here.

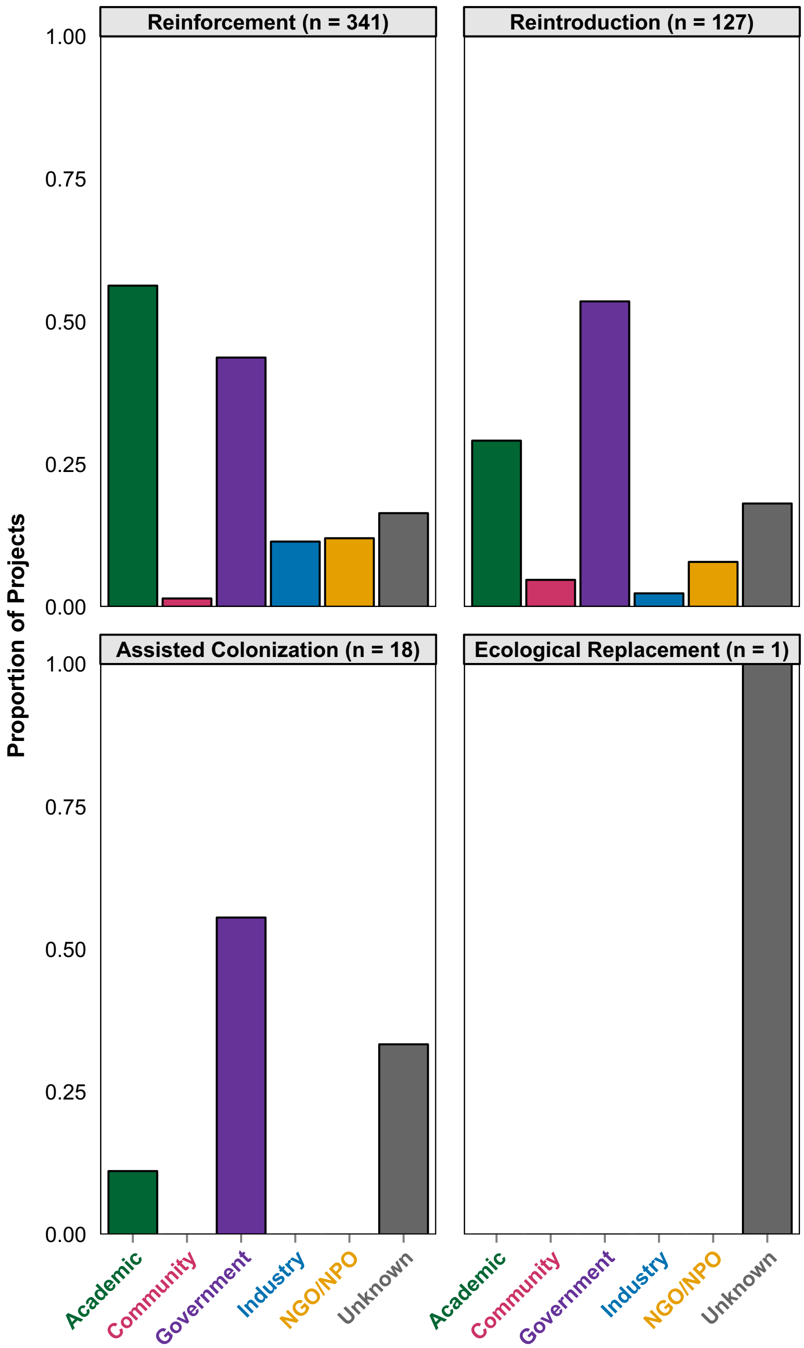

Figure 6 Organizational involvement in reinforcement ($n = 341$), reintroduction ($n = 127$), assisted colonization ($n = 18$), and ecological replacement ($n = 1$) projects. Multiple organizations may have been involved in a single project; hence proportions do not add up to 1. Academic = university affiliated organizations and research groups; Community = local community or Aboriginal groups; Government = any level of government organization (municipal, state, provincial, or national); Industry = for-profit organizations; NGO/NPO = Nongovernmental or nonprofit organizations; Unknown = organizations involved in the project were not named.

the species' local decline, but also to improve and provide habitat for other invertebrates and fish (Rossi-Snook *et al.* 2010). Mangroves and seagrasses, which comprised 22% of all projects, likewise provide foraging and nursery habitat for many marine species (Robertson and Duke 1987; Heck *et al.* 2003). Marine conservation translocations therefore often intend to recover ecosystems and their services, rather than (solely) prevent the extinction of particular species. Efforts to restore coastal marine habitats are common and promoted by global consortia such as the Society for Ecological Restoration International and the World Bank (e.g., Edwards 2010; Roman & Burdick 2012).

It might not be surprising then that only a minority (23%) of the marine species translocated for conservation purposes are actually of international conservation concern. The ecosystem focus of many marine translocations undoubtedly offers a partial explanation. Foundation species that anchor imperiled coastal ecosystems and are suitable for translocation in large numbers, such as coral reefs and mangroves, need not themselves be threatened. But even in species-focused projects, the majority of translocated taxa (66%) were not considered threatened according to the IUCN Red List. Similar trends were reported by a previous (predominantly terrestrial) review (Seddon *et al.* 2005). One explanation might be that such translocations are motivated by regional rather than global conservation status: a recent review of North American conservation translocations (terrestrial and marine) indicates translocated species are often of greater conservation concern at the state or provincial level than at the international (IUCN Red List) level (Typhenn Brichieri-Colombi, personal communication). Given the difficulty of locating and deciphering time-sensitive, state-level evaluations of species' threat-status within all 57 countries represented in our review, we were unable to verify if such discrepancy between local and international conservation status is common among translocated marine species. We are, however, aware of some examples. Osprey were listed as Least Concern on the IUCN Red List, but Critically Endangered in Spain, when they were reintroduced to mainland Spain in 2003 (Triay and Siverio 2008). Atlantic salmon, also Least Concern on the IUCN Red List (but in need of re-assessment), are considered Endangered in the Gulf of Maine, United States, where their populations are reinforced by hatchery-bred fry (Bailey and Kinnison 2010).

Although the majority of translocated marine species are not themselves of international conservation concern, they do represent the most threatened marine groups: 48% of all marine plants and 29% of all marine invertebrates assessed by the IUCN are categorized as Near Threatened or higher, and like the taxa translocated, all inhabit coastal environments (excluding Data Deficient species; IUCN 2014). Coastal ecosystems suffer the greatest cumulative impact of human activities in and around oceans, with the coasts of Eastern North America, the South and East China seas, and the Mediterranean Sea among those worst affected (Halpern *et al.* 2008). The concentration of marine translocation projects in the United States, the Philippines, Thailand, and the Mediterranean therefore suggests marine conservation translocation efforts are generally focused on the geographic areas, ecosystems, and taxonomic groups under greatest threat from human impact.

With that in mind, a noteworthy difference to previous reviews of the (primarily terrestrial) conservation translocation literature is the diversity of taxa involved in translocations. Seddon *et al.* (2005) and Bajomi *et al.* (2010) documented a strong taxonomic bias towards reintroduction of birds and mammals, but in our review, these taxa had low representation relative to fish, invertebrates and plants. Again, the ecosystem-focus of many marine translocation projects may explain this finding, as it transfers the common emphasis in conservation on charismatic species to taxa that in themselves might have less public appeal but provide critical habitat to some of the captivating species. Similarly, translocation feasibility is likely to play a role. Some of the marine birds and mammals of highest conservation concern, such as the vaquita (*Phocoena sinus*) or the Chinese crested tern (*Thalasseus bernsteini*), may be more challenging candidates for translocations, for example because no wild population is sufficiently numerous to act as a source, captive breeding is difficult, transport logistics or public opposition impede translocations, or the species is philopatric and highly motile, thus unlikely to remain near the release site. However, such challenges have not prevented conservation translocations of Bermuda petrels (*Pterodroma cahow*; Carlile *et al.* 2012), gray seals (*Halichoerus grypus*; Duguy & Prieur 1980), or many terrestrial species [e.g., the whooping crane (*Grus americana*) or California condor (*Gymnogyps californianus*)], for that matter. Factors influencing the diversity of marine conservation translocations may be biological, social, and/or logistical, but it is clear that invertebrate and plant species are the most common subjects of conservation translocations in oceans, and ecosystem recovery is the primary objective.

Why have the ecosystem focus and taxonomic spread of marine translocations apparently gone undocumented in conservation translocation reviews? We identified nearly 500 marine translocation projects in the published literature. Communication barriers might be at fault: marine publications employed numerous terms to describe conservation translocations, including some so general they could pertain to commercial or aesthetic translocations. Existing reviews, in contrast, have employed only a few, specific search terms (Seddon *et al.* 2007; Bajomi *et al.* 2010), excluding "restoration"—the word used to describe 58% of the marine projects we identified. We recommend that practitioners of marine restoration projects incorporate terminology consistent with the IUCN Guidelines for Reintroductions and Other Conservation Translocations (IUCN 2013) and employ these terms in reports and publications alongside the more general term of "restoration." Additionally, we encourage authors of reviews to use broadly inclusive search terms that avoid missing relevant articles. Future studies might also need to search literature in other languages to verify if the trends we observed hold when, for example, Chinese, French, and Spanish search terms are included.

Our comprehensive review indicates marine conservation translocations are increasingly common and geographically widespread. The natural question that follows is, "how successful are these translocations?" Unfortunately, there are no broadly accepted criteria for evaluating translocation success (Seddon 1999; Fischer & Lindenmayer 2000; Moehrenschlager *et al.* 2013; Robert *et al.* 2015). Success might be measured by the survival of released individuals, the (re-)establishment of a self-sustaining population (or ecosystem) in the release location, or a change in threat status for the translocated species. Furthermore, assessments of success vary with time. For example, the outcomes of plant reintroduction projects are typically published after three years of monitoring, but those monitored for at least 10 years have much higher failure rates (Dalrymple *et al.* 2011). The dominance of ecosystem recovery goals in marine conservation translocations adds further complexity – metrics for evaluating ecosystem status and function are often highly subjective (Boitani *et al.* 2015). Additionally, our review was limited to published reports and scientific articles, which might be inherently biased towards positive outcomes (Fanelli 2012). Nonetheless, we acknowledge the need for careful evaluation of species translocation as a conservation intervention in both marine and terrestrial environments. Taxon-specific assessments would be particularly useful to conservation practitioners; fortunately, some progress on this has already been made, including: studies on the efficacy of mangrove planting (Chen *et al.* 2009), seagrass meadow restoration (Bell *et al.* 2008; van Katwijk *et al.* 2009), and giant clam reintroductions (Teitelbaum & Friedman 2008). Conservation translocation projects should also publish clear, time-constrained, and measurable targets to assist future evaluation of the methods employed.

Greater consistency in the implementation, monitoring, and evaluation of conservation translocations is essential to the refinement of this important conservation tool. Accordingly, we recommend the IUCN Guidelines (IUCN 2013) be used as a framework for planning and evaluating marine conservation translocations. Formal adoption of the IUCN Guidelines by government agencies, as recently done by Scotland (National Species Reintroduction Forum 2014) and 50 signatories to the Bern Convention on the Conservation of European Wildlife and Natural Habitats (Council of Europe 2014), would be particularly impactful, given the direct involvement of government agencies in over half of the projects conducted in oceans (and presumably, their indirect involvement in many others). In turn, legislation to ensure compliance with these (or other) guidelines is essential, as marine conservation translocations are increasing in prevalence and many projects (particularly reinforcements) are apparently undertaken without government involvement.

Notable progress has been made in the development of coastal restoration guidelines and legislation, particularly in the two countries home to the greatest number of marine conservation translocations: the U.S. and the Philippines. Some guidelines are specific to certain regions [e.g., the Florida Keys National Marine Sanctuary (Miller *et al.* 1993) and Massachusetts coastal waters (Evans & Leschen 2010)] while others are applicable to particular taxonomic groups/habitats [e.g., mangroves (Primavera *et al.* 2012), coral reefs (Edwards 2010), and oysters (Baggett *et al.* 2014)]. However, the aforementioned guidelines and related national legislation (such as the U.S. Estuary Restoration Act of 2000, Philippines DENR Administrative Order #2013-12, and U.S. Coastal Wetlands Planning, Protection, and Restoration Act), do not distinguish between conservation-motivated translocations and those motivated by commercial, aesthetic, or other objectives. In some practical ways this distinction might not matter (given the common objective that translocated individuals survive and reproduce), but many critical decisions, such as what species to translocate for ecosystem recovery, what levels of risk are acceptable, and when to abandon failed translocation efforts, will greatly depend on the motivation behind the translocation itself. We suggest that the IUCN Guidelines be adopted by governments as the overarching standard for conservation translocations, regardless of the environment or species of interest. Taxon- or ecosystem-specific protocols are also advantageous and should align with these international standards—indeed, some marine protocols already do (e.g., Edwards 2010). The global IUCN Guidelines can be expanded upon for different taxonomic groups, as recently done for gibbons (Campbell *et al.* 2015) and rhinoceros (Emslie *et al.* 2009).

Wide adoption of appropriate guidelines will help ensure that future conservation translocations, marine or otherwise, are implemented and evaluated responsibly. The growing trend revealed by this review, to move marine species into both former and new habitats, is likely to continue. Assisted colonization is increasingly considered a potential response to the threat of climate change (Lunt *et al.* 2013): a glimmer of hope for dispersal-limited species that might otherwise vanish under new, unsuitable environmental conditions, albeit with considerable risk to translocated individuals and/or recipient ecosystems (Lunt *et al.* 2013; Moehrenschlager *et al.* 2013; Seddon *et al.* 2014). Similarly, ecological replacement projects could become more common as the ocean ecosystems humans depend on are disrupted by marine regime shifts (Rocha *et al.* 2015) and biodiversity loss (Worm *et al.* 2006). Our review has identified a wealth of experience to inform future translocations of marine species. The majority of species we documented were not categorized at high IUCN Red List threat levels, but given the depth of knowledge presented, we now encourage practitioners and policy makers to increasingly consider potential benefits of conservation translocations for imperiled marine species. However, we caution that without adequate marine habitat protection, drastic reductions in global carbon dioxide pollution, and improved governance of marine fisheries, conservation translocations can do little more than buy time for species facing imminent extinction.

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Supporting Information

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

Table S1. Marine species that have been translocated for conservation purposes and the method of translocation (reinforcement, reintroduction, assisted colonization, or ecological replacement) performed for each. Species names are taken directly from publications in our review. Common English names, when not included in the publications, were obtained from the IUCN Red List, Marine Species Identification Portal (2014), World Register of Marine Species (2015), or FishBase (Froese & Pauly 2014). Common names are not exhaustive and are provided for general reference only. Full bibliography is available upon request.

References

Baggett, L.P., Powers, S.P, Brumbaugh, R., et al. (2014). *Oyster habitat restoration monitoring and assessment handbook*. The Nature Conservancy, Arlington, USA, 96 pp.

Bailey, M.M. & Kinnison, M.T. (2010). Habitat-mediated size selection in endangered Atlantic salmon fry: selectional restoration assessment. *Evol. Appl.*, **3**, 352-362.

Bajomi, B., Pullin, A.S., Stewart, G.B. & Takács-Sánta, A. (2010). Bias and dispersal in the animal reintroduction literature. *Oryx*, **44**, 358-365.

Bell, J.D., Bartley, D.M., Lorenzen, K. & Loneragan, N.R. (2006). Restocking and stock enhancement of coastal fisheries: potential, problems and progress. *Fish. Res.*, **80**, 1-8.

Bell, S.S., Tewfik, A., Hall, M.O. & Fonseca, M.S. (2008). Evaluation of seagrass planting and monitoring techniques: implications for assessing restoration success and habitat equivalency. *Restor. Ecol.*, **16**, 407-416.

Boitani, L., Mace, G.M. & Rondinini, C. (2015). Challenging the scientific foundations for an IUCN Red List of Ecosystems. *Conserv. Lett.*, **8**, 125-131.

Born, A.F., Immink, A.J. & Bartley, D.M. (2004). Marine and coastal stocking: global status and information needs. *FAO Fish. Tech. Paper*, **429**, 1.

Briggs, J.C. (2011). Marine extinctions and conservation. *Mar. Biol.*, **158**, 485-488.

Campbell, C.O., Cheyne, S.M. & Rawson, B.M. (2015). *Best practice guidelines for the rehabilitation and translocation of gibbons*. IUCN SSC Primate Specialist Group, Gland, Switzerland, 56 pp.

Carlile, N., Priddel, D. & Madeiros, J. (2012). Establishment of a new, secure colony of Endangered Bermuda Petrel Pterodroma cahow by translocation of near-fledged nestlings. *Bird Cons. Int.*, **22**, 46-58.

Chen, L., Wang, W., Zhang, Y. & Lin, G. (2009). Recent progresses in mangrove conservation, restoration and research in China. *J. Plant Ecol.*, **2**, 45-54.

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R. & Pauley, D. (2009). Projecting global marine biodiversity impacts under climate change scenarios. *Fish.*, **10**, 235-251.

Cottam, C. & Addy, C.E. (1947). Present eelgrass condition and problems on the Atlantic coast of North America. *T. N. Am. Wildl. Res.*, **12**, 387-398.

Council of Europe. (2014). Recommendation No. 158 (2012) of the Standing Committee, adopted on 30 November 2012 on Conservation translocations under changing climatic conditions. Available from https://wcd.coe.int/ViewDoc.jsp ?id = 2010653&Site = . Accessed 12 Dec 2014.

Crain, C.M., Halpern, B.S., Beck, M.W. & Kappel, C.V. (2009). Understanding and managing human threats to the coastal marine environment. *Annal. N.Y. Acad. Sci.*, **1162**, 39-62.

Dalrymple, S.E., Stewart, G.B. & Pullin, A.S. (2011). Are re-introductions an effective way of mitigating against plant extinctions? Collaboration for Environmental Evidence Review 07–008 (SR32). Available from www.environmentalevidence.org/SR32.html. Accessed 22 June 2015.

Duguy, R. & Prieur, D. 1980. Remarks on the reintroduction of grey seals and common seals along the French coast. *Aquat. Mamm.*, **8**, 19-20.

Dulvy, N.K., Sadovy, Y. & Reynolds, J.D. (2003). Extinction vulnerability in marine populations. *Fish. Fish.*, **4**, 25-64.

Edwards, A.J. (2010). *Reef rehabilitation manual*. Coral Reef Targeted Research & Capacity Building for Management Program, St Lucia, Australia. 166 pp.

Elliott, M., Burdon, D., Hemingway, K.L. & Apitz, S.E. (2007). Estuarine, coastal and marine ecosystem restoration: confusing management and science—a revision of concepts. *Estuar, Coast Shelf Sci*., **74**, 349-366.

Emslie, R.H., Amin, R. & Kock, R. (2009). *Guidelines for the in situ re-introduction and translocation of African and Asian rhinoceros*. IUCN, Gland, Switzerland, 115 pp.

Evans, N.T. & Leschen, A.S. (2010). Technical guidelines for the delineation, restoration, and monitoring of eelgrass (Zostera marina) in Massachusetts coastal waters. Massachusetts Division of Marine Fisheries Technical Report TR-43, New Bedford, MA, 9 pp.

Fanelli, D. (2012). Negative results are disappearing from most disciplines and countries. *Scientometrics*, **90**, 891-904.

Fischer, J. & Lindenmayer, D.B. (2000). An assessment of the published results of animal relocations. *Biol. Conserv*., **96**, 1-11.

Froese, R. & Pauly, D. (2014). FishBase. Available from www.fishbase.org. Accessed 25 October 2014.

Global Ocean Commission. (2014). From decline to recovery—a rescue package for the global ocean. Global Ocean Commission Report 2014, 92 pp.

Gomez, E.D., Yap, H.T., Cabaitan, P.C. & Dizon, R.M. (2011). Successful transplantation of a fragmenting coral, *Montipora digitata*, for reef rehabilitation. *Coast. Manage*., **39**, 556-574.

Griffith, B., Scott, J.M., Carpenter, J.W. & Reed, C. (1989). Translocation as a species conservation tool: status and strategy. *Science*, **245**, 477-480.

Halpern, B.S., Walbridge, S., Selkoe, K.A. *et al*. (2008). A global map of human impact on marine ecosystems. *Science*, **319**, 948-952.

Harrington, L.A., Moehrenschlager, A., Gelling, M., Atkinson, R.P., Hughes, J. & Macdonald, D.W. (2013). Conflicting and complementary ethics of animal welfare considerations in reintroductions. *Cons. Biol*., **27**, 486-500.

Heck, K.L., Hays, G. & Orth, R.J. (2003). Critical evaluation of the nursery role hypothesis for seagrass meadows. *Mar. Ecol. Prog. Ser*., **253**, 123-136.

Hilborn, R., Branch, T.A., Ernst, B. *et al*. (2003). State of the world's fisheries. *Annu. Rev. Env. Resour*., **28**, 359-399.

Hoegh-Guldberg, O. & Bruno, J.F. (2010). The impact of climate change on the world's marine ecosystems. *Science*, **328**, 1523-1528.

IUCN. (2013). Guidelines for Reintroductions and Other Conservation Translocations. IUCN SSC, Gland, Switzerland, ed. 1.0. Available from https://portals.iucn.org/library/sites/library/files/documents/2013-009.pdf. Accessed 22 June 2015.

IUCN. (2014). The IUCN Red List of Threatened Species. Version 2014.2. Available from *http://www.iucnredlist.org*. Accessed 22 October 2014.

Lotze, H.K., Lenihan, H.S., Bourque, B.J. *et al*. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science*, **312**, 1806-1809.

Lunt, I.D., Byrne, M., Hellmann, J.J. *et al*. (2013). Using assisted colonisation to conserve biodiversity and restore ecosystem function under climate change. *Biol. Conserv*., **157**, 172-177.

Marine Species Identification Portal. (2014). Available from species-identification.org. Accessed 25 October 2014.

Miller, S.L., McFall, G.B. & Hulbert, A.W. (1993). Guidelines and recommendations for coral reef restoration in the Florida Keys National Marine Sanctuary. *National Undersea Research Center, University of North Carolina at Wilmington, 38 pp*.

Moehrenschlager, A., Shier, D.M., Moorhouse, T.P. & Stanley Price, M.R. (2013). Righting past wrongs and ensuring the future. Pp. 405-429 *Key Topics in conservation biology*, Vol. 2, D.W., Macdonald, K.J., Willis, editors. Wiley-Blackwell, Oxford.

National Species Reintroduction Forum. (2014). The Scottish Code for Conservation Translocations & Best Practice Guidelines for Conservation Translocations in Scotland. Version 1.1. Scottish National Heritage. Available from http://www.gwct.org.uk/media/406156/Scottish-Code-for-Conservation-Translocations.pdf. Accessed 15 September 2014.

Primavera, J.H., Savaris, J.D., Bajoyo, B., Coching, J.D., Curnick, D.J., Golbeque, R., Guzman, A.T., Henderin, J.Q., Joven, R.V., Loma, R.A. & Koldewey, H.J. (2012). *Manual on community-based mangrove rehabilitation. Mangrove Manual Series No. 1*, London, UK, 240 pp.

Pullin, A.S. & Stewart, G.B. (2006). Guidelines for systematic review in conservation and environmental management. *Conserv. Biol*., **20**, 1647-1656.

Ripple, W.J. & Beschta, R.L. (2012). Trophic cascades in Yellowstone: the first 15 years after wolf reintroduction. *Biol. Conserv*., **145**, 205-213.

Robert, A., Colas, B., Guigon, I. *et al*. (2015). Defining reintroduction success using IUCN criteria for threatened species: a demographic assessment. *Anim. Conserv*., **18**, 397-406.

Robertson, A.I. & Duke, N.C. (1987). Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. *Mar. Biol*., **96**, 193-205.

Robertson, H.A., Colbourne, R.M., Graham, P.J., Miller, P.J. & Pierce, R.J. (2011). Experimental management of brown kiwi Apteryx mantelli in central Northland, New Zealand. *Bird Conserv. Int*., **21**, 207-220.

Rocha, J., Yletyinen, J., Biggs, R., Blenckner, T. & Peterson, G. (2015). Marine regime shifts: drivers and impacts on ecosystems services. *Phil. T. Roy. Soc. B*, **370**, doi:10.1098/rstb.2013.0273.

Rogers, A.D. & Laffoley, D.d'A. (2011). *International Earth System expert workshop on ocean stresses and impacts. Summary Report*. International Program on the State of the Ocean, Oxford, 18 pp.

Roman, C.T. & Burdick, D.M. (2012). *Tidal marsh restoration: A synthesis of science and management*. Island Press, Washington, D.C.

Rossi-Snook, K.O., Ozbay, G. & Marenghi, F. (2010). Oyster (Crassostrea virginica) gardening program for restoration in Delaware's Inland Bays, USA. *Aquacult. Int*, **18**, 61-67.

Sala, E. & Knowlton, N. (2006). Global marine biodiversity trends. *Annu. Rev. Environ. Resour.*, **31**, 93-122.

Seddon, P. J. (1999). Persistence without intervention: assessing success in wildlife reintroductions. *Trends Ecol. Evol.*, **14**, 503-503.

Seddon, P.J., Soorae, P.S. & Launay, F. (2005). Taxonomic bias in reintroduction projects. *Anim. Conserv.*, **8**, 51-158.

Seddon, P.J., Armstrong, D.P. & Maloney, R.F. (2007). Developing the science of reintroduction biology. *Conserv. Biol.*, **21**, 303-312.

Seddon, P.J., Griffiths, C.J., Soorae, P.S. & Armstrong, D.P. (2014). Reversing defaunation: restoring species in a changing world. *Science*, **345**, 406-412.

Teitelbaum, A. & Friedman, K. (2008). Successes and failures in reintroducing giant clams in the Indo-Pacific region. *SPC Trochus Inform. Bull*, **14**, 19-26.

Thayer, G.W. & Kentula, M.E. (2005). Coastal restoration: Where have we been, where are we now, and where should we be going? *J. Coast. Res.*, 1-5.

Triay, R. & Siverio, M. (2008). *The osprey in Spain. Population in 2008 and census methods*. SEO/Birdlife, Madrid.

van Katwijk, M.M., Bos, A.R., De Jonge, V.N., Hanssen, L.S.A.M., Hermus, D.C.R. & De Jong, D.J. (2009). Guidelines for seagrass restoration: importance of habitat selection and donor population, spreading of risks, and ecosystem engineering effects. *Mar. Poll. Bull.*, **58**, 179-188.

VLIZ. (2014). Maritime Boundaries Geodatabase, version 8. Available from http://www.marineregions.org/. Accessed 4 September 2014.

Webb, T.J. & Mindel, B.L. (2015). Global patterns of extinction risk in marine and non-marine systems. *Curr. Biol.*, **25**, 506-511.

Wingate, D.B. (2006). Update on the night heron substitution in Bermuda. *Re-Introduct. News*, **25**, 46-47.

Wolf, C.M., Griffith, B., Reed, C. & Temple, S.A. (1996). Avian and mammalian translocations: update and re-analysis of the 1985 survey data. *Cons. Biol.*, **10**, 1142-1154.

Wolf C.M., Garland T.J. & Griffith B. (1998). Predictors of avian and mammalian translocation success: reanalysis with phylogenetically independent contrasts. *Biol. Conserv.* **86**, 243-255.

Worm, B., Barbier, E.B., Beaumont, N. *et al*. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science*, **314**, 787-790.

World Register of Marine Species. (2015). Available from http://www.marinespecies.org at VLIZ. Accessed 30 December 2014.

