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Ocean Optimism: Moving Beyond the Obituaries in Marine Conservation

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Abstract

While the ocean has suffered many losses, there is increasing evidence that important progress is being made in marine conservation. Examples include striking recoveries of once-threatened species, increasing rates of protection of marine habitats, more sustainably managed fisheries and aquaculture, reductions in some forms of pollution, accelerating restoration of degraded habitats, and use of the ocean and its habitats to sequester carbon and provide clean energy. Many of these achievements have multiple benefits, including improved human well-being. Moreover, better understanding of how to implement conservation strategies effectively, new technologies and databases, increased integration of the natural and social sciences, and use of indigenous knowledge promise continued progress. Enormous challenges remain, and there is no single solution; successful efforts typically are neither quick nor cheap and require trust and collaboration. Nevertheless, a greater focus on solutions and successes will help them to become the norm rather than the exception.

1. INTRODUCTION

The ocean's immensity long led to the assumption that it was beyond the reach of people to substantively alter, either physically or biologically. The phenomenon of shifting baselines compounded our inability to recognize the magnitude of human impacts, and modern marine ecology began only after humans had already profoundly changed ocean life (Jackson et al. 2001, Jackson 2008). We now recognize, however, that over centuries and millennia the ocean has been transformed by human activities, both physically and biologically (Bindoff et al. 2019). Some of these changes, such as rising temperatures and falling pH, are global but comparatively recent. Others, such as overfishing, pollution, and habitat destruction, began earlier (Jackson et al. 2001) and, although local, in total now affect a large proportion of the ocean (Halpern et al. 2008). As the enormous magnitude of these changes and future threats became apparent, we moved from a worldview that the ocean was too big to harm to one in which it was too big to fix. Recently, however, this unrelenting chorus of doom and gloom has been punctuated by more positive messages. Lubchenco & Gaines (2019) have argued for a new ocean narrative that emphasizes how the ocean is also "too big to ignore" (p. 911) given its enormous role in sustaining life, including human life.

Fortunately, there have been relatively few marine extinctions to date, and harm to life is less advanced in the ocean than it is on land (McCauley et al. 2015), meaning that the building blocks of damaged ecosystems are still with us. Duarte et al. (2020) have boldly argued that substantial recovery of marine biodiversity can be achieved by 2050 should pressures (including climate change) be alleviated. This conclusion is supported by important examples of positive outcomes in ocean conservation, many of them underappreciated or largely unknown, even by professionals in the field. Failure to recognize, study, and celebrate these examples of success and opportunity gets in the way of their lessons being applied more broadly, both through lack of knowledge and because the public can become apathetic and policy makers uninterested in the face of huge problems with no apparent solutions (Balmford & Knowlton 2017, Cvitanovic & Hobday 2018).

Hence, the purpose of this review is to consider more fully the ocean conservation successes that have been achieved to date. These are organized into six partially overlapping categories: saving species, protecting spaces, catching and cultivating wisely, reducing pollution, restoring habitats, and mitigating warming and acidification, with an explicit discussion of how some of these successes have multiple benefits, including for human well-being. The focus on achievements is deliberate, to facilitate expanding what has been accomplished by synthesizing what has already worked. Included are some aspects of policy improvements, but this review is more about outcomes in the ocean itself. Although the focus is on marine conservation successes, this is not an effort to sweep bad news under the rug, and the limits of and future challenges for marine conservation are also considered. The review concludes with a consideration of solutions that are only now emerging and why hope is both reasonable and essential for marine conservation success.

2. SAVING SPECIES

Because "extinction is forever" (at least in practice, for the moment), its prevention remains a crucially important goal in marine conservation. The number of marine species that are known to have gone extinct recently (∼20) is smaller than that on land, so it is often assumed that risks to marine species are smaller. However, this may in part reflect differences in assessment efforts between the two realms (Webb & Mindel 2015) and may not extrapolate into the future (Harnik et al. 2012). Nevertheless, attempts to save endangered marine species provide some of the earliest examples of marine conservation successes. Indeed, some of these efforts have been so successful that many people today do not realize how endangered now-abundant species once were—an inverse to the usual trend of shifting baselines (Roman et al. 2015).

Marine mammals have experienced a number of notable successes in conservation, particularly pinnipeds, sea otters, and coastal cetaceans. This is due largely to the elimination of most hunting but also to other protection measures aimed at reducing collisions with vessels, bycatch, entanglements, and pollution (Magera et al. 2013, Valdivia et al. 2019). Analysis of 124 populations representing more than 45 species indicated that 47% were significantly increasing, while only 13% were significantly decreasing (updated numbers are given in supplemental table 2 of Duarte et al. 2020). Some of these recoveries are striking in scale. Sea otters, for example, were hunted so severely that the southern subspecies was thought to be extinct, but following protection, their numbers have rebounded from the original 50 individuals discovered in 1914 to more than 3,000 in 2018 (Hughes et al. 2019). The Hawaiian population of humpback whales grew from approximately 800 individuals in 1979 to more than 10,000 in 2005 and has been delisted (no longer considered threatened according to the provisions of the US Endangered Species Act), as have the West Indian population of humpbacks, the eastern North Pacific population of gray whales, and the eastern population of Steller sea lions (Valdivia et al. 2019).

Sea turtles need protection both on land and in the ocean, which makes their conservation especially challenging. Nevertheless, a recent survey suggests that 12 of 17 populations, representing five of the six species, are now growing (Mazaris et al. 2017). Moreover, for those populations with significant change over time, populations with low initial numbers did not exhibit lower growth rates—an important result because small populations can be vulnerable to population collapse due to Allee effects (e.g., from inbreeding or failure to find mates; Aalto et al. 2019). An extreme exemplar of recovery from low numbers is Kemp's ridley turtle in Texas, where the number of nests increased from 1 to 353 (Valdivia et al. 2019). Green turtle populations include some of the most striking increases, of more than 2,000% and 3,000% in North and South Atlantic populations, respectively; in Florida, the estimated number of nests rose from 62 in 1979 to 37,341 in 2015 (Valdivia et al. 2019).

Seabirds and shorebirds have played foundational roles in marine conservation history, with striking recoveries from severe hunting. For example, the showy breeding plumage of some egrets led to their global decimation during the mid-to-late nineteenth century, as growing middle-class wealth resulted in enormous demand for feathers for women's hats (a social phenomenon similar to the impact of middle-class demand for shark fin soup more recently). The carnage (192,000 egrets killed in 1902 alone) led to the creation of the Plumage League in London in 1889 (now the Royal Society for the Protection of Birds, with 1 million members), the National Audubon Society in the United States (which still uses the symbol of a flying great egret), and the Lacey Act and Migratory Bird Treaty Act (Lotze et al. 2011, Kushlan 2018). Puffins were similarly decimated by hunting, but their recovery required active interventions to encourage birds to return to once-occupied islands, such as call playbacks, decoys, and translocations (Jones & Kress 2012). These efforts take substantial commitment; at Eastern Egg Rock Island in Maine, for example, 954 puffin chicks were translocated over 12 years, and it took "4 years for the first translocated puffin to return, 8 years for the first nesting attempt, and 35 years for the colony to reach 100 pairs" (Jones & Kress 2012, p. 4). Nevertheless, this approach has become a cornerstone of recovery efforts for many colonially nesting seabirds, which, when reviewed by Jones & Kress (2012), constituted 128 projects involving 47 seabird species across 100 sites in 14 countries. Importantly, 55 of the 88 projects with sufficient data to assess were deemed successful, and two of the four most threatened families of seabirds showed the highest rates of success.

Sharks are highly vulnerable to fishing because of high demand for their fins and their relatively slow rate of reproduction. Although sustainable fishing of more rapidly reproducing species is possible (Simpfendorfer & Dulvy 2017), the cruelty and waste associated with shark finning, together with the fact that one-quarter of all sharks and shark relatives are at risk of extinction, have engendered considerable public engagement in their conservation, and even the existence of popular Twitter accounts for individually tagged sharks. This makes them more akin to other charismatic endangered marine megafauna in many respects. While shark numbers remain generally far below prefishing levels, there have been numerous successful campaigns to ban various aspects of the trade in shark fins (Ferretti et al. 2020), and the prices of shark fins have dropped substantially, indicating reduced demand (Jaiteh et al. 2017). There has also been a concomitant increase in shark numbers in some locations and shark tourism (see Section 8).

Most marine bony fish and invertebrate species have not been the target of strict conservation actions (as opposed to fisheries regulations; see Section 4), because political and economic considerations have made their inclusion in international conservation accords controversial (Vincent et al. 2014) and because their typically greater reproductive potential makes them less susceptible to extinction. There are, however, important exceptions of highly fecund species being decimated by overexploitation. Nassau groupers form vast spawning aggregations, which, because fishers know when and where they occur, has made them highly vulnerable to not only overfishing but complete extirpation (Erisman et al. 2015). This was once the most important Caribbean reef fishery, but population collapses throughout the region following targeting of spawning aggregations led to the species being assessed on the International Union for Conservation of Nature's Red List as critically endangered and as threatened under the US Endangered Species Act. However, recent modest increases in numbers of spawning Nassau groupers in the Cayman Islands suggest that recovery is possible (Waterhouse et al. 2020). In the Cayman Islands, a small nongovernmental organization provides monitoring data to the government, and conservation actions include not only the protection of all spawning sites during the reproductive season, but also seasonal closures on harvest and limits on size, quantity harvested, and gear. The result has been a more than tripling of numbers on Little Cayman, with hints of recovery on Cayman Brac as well. Spawning aggregations have been documented around the world involving 300 fish species from 44 families in 53 countries; other successes associated with their protection and the fact that multiple species often use the same sites point to considerable potential for this targeted approach (Erisman et al. 2015).

3. PROTECTING SPACES

Marine protected areas (MPAs) are the best-known technique in the marine conservation toolbox, and the power of strongly protected no-take reserves to achieve conservation goals is well established (Lubchenco & Grorud-Colvert 2015). The differences in outcomes between strong protection and weak or no protection can be striking; for example, a recent review of a variety of sites (including in Hawaii, the Mediterranean, the Canary Islands, and the Gulf of California) indicated that, on average, fish biomass in no-take marine reserves exceeded that of partially protected reserves by 343% and unprotected areas by 670% (Sala & Giakoumi 2017). Spatial protection as a conservation strategy takes many forms and has a long history, as MPA-like structures preceded modern western management by centuries in Oceania (Johannes 2002). Like national parks on land, MPAs explicitly protect habitats rather than individual species, which in sum are too numerous to protect individually. They thus have benefits ranging from conservation generally (e.g., the large MPA protecting the Ross Sea in Antarctica) to fisheries enhancement (including protection against catastrophic events causing population collapses due to Allee effects; Aalto et al. 2019). The extent of MPAs has grown substantially over the last two decades, increasing from 3.2 million km^2 in 2000 to 26.9 million km^2 in 2020; in terms of area, this represents an increase from 0.9% to 7.4% of the ocean's area protected (5.3% of which is fully implemented), and coverage continues to grow at a rate of approximately 8% annually (Duarte et al. 2020).

For fisheries, MPAs work when fish spill over from protected areas to areas open to fishing and when larger females survive. The latter strongly increases total reproductive output (both egg numbers and total energy output), because for 95% of fish species reproductive output increases disproportionately with body size (Barneche et al. 2018). For the widow rockfish, as an example, this translates into 60% more eggs and 74% more reproductive energy output because fish inside MPAs are 7% larger, on average, than they are outside MPAs (Barneche et al. 2018). The role of MPAs in fisheries management has been particularly important in the tropics, where spatial regulation is easier to execute than other types of regulation given the high diversity of catches, the prevalence of artisanal fisheries, and weak governance. However, in some cases MPAs are designed with specific species in mind (e.g., spawning aggregation sites, as described above), and MPAs with fisheries benefits are not limited to the tropics.

In the modern era, early MPAs were small, and some have become exemplars of successful community-led conservation, such as those established in the 1970s and 1980s in the Philippines (Alcala & Russ 2006). More recently, in Cabo Pulmo, Mexico, a small village confronted the consequences of severe overfishing by establishing what is now the site of a national park and one of the most successful and well-publicized turnarounds in marine ecosystem health (Aburto-Oropeza et al. 2011). Not only have fish rebounded dramatically, but the local economy and individual incomes have increased substantially from the resulting tourism; in 2011, for example, the park generated US$590,400 in income from recreational diving and snorkeling (Langle-Flores et al. 2017). Another case study of an abalone fishery, also in Mexico, demonstrated how even two small reserves, with their larger and more fecund females, provided resilience against the effects of mass mortality associated with shoaling of hypoxic waters (Micheli et al. 2012). Recruitment rates were unaffected in the reserves, but recruitment in the fished areas, formerly 3.8 times lower than in the reserves, dropped to 9.1 times lower afterward. Small MPAs remain the norm in many developing countries because of the impracticality of excluding large areas from fishing, and even in the main Hawaiian Islands, the median area of protection is only 1.2 km^2 (Friedlander et al. 2019). Although by definition what they directly protect is small, their success can transform conservation more broadly by significantly stimulating other efforts and helping shape policies at various levels, as has occurred, for example, in the Philippines (Alcala & Russ 2006) and the United Kingdom (Stewart et al. 2020). Small MPAs can also protect habitats of outsized importance, such as spawning sites (see above) and other critically important habitats (e.g., feeding and resting grounds for migrating shorebirds).

A number of the limitations of smaller reserves can be overcome by linking them into networks, which helps reduce socioeconomic conflicts as well (Gaines et al. 2010, Grorud-Colvert et al. 2014). Networks facilitate recovery at one location via larvae arriving from nearby unimpacted sites and allow for coverage of a variety of habitat types needed by different species and life stages. While such networks are often de facto assembled piecemeal as small reserves are created, in some cases the network structure is explicitly planned using various criteria (Grorud-Colvert et al. 2014), usually in consultation with a diverse array of stakeholders. Two examples of the latter are the expansion of protection of the Great Barrier Reef in Australia in 2004 and the network of reserves completed along the California coast by the Marine Life Protection Act in 2012. Both have had significant positive biological effects: an increase in fish abundance and biomass and a decrease in outbreaks of the coral-eating crown-of-thorns sea star in the case of the former (McCook et al. 2010) and increases in a variety of fish and invertebrate species in the case of the latter (Murray & Hee 2019). An explicit test of networked and nonnetworked MPAs in Hawaii designed to protect populations of a popular aquarium fish species indicated that networked MPAs performed better than nonnetworked MPAs in terms of fish density (Grorud-Colvert et al. 2014).

Increasingly, national governments are turning to the protection of large contiguous and often remote areas; between 2006 and 2016, 18 large MPAs (with areas greater than 100,000 km^2) were established (Richmond et al. 2019). Large and remote MPAs are on average more effective biologically (e.g., sustaining higher fish biomass; Edgar et al. 2014), and they are particularly important for large migratory species, such as sharks (White et al. 2017). They also allow countries to meet political goals and agreements (e.g., Aichi Target 11, which aims to protect at least 10% of coastal and marine areas by 2020) with less overt political conflict (but see Richmond et al. 2019).

The issue of conflict is critical, as local buy-in is core to the success of almost any MPA, regardless of setting and size; its absence usually results in a paper park with little effective enforcement. An analysis of 27 case studies spanning the globe found that the top factor associated with success was high levels of stakeholder participation (Giakoumi et al. 2018). A more fine-grained analysis of MPAs in the Gulf of California (Ulate et al. 2018) gave a comparable result: The only spatial protection schemes that were effective in terms of both increasing the biomass of fish and decreasing the biomass of destructively grazing echinoderms were no-take areas comanaged by local communities and the government and those patrolled by the military, the latter being the exception that proved the rule. The differences were striking, with successful MPAs having more than twice the fish density and almost an order of magnitude lower echinoderm densities than open access areas, no-take areas managed by the federal government, and mixed-use areas managed by the federal government.

4. CATCHING AND CULTIVATING WISELY

Evidence for the consumption of seafood dates back to anatomically modern humans in Africa and Neanderthals in Europe (Zilhão et al. 2020). Currently, the reported annual marine catch is approximately 80 million metric tons; marine and coastal aquaculture of animal species produces another 29 million tons, the majority of which is shellfish (FAO 2018).

While MPAs contribute to the sustainable management of some ocean resources and have many other conservation benefits, the harvest of all ocean resources is not readily managed only by setting aside areas as off-limits to fishing. A range of strategies have been successfully employed, some dating back centuries (Johannes 2002), to ensure that resources can be harvested into the future. Today, many of these involve socioeconomic strategies, while others concern how we harvest what we take from the ocean to minimize damage to biodiversity. Improvements in the sustainability of aquaculture are also increasingly important. While the picture remains mixed overall, there are areas of clear success.

Large, highly valuable, industrial-scale fisheries are associated mostly with the developed world; they represent approximately 34% of the global catch and are the stocks with the resources allowing formal assessments (Costello & Ovando 2019). These fisheries became heavily overexploited with increases in effort and efficiency after World War II. In the 1990s and 2000s, prompted by sharp declines in stocks, modern fisheries management methods were instituted, which led to cuts in fishing levels that have greatly improved their status. For example, a recent analysis showed that the percentage of stocks with harvesting levels compatible with sustainability rose from 60% in 2000 to 68% in 2012 (Duarte et al. 2020).

There has been a steady improvement in the management of these fisheries, as the initial failures from some approaches led to refinements and the development of new ones (Anderson et al. 2019). For example, it is now recognized that simply limiting entry (capping the number of fishers) can fail because nothing prevents existing fishers from fishing more often with more efficient methods. Simply setting a total allowable catch may improve ecosystem and stock health if the catch level is set properly (although this can be difficult to do for both scientific and political reasons) but can lead to extremely short seasons, sometimes just one or two days per year, that flood markets, increase wasteful practices, fail to provide stable employment, and endanger fishers' lives (Anderson et al. 2019). For these reasons, large-scale fisheries are increasingly adopting various kinds of catch share schemes, which can be allocated to communities or individuals, be tradable or nontradable, and work by providing economic incentives to fish sustainably. An analysis of 11,135 fisheries from 1950–2003 showed that by the end of the study, fisheries with individual transferable quotas were half as likely to have collapsed (Costello et al. 2008), and catch shares have also been shown to reduce the race to fish (Birkenbach et al. 2017). These quotas have been adopted by fisheries in approximately 20 mostly developed countries, and the fisheries represented constitute approximately 20% of the annual global catch (Costello & Ovando 2019). While quotas have intrinsic limitations and problems related to details of execution, which can result in social unrest due to consolidation of control and perceptions of unfairness (Sumaila 2010), lessons are being learned so that mistakes are not repeated.

In contrast to the situation with well-assessed stocks, the remainder of fisheries, mostly in developing countries and representing approximately 66% of the global catch, are increasingly overfished and declining (Costello & Ovando 2019). In developing countries, much fishing is done by small-scale artisanal fishers, who represent more than 90% of the people directly employed in fishing globally (Defeo et al. 2016). Although their individual catches may be small, in the aggregate their activities can and have had serious impacts on the environments where they work, sometimes resulting in the collapse of the resources upon which they depend (Defeo et al. 2016). There are, however, examples of rights-based fisheries management emerging in these settings as well (including the return to traditional approaches; Johannes 2002), leading to greater sustainability. In some cases, small MPAs have been established, as in the two communities in Mexico described above, but in other cases the strategy is to manage fishing effort. As with small MPAs, the most successful examples typically involve primarily local control of fishing, where the government contributes to the management with a light touch. Fishing controls such as community quotas may also be combined with spatial controls, not only small MPAs but also spatially structured fishing, where each fisher has the right to fish in a certain area [known as territorial user rights to fisheries (TURFs)]. As with other management strategies, the details—for example, TURF size—matter (Viana et al. 2018). Success for several Latin American examples has been well documented, such as the loco in Chile, the yellow clam in Uruguay, and the spiny lobster in Mexico (now certified by the Marine Stewardship Council), with success being defined by such factors as larger caught individuals and higher resource abundance, more stable catches and higher catch per unit effort, and higher incomes (Defeo et al. 2016). In total, these rights-based management schemes involving TURFs and community cooperatives represent only approximately 2% of the global catch (Costello & Ovando 2019), so there is much room for expansion of these approaches.

In addition to these broader-scale improvements in management structure, there are also examples of specific steps taken to reduce particularly destructive fishing practices. As noted above, there is increasing recognition of the importance of protecting breeding aggregations. Similarly, the removal of nearshore gill nets in the Southern California Bight reduced the catch of spawning and pupping white and giant sea bass, soupfin sharks, and leopard sharks; the result has been the recovery of these large apex predators from a state of collapse or sharp decline (Pondella & Allen 2008). Another example is the prohibition of fish traps and other measures in Bonaire and Bermuda, which has not only reduced ghost fishing (the killing of fish by abandoned gear) but also improved reef health and resilience by increasing the number of parrotfish capable of grazing down macroalgae (Jackson et al. 2014, Steneck et al. 2019).

Ghost fishing is but one kind of bycatch, a phenomenon defined loosely as unintentional and unwanted catch. Bycatch that is discarded reduces the sustainability of fishing activities, and fish and invertebrate bycatch appears to be declining in both absolute and relative terms thanks to more selective gear, bans on discarding in some countries, and greater use of formerly discarded catch (e.g., for fishmeal), although it still constitutes approximately 10% of the annual catch (Zeller et al. 2018). Bycatch has particularly devastating consequences for air-breathing marine megafauna, in some cases being the single biggest threat to individual species (Lewison et al. 2014). Methods to reduce bycatch include deterrents such as pingers and scaring lines to reduce interactions, modified timing of fishing, weakened gear designed to allow animals to break free, ropeless gear, and exclusion devices (Hamilton & Baker 2019, Melvin et al. 2019). The results have been mixed and may be highly location and fishery specific, and implementation can be hampered by resistance from fishers who fear reducing their catches or increasing their costs. Nevertheless, there are some notable successes. For example, in the Alaskan long-line fishery, deployment of bird-scaring lines resulted in a 78% reduction in seabird bycatch; the effort was notable for the careful research and coordination with stakeholders that preceded implementation (Melvin et al. 2019). Similarly, use of turtle excluder devices in Australian trawl fisheries reduced sea turtle bycatch by 90% (Lewison et al. 2014).

Last, but certainly not least, humans are increasingly turning to aquaculture, including aquaculture of marine organisms (mariculture), for food production, with growth substantially higher in this sector than for other sources of food (Troell et al. 2014). Between 2011 and 2016, marine capture fisheries declined from 81.5 to 79.3 million tons, whereas animal mariculture increased from 23.2 to 28.7 million tons, which translates as the percentage of the total increasing from 22.2% to 26.6% (FAO 2018). Future growth could be much more substantial; however, the extent to which growth in mariculture is an environmental success story depends on where mariculture is sited and how growth is achieved, because damage to adjacent ecosystems and dependence on wild fish for feed are serious concerns. Marine bivalves, such as mussels and oysters, which currently represent approximately 59% of animal mariculture (FAO 2018), do not require outside sources of food and are thus more likely to contribute to food security; they can also help reduce eutrophication in coastal waters, and their cultivation has fewer animal welfare concerns (benefits they share with seaweed mariculture; Jacquet et al. 2017). Offshore mariculture has the advantage of being sited farther away from sensitive nearshore environments (Lester et al. 2018). There are also promising developments in terms of integrated mariculture (cultivating organisms from different trophic levels together) and the use of mariculture waste products (Stevens et al. 2018), as well as increases in the efficiency with which feed becomes food. For example, the fish-in:fish-out ratio for salmon, among the least efficient maricultural products in this regard, has dropped from more than 3.0 in 2000 to approximately 1.3 (Stevens et al. 2018).

5. REDUCING POLLUTION

For millennia, the ocean was used as a dumping ground—the personification of "dilution is the solution to pollution." Some of this pollution can be highly visible, such as oil and large plastics, thus guaranteeing a public response. Other types of pollution are much less conspicuous, such as toxins and microplastics. Some forms of pollution are potentially harmful in any amounts, such as highly toxic industrial waste and insecticides, whereas others are harmful in excess, such as nutrients. Not all pollution is chemical in nature (e.g., noise pollution). Although many problems remain, there have been notable successes as well.

Perhaps the most famous of these is the reduction in DDT, which was banned in the United States 10 years after the publication of Rachel Carson's *Silent Spring* in 1962. The effects of DDT were particularly damaging for avian apex predators, because the compound was concentrated up the food chain and caused eggshells to thin to the point that nesting failed. On the coast, the numbers of birds such as ospreys, bald eagles, and brown pelicans plummeted but have now largely recovered. For example, populations of bald eagles on the Chesapeake Bay dropped from 600–800 breeding pairs in the 1930s down to 60 pairs in the early 1970s but are now back to 1930s levels (Watts et al. 2007). Less well known but comparably important are the return to baseline levels of lead in the ocean following the transition to unleaded gasoline beginning in the 1980s, the sharp decline of imposex (anatomically deformed) dog whelk females following the ban of the antifouling compound tributyltin in 2008, and the improvement of safety regulations for large oil tankers, which has led to a 14-fold reduction in oil tanker spills since the 1970s (Duarte et al. 2020). All of these are testaments to the power of decisive conservation action.

On a more local level, there have been a number of successful reductions in nutrient pollution (Gross & Hagy 2017, Boesch 2019, de los Santos et al. 2019), including several notable cases of consequent recoveries of ecosystem health. In Europe, strong recoveries of seagrasses have been attributed to reductions in nutrient pollution in Denmark, Portugal, and Spain, and since the beginning of the twenty-first century, gains have exceeded losses in the region (de los Santos et al. 2019). In the Chesapeake Bay region, despite a doubling of the human population, total nitrogen discharges from point sources were cut in half, phosphorus discharges were reduced by almost 75%, and nitrate levels in streams draining forests (due in particular to reductions in airborne emissions) declined by 41% between 1984–1986 and 2012–2014 (Leslie 2018). The result has been a 316% increase in the subaquatic vegetation in the bay (Lefcheck et al. 2018). Even more striking is the example of Tampa Bay, Florida: After this area lost 47% of its seagrass cover between 1950 and 1999, restorative action achieved a 90% reduction in nitrogen from point sources and a recovery of seagrasses to 1950s levels by 2016 (Tomasko et al. 2018). These successes were hard fought, and in the US examples described above, efforts began in the 1970s. The Chesapeake Bay watershed encompasses six states, and restoration has required a partnership of local, state, and federal agencies; in Tampa Bay, more than 900 public and private projects were involved (Beck et al. 2019), and the effort cost more than US$500 million (Boesch 2019).

The establishment of Earth Day in the United States in 1970 was inspired by a major oil spill; 50 years later, it is plastic pollution that has captured public attention. Plastic production has exploded since first becoming a commercial product in the 1950s, and its negative effects, including the use of fossil fuels in its production and costs associated with managing it, are extensive and growing (Geyer et al. 2017, Law 2017, Schnurr et al. 2018). We are far from a solution to this problem, which will involve reduced usage, better waste management, and the development of alternatives to replace nondecomposing single-use plastics. There have been numerous public awareness campaigns (Vince & Hardesty 2018) and well-publicized efforts to collect and recycle waste from the ocean (e.g., trash-to-treasure programs; UN Environ. 2017), which also includes abandoned fishing gear. Among the various policy approaches (Abbott & Sumaila 2019), some of the most conspicuous achievements have been bans and taxes imposed on single-use consumer items such as plastic bags, eating and drinking utensils, and microbeads. As of the most recent reviews, these applied to all or parts of 26 individual countries in Europe, 17 in Asia and Oceania, 18 in Africa, and 14 in the Americas (Xanthos & Walker 2017, Schnurr et al. 2018). In some cases, these efforts have had marked impacts on usage; for example, in Ireland, annual per capita use of plastic bags dropped from 328 to 14 following the imposition of bag taxes. In addition, there have been individual efforts from the private sector; in the Netherlands, 80% of cosmetics companies were microbead free by 2017 in the absence of legislation. Evidence for impacts underwater are far more limited, but one study around the United Kingdom detected a drop in the percentage of trawls containing plastic bags between 1992 and 2017 (Maes et al. 2018).

6. RESTORING HABITATS

Nature has an enormous ability to repair itself when left to its own devices; witness the substantial recovery of coral reefs on Bikini Atoll from nuclear bomb testing in the 1940s and 1950s (Richards et al. 2008). Nevertheless, while it is sometimes the case that just leaving nature alone to recover after removing stressors is adequate or more cost-effective, in other cases, after mitigating the source of the problem, jump-starting the recovery process is either essential (e.g., in the case of Allee effects or alternate stable states) or desirable (because delayed recovery could result in increased vulnerability to future catastrophic events). Indeed, in some cases investment in restoration is preferred to habitat protection if its costs are outweighed by the speed with which degraded habitat is transformed into higher-quality habitat (Possingham et al. 2015). The following concentrates on active steps taken to repair habitats by restoring critical components of the ecosystem, such as ecosystem engineers; by removing or reducing marine invasive species; or by taking steps on land that have positive consequences for the ocean.

Restoration of the critical structural components of coastal marine ecosystems, such as mangroves, seagrasses, salt marsh grasses, kelps, shellfish, and corals, has been widely practiced for decades, although most of these efforts have been small in scale, and there is no global inventory of what has been restored (Duarte et al. 2020). Nevertheless, there is growing interest in restoration because the scale of past habitat destruction has been so large (Jackson 2008), as well as increased attention to strategies based on sound natural and social science because restoration is costly and often fails. Between 1992 and 2014, the United States spent more than US$665 million on 1,620 coastal restoration projects covering 243,064 acres (Li et al. 2019). Median restoration costs per hectare and survival rates globally have been estimated at US$8,961 and 51.3% for mangroves, US$66,821 and 56.2% for oyster reefs, US$67,128 and 64.8% for salt marshes, US$106,782 and 38.0% for seagrasses, and US$165,607 and 64.5% for coral reefs (Bayraktarov et al. 2016). There is also growing recognition that restoration efforts themselves, which previously were often small-scale gardening efforts, can, if properly designed, improve scientific understanding for future efforts (e.g., the importance of positive interactions and scale; Schulte et al. 2009, Renzi et al. 2019). Learning is also increasingly enhanced through the formation of networks of practitioners (e.g., the Coral Restoration Consortium; **http://crc.reefresilience.org**).

In their review, Duarte et al. (2020) extensively analyzed global restoration efforts for coral and oyster reefs, kelps, salt marshes, and mangroves. They reported that restoration efforts began to increase rapidly in the 1990s and 2000s and now total, for example, 1,768 oyster restoration projects along the east coast of the United States, 140 salt marsh restoration projects across Europe, and 250 kelp restoration projects in Japan, with successful projects even occurring in challenging urban landscapes. Some of these efforts are logistically and sociologically complex; for example, kelp restoration in Japan involves fishers, citizens, and government scientists working together to clean rocks of sediments, relocate excess herbivorous fish and sea urchins, and plant kelp juveniles. Importantly, in some cases restoration successes have occurred at substantial scales (Duarte et al. 2020). On the Virginia coast, more than 6 million eelgrass seeds were planted over two years across 125 hectares, and plants have since expanded to 1,714 hectares. San Francisco tidal marshes, which had declined to 8% of historic levels, by 2015 had been restored to 30% of their previous coverage, with another 10% privately purchased for restoration. In Brisbane, mangroves have been restored to 1946 levels, and similar efforts worldwide contribute to a marked slowing in net rates of mangrove loss (Hamilton & Casey 2016).

As alluded to above, restoration can involve the removal of organisms as well as their addition. The challenge is immense for marine invasive species, because once truly established, they are effectively impossible to eradicate. Successful examples of eradication include several species of seaweeds in California, Hawaii, and New Zealand and mussels in Australia (Williams & Grosholz 2008). These efforts are expensive (e.g., NZ$423,500 to eradicate an invasive seaweed fouling a single sunken ship in the Chatham Islands; Wotton et al. 2004) and must often be sustained. When eradication is not feasible, control can sometimes be effective, including the development of a market for the removed organisms (e.g., for lionfish in the Caribbean; Chapman et al. 2016).

The above examples have all involved restoration in the ocean, but restoration on land can aid marine organisms as well, both directly and indirectly. This is not surprising given the intimate connections between watersheds and coastal waters (Lefcheck et al. 2018, Beck et al. 2019). For example, restoring degraded landscapes increases the potential for terrestrial plants to capture nutrients before they enter the ocean.

For seabirds, removals of invasive rats and other mammals on islands have had notable successes, including on large scales (although for some slowly reproducing species vulnerable to Allee effects, eradication must be coupled with active restoration of the birds themselves; Kappes & Jones 2014). In some cases, recoveries are rapid; for example, within a decade of rat eradication on Anacapa Island in the Channel Islands, California, the Scripps's murrelet exhibited a threefold increase in hatching success and a 14% annual increase in the number of nests (Whitworth et al. 2013). The most extensive successful eradication effort to date occurred from 2011 to 2018 on the subantarctic island of South Georgia, a location of extraordinary biological importance for seabirds. Rats and mice were cleared from an area more than an order of magnitude larger than any previously attempted (Martin & Richardson 2019); approximately 90% of the US$11 million cost (~US$104 per hectare) came from private philanthropy.

There are many benefits from such efforts, and not just on land, because seabirds forage in high-productivity areas and through their guano enrich waters surrounding nesting and resting sites. For example, a comparison of rat-free (not from eradication) and rat-infested islands in the Indian Ocean showed not only that rat-free islands had 760 times more seabirds, but also that the biomass of fish on surrounding reefs was 48% higher, with ecologically critical herbivorous fish being 93% more abundant (Graham et al. 2018). These differences also appear to translate into a greater potential ability to rebound from bleaching-caused mortality (Benkwitt et al. 2018).

Another important conservation action on land that can have large positive impacts on the ocean is the removal of dams, because they block the movement of marine species that use fresh waters to spawn. For example, in Maine, dams reduced access to lake spawning habitats of alewives by 95%, but dam removal efforts have resulted in dramatic increases in alewife numbers in rivers (McClenachan et al. 2015); importantly, because alewives are prey for many marine species, there is preliminary evidence of positive impacts on coastal food webs (Willis et al. 2017).

7. MITIGATING OCEAN WARMING AND ACIDIFICATION

The various steps being taken to reduce greenhouse gas emissions are beyond the scope of this review, although recent successes mean that former business-as-usual scenarios are no longer the best metric against which to measure progress (Hausfather & Peters 2020). Moreover, this field is changing so rapidly that any review is likely to soon be out of date. Nevertheless, the following provides a brief discussion of the role of marine ecosystems in carbon storage and ocean-based sources of energy, the two strategies that overall offer the greatest promise with respect to ocean strategies for addressing climate change (Gattuso et al. 2018). These ocean-based solutions have been largely ignored until relatively recently (Gattuso et al. 2018, Solan et al. 2020) but are potentially crucial because of the ocean's size.

Vegetated coastal ecosystems—seagrasses, mangroves, and tidal marshes—are now well recognized as carbon sinks and are sometimes referred to as blue carbon ecosystems (Macreadie et al.

2017). Although they represent only 0.2% of the ocean surface, they are highly efficient, storing perhaps 50% of all the carbon in marine sediments and being capable of playing that role for thousands of years. They can also be managed to maximize their carbon storage potential by reducing nutrient inputs, restoring water-flow regimes, and enhancing predators to minimize excessive disturbance of sediments by surface-dwelling and infaunal animals, approaches that serve other biodiversity goals as well. Thus, the successes outlined above in protecting and restoring these ecosystems also have important positive implications for climate change. This is particularly true because these ecosystems can shift from carbon sinks to carbon sources if they are degraded; losing 1 hectare of these ecosystems is comparable to losing 10 hectares of native forest in terms of carbon emissions, leading to the suggestion that protecting and restoring them for their other positive attributes is actually a secondary aim (Macreadie et al. 2017). In reflection of this, some countries have begun to use carbon financing mechanisms to conserve and restore these ecosystems (Wylie et al. 2016).

The ocean is also already making an important contribution to reducing fossil fuel emissions, as ocean-based wind power facilities, both anchored and floating, are now being deployed around the world. However, the potential is much greater, as wind generation over some parts of the open ocean might be able to exceed power generation on land or near shore by a factor of three or more (Possner & Caldeira 2017). Other sources of ocean energy could come from tapping the power of the tides (both currents and range), other ocean currents, waves, and heat and salinity gradients, as well as marine algae as a fuel source (Borthwick 2016), but these are still largely in the preliminary research or pilot stage in terms of implementation. Although ocean-based sources of energy present a range of technical, political, environmental, and economic challenges, the need for a far fuller use of ocean energy and its consideration in the context of marine spatial planning is clear.

8. CO-BENEFITS AND ECOSYSTEM-BASED MANAGEMENT

The previous sections have, for purposes of presentation, divided examples of conservation success into different categories, but as mentioned, these divisions are artificial because strategies designed for one purpose may serve other goals as well. Even more to the point, conservation is increasingly organized around the concept of ecosystem-based management, where the multiplicity of benefits is by design rather than an accidental outcome. Ecosystem-based management approaches explicitly "consider the connections between different elements of the ecosystem, including people, and also recognize the full range of benefits that marine systems provide" (Leslie 2018, p. 3,519). While these connections can be difficult to document, even for something as well established ecologically as trophic cascades (e.g., Steneck et al. 2018), this does not mean they are absent.

There are many examples, including some noted above, of how conservation successes can exhibit a multiplicity of ecosystem benefits: Eradication of rats benefits not only seabirds but also reefs (Graham et al. 2018), restoration of blue carbon ecosystems contributes to biodiversity and climate change goals (Macreadie et al. 2017), recovery of sea otters facilitates the recovery of seagrasses (Hughes et al. 2019), slowing vessels to reduce ship strikes with whales reduces greenhouse gas emissions and underwater noise pollution (Leaper 2019), MPAs lower the release of carbon by reducing disturbance of sediments by fishing gear (Roberts et al. 2017), seagrass meadows can locally ameliorate the impacts of ocean acidification (Albright & Cooley 2019) and reduce disease (Lamb et al. 2017) on nearby coral reefs, and TURFs established for fisheries management can have substantial biodiversity benefits as well (Gelcich et al. 2019).

People, as part of marine ecosystems, also benefit enormously from their health (Barbier 2017, Duarte et al. 2020). Their ecosystem services, improving human lives today, range from food and income to health and safety, in addition to recreational and other social values. Effective large-scale fisheries management prevents not only a biological tragedy of the commons, but also an economic one, and can even saves lives (Anderson et al. 2019). MPAs and TURFs similarly have a wide array of positive human impacts (Gelcich et al. 2019, Rasheed 2020). Around the world, nature-based tourism creates new and substantial sources of income; in addition to the Cabo Pulmo, Mexico, case study described above, other examples include a 25-fold increase in tourism visitations associated with sperm whale increases in New Zealand (Hammerschlag et al. 2019) and the value of shark-diving tourism for the economies of Australia (Huveneers et al. 2017) and Palau (where it represents 8% of the country's annual gross domestic product; Vianna et al. 2012). Healthy marine ecosystems can also potentially reduce human disease; in a study in Indonesia, levels of the pathogen *Enterococcus* were two to three times lower in coastal waters where seagrasses were present compared with waters where they were absent (Lamb et al. 2017).

Ecosystem- or nature-based solutions (Nesshöver et al. 2017) epitomize the concept that helping nature and people can go hand in hand. For coastal defense in particular, these approaches have been shown to be both effective and good value for money, and have been implemented in a few places at moderately large scales (Temmerman et al. 2013, Narayan et al. 2016). Annually across the globe, reefs reduce expected damages from storms by hundreds of millions of dollars per year for many tropical nations (Reguero et al. 2020), and in the United States, between 1996 and 2016, the economic value of wetlands in flood protection during cyclones averaged US$1.8 million per square kilometer per year (Sun and Carson 2020). Oyster and marsh restorations were found to be much more cost-effective along the US Gulf Coast, even when considering only the direct benefits of risk reduction, as compared with almost all human-built infrastructure (sandbags were the only exception; Reguero et al. 2018).

While incomes and some physical health metrics are comparatively easy to quantify, other aspects of human benefits, particularly those associated with human capital (e.g., mental health and education) and social capital (e.g., interpersonal connections and trust), are more challenging to quantify and are much less often studied. However, they can be substantial in locally run conservation efforts [e.g., for MPAs (Rasheed 2020) and TURFs (Gelcich et al. 2019)] and may even exceed biological benefits, particularly initially (e.g., the educational program of the Billion Oyster Project in New York Harbor; O'Neil et al. 2020). Similarly, the return of alewives to the rivers of Maine following dam removal has had profound social benefits (as indicated by multiple quotations given in McClenachan et al. 2015). These kinds of benefits work as intrinsic motivators by enhancing the sense that people can affect their own future, have the capability to do so, and are connected to each other and place (autonomy, competence, and relatedness), factors that are correlated with meeting socioeconomic or ecological goals (Cetas & Yasué 2017).

9. CAVEATS

The preceding discussion has deliberately focused almost exclusively on successes in marine conservation writ large. Before looking forward to what might lie ahead, it is worth reflecting on the challenges we face to (*a*) preserve what we have achieved, (*b*) manage the trade-offs that will become increasingly common as progress made on one front leads to problems on another, and (*c*) vastly scale up or replicate the successes achieved to date.

As proud as we should be of what marine conservation has accomplished, a continuation of these successes can never be assumed, as they often must be actively maintained. Moreover, the potential for setbacks will inexorably increase with growing human numbers and per capita consumption. Indeed, in some cases, success itself creates the pressures that make a setback more likely, as exemplified by the threat of large-scale touristic development prompted by and threatening the marine reserve at Cabo Pulmo, Mexico (Langle-Flores et al. 2017). Changing political situations (e.g., due to war and, most recently, the global coronavirus pandemic) can unexpectedly undermine achievements once thought to be settled. The ultimate setback, which affects almost all marine conservation, is, of course, global change driven by greenhouse gas emissions, which can undo previous accomplishments (as epitomized by the mass mortality of corals on the Great Barrier Reef despite protection; Hughes et al. 2017) or generate future conflicts that undermine current policies (Mendenhall et al. 2020). Moreover, even unambiguous and sustained success in one aspect of conservation can represent trade-offs with respect to other conservation goals—for example, when increases in one endangered species threaten the recovery of another or human well-being (Cammen et al. 2019) or when green energy infrastructure comes with environmental costs.

Even if today's successes were immune to setbacks and trade-offs, we would still face the problem of the small overall scale of success to date. Single-species recoveries represent a tiny fraction of all threatened marine biodiversity, and these recoveries are generally incomplete or mixed geographically (Duarte et al. 2020), even when they are acclaimed as successes [e.g., the recoveries of alewives (McClenachan et al. 2015) and sea otters (Hughes et al. 2019)]. Most species remain at or close to their lowest recorded levels, with only whales and other marine mammals being exceptions (Lotze & Worm 2009), and overall only 10–50% of species and ecosystems have exhibited even partial recovery (Lotze et al. 2011). Restoration remains typically small in scale (Duarte et al. 2020), and restored ecosystems do not necessarily function at the level they did before degradation. We have slowed the rate of mangrove loss dramatically, but losses still exceed gains, and loss rates remain high in Southeast Asia (Hamilton & Casey 2016), the most biodiverse of all mangrove regions. There is also a temptation to focus on outputs (e.g., percentage of ocean area protected) as opposed to outcomes (biological responses to protection)—ignoring, for example, that in some places MPAs may in fact be more heavily trawled than unprotected areas (Dureuil et al. 2018), that many MPAs have inadequate resources, leading to poor outcomes (Gill et al. 2017), and that MPAs are not placed optimally with respect to the threats they could reduce (or, indeed, that even random placement would be preferable to the current placements; Kuempel et al. 2019). As of 2015, only 9% of plastic produced to date had been recycled, while plastic production continues to grow (Geyer et al. 2017) and recycling has become more difficult due to policy changes in Asia. We remain far from achieving the targets of the 2016 Paris Agreement, and even these are not adequate to achieve stated goals (Hausfather & Peters 2020). With data like these, it is easy to see the marine conservation glass as half empty and respond to any reported success with, "Yes, but. . . . " However, we then risk having hopelessness itself be a factor in the demise of ocean organisms and ecosystems (Balmford & Knowlton 2017) and ignore the counterfactual argument, difficult to answer but important nonetheless: What would have happened if we had done nothing?

10. LOOKING FORWARD

Despite the highly concerning studies noted above, meaningfully recovering marine biodiversity remains feasible. A recent study (Duarte et al. 2020) concluded that substantial recovery (defined as the restoration of marine ecological structure, functions, resilience, and services, which would require a 2.4% annual improvement in key metrics) could be achieved by 2050, assuming that threats, including climate change, were abated (admittedly a big assumption). They emphasized how trends are moving in a more positive direction for many conservation statistics and how past rates of recovery have often been relatively rapid when threats were reduced.

Part of the reason for the more positive trend lines of recent decades is that conservation is increasingly science based, which improves outcomes (e.g., Hilborn et al. 2020). Focused, solutions-oriented conservation science includes more accurate assessments of where to concentrate conservation and restoration efforts and more careful analysis of conditions leading to success (and failure) in past efforts (i.e., evidence-based conservation; Salafsky et al. 2019). Fortunately, there is increasing academic interest in analyzing not only what leads to conservation failure and vulnerability in the ocean, but also what leads to success, including unusual successes or bright spots (Jackson et al. 2014, Cinner et al. 2016, O'Leary et al. 2017, Cvitanovic & Hobday 2018).

New databases and indices keep track of progress (Hamilton and Casey 2016, Halpern et al. 2017, Akçakaya et al. 2018), and conservation technologies are being developed at an accelerating pace (e.g., Natl. Acad. Sci. Eng. Med. 2019, Queiroz et al. 2019, Asner et al. 2020). Coverage of ocean environmental issues in the media has increased dramatically over the last two decades (Johns & Jacquet 2018), and the increasingly open access to and rapid transmission of information allows lessons to be shared more readily, with the potential for more rapid synthesis using artificial intelligence (e.g., Van Houtan et al. 2020). There is also a vastly increased appreciation of the importance of social science (Bennett et al. 2017). New policy and financing ideas are being explored (Sala et al. 2016, Maxwell et al. 2020, Reguero et al. 2020), and there is now nearly universal recognition that successful efforts depend on integration of local and indigenous knowledge and perspectives, although execution still lags behind recognition (e.g., Giakoumi et al. 2018).

Indeed, it is the social science perspective that points to the importance of shining a spotlight on marine conservation success. This is sometimes framed as an argument about the appropriate balance between positive and negative messaging to inspire public action: Too much positivity leads to complacency, whereas too much negativity leads to hopelessness and disengagement. Messaging is a complex topic about which there is considerable debate and context dependence in terms of the answer (Drummond & Fischhoff 2017, Kidd et al. 2019, McAfee & Connell 2019). Even the character of the balance is unclear; contrary to prevailing assumptions, positive stories about marine conservation outweigh negative stories in the media (Johns & Jacquet 2018), but the impact of positive stories is likely less because negative information is stickier (Ledgerwood & Boydstun 2014).

This is, however, more than an argument about messaging. Conservation professionals and policy makers benefit from exemplars, both as data and as stories (Leslie et al. 2013), to motivate their work (Cvitanovic & Hobday 2018). While studies featuring recovery, success, and improvement are a growing feature of marine conservation studies (**Table 1**), it remains difficult to find them, and most educational resources do not currently capture this change. This was part of the rationale behind launching the #OceanOptimism hashtag in 2014; it has since been used by more than 45,000 Twitter accounts (Hashtracking account accessed March 31, 2020), and a search for it can unearth examples of success, old and new, that are otherwise poorly known. However, a hashtag is no substitute for a more formal consideration of success in marine conservation, hence this review.

Table 1 Results of Web of Science searches for articles about marine conservation

Years	Number of articles	
	Marine conservation[a]	Subset with words suggesting positive outcomes[b]
1980–1989	22	1 (4.5%)
1990–1999	90	10 (11.1%)
2000–2009	401	80 (20.0%)
2010–2019	1,010	313 (31.0%)

[a]Search term: "marine conservation" OR "ocean conservation".

[b]Search term: ("marine conservation" OR "ocean conservation") AND (success* OR recover* OR improve*).

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