Received: 30 January 2019 | Revised: 6 May 2019 | Accepted: 13 May 2019
DOI: 10.1002/aqc.3182

VIEWPOINT

WILEY

Eight urgent, fundamental and simultaneous steps needed to restore ocean health, and the consequences for humanity and the planet of inaction or delay

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Abstract

1. The ocean crisis is urgent and central to human wellbeing and life on Earth; past and current activities are damaging the planet's main life support system for future generations. We are witnessing an increase in ocean heat, disturbance, acidification, bio-invasions and nutrients, and reducing oxygen levels. Several of these act like ratchets: once detrimental or negative changes have occurred, they may lock in place and may not be reversible, especially at gross ecological and ocean process scales.
2. Each change may represent a loss to humanity of resources, ecosystem function, oxygen production and species. The longer we pursue unsuitable actions, the more we close the path to recovery and better ocean health and greater benefits for humanity in the future.
3. We stand at a critical juncture and have identified eight priority issues that need to be addressed in unison to help avert a potential ecological disaster in the global ocean. They form a purposely ambitious agenda for global governance and are

aimed at informing decision-makers at a high level. They should also be of interest to the general public.

4. Of all the themes, the highest priority is to rigorously address global warming and limit surface temperature rise to 1.5°C by 2100, as warming is the pre-eminent factor driving change in the ocean. The other themes are establishing a robust and comprehensive High Seas Treaty, enforcing existing standards for Marine Protected Areas and expanding their coverage, especially in terms of high levels of protection, adopting a precautionary pause on deep-sea mining, ending overfishing and destructive fishing practices, radically reducing marine pollution, putting in place a financing mechanism for ocean management and protection, and lastly, scaling up science/data gathering and facilitating data sharing.
5. By implementing all eight measures in unison, as a coordinated strategy, we can build resilience to climate change, help sustain fisheries productivity, particularly for low-income countries dependent on fisheries, protect coasts (e.g. via soft-engineering/habitat-based approaches), promote mitigation (e.g. carbon storage) and enable improved adaptation to rapid global change.

KEYWORDS

climate change, deep-sea mining, finance, fisheries, fishing, high seas, MPAs, ocean, pollution, protection, scientific research, sustainability

1 | INTRODUCTION

The Apollo 8 photographs taken on Christmas Eve 1968 revealed our world as the blue planet, finite and beautiful in the dark void of space. Back then, few could have imagined the impact we are now having on this ocean world. In the intervening years, we have witnessed much discussion, some valued key actions, but nowhere near the scale of what is needed to keep pace with, let alone get ahead of the problems our activities are causing to the natural world.

The ocean, by its breadth and depth, occupies more than 97% of the living space on Earth. It dominates the processes that keep our planet habitable such as regulating the climate by absorbing excess carbon dioxide and heat (e.g. Bijma, Pörtner, Yesson, & Rogers, 2013; IPCC, 2018; Levitus, Antonov, & Boyer, 2005; Reid et al., 2009; Rogers, Sumaila, Hussain, & Baulcomb, 2014; Wijffels, Roemmich, Monselesan, Church, & Gilson, 2016). Yet this protection comes at a cost as the ocean is now becoming more acidic (Cattano, Claudet, Domenici, & Milazzo, 2018; Duffy et al., 2018; Good et al., 2018), is heating up with virtually every year now being a record-breaking hot year (Cheng, Abraham, Hausfather, & Trenberth, 2019; Frölicher, Fischer, & Gruber, 2018; Gleckler, Durack, Stouffer, Johnson, & Forest, 2016; Zanna, Khatiwala, Gregory, Ison, & Heimbach, 2019), and is losing its life-giving oxygen (Levin, 2018). The concern is how much longer the ocean can continue to function as it is, whilst subject to the pressures of climate change and other impacts. We are already witnessing against historical baselines the impacts of a changing ocean on marine life and the economy (Cheung, Watson, & Pauly, 2013; Gattuso et al., 2015; Sumaila et al., 2019; Sumaila, Cheung, Lam, Pauly, & Herrick, 2011). For too long we have mistaken the immensity of the ocean for inviolability, but those days are gone, and we stand at a critical juncture. Cutting emissions, while essential, alone will not solve the environmental problems we face. What is needed is a suite of measures, implemented together, to help gain the maximum opportunity to restore ocean health.

Here, we propose eight measures which, if acted upon simultaneously, would represent major progress towards recovering ocean health and safeguarding planetary and human wellbeing – the overall effect being far more than if the actions were implemented in isolation. They form a purposely ambitious agenda for governments and senior policy advisers and decision-makers. This is because the challenges we face are now so vast that grand ambition, strong leadership and direction are needed if we are to avoid reaching ecological thresholds beyond which ocean health will decline abruptly. The points raised should also be of interest to the general public given heightened interest in such topics of late.

The consensus is that we have about 10 years to make these changes, and the opportunity to make this happen is now. The reason for this is that 2020 is the deadline for many international processes and policies. The Paris Climate Agreement comes into force in 2020 with its implementation plan, negotiations for the UN Treaty on biodiversity protection beyond national jurisdiction are scheduled to be completed by 2020, and an ocean Sustainable Development Goal has targets that are to be delivered by 2020. Properly implementing these policy opportunities and bringing these global efforts together must bear fruit as scientists warn that tipping points in ocean decline are now significantly more likely to happen if action is not taken (Beaugrand et al., 2019; Steffen et al., 2018).

2 | DEVELOPING THE CONSENSUS

In late 2018, the International Programme on the State of the Ocean (IPSO) convened experts for a workshop on ocean health. This repeated an exercise in 2011 that produced a global State of the Ocean report (Rogers & Laffoley, 2013). The 2011 report warned of the threat of mass marine extinctions caused by the multiple stressors affecting ocean health. It garnered worldwide government and media attention and was part of a step-change in the visibility of the increasing rate of decline in the functioning of the ocean.

This time IPSO asked ocean experts across science, law, policy and economics to consider the major actions needed to achieve ocean protection, considering changes already locked into the ecosystem, the current and likely future operating environment for policy, legal and other solutions, and emerging threats and opportunities. Without exception, the experts are united on four points:

- they highlight our improving understanding of ocean ecosystems and processes, which provide a multitude of vital services on which we all rely, but that there is still much to learn;
- they are alarmed by the significant rate of human-induced change occurring *now* which threatens that life;
- they are gravely concerned that the window of opportunity for action is closing; and
- they are united in proposing an urgent suite of measures to better protect and manage the ocean.

The analysis was based around the following questions:

1. From your perspective, where are the major gaps in ocean protection/conservation effort?
2. Which three interventions would make the biggest positive impacts in arresting the trajectory of ocean decline?
3. What one action should be taken within the next three years if we are going to make 'the difference' in time, or what do we have to do now because delay will mean the negative impacts will be irreversible/catastrophic?
4. Are there recent trends in ocean change which, in your view, are cause for concern and need more attention?
5. If you had the power, what would you change/do/implement tomorrow?

By identifying key opportunities for ocean protection, the IPSO exercise enabled strategic decisions to be made about where existing work can be amplified or augmented. It helped identify gaps in effort, funding and geographic capacity and showed how existing work, approaches and solutions could be replicated, scaled and aligned.

3 | KEY MESSAGES

There is growing understanding of the functioning of the ocean and of its essential role in making life on Earth possible (e.g. Steffen et al., 2018). New science has made the deteriorating state of the ocean clearer than ever (e.g. Breitburg et al., 2018; Oschlies, Brandt, Stramma, & Schmidtko, 2018) with deoxygenation of vast regions of particular concern (Levin, 2018) as well as increasing rates of acidification (e.g. Cattano et al., 2018; Duffy et al., 2018) and warming owing to increasing levels of CO_2 (e.g. Wijffels et al., 2016), as well as evidence that the ocean is becoming less productive (e.g. Laufkotter et al., 2015). Alongside the ever-present issue of overfishing, these threats come during a rush to secure extraction rights (e.g. oil and gas, seabed mining) over increasing areas and depths, with existing regulatory bodies poorly equipped to coordinate activities and consider potential impacts in a systematic way. Advances in technology play an important role in data gathering, monitoring and enforcement of rules, but human action is key. All of the experts surveyed called for the need to increase ocean literacy through the global spread of scientific information about the ocean and the economic activities that are dependent on it.

The experts identified the following eight priority actions needed to avert ecological disaster in the global ocean:

- address climate change – implement policies to limit the temperature rise to 1.5°C, but prepare for a 2–3°C temperature rise;
- secure a robust and comprehensive High Seas Treaty with a Conference of the Parties and a Scientific Committee;
- enforce existing standards for effective marine protected areas (MPAs), and in particular fully protected marine reserves, and extend their scope to fully protect at least 30% of the ocean, including representation of all habitats and the high seas, while ensuring effective management to prevent significant adverse effects for 100% of the rest of the ocean;
- adopt a precautionary pause on deep-sea mining to allow time to gain sufficient knowledge and understanding to support informed decisions and effective management;
- end overfishing and destructive practices including illegal, unreported and unregulated (IUU) fishing;
- radically reduce marine water pollution;
- provide a financing mechanism for ocean management and protection; and
- scale up scientific research on the ocean and increase transparency and accessibility of ocean data from all sources (i.e. science, government, industry).

The last two areas cut across the first six. Each topic is considered in more detail below to justify and to explain the main points for action.

3.1 | Address climate change – implement policies to limit the temperature rise to 1.5°C, but prepare for a 2–3°C temperature rise

Climate change, driven by rising atmospheric carbon dioxide levels and other greenhouse gases such as methane, with associated ocean warming, acidification and deoxygenation, was a critical concern for all of the experts surveyed. It is a difficult political and socio-economic problem that is being sidelined in favour of more easily tackled issues such as reducing plastic pollution (Stafford & Jones, 2019). There was unanimity on the need to maintain a strong focus on climate change as the central issue, and not get side tracked by other issues, which still need to be addressed but not at the cost of addressing climate change. It is the pre-eminent factor driving change in the ocean, and climate change must remain at the forefront of all actions.

Climate change impacts in the ocean are pervasive and accelerating, and they interact with most of the other human oceanic impacts. The most familiar impacts are often seen as sea-level rise and increased storm intensity, but alongside surface warming from climate change, ocean warming, acidification and deoxygenation are now of such serious concern that they have been referred to by the IPSO workshop experts as the other three of 'the four horsemen of the apocalypse'. These stressors are not being addressed by the global community with the urgency that is needed. Already we have seen the threat of extinction of reef-forming corals increase dramatically, largely as a result of ocean warming driving repeated mass coral bleaching events (see Carpenter et al., 2008; Hughes, Anderson, et al., 2018; Hughes, Kerry, et al., 2018; Veron et al., 2009). Polar ecosystems are under major threat from environmental changes including rising temperatures, loss of sea ice, changes in primary productivity and invasive species. These threats are already manifesting in the Arctic and regionally within the Antarctic (e.g. Atkinson et al., 2019; Constable et al., 2014; Eamer et al., 2013). Even the deep sea is not protected from the effects of climate change (Sweetman et al., 2017). Both direct impacts from warming and deoxygenation and indirect effects via changes in the quantity and quality of surface primary production are likely to impact the abundance and biomass of the biota on the sea bed and in the water column, with significant consequences for vital ocean functions, such as food provision through poleward shifts and consequences for changes in fisheries catch (Barange et al., 2014; Cheung et al., 2010), and active transport and burial of carbon (e.g. Ashford et al., 2018; Rogers, 2015; Sumaila et al., 2019). Overall, the effects of climate change on marine ecosystems have been global and have manifested rapidly and at large scales (Beaugrand et al., 2019) with major impacts on ecosystem structure, function and service provision to humankind with measurable social and economic consequences (Gattuso et al., 2015; Lam, Cheung, Reygondeau, & Sumaila, 2016).

Climate change combined with acidification and marine heat waves, and pulses of low-oxygen water are causing marine organisms to suffocate, starve, die of heatstroke or become corroded (e.g. Birkeland, 2019; Frölicher et al., 2018). The emergence of novel ocean conditions for organisms, from plankton to mammals, is driving shifts in species distributions and rapidly altering the fundamental ecology of coastal habitats upon which people rely for income and wellbeing (Agostini et al., 2018).

Whilst it is imperative that the Paris Agreement be implemented in full, and that surface temperature rises be limited to 1.5°C, not 2°C (IPCC, 2018; Veron et al., 2009), if we are to protect marine biodiversity, jobs and incomes of fishers and household budgets for seafood (Sumaila et al., 2019), we should also prepare for the worst. If the Paris Agreement is to be successful then the ocean must be fully integrated into the climate regime with an appropriate carbon price, so ocean–climate interactions and consequences are properly recognized and managed.

3.1.1 | The need for action

Research shows that the ocean has been heating faster and deeper than scientists had previously thought (e.g. Breitburg et al., 2018; Oschlies et al., 2018). There are signs that the ocean might be starting to release some of that stored thermal energy as seen during the 2015–16 El Nino, which could contribute to significant global temperature increases in the coming years (Yin, Overpeck, Peyser, & Stouffer, 2018). Increasing the understanding of heat absorption and heat release from the sea to the atmosphere should be a research priority. Recent reports and papers (e.g. Altieri & Diaz, 2019; Breitburg et al., 2018) show an alarming trend of declining oxygen levels in the ocean. The Bay of Bengal stands out as an example, where increasing seawater temperatures have changed currents and monsoon cycles at the same time as agrochemical and sewage levels have built up, threatening to push this entire system to ocean basin anoxia. This would have severe impacts on regional food security and the global nitrogen cycle (Bristow et al., 2016).

Ocean acidification is also of great concern as it is rapidly changing the chemistry of sea water and yet scientists have very little confidence in their ability to predict the knock-on effects of these major changes on marine food-webs and ecosystems. One of the clearest signatures of accelerating ocean catastrophe is seen in coral reefs, both deep and shallow, from ocean warming and acidification (Hughes, Kerry, et al., 2018; Steiner, Turchyn, Harpaz, & Silverman, 2018). Around 90% of coral reefs are already damaged through unsustainable use (Birkeland, 2019), with all reefs, even those that are less exploited, severely threatened by warming and acidification. We are potentially witnessing the end of the greatest era of coral reef growth in geological history and are faced with the challenge of managing their decline by working to keep as many of them as productive as possible. If a reduction in carbon emissions occurs soon, we will still have the building blocks of coral reef biodiversity to enable recovery and start restoring the damage already done.

3.2 | Secure a robust and comprehensive High Seas Treaty with a Conference of the Parties and a Scientific Committee

The high seas occupy about 61% of the ocean surface and 43% of the surface of the planet, but there are only piecemeal regional and sectoral means to protect marine areas for biodiversity conservation and no coherent approach to effectively assess, monitor and manage the environmental impacts of human activities (Boyd et al., 2018). Efforts to protect global-scale biodiversity such as through representative networks of MPAs are flawed without the high seas being included (Sumaila et al., 2015).

It is essential that an ambitious treaty on the conservation and sustainable use of marine biodiversity beyond national jurisdiction (BBNJ) be achieved by 2020. A robust fit-for-purpose treaty is essential if we are to meet current and impending challenges to sustaining vital ocean services and variety of marine life. The treaty is seen as a once in a generation opportunity, which if missed will haunt humankind for decades to come. Such a treaty should include:

- a Conference of the Parties (COP) to ensure better coordination, cooperation, oversight and governance;
- an independent scientific committee, and other necessary governance arrangements;
- global institutional arrangements through which State Parties can act directly, and which can also raise the ambition, performance and conservation capacities of disparate regional and sectoral bodies;
- voting procedures that ensure that self-interested parties cannot veto effective actions; and
- adequate funding mechanisms for the COP and supporting activities.

In the interim, activities thought to be unequivocally damaging, such as deep-sea mining in international waters, should not take place until proper governance, science and precautionary management tools are secured that will ensure effective protection of the marine environment and its biodiversity (see Section 3.4).

3.2.1 | The need for action

Ocean life in the high seas and deep seas beyond national boundaries is under threat (Merrie et al., 2014). It has taken 15 years of effort to get to the point of negotiating a BBNJ Treaty (Wright, Rochette, Gjerde, & Seeger, 2018) and now that negotiations have begun, it is essential to achieve an agreement that will ensure effective biodiversity protection for the global ocean beyond national boundaries. This needs a whole ocean approach that encompasses the upper sunlit water column, the mid-water column and the deep sea bed below. The UN BBNJ process is seen as a crucial opportunity to reset the balance in favour of sustainability and protection and away from destructive practices and unsustainable use. The treaty process is an opportunity to create an empowered international organization dedicated to a holistic approach to protecting and preserving ocean life and the services it provides to humankind. The treaty process is also seen as an urgently needed opportunity to shine a spotlight on governments and require them to act, including in the realm of fisheries management. Fisheries have a significant impact on biodiversity (Crespo & Dunn, 2017; Thrush, Ellingsen, & Davis, 2016; Worm et al., 2006) and thus measures such as MPAs and environmental impact assessments to protect biodiversity from the impacts of high seas activities need to be a core focus of the negotiations and all activities under the jurisdiction and control of State Parties made subject to any protection measures agreed.

So that we can look at the ocean holistically and in an integrated manner, the Treaty must combine different aspects of ocean management (fisheries management, ocean protection, the managing of mining and shipping). Sectoral organizations such as regional fisheries management organizations (RFMOs), the International Maritime Organization and the International Seabed Authority must be better coordinated and integrated in order to conserve marine biodiversity. The treaty will need to contain overarching goals, principles and objectives as well as robust accountability, reporting and compliance mechanisms that are applicable to all States and international organizations.

Action is also needed to reform voting rights in sectoral organizations as too many have a few dominant economic stakeholders who can, through consensus requirements, make or break reform and control how decisions are agreed, or which resolutions are adopted. Too often decisions are taken – or not taken – that simply maintain the status quo, and do not reflect the ambition required to confront challenges to ocean health. There needs to be a transformation in our approach to managing economic activities in Areas Beyond National Jurisdiction (ABNJ), one that puts biodiversity and ecosystem resilience at the forefront of policy, planning and management. In other words, activities should be undertaken in ways that do not undermine the integrity of marine ecosystems or adversely affect their ability to sustain viable populations of target and non-target species and maintain vital ecosystem functions.

The treaty needs to ensure that decisions are based on independent science. A future ocean COP needs to design an effective scientific advisory process that ensures balanced participation and adherence to scientific advice and recommendations, and also supports the marine scientific research needed to ensure informed decision-making. In RFMOs, science is all too often not addressed, ignored, sidelined or politicized (e.g. Wakefield, 2019). Negotiations must identify the metrics and tools needed to make agreements work. A rigorous approach and more work are needed in this area, which will also help galvanize support for the processes. Effective funding mechanisms will be essential to ensure that the structures agreed can function (see Section 3.7 below).

3.3 | Enforce existing standards for effective MPAs and extend their scope to protect at least 30% of the ocean, including the high seas

The third priority relates to MPAs where the focus needs to be to radically increase the level of protection afforded by existing MPAs and to expand their coverage – employing full protection mechanisms – to at least 30% of the ocean (O'Leary et al., 2016). No-take MPAs are important in increasing the biodiversity, abundance and biomass of marine life, including threatened species (e.g. Edgar et al., 2014). They allow recovery of marine life from over-exploitation or other destructive effects, maintain the structure of marine ecosystems and improve their resilience (e.g. Mellin, MacNeil, Cheal, Emslie, & Caley, 2016; Speed, Cappo, & Meekan, 2018). There is also a need to institute a higher level of transparency and accountability in their definition, management and enforcement. About half of existing MPAs are only nominally protected (Laffoley et al., 2019). At present, UNEP simply records MPAs reported to it, rather than including information on their stage of establishment, level of protection or effectiveness of management. Reporting needs to be undertaken against agreed metrics and standards so that country inventories of MPAs are accountable and transparent and can be independently assessed for their compliance with international agreements, such as Sustainable Development Goal 14, and the Convention on Biological Diversity (CBD) 10% target for ocean protection by 2020 set out in Target 11. In addition to area-based targets (Agardy, Claudet, & Day, 2016; Roberts, Valkan, & Cook, 2018) we need to be more strategic with MPA placement, design (size, shape) and network coherence including social–ecological coherence (Rees et al., 2018). We also need to consider geographic heterogeneity, plus dynamic ocean patterns and processes with regard to climate change, and identify and mitigate threats to MPA performance.

There has been no increase in the official, politically agreed ambition for ocean protection under the CBD since 1983 when the non-governmental organization community first posited 10% at the World Parks Congress in Bali. The official CBD ocean protection target, now recognized to be inadequate to achieve sufficient protection for marine life (O'Leary et al., 2016), will be reviewed in 2020 and it needs bold and radical reform if protection priorities are to keep anything like pace with climate- and human-related deterioration and losses now being seen in marine ecosystems and species. Increased targets are warranted post-2020, namely a network of strongly to fully protected MPAs covering 30% of the sea by 2030. Truly sustainable measures and actions then also need to be applied to the remaining 70% of the ocean so a whole ocean approach is taken. Beyond 2030, consideration should also be given to eventually ratcheting up coverage to 50% of fully protected MPAs in line with the recent 'Nature Needs Half' initiative (Dinerstein et al., 2017; Kopnina, Washington, Gray, & Taylor, 2018), although it is clear, at least on land, that this would have major implications for world food production (Mehrabi, Ellis, & Ramankutty, 2018).

3.3.1 | The case for action

Building on the current view of protected areas that has developed since the 19th century, there is now an important opportunity to increase, improve and use ocean observation infrastructure and data flows to help in their establishment and management. The MPA agenda should be to create a Noah's Ark of protected areas for marine organisms, ramping up ecosystem resilience, radically reducing the footprint of human activities, as well as safeguarding the diminishing number of places that have not yet been reached by extractive, impacting activities such as fishing. Given existing global threats from climate change (Bruno et al., 2018; Yumashev et al., 2019), the case for reinforcing and expanding protection is even more urgent.

Governments and responsible authorities must also recognize that, rather than just announcing MPAs, there are already agreed standards (www.iucn.org/mpastandards) for how these areas should be treated and managed, and such standards need to be applied rigorously. The protection agenda needs to join up with the push on more effective fisheries management and the climate change mitigation agenda, in terms of the crucial role the ocean plays in the Earth's climate, carbon cycle and the sequestration of blue carbon (Roberts et al., 2017). Effective conclusion of the BBNJ Treaty will enable establishment of high seas MPAs, currently all but impossible to secure in most parts of the ocean.

Questions have been raised as to how to implement a global network of marine reserves and how they might be enforced. Scientists have recently used modelling approaches to design global networks of MPAs for the high seas taking into account already-established protection, ecologically and biologically significant areas and human uses of the ocean (O'Leary et al., n.d.). Whilst such a design may be viewed as a work in progress, it demonstrates the feasibility of reaching the 30% or even 50% targets for a representative network of marine reserves. Enforcement of high seas marine protected areas has been viewed as challenging and potentially expensive. However, a range of new technologies, including satellite surveillance (e.g. Rowlands, Brown, Soule, Boluda, & Rogers, 2019), on-board surveillance and electronic log books together with improved global coordination in fisheries management, such as through the Port State Measures Agreement, are providing the tools to realize effective implementation of protected areas.

3.4 | Adopt a precautionary pause on deep-sea mining to allow time to gain sufficient knowledge and understanding to support informed decisions and effective management

There has been a rapid increase in the number of countries and companies seeking exploration access to the ocean floor. The area of commercial interest for mining activity is estimated at over 4 million km^2, larger than the total landmass of the top 20 EU countries (Rogers, 2019). Meanwhile, scientific surveys conducted in prospective mining regions (ferromanganese encrusted seamounts, polymetallic nodules on abyssal plains and seafloor massive sulphides at hydrothermal vents) have confirmed hundreds of new species, as well as high diversity in both species and habitats. Many of these areas are considered vulnerable marine ecosystems, in that they are structurally complex, and contain endemic, rare, long-lived, slow-growing and fragile species (e.g. Rogers, 2018; http://www.fao.org/in-action/vulnerable-marine-ecosystems/criteria/en/). Deep-sea mining will add to the stressors already facing the ocean, and probably lead to cumulative impacts, which will further undermine ocean health and resilience.

3.4.1 | The case for action

For each million tonnes of ore extracted, deep-sea mining will result in disturbance to an area orders of magnitude larger than for the same level of mineral production on land. For example, to extract a million tonnes of manganese from land requires mining half a square kilometre; for the same quantity from polymetallic nodules on the ocean floor, mining needs to cover 80 km^2. The Clarion–Clipperton Zone in the Pacific between Mexico and Hawaii is the site of 16 exploration licences for polymetallic nodules, stretching across an area of ocean nearly the width of the contiguous USA. Amon et al. (2016) found that more than half of the megafaunal species collected in the eastern Clarion–Clipperton Zone were new to science, reiterating how little is known about the biodiversity in this region, as well as that roughly half of observed megafaunal species relied on the polymetallic nodules for attachment surfaces, underscoring their importance to this ecosystem. A subsequent study (Niner et al., 2018) found that deep-sea mining will be destructive, and it will be impossible to achieve no net loss of biodiversity.

Deep-sea mining proposals have been made or exist both in and beyond national jurisdictions (e.g. New Zealand, Namibia, Papua New Guinea). Information for the environments where mining may take place is lacking and as a result, scientists are ill-equipped to make estimates of the likely impacts from mining. Internationally, technologies have not yet been developed or tested so it is near impossible to know the impacts. A concerted scientific push is needed urgently to determine what the potential risks are from the exploitation of the target minerals. It is critical that scientific knowledge, and associated uncertainties, be applied to preserve the biodiversity and functions of the deep ocean if and when sea bed mining proceeds. There should be a precautionary pause on deep-sea mining adopted, to allow time to gain sufficient knowledge and understanding of deep-ocean communities, ecosystem functions, processes and roles in the global earth system to support informed decisions and effective management. Areas such as active hydrothermal vent sites should already be placed permanently off limits given their ability to support abundant and often endemic biological communities. Active vents in total occupy only an estimated global area of 50 km^2 (Van Dover et al., 2018), with more than 60% of species being unique to a single vent site.

3.5 | End overfishing and destructive practices including IUU fishing

In a world heading towards 10 billion people, seafood is critical to global food security, both as a source of protein but also for micronutrients needed in aquaculture. Catches from wild fisheries peaked in 1996 at around 130 million tonnes per year and have been declining by 1 million tonnes per year since then (Pauly & Zeller, 2016; Thurstan & Roberts, 2014). There is strong consensus that, despite all efforts, current fisheries management globally is not effective enough to secure sustainability and sufficiently limit environmental harm. In revising global fisheries landings to account for unreported catches, Pauly and Zeller (2016) showed catches were nearly 50% higher than previously thought, with evidence that overfishing in many regions is still increasing. Experts concluded that tackling overfishing is a winnable challenge, which can connect communities reliant on fish and fishing to the wider problem of ocean decline and the need for protection.

What is primarily needed to solve this problem is to enforce and enhance existing regulations, to refine and expand the technological advances to assist enforcement, and to use the existing technology to track all fishing gear and make sure it is disposed of sustainably. This is something that can be solved now if there is the will to do so. Alongside this, complementary strategies are needed to address such issues as improved education to promote sustainable practices (Gifford & Nilsson, 2014), realigned incentives and improved social marketing.

3.5.1 | The case for action

There is currently a pincer movement on ocean productivity from climate change and overfishing, which is reducing fisheries productivity and threatening stock health. The warming of the ocean is, at the simplest level, doing two things: reducing ocean mixing, which reduces nutrient transfer to shallower waters; and reducing oxygen content, which means that fish will grow more slowly to smaller sizes (Pauly & Cheung, 2018a, b). At the same time, overfishing continues: recent FAO figures averaged for the world disclose that the proportion of fully and overexploited fisheries increased to 93%, and the proportion of non-fully exploited fisheries declined to 7% (FAO, 2018). Often overlooked too in terms of fish stock reduction, especially benthic species, is the issue of 'ghost fishing' (Lively & Good, 2019). The removal of top predators (e.g. sharks, rays and chimaeras), many with long evolutionary histories, from marine ecosystems by overfishing is especially problematic (Stein et al., 2018).

Consideration should therefore be given to cutting global fishing effort by up to 50% to buffer against the effects of climate change. Harmful fishing subsidies should also be removed (Sumaila et al., 2010), and the funds redirected to support the creation of effective MPAs and other management mechanisms to safeguard stocks. An economic analysis in 2018 (Sala et al., 2018) concluded that, if subsidies were removed, and adequate labour and human rights were enforced, most high seas fishing would be too uneconomical to survive.

There is also a need to introduce moratoria/bans for highly damaging activities. Examples include deep-water gillnets and bottom trawling, and for poorly managed longlining resulting in high levels of bycatch, such as turtles, sharks and seabirds. The potential implications of recently granted licences by Norway and Pakistan for exploratory fishing on mesopelagic fish stocks need to be considered. Certification standards also need to be more stringent. The Marine Stewardship Council has become the subject of a campaign to ensure they uphold and strengthen their sustainability standards, so helping drive positive change in the fisheries sector. Many of their certified fisheries cannot be described as sustainable or non-damaging to the environment or bycatch species. There is a real danger that the label will lose credibility and public trust, risking an important tool for improving fisheries. And then there is the possibility, in parts of the world where fish is optional rather than essential as a food type, of simply consuming less, and thereby reducing the demand and consequently the threat.

Alongside such measures is the growing need to ban all bottom trawling on seamounts and other submarine topographical features to protect corals, sponges and the unique ecosystems associated with these sites. Consideration should also be given to ending some aquaculture, e.g. unsustainable shrimp farming, which is too damaging for poorer communities in terms of feed provision, water use, pollution, coastal habitat destruction and other impacts, to justify meeting the demand for luxury seafood.

Ending IUU fishing is an important issue that will also help connect communities reliant on fish and fishing to the wider problem of ocean decline and need for protection. There are sufficient regulations to solve this problem, especially by harnessing and refining the technological advances that have been made in monitoring, surveillance and enforcement. There is no doubt that satellite remote sensing and other forms of technology are getting to the stage where illegal fishers should have nowhere to hide (Dunn et al., 2018; McCauley et al., 2016). There should be proper sanctions for flag states that continue to ignore their obligations, with test cases needed before the UNCLOS Tribunal. Associated problems with ghost fishing gear needs to be solved using technology to tag and track gear on all vessels.

3.6 | Radically reduce marine water pollution

Eutrophication, chemical and plastics pollution are mounting causes of concern. Pollution by plastic debris is ubiquitous in the ocean (Sanchez-Vidal et al., 2014) and has been recently recognized as a risk whose management requires a global-level response (Lamb et al., 2018; Seltenrich, 2015; Vince & Hardesty, 2016). In contrast, marine nutrient and chemical pollution have been a continuous problem for the past century, whose distribution and impacts have only expanded, and are causing ecological collapse and destabilizing large coastal regions (Clark, 2001; Diaz-Cruz & Barcelo, 2015; Kennish, Kennish, & Lutz, 1997; Vernberg, Thurberg, & Calabrese, 1979). Governance and other forms of management of nutrient and chemical pollution have made small gains over the past decades, but not enough to mitigate their impact (Hassan, 2006). Failure analysis indicates that more stringent and innovative policy actions need to be implemented at multiple levels of social and economic hierarchies, with an emphasis on managing explicit pollution sources as point sources of origin, rather than ambiguous non-point sources of pollution (D'Angelo & Wiedenmann, 2014; Liu et al., 2018; Selman, Greenhalgh, Diaz, & Sugg, 2016; Vilmin, Mogollón, Beusen, & Bouwman, 2018). To ensure effective pollution mitigation, there is a need to:

- Effectively manage sewage discharges in major river catchments and in coastal communities. This requires innovative technologies that reduce eutrophic factors, as well as chemical pollutants. Since 70% of the world's population lives in coastal regions, this could have an enormous local and global impact in increasing ecological resilience to other stressors, as well as enhancing the recovery of degraded ecosystems.
- Increase the public awareness about nutrient pollution and its degradation to local and regional ecosystems that are critical resources for tourism, fisheries and residential/commercial property valuation. This awareness, in turn, can be used as leverage to drive effective policies for both mitigation of pollution impacts and prevention of pollution. Reducing nutrient pollutants would increase fisheries productivity and reduce the exacerbation that climate change factors would have on dead zone formation and longevity, harmful algal blooms and coastal erosion.
- Recognize and characterize marine chemical contaminants of emerging concern, including personal care product chemicals, pharmaceuticals and antibiotics, anti-foulant chemicals and pesticides. Some of these chemicals are persistent in the environment and will be transferred through the food chain. For example, some personal-care product chemicals can be passed from human sewage to fisheries, and then consumed by humans (Henriquez-Hernandez et al., 2017). The extent of chemical corruption throughout the food chain is uncertain, but studies to date show that it is far more extensive than expected.
- Reversal of the burden of proof in approval of use of chemicals in industrial and household applications. Industry should bear the cost of certifying that their products are not causing unacceptable levels of damage to the ocean.
- Innovate to replace single-use plastic packaging with biodegradable and non-chemical-polluting alternatives. Industry investment in innovation is paramount and can be leveraged through restricting the use of single-use plastic packaging, but also in providing financial awards for corporations that innovate and implement non-plastic, environmentally sustainable packaging through taxation mechanisms.

3.6.1 | The case for action

Pollution is the presence of anthropogenic contaminants in the natural environment that causes an adverse impact. The challenge is understanding not just specific impacts but also cumulative impacts and multiple interactions among stressors. The three biggest forms of oceanic and coastal pollution addressed in this section are (a) nitrogen–phosphorous factors coming from sewage, residential and agricultural activities, (b) chemical pollution that comprises, but is not limited to, pesticides, petroleum, pharmaceuticals and personal care products, and industrial discharges and (c) plastic-debris pollution.

Nitrogen–phosphorus pollution, also called nutrient or eutrophic pollution, has had a global impact on ocean bodies. These nutrients create algal blooms in contaminated areas where, when the algal bloom dies, a process of decay is established that can radically shift oceanic alkalinity, induce harmful algal blooms, and change the ecological structure of coastal and pelagic communities (Diaz & Rosenberg, 2008). Some of the international impacts include the *Sargassum* blooms that plague beaches throughout the entire Caribbean Sea and Gulf of Mexico, harmful algal bloom outbreaks (‘Red and Brown

Tides') all over the world and increasing dead zone formations that range from Barbados to China (Diaz & Rosenberg, 2008; Heisler et al., 2008; Paerl & Scott, 2010). The economic impacts of these forms of pollution are both insidious and extensive, including shifting the feeding grounds of important commercial fisheries, localized ecological extinctions that impact fisheries, degraded coastlines incurring a loss of ecological services that impact residential communities and a decrease in local economic stability and resilience as a result of declining coastal tourism (Eliff & Kikuchi, 2017; Moberg & Folke, 1999; Nordlund et al., 2018; Sanseverino, Conduto, Pozzoli, Dobricic, & Lettieri, 2016). Forensic data are needed to identify both the source of the nutrient pollution plumes, as well as characterization of the geographical size and ecological impact. Technology and effective policies are needed to mitigate these discharges. Passing legislation to restrict cesspools, septic systems, suck-wells and other forms of untreated sewage, and implementing advanced waste-water treatment systems (e.g. membrane/bioreactor systems) can be very effective in reducing discharge levels. Innovations in landscape engineering technologies for agricultural and residential settings, such as filters/bioreactors retention, as well as better regulated fertilizer applications and application technologies can reduce fertilizer runoff (Klein, 2017).

The release of persistent or pseudo-persistent organic pollutants into the ocean is having a negative impact on marine species. Chemical pollutants, especially those recognized as endocrine disruptors and teratogens, are directly impacting the reproductive viability of species in marine ecosystems (Richmond et al., 2017; Windsor, Ormerod, & Tyler, 2018). Chemicals that can cause these reproductive and developmental disorders range from polyaromatic hydrocarbons in crude oil and other petroleum products to antifoulants, pesticides, pharmaceuticals and personal care product chemicals. One manifestation of this impact is the rise of 'zombies' – marine populations with a reduced fecundity or reduced offspring survival that undergo localized extinction over a decadal or generational period of time (Côté, Darling, & Brown, 2016). Cryptic chemicals in personal-care products are having significant implications for both human and ocean health (Dinardo & Downs, 2018). A recent example is the finding that oxybenzone, a common ingredient in sunscreens and other personal care products, negatively impacts coral health and reproduction (Downs et al., 2016). The burden of proof should be on industry to show that the use of these chemicals is safe for both public and ecological health via a government-regulated process that has transparency, inclusion of engaged stakeholders that represent public welfare and absence of a corruptive conflict of interest (European Environment Agency, 2018). It must be up to manufacturers to prove that chemicals are benign or have minimal impact to justify their use. The 'polluter pays principle' should be enforced, so that all land-based actors that have ocean impacts are made responsible for their actions and the resulting financial costs. This will impact the bad actors, whether for plastics or any other polluting product. Furthermore, accountability and restrictions can be an effective driver for technological innovations for the search and development of safer products. Finally, there is an urgent need to increase the scientific and forensic evidence needed to drive robust policy, which then needs to be accurately monitored for effectiveness.

Plastic pollution has caught the global public's attention, both in its large form as oceanic garbage patches and its breakdown products as ingestible microplastics (e.g. Barboza, Cózar, et al., 2019; Barboza, Frias, et al., 2019). Most of this marine plastic debris comes from about 10 major river catchment systems (Schmidt, Krauth, & Wagner, 2017). Microplastics beads and fibres can also come from personal care products and laundry processing, transported through municipal sewage systems and into the marine environment (Law & Thompson, 2014; Suran, 2018). Plastic marine debris can be ingested by many organisms ranging from whales and top predators to corals and zooplankton, causing morbidity through gastric or intestinal blockage (Cole et al., 2013; Hall, Berry, Rintoul, & Hoogenboom, 2015; Thiel et al., 2018). Plastic debris, especially during the 'weathering' and degradation process, can leach a large number of chemicals including endocrine disruptors such as nonylphenols, bisphenols, phthalates, and benzophenones, and result in significant pathologies and morbidity (Asimakopoulos, Elangovan, & Kannan, 2016; Hermabessiere et al., 2017; Lu et al., 2016). Micro- and nano-particles of plastic can contaminate shellfish and could be a hazard for human consumption (Rochman et al., 2015). Because of their ubiquity in the marine environment, plastics pose an alarming hazard to incurring reproductive failure in organisms at all levels of the ecological and community structure, and thereby causing a direct assault on population mortality. Reduction of marine plastic debris, especially single-use plastic packaging, is paramount in order to reduce a stressor that has the capacity for localized and oceanic-wide extinctions.

3.7 | Establish a financing mechanism for ocean management and protection

The above six actions need to be complemented by an approach to ocean finance that is consistent with the diversity, scale and urgency of the challenge. Adequate and comprehensive funding mechanisms need to be put in place rapidly to deliver the actions proposed, with enough human capacity to effectively preserve marine biodiversity.

This finance approach should align itself with broader sustainable finance efforts, such as climate finance for mitigation, adaptation and resilience. Appropriate accounting for blue natural capital, in line with concepts of inclusive wealth, provides a valuation framework that helps to set more appropriate economic incentives to support ocean recovery. Marine activities that have negative impacts need to be taxed sufficiently to fully internalize the externalities, the cost to the global commons. Such taxes will incentivize a transition to lower impact activities and so encourage better behaviour, and the funds raised can be spent to finance the actions proposed. Ocean industries, like all other sectors, need to move rapidly towards investments in innovation to reduce pollution, waste, carbon and impacts on biodiversity. Financial tools can help to speed up this transition.

In addition to addressing ocean stressors and to allow for ocean recovery through public and private sector investments that encourage protection of marine ecosystems, innovative ocean finance needs to be put in place to create an appropriate ocean funding architecture. This could include:

- global funds and insurance structures for key marine assets such as coral reefs, seamounts and the high and deep sea;
- public–private partnerships for a global ocean data infrastructure;
- debt for nature swaps and other financial incentives for MPA management;
- an Ocean Sustainability Bank; and
- other core components of ocean action (Thiele & Gerber, 2017).

Governments, the private sector and multilateral banks have a key role to play to catalyse this transition to sustainable, nature-based marine and coastal infrastructure. That way the broader societal response, including the voices of the most affected people and of progressive businesses, will be part of developing a common language around ocean action. The financial sector, banks, insurance and asset managers as well as the private sector must engage with such a policy to help ensure delivery of effective responses as well as new tools to address growing ocean risk.

3.8 | Scale up science/data gathering and sharing

All of the experts highlighted a second critical cross-cutting priority to the six actions set out above. This was the need to significantly scale up scientific research efforts on the ocean. There is still much to be understood about all aspects of the ocean, its ecosystems and species. There is a need for a much greater expansion of long-term, in-depth studies across a variety of areas to obtain more clarity on the heterogeneity of the ocean across geography and time. Together these efforts will help science better contribute to future ocean policy needs. Solid science means better policy and allows us to understand and measure the effectiveness of that implemented policy and make appropriate course corrections. Priorities here include:

- extending global ocean exploration, mapping, and observation with a particular focus on more biological data gathering;
- ensuring adequate funding for long-term time series observations (e.g. the long-running Continuous Plankton Survey which recently has seen heavy cuts);
- expanding the Argo buoy network to shelf and deeper waters; and
- using technology to join up data-gathering more coherently and systematically.

International initiatives such as the UN Decade of Ocean Science for Sustainable Development and a comprehensive High Seas Treaty provide timely opportunities to both significantly upscale marine science and to build the human capacity of many states to undertake research and to gain scientific input into policy decisions, whether they are related to domestic waters or areas beyond national jurisdiction. Therefore, there should be increased effort to provide training and career opportunities particularly for least developed countries so that their participation in the sustainable ocean economy and governance can be realized. Such efforts need to be sustainable in themselves so consideration of research infrastructure whether at state level or transnational in nature (e.g. globally available research platforms such as ships or monitoring networks) needs to form part of a global strategy to increase international participation in ocean governance. Engaging public and private support for the Ocean Decade, the High Seas Treaty and other initiatives will be vital.

A final area where international cooperation between scientists, governments and industry is critical is that of data transparency and accessibility. Despite a requirement by many funding agencies to make scientific data publicly available, much of it is still inaccessible because it has either not been deposited in appropriate databases or such databases have a limited availability to a broad range of users including scientists, policymakers, industry and the public. Likewise, government departments and industry sit upon significant repositories of data that are unavailable. It is likely to be the case that this leads to survey and other types of work being repeated, wasting precious resources for research and other ocean-related management activities. Ocean data gateways operating with globally agreed standards are needed to provide an ecosystem where data applications can be developed through private and public initiatives to allow access to appropriate data by specific user groups from science, government, industry and the public together with support where needed for those managing the individual databases. Data transparency is an issue which is especially problematic within government, intergovernmental agencies (e.g. RFMOs) and industry that needs addressing within itself. In a well-managed ocean, the only data that should be regarded as confidential are those relating to national security or which are of immediate commercial sensitivity where access to resources cannot be controlled. In a well-managed, limited-access fishery, for example, grounds for confidentiality of where a vessel goes and what it catches are difficult to justify.

4 | CONCLUSIONS

Addressing the ocean crisis is urgent and central to the lives and livelihoods of hundreds of millions of directly dependent especially low-income people; past and current activities are damaging the planet's main life support system for future generations. We are witnessing an increase in ocean heat, disturbance, acidification, bio-invasions and nutrients, and reducing oxygen. This paper sets out eight practical, but ambitious steps that need, if possible, to be implemented simultaneously in order to help recover ocean health.

The ocean provides a wide range of benefits to human society ranging from the spiritual, to living and mineral resources, weather and rainfall, and fundamental to our survival, the main reservoirs of heat, carbon dioxide, oxygen and water. Given its importance we need to radically rethink how we value these benefits and the ocean on which they rely. Owing to present methods of externalizing costs, much ocean activity is conducted under a principle of getting someone else, or society generally, to pay for any damage. Such costs need to be based on ensuring that ocean functions are maintained for future generations and that its wealth is exploited sustainably to the benefit of all humanity. The ocean is changing rapidly as a result of global warming, natural variability and human impacts; this variability needs to be taken account of in any future costing mechanism.

This paper identifies eight priority issues that need to be addressed to help avert a potential ecological disaster in the global ocean. Of all the issues, the highest priority is to rigorously address global warming and limit surface temperature rise to 1.5°C by 2100 as warming is the pre-eminent factor driving change in the ocean. The other issues are: to establish a robust and comprehensive High Seas Treaty; to enforce existing standards for MPAs and expand their coverage especially in terms of high levels of protection; to adopt a precautionary pause on deep-sea mining; to end overfishing and destructive fishing practices; to radically reduce pollution; to put in place a financing mechanism for ocean management and protection; and lastly to scale up science/data gathering and to facilitate data sharing. Implementing this cross-cutting package of measures will build resilience to climate change, help sustain fisheries productivity, particularly for low-income countries that depend on fisheries, protect coasts (e.g. via soft-engineering/habitat-based approaches), promote mitigation (e.g. carbon storage) and enable improved adaptation to rapid global change.

Once detrimental or negative changes have occurred, they may lock in place and may not be reversible, especially at gross ecological and ocean process scales. Each change may represent a loss to humanity of resources, ecosystem function, oxygen production and species. Thus, we may 'think' we can simply stop doing things and assume that previous conditions that we view as more benign/natural or beneficial will return, when in reality the longer we pursue damaging actions, the more we close the path to recovery and better ocean health and greater benefits for humanity in the future.

Time is not on our side and we need to take action now. It is evident just within the few months of 2019 that worrying trends are being reported by multiple scientific research groups as a result of climate change effects taking hold in the ocean, just as atmospheric carbon dioxide levels are expected to jump still further owing to climate feedbacks (Met Office, 2019). These changes include the facts that: ocean warming is accelerating, heating up 40% faster on average than a United Nations panel estimated five years ago (Cheng, Abraham, et al., 2019); upper-ocean warming, a consequence of anthropogenic global warming, is changing the global wave climate, making waves stronger (Reguero, Losada, & Méndez, 2019); Greenland's ice is melting faster than scientists previously thought, with unexpectedly most of this ice loss coming from the land-fast ice sheet itself, not Greenland's glaciers (Bevis et al., 2019); the Barents Sea is said to be at a tipping point, changing from an Arctic climate to an Atlantic climate as the water gets warmer (Lind, Ingvaldsen, & Furevik, 2018); ice in the Antarctic is melting at a record-breaking rate and the subsequent sea-level rise could have catastrophic consequences for cities around the world (Rintoul et al., 2018; Witze, 2018); and krill, the keystone species of Antarctic waters, have now moved four degrees of latitude, tracking south to where more favourable conditions are found (Atkinson et al., 2019).

The challenges may seem insurmountable but if we act now, together and enforce the eight themes outlined above, even with our current state of knowledge of the ocean, a more positive and sustainable future for the ocean is possible. Acting now with urgency and with a massive increase in the level of ambition has to be *the* no-regrets policy to protect us and future generations from our short-termism and ignorance about why a healthy ocean should and does matter to all of us.

ACKNOWLEDGEMENTS

The authors are grateful to IPSO and the wider scientific and expert community for their contributions to the development of this paper and to funders The Islamic Development Bank.

The authors would like to thank the following people for their varied support, including organising the workshops and other processes leading to publication: Brittney Francies, Gail Galiee, Louisa Hooper, Sophie Hulme, Lydia Mogridge East, Charlotte Smith and Mirella von Lindenfels.

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REFERENCES

Agardy, T., Claudet, J., & Day, J. C. (2016). 'Dangerous targets' revisited: Old dangers in new contexts plague marine protected areas. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*, 7–23. https://doi.org/10.1002/aqc.2675

Agostini, S., Harvey, B. P., Wada, S., Kon, K., Milazzo, M., Inaba, I., & Hall-Spencer, J. M. (2018). Ocean acidification drives community shifts towards simplified non-calcified habitats in a subtropical–temperate transition zone. *Scientific Reports*, *8*, 11354. https://doi.org/10.1038/s41598-018-29251-7

Altieri, A. H., & Diaz, R. J. (2019). Chapter 24 – Dead zones: Oxygen depletion in coastal ecosystems. In C. Sheppard (Ed.), *World seas volume III: Ecological issues and environmental impacts* (pp. 453–473). London: Elsevier.

Amon, D. J., Ziegler, A. F., Dahlgren, T. G., Glover, A. G., Goineau, A., Gooday, A. J., … Smith, C. R. (2016). First insights into the abundance and diversity of abyssal megafauna in a polymetallic-nodule region in the eastern Clarion–Clipperton Zone. *Scientific Reports*, *6*, 30492. https://doi.org/10.1038/srep30492

Ashford, O. S., Kenny, A. J., Froján, C. R. S., Bonsall, M. B., Horton, T., Brandt, A., … Rogers, A. D. (2018). Phylogenetic and functional evidence suggests that deep-ocean ecosystems are highly sensitive to environmental change and direct human disturbance. *Proceedings of the Royal Society of London B: Biological Sciences*, *285*, 20180923. https://doi.org/10.1098/rspb.2018.0923

Asimakopoulos, A. G., Elangovan, M., & Kannan, K. (2016). Migration of parabens, bisphenols, benzophenone-type UV filters, triclosan, and triclocarban from teethers and its implications for infant exposure. *Environmental Science & Technology*, *50*, 13539–13547. https://doi.org/10.1021/acs.est.6b04128

Atkinson, A., Hill, S. L., Pakhomov, E. A., Siegel, V., Reiss, C. S., Loeb, V. J., … Sailley, S. F. (2019). Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming. *Nature Climate Change*, *9*, 142–147. https://doi.org/10.1038/s41558-018-0370-z

Barange, M., Merino, G., Blanchard, J. L., Scholtens, J., Harle, J., Allison, E. H., … Jennings, S. (2014). Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nature Climate Change*, *4*, 211–216. https://doi.org/10.1038/nclimate2119

Barboza, L. G. A., Cózar, A., Gimenez, B. C. G., Barros, T. L., Kershaw, P. J., & Guilhermino, L. (2019). Chapter 17 – Macroplastics pollution in the marine environment. In C. Sheppard (Ed.), *World seas volume III: Ecological issues and environmental impacts* (pp. 305–328). London: Elsevier.

Barboza, L. G. A., Frias, J. P. G. L., Booth, A. M., Vieira, L. R. J., Baker, J., Foster, G., & Guilhermino, L. (2019). Chapter 18 – Microplastics pollution in the marine environment. In C. Sheppard (Ed.), *World seas volume III: Ecological issues and environmental impacts* (pp. 329–251). London: Elsevier.

Beaugrand, G., Conversi, A., Atkinson, A., Cloern, J., Chiba, S., Fonda-Umani, S., … Edwards, M. (2019). Prediction of unprecedented biological shifts in the global ocean. *Nature Climate Change*, *9*, 237–243. https://doi.org/10.1038/s41558-019-0420-1

Bevis, M., Harig, C., Khan, S. A., Brown, A., Simons, F. J., Willis, M., … Nylen, T. (2019). Accelerating changes in ice mass within Greenland, and the ice sheet's sensitivity to atmospheric forcing. *Proceedings of the National Academy of Sciences of the United States of America*, *116*, 1934–1939. https://doi.org/10.1073/pnas.1806562116

Bijma, J., Pörtner, H.-O., Yesson, C., & Rogers, A. D. (2013). Climate change and the oceans – What does the future hold? *Marine Pollution Bulletin*, *74*, 495–505. https://doi.org/10.1016/j.marpolbul.2013.07.022

Birkeland, C. (2019). Chapter 2 – Global status of coral reefs: In combination, disturbances and stressors become ratchets. In C. Sheppard (Ed.), *World seas volume III: Ecological issues and environmental impacts* (pp. 35–56). London: Elsevier.

Boyd, R., Richerson, P. J., Meinzen-Dick, R., De Moor, T., Jackson, M. O., Gjerde, K. M., … Dye, C. (2018). Tragedy revisited. *Science*, *362*, 1236–1241. https://doi.org/10.1126/science.aaw0911

Breitburg, D., Levin, L. A., Oschlies, A., Gregoire, M., Chavez, F. P., Conley, D. J., … Zhang, J. (2018). Declining oxygen in the global ocean and coastal waters. *Science*, *359*, 46.

Bristow, L. A., Callbeck, C. M., Larsen, M., Altabet, M. A., Dekaezemacker, J., Forth, M., … Canfield, D. E. (2016). N_2 production rates limited by nitrite availability in the Bay of Bengal oxygen minimum zone. *Nature Geoscience*, *10*, 24–29. https://doi.org/10.1038/ngeo2847

Bruno, J. F., Bates, A. E., Cacciapaglia, C., Pike, E. P., Amstrup, S. C., Van Hooidonk, R., … Aronson, R. B. (2018). Climate change threatens the world's marine protected areas. *Nature Climate Change*, *8*, 499–503. https://doi.org/10.1038/s41558-018-0149-2

Carpenter, K. E., Abrar, M., Aeby, G., Aronson, R. B., Banks, S., Bruckner, A., … Wood, E. (2008). One third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science*, *321*, 560–563. https://doi.org/10.1126/science.1159196

Cattano, C., Claudet, J., Domenici, P., & Milazzo, M. (2018). Living in a high CO_2 world: A global meta-analysis shows multiple trait-mediated fish responses to ocean acidification. *Ecological Monographs*, *88*, 320–335. https://doi.org/10.1002/ecm.1297

Cheng, L., Abraham, J., Hausfather, Z., & Trenberth, K. E. (2019). How fast are the oceans warming? *Science*, *363*, 128–129. https://doi.org/10.1126/science.aav7619

Cheung, W. W., Lam, V. W., Sarmiento, J. L., Kearney, K., Watson, R. E. G., Zeller, D., & Pauly, D. (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, *16*, 24–35. https://doi.org/10.1111/j.1365-2486.2009.01995.x

Cheung, W. W. L., Watson, R., & Pauly, D. (2013). Signature of ocean warming on global marine fisheries. *Nature*, *497*, 365–368. https://doi.org/10.1038/nature12156

Clark, R. B. (2001). *Marine pollution* (5th ed.). Oxford, UK: Oxford Univ. Press. ISBN: 0–19–879292-1

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., & Galloway, T. S. (2013). Microplastic ingestion by zooplankton. *Environmental Science & Technology*, *47*, 6646–6655. https://doi.org/10.1021/es400663f

Constable, A. J., Melbourne-Thomas, J., Corney, S. P., Arrigo, K. R., Barbraud, C., Barnes, D. K. A., … Ziegler, P. (2014). Climate change and Southern Ocean ecosystems I: How changes in physical habitats directly affect marine biota. *Global Change Biology*, *20*, 3004–3025. https://doi.org/10.1111/gcb.12623

Côté, I. M., Darling, E. S., & Brown, C. J. (2016). Interactions among ecosystem stressors and their importance in conservation. *Proceedings of the Royal Society B: Biological Sciences*, *283*, 20152592. https://doi.org/10.1098/rspb.2015.2592

Crespo, G. O., & Dunn, D. (2017). A review of the impacts of fisheries on open-ocean ecosystems. *ICES Journal of Marine Science*, *74*, 2283–2297. https://doi.org/10.1093/icesjms/fsx084

D'Angelo, C., & Wiedenmann, J. (2014). Impacts of nutrient enrichment on coral reefs: New perspectives and implications for coastal management and reef survival. *Current Opinion in Environmental Sustainability*, *7*, 82–93. https://doi.org/10.1016/j.cosust.2013.11.029

Diaz, R. J., & Rosenberg, R. (2008). Spreading dead zones and consequences for marine ecosystems. *Science*, *32*, 926–929. https://doi.org/10.1126/science.1156401

Diaz-Cruz, M. S., & Barcelo, D. (2015). *Personal care products in the aquatic environment*. Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-18809-6

Dinardo, J. C., & Downs, C. A. (2018). Dermatological and environmental toxicological impact of the sunscreen ingredient oxybenzone/benzophenone-3. *Journal of Cosmetic Dermatology*, *17*, 15–19. https://doi.org/10.1111/jocd.12449

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. . D., Wikramanayake, E., … Saleem, M. (2017). An ecoregion-based approach to protecting half the terrestrial realm. *BioScience*, *67*, 534–545. https://doi.org/10.1093/biosci/bix014

Downs, C. A., Kramarsky-Winter, E., Fauth, J. E., Knutson, J. E., Segal, R., Bronstein, O., … Loya, Y. (2016). Toxicopathological effects of the sunscreen UV filter, oxybenzone (benzophenone-3), on coral planulae and cultured primary cells and its environmental contamination in Hawaii and the U.S. Virgin Islands. *Archives of Environmental Contamination and Toxicology*, *70*, 265–288. https://doi.org/10.1007/s00244-015-0227-7

Duffy, P. B., Field, C. B., Diffenbaugh, N. S., Doney, S. C., Dutton, Z., Goodman, S., … Williams, A. P. (2018). Strengthened scientific support for the Endangerment Finding for atmospheric greenhouse gases. *Science*, *363*, eaat5982. https://doi.org/10.1126/science.aat5982

Dunn, D. C., Jablonicky, C., Crespo, G. O., McCauley, D. J., Kroodsma, D. A., Boerder, K., … Halpin, P. N. (2018). Empowering high seas governance with satellite vessel tracking data. *Fish and Fisheries*, *19*, 729–739. https://doi.org/10.1111/faf.12285

Eamer, J., Donaldson, G. M., Gaston, A. J., Kosobokova, K. N., Larusson, K. F., Melnikov, I. A., … von Quillfeldt, C. H. (2013). *Life linked to ice: A guide to sea-ice-associated biodiversity in this time of rapid change*. CAFF Assessment Series No. 10. Iceland: Conservation of Arctic Flora and Fauna. ISBN: 978–9935–431-25-7

Edgar, G. J., Stuart-Smith, R. D., Willis, J. J., Kininmonth, S., Baker, S. C., Banks, S., … Thomson, R. J. (2014). Global conservation outcomes depend on marine protected areas with 5 key features. *Nature*, *506*, 216–220. https://doi.org/10.1038/nature13022

Eliff, C. I., & Kikuchi, R. K. P. (2017). Ecosystem services provided by coral reefs in a southwestern Atlantic archipelago. *Ocean and Coastal Management*, *136*, 49–55. https://doi.org/10.1016/j.ocecoaman.2016.11.021

European Environment Agency. (2018). Chemicals for a sustainable future. Report of the EEA Scientific Committee Seminar. ISSN 1725–8449. https://doi.org/10.2800/92493

FAO. (2018). The state of the world's fisheries and aquaculture.

Frölicher, T. L., Fischer, E. M., & Gruber, N. (2018). Marine heatwaves under global warming. *Nature*, *560*, 360–364. https://doi.org/10.1038/s41586-018-0383-9

Gattuso, J.-P., Magnan, A., Billé, R., Cheung, W. W. L., Howes, E. L., Joos, F., … Turley, C. (2015). Contrasting futures for ocean and society from different CO_2 emissions scenarios. *Science*, *349*, 6243. https://doi.org/10.1126/science.aac4722

Gifford, R., & Nilsson, A. (2014). Personal and social factors that influence pro-environmental concern and behaviour: A review. *International Journal of Psychology*, *49*, 141–157. https://doi.org/10.1002/ijop.12034

Gleckler, P. J., Durack, P. J., Stouffer, R. J., Johnson, G. C., & Forest, C. E. (2016). Industrial-era global ocean heat uptake doubles in recent decades. *Nature Climate Change*, *6*, 394–398. https://doi.org/10.1038/nclimate2915

Good, P., Bamber, J., Halladay, K., Harper, A. B., Jackson, L. C., Kay, G., … Williamson, P. (2018). Recent progress in understanding climate thresholds: Ice sheets, the Atlantic meridional overturning circulation, tropical forests and responses to ocean acidification. *Progress in Physical Geography: Earth and Environment*, *42*, 24–60. https://doi.org/10.1177/0309133317751843

Hall, N. M., Berry, K. L. E., Rintoul, L., & Hoogenboom, M. O. (2015). Microplastic ingestion by scleractinian corals. *Marine Biology*, *162*, 725–732. https://doi.org/10.1007/s00227-015-2619-7

Hassan, D. (2006). *Protecting the marine environment from land-based sources of pollution*. London: Routledge.

Heisler, J., Gilbert, P. M., Burkholder, J. M., Anderson, D. M., Cochlan, W., Dennison, W. C., … Suddleson, M. (2008). Eutrophication and harmful algal blooms: A scientific consensus. *Harmful Algae*, *8*, 3–13. https://doi.org/10.1016/j.hal.2008.08.006

Henriquez-Hernandez, L. A., Montero, D., Camacho, M., Gines, R., Boada, L. D., Bordon, B. R., … Luzardo, O. P. (2017). Comparative analysis of selected semi-persistent and emerging pollutants in wild-caught fish and aquaculture associated fish using Bodue (*Boops boops*) as sentinel species. *Science of the Total Environment*, *581–582*, 199–208. https://doi.org/10.1016/j.scitotenv.2016.12.107

Hermabessiere, L., Dehaut, A., Paul-Pont, I., Lacrois, C., Jezequel, R., Soudant, P., & Duflos, G. (2017). Occurrence and effects of plastic additives on marine environments and organisms: A review. *Chemosphere*, *182*, 781–793. https://doi.org/10.1016/j.chemosphere.2017.05.096

Hughes, T. P., Anderson, K. D., Connolly, S. R., Heron, S. F., Kerry, J. T., & Lough, J. M. (2018). Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science*, *359*, 80–83. https://doi.org/10.1126/science.aan8048

Hughes, T. P., Kerry, J. T., Baird, A. H., Connolly, S. R., Dietzel, A., Eakin, C. M., … Torda, G. (2018). Global warming transforms coral reef assemblages. *Nature*, *556*, 492–496. https://doi.org/10.1038/s41586-018-0041-2

IPCC. (2018). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, et al. (Eds.), *Global warming of 1.5°C. an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (p. 32). Geneva: World Meteorological Organization.

Kennish, M., Kennish, M., & Lutz, P. (1997). *Practical handbook of estuarine and marine pollution*. Boca Raton, FL: CRC Press.

Klein, A. (2017). Plan to save the Great Barrier Reef from encroaching farm pollution. *NewScientist*. Retrieved from https://www.newscientist.com/article/2148247-plan-to-save-great-barrier-reef-from-encroaching-farm-pollution/

Kopnina, H., Washington, H., Gray, J., & Taylor, B. (2018). The 'future of conservation' debate: Defending ecocentrism and the Nature Needs Half movement. *Biological Conservation*, *217*, 140–148. https://doi.org/10.1016/j.biocon.2017.10.016

Laffoley, D., Baxter, J. M., Day, J. C., Wenzel, L. W., Bueno, P., & Zischka, K. (2019). Chapter 29 – Marine Protected Areas. In C. Sheppard (Ed.), *World seas volume III: Ecological issues and environmental impacts* (pp. 549–569). London: Elsevier.

Lam, V. W. L., Cheung, W. W. L., Reygondeau, G., & Sumaila, U. R. (2016). Projected change in global fisheries revenues under climate change. *Scientific Reports*, *6*, 32607. https://doi.org/10.1038/srep32607

Lamb, J. B., Willis, B. L., Fiorenza, E. A., Couth, C. S., Howard, R., Rader, D. N., … Harvell, C. D. (2018). Plastic waste associated with disease on coral reefs. *Science*, *359*, 460–462. https://doi.org/10.1126/science.aar3320

Laufkotter, C., Vogt, M., Gruber, N., Aita-Noguchi, M., Aumont, O., Bopp, L., … Volker, C. (2015). Drivers and uncertainties of future global marine primary production in marine ecosystem models. *Biogeosciences*, *12*, 6955–6984. https://doi.org/10.5194/bg-12-6955-2015

Law, K. L., & Thompson, R. C. (2014). Microplastics in the seas. *Science*, *345*, 144–145. https://doi.org/10.1126/science.1254065

Levin, L. A. (2018). Manifestation, drivers, and emergence of open ocean deoxygenation. *Annual Review of Marine Science*, *10*, 1–32. https://doi.org/10.1146/annurev-marine-121916-063359

Levitus, S., Antonov, J., & Boyer, T. (2005). Warming of the world ocean 1955–2003. *Geophysical Research Letters*, *32*, L02604. https://doi.org/10.1029/2004GL021592

Lind, S., Ingvaldsen, R. B., & Furevik, T. (2018). Arctic warming hotspot in the northern Barents Sea linked to declining sea-ice import. *Nature Climate Change*, *8*, 634–639. https://doi.org/10.1038/s41558-018-0205-y

Liu, X., Beusen, A. H. W., Van Beek, L. P. H., Mogollón, J. M., Ran, X., & Bouwman, A. F. (2018). Exploring spatiotemporal changes of the Yangtze River (Changjiang) nitrogen and phosphorus sources, retention and export to the East China Sea and Yellow Sea. *Water Research*, *142*, 246–255. https://doi.org/10.1016/j.watres.2018.06.006

Lively, J. A., & Good, T. P. (2019). Chapter 10 – Ghost fishing. In C. Sheppard (Ed.), *World seas volume III: Ecological issues and environmental impacts* (pp. 183–196). London: Elsevier.

Lu, Y., Zhang, Y., Deng, Y., Jiang, W., Zhao, Y., Geng, J., … Ren, H. (2016). Uptake and accumulation of polystyrene microplastics in zebrafish (*Danio rerio*) and toxic effects in liver. *Environmental Science & Technology*, *50*, 4054–4060. https://doi.org/10.1021/acs.est.6b00183

McCauley, D. J., Woods, P., Sullivan, B., Bergman, B., Jablonicky, C., Roan, A., … Worm, B. (2016). Ending hide and seek at sea. *Science*, *351*, 1148–1150. https://doi.org/10.1126/science.aad5686

Mehrabi, Z., Ellis, E. C., & Ramankutty, N. (2018). The challenge of feeding the world while conserving half the planet. *Nature Sustainability*, *1*, 409–412. https://doi.org/10.1038/s41893-018-0119-8

Mellin, C., MacNeil, M. A., Cheal, A. J., Emslie, M. J., & Caley, M. J. (2016). Marine protected areas increase resilience among coral reef communities. *Ecology Letters*, *19*, 629–637. https://doi.org/10.1111/el.12598

Merrie, A., Dunn, D. C., Metian, M., Boustany, A. M., Takei, Y., Elferink, A. O., … Österblom, H. (2014). An ocean of surprises – Trends in human use, unexpected dynamics and governance challenges in areas beyond national jurisdiction. *Global Environmental Change*, *24*, 19–31. https://doi.org/10.1016/j.gloenvcha.2014.04.012

Met Office. (2019). Retrieved from https://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range/forecasts/co2-forecast

Moberg, F., & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics*, *29*, 215–233. https://doi.org/10.1016/S0921-8009(99)00009-9

Niner, H. J., Ardron, J. A., Escobar, E. G., Gianni, M., Jaeckel, A., Jones, D. O. B., … Gjerde, K. M. (2018). Deep-sea mining with no net loss of biodiversity – An impossible aim. *Frontiers in Marine Science*, *5*, 53. https://doi.org/10.3389/fmars.2018.00053

Nordlund, L. M., Jackson, E. L., Nakaoka, M., Samper-Villarreal, J., Beca-Carretero, P., & Creed, J. C. (2018). Seagrass ecosystem services – What's next? *Marine Pollution Bulletin*, *134*, 145–151. https://doi.org/10.1016/j.marpolbul.2017.09.014

O'Leary, B. C., Allen, H. L., Yates, K. L., Page, R. W., Tudhope, A. W., McClean, C., … Roberts, C. M. (2019). 30X30 A Blueprint for Ocean Protection. How we can protect 30% of our oceans by 2030. Part 2. Designing a marine protected area network for the high seas. Greenpeace, UK and Germany.

O'Leary, B. C., Winther-Janson, M., Bainbridge, J. M., Aitken, J., Hawkins, J. P., & Roberts, C. M. (2016). Effective coverage targets for ocean protection. *Conservation Letters*, *9*, 398–404. https://doi.org/10.1111/conl.12247

Oschlies, A., Brandt, P., Stramma, L., & Schmidtko, S. (2018). Drivers and mechanisms of ocean deoxygenation. *Nature Geoscience*, *11*, 467–473. https://doi.org/10.1038/s41561-018-0152-2

Paerl, H. W., & Scott, J. T. (2010). Throwing fuel on the fire: Synergistic effects of excessive nitrogen inputs and global warming on harmful algal blooms. *Environmental Science & Technology*, *44*, 7756–7758. https://doi.org/10.1021/es102665e

Pauly, D., & Cheung, W. W. L. (2018a). Sound physiological knowledge and principles in modelling shrinking of fishes under climate change. *Global Change Biology*, *24*, 15–26. https://doi.org/10.1111/gcb.13831

Pauly, D., & Cheung, W. W. L. (2018b). On confusing cause and effect in the oxygen limitation of fish. *Global Change Biology*, *24*, 743–744. https://doi.org/10.1111/gcb.14383

Pauly, D., & Zeller, D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications*, *7*, 10244. https://doi.org/10.1038/ncomms10244

Rees, S., Pittman, S. J., Foster, N., Langmead, O., Griffiths, C., Fletcher, S., … Attrill, M. (2018). Bridging the divide: A framework for social-ecological coherence in Marine Protected Area network design. *MarXiv*, *August*, 8. https://doi.org/10.31230/osf.io/neadb

Reguero, B. G., Losada, I. J., & Méndez, F. J. (2019). A recent increase in global wave power as a consequence of oceanic warming. *Nature Communications*, *10*, 205. https://doi.org/10.1038/s41467-018-08066-0

Reid, P. C., Fischer, A. C., Lewis-Brown, E., Meredith, M. P., Sparrow, M., Andersson, A. J., … Washington, R. (2009). Impacts of the oceans on climate change. *Advances in Marine Biology*, *56*, 1–151. https://doi.org/10.1016/S0065-2881(09)56001-4

Richmond, E. K., Grace, M. R., Kelly, J. J., Reisinger, A. J., Rosi, E. J., & Walters, D. M. (2017). Pharmaceuticals and personal care products are ecological disrupting compounds. *Elementa: Science of the Anthropocene*, *5*, 66. https://doi.org/10.1525/elementa.252

Rintoul, S. R., Chown, S. L., DeConto, R. M., England, M. H., Fricker, H. A., Masson-Delmotte, V., … Xavier, J. C. (2018). Choosing the future of Antarctica. *Nature*, *558*, 233–241. https://doi.org/10.1038/s41586-018-0173-4

Roberts, C. M., O'Leary, B. C., McCauley, D. M., Cury, P. M., Duarte, C. M., Lubchenco, J., … Castilla, J. C. (2017). Marine reserves can mitigate and promote adaptation to climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *114*, 6167–6175. https://doi.org/10.1073/pnas.1701262114

Roberts, K. E., Valkan, R. S., & Cook, C. N. (2018). Measuring progress in marine protection: A new set of metrics to evaluate the strength of marine protected area networks. *Biological Conservation*, *219*, 20–27. https://doi.org/10.1016/j.biocon.2018.01.004

Rochman, C. M., Tahir, A., Williams, S. L., Baxa, D. V., Lam, R., Miller, J. T., … Werorilangi, S. J. T. (2015). Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Scientific Reports*, *5*. https://doi.org/10.1038/srep14340

Rogers, A. (2018). The biology of seamounts: 25 years on. In C. Sheppard (Ed.), *Advances in marine biology* (pp. 137–224). London: Academic Press. https://doi.org/10.1016/BS.AMB.2018.06.001

Rogers, A. (2019). Chapter 23 – Threats to seamount ecosystems and their management. In *World seas: an environmental evaluation (second edition). Volume III: Ecological issues and environmental impacts* (pp. 427–451). London: Academic Press.

Rogers, A. D. (2015). Environmental change in the deep ocean. *Annual Review of Environment and Resources*, *40*, 1–38. https://doi.org/10.1146/annurev-environ-102014-021415

Rogers, A. D., & Laffoley, D. (2013). Introduction to the Special Issue: The Global State of the Ocean; Interactions Between Stresses, Impacts and Some Potential Solutions. Synthesis papers from the International Programme on the State of the Ocean 2011 and 2012 Workshops. *Marine Pollution Bulletin*, *74*, 491–494. https://doi.org/10.1016/j.marpolbul.2013.06.057

Rogers, A. D., Sumaila, U. R., Hussain, S. S., & Baulcomb, C. (2014). *The high seas and us: Understanding the value of high-seas ecosystems* (p. 22). Oxford: Global Ocean Commission.

Rowlands, G., Brown, J., Soule, B., Boluda, P. T., & Rogers, A. D. (2019). Satellite surveillance of fishing vessel activity in the Ascension Island Exclusive Economic Zone and Marine Protected Area. *Marine Policy*, *101*, 39–50. https://doi.org/10.1016/j.marpol.2018.11.006

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, D., Pauly, D., … Zeller, D. (2018). The economics of fishing the high seas. *Science*, *4*, eeat2504. https://doi.org/10.1126/sciadv.aat2504

Sanseverino, I., Conduto, D., Pozzoli, L., Dobricic, S., & Lettieri, T. (2016). Algal bloom and its economic impact. European Commission JRC Technical Reports. EUR 27905 EN; https://doi.org/10.2788/660478.

Schmidt, C., Krauth, T., & Wagner, S. (2017). Export of plastic debris by rivers into the sea. *Environmental Science & Technology*, *15*, 12246–12253. https://doi.org/10.1021/acs.est.7b02368

Selman, M., Greenhalgh, S., Diaz, R., & Sugg, Z. (2016). *Eutrophication and hypoxia in coastal areas: A global assessment of the state of knowledge*. WRI Policy Note. Water Quality: Eutrophication and Hypoxia No. 1 (p. 6). Washington, DC: Water Resources Institute.

Seltenrich, N. (2015). New link in the food chain? marine plastic pollution and seafood safety. *Environmental Health Perspectives*, *123*, A34–A41. https://doi.org/10.1289/ehp.123-A34

Speed, C. W., Cappo, M., & Meekan, M. G. (2018). Evidence for rapid recovery of shark populations within a coral reef marine protected area. *Biological Conservation*, *220*, 308–319. https://doi.org/10.1016/j.biocon.2018.01.010

Stafford, R., & Jones, P. J. (2019). Viewpoint – Ocean plastic pollution: A convenient but distracting truth? *Marine Policy*, *103*, 187–191. https://doi.org/10.1016/j.marpol.2019.02.003

Steffen, W., Rockstrom, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., … Schellenhuber, H. J. (2018). Trajectories of the Earth system in the Anthropocene. *Proceedings of the National Academy of Sciences of the United States of America*, *115*, 8252–8259. https://doi.org/10.1073/pnas.1810141115

Stein, R. W., Mull, C. G., Kuhn, T. S., Aschliman, N. C., Davidson, L. N. K., Joy, J. B., … Mooers, A. O. (2018). Global priorities for conserving the evolutionary history of sharks, rays and chimaeras. *Nature Ecology & Evolution*, *2*, 288–298. https://doi.org/10.1038/s41559-017-0448-4

Steiner, Z., Turchyn, A. V., Harpaz, E., & Silverman, J. (2018). Water chemistry reveals a significant decline in coral calcification rates in the southern Red Sea. *Nature Communications*, *9*, 3615. https://doi.org/10.1038/s41467-018-06030-6

Sumaila, U. R., Cheung, W. W. L., Lam, V. W. Y., Pauly, D., & Herrick, S. (2011). Climate change impacts on the biophysics and economics of world fisheries. *Nature Climate Change*, *1*, 449–456. https://doi.org/10.1038/nclimate1301

Sumaila, U. R., Khan, A., Dyck, A., Watson, R., Munro, G., Tyedmers, P., & Pauly, D. (2010). A bottom up re-estimation of global fisheries subsidies. *Journal of Bioeconomics*, *12*, 201–225. https://doi.org/10.1007/s10818-010-9091-8

Sumaila, U. R., Lam, V. W. Y., Miller, D. D., Teh, L., Watson, R. A., Zeller, D., … Pauly, D. (2015). Winners and losers in a world where the high seas is closed to fishing. *Scientific Reports*, *5*, 8481. https://doi.org/10.1038/srep08481

Sumaila, U. R., Tai, T. C., Lam, V. W. Y., Cheung, W. W. L., Bailey, M., Cisneros-Montemayor, A. M., … Gulati, S. S. (2019). Benefits of the Paris agreement to ocean life, economies and people. *Science Advances*, *5*, eaau3855. https://doi.org/10.1126/sciadv.aau3855

Suran, M. (2018). A planet too rich in fibre: Microfibre pollution may have major consequences on the environment and human health. *EMBO Reports*, *19*, e46701. https://doi.org/10.15252/embr.201846701

Sweetman, A. K., Thurber, A. R., Smith, C. R., Levin, L. A., Mora, C., Wei, C.-L., … Dunlop, K. M. (2017). Major impacts of climate change on deep-sea benthic ecosystems. *Elementa Science of the Anthropocene*, *5*, 1–23. https://doi.org/10.1525/elementa.203

Thiel, M., Luna-Jorquera, G., Álvarez-Varas, R., Gallardo, C., Hinojosa, I. A., Luna, N., … Zavalaga, C. (2018). Impacts of marine plastic pollution from continental coasts to subtropical gyres – Fish, seabirds, and other vertebrates in the SE Pacific. *Frontiers in Marine Science*, *5*, 238. https://doi.org/10.3389/fmars.2018.00238

Thiele, T., & Gerber, L. (2017). Innovative financing for the high seas. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*, 89–99. https://doi.org/10.1002/aqc.2794

Thrush, S. F., Ellingsen, K. E., & Davis, K. (2016). Implications of fisheries impacts to seabed biodiversity and ecosystem-based management. *ICES Journal of Marine Science*, *73*, 44–50. https://doi.org/10.1093/icesjms/fsv114

Thurstan, R. H., & Roberts, C. M. (2014). The past and future of fish consumption: Can supplies meet healthy eating recommendations? *Marine Pollution Bulletin*, *89*, 5–11. https://doi.org/10.1016/j.marpolbul.2014.09.016

Van Dover, C. L., Arnaud-Haond, S., Gianni, M., Helmreich, S., Huber, J. A., Jaeckel, A. L., … Yamamoto, H. (2018). Scientific rationale and international obligations for protection of active hydrothermal vent ecosystems from deep-sea mining. *Marine Policy*, *90*, 20–28. https://doi.org/10.1016/j.marpol.2018.01.020

Vernberg, W. B., Thurberg, F. P., & Calabrese, A. (1979). In F. J. Vernberg (Ed.), *Marine pollution: Functional responses*. Georgetown, South Carolina: Academic Press.

Veron, J. E. N., Hoegh-Guldberg, O., Lenton, T. M., Lough, J. M., Obura, D. O., Pearce-Kelly, P., … Rogers, A. D. (2009). The coral reef crisis: The critical importance of < 350 ppm CO_2. *Marine Pollution Bulletin*, *58*, 1428–1436. https://doi.org/10.1016/j.marpolbul.2009.09.009

Vilmin, L., Mogollón, J. M., Beusen, A. H. W., & Bouwman, A. F. (2018). Forms and subannual variability of nitrogen and phosphorus loading to global river networks over the 20th century. *Global and Planetary Change*, *163*, 67–85. https://doi.org/10.1016/j.gloplacha.2018.02.007

Vince, J., & Hardesty, B. D. (2016). Plastic pollution challenges in marine and coastal environments: From local to global governance. *Restoration Ecology*, *25*, 123–128. https://doi.org/10.1111/rec.12388

Wakefield, J. (2019). Chapter 9 – European protection of fisheries in the North East Atlantic. In C. Sheppard (Ed.), *World seas volume III: Ecological issues and environmental impacts* (pp. 173–182). London: Elsevier.

Wijffels, S., Roemmich, D., Monselesan, D., Church, J., & Gilson, J. (2016). Ocean temperatures chronicle the ongoing warming of Earth. *Nature Climate Change*, *6*, 116–118. https://doi.org/10.1038/nclimate2924

Windsor, F. M., Ormerod, S. J., & Tyler, C. R. (2018). Endocrine disruption in aquatic systems: Up-scaling research to address ecological consequences. *Biological Reviews*, *93*, 626–641. https://doi.org/10.1111/brv.12360

Witze, A. (2018). East Antarctica is losing ice faster than anyone thought. *Nature*. https://doi.org/10.1038/d41586-018-07714-1

Woodall, L. C., Sanchez-Vidal, A., Canals, M., Paterson, G. L. J., Coppock, R., Sleight, V., … Thompson, R. C. (2014). The deep sea is a major sink for microplastic debris. *Royal Society Open Science*, *1*, 140317. https://doi.org/10.1098/rsos.140317

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., … Watson, R. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science*, *314*, 787–790. https://doi.org/10.1126/science.1132294

Wright, G., Rochette, J., Gjerde, K., & Seeger, I. (2018). The long and winding road: Negotiating a treaty for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction. IDDRI, Studies N°08/18, 82 p. Retrieved from https://www.iddri.org/en/publications-and-events/study/long-and-winding-road-negotiating-high-seas-treaty

Yin, J., Overpeck, J., Peyser, C., & Stouffer, R. (2018). Big jump of record warm global mean surface temperature in 2014–2016 related to unusually large oceanic heat releases. *Geophysical Research Letters*, *45*, 1069–1078. https://doi.org/10.1002/2017GL076500

Yumashev, D., Hope, C., Schaefer, K., Riemann-Campe, K., Iglesias-Suarez, F., Jafarov, E., … Whiteman, G. (2019). Climate policy implications of nonlinear decline of Arctic land permafrost and other cryosphere elements. *Nature Communications*, *10*, 1900. https://doi.org/10.1038/s41467-019-09863-x

Zanna, L., Khatiwala, S., Gregory, J. M., Ison, J., & Heimbach, P. (2019). Global reconstruction of historical ocean heat storage and transport. *Proceedings of the National Academy of Sciences of the United States of America*, *116*, 1126–1131. https://doi.org/10.1073/pnas.1808838115

How to cite this article: Laffoley D, Baxter JM, Amon DJ, et al. Eight urgent, fundamental and simultaneous steps needed to restore ocean health, and the consequences for humanity and the planet of inaction or delay. *Aquatic Conserv: Mar Freshw Ecosyst*. 2019;1–15. https://doi.org/10.1002/aqc.3182