Title
Evolving the narrative for protecting a rapidly changing ocean, post-COVID-19

Journal
Aquatic Conservation Marine and Freshwater Ecosystems, 31(6)

ISSN
1052-7613

Authors
Laffoley, D
Baxter, JM
Amon, DJ
et al.

Publication Date
2021-06-01

DOI
10.1002/aqc.3512

Peer reviewed

Received: 21 July 2020 | Revised: 6 October 2020 | Accepted: 8 October 2020
DOI: 10.1002/aqc.3512

VIEWPOINT

WILEY

Evolving the narrative for protecting a rapidly changing ocean, post-COVID-19

D. Laffoley[1] | J.M. Baxter[2] | D.J. Amon[3] | J. Claudet[4] | J.M. Hall-Spencer[5,6] | K. Grorud-Colvert[7] | L.A. Levin[8] | P.C. Reid[5,9] | A.D. Rogers[10,11] | M.L. Taylor[12] | L.C. Woodall[13] | N.F. Andersen[14,15]

[1]IUCN World Commission on Protected Areas, IUCN (International Union for Conservation of Nature), Gland, Switzerland
[2]Marine Alliance for Science and Technology for Scotland, School of Biology, East Sands, University of St Andrews, St Andrews, UK
[3]Department of Life Sciences, Natural History Museum, London, UK
[4]National Centre for Scientific Research, PSL Université Paris, CRIOBE, USR 3278 CNRS-EPHE-UPVD, Paris, France
[5]School of Marine and Biological Sciences, University of Plymouth, Plymouth, UK
[6]Shimoda Marine Research Center, University of Tsukuba, Shimoda, Japan
[7]Department of Integrative Biology, Oregon State University, Corvallis
[8]Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, University of California San Diego, La Jolla
[9]The Laboratory, The Continuous Plankton Recorder Survey, Marine Biological Association, Citadel Hill, Plymouth, UK
[10]Somerville College, University of Oxford, Oxford, UK
[11]REV Ocean, Lysaker, Norway
[12]University of Essex, Colchester, UK
[13]Department of Zoology, University of Oxford, Oxford, UK
[14]Department of Environment and Geography, University of York, York, UK
[15]Centre for Ecology and Conservation, University of Exeter, Penryn, UK

Correspondence
D. Laffoley, IUCN World Commission on Protected Areas, IUCN (International Union for Conservation of Nature), 28 rue Mauverney, CH-1196 Gland, Switzerland.
Email: danlaffoley@btinternet.com

Abstract

1. The ocean is the linchpin supporting life on Earth, but it is in declining health due to an increasing footprint of human use and climate change. Despite notable successes in helping to protect the ocean, the scale of actions is simply not now meeting the overriding scale and nature of the ocean's problems that confront us.
2. Moving into a post-COVID-19 world, new policy decisions will need to be made. Some, especially those developed prior to the pandemic, will require changes to their trajectories; others will emerge as a response to this global event. Reconnecting with nature, and specifically with the ocean, will take more than good intent and wishful thinking. Words, and how we express our connection to the ocean, clearly matter now more than ever before.
3. The evolution of the ocean narrative, aimed at preserving and expanding options and opportunities for future generations and a healthier planet, is articulated around six themes: (1) all life is dependent on the ocean; (2) by harming the ocean, we harm ourselves; (3) by protecting the ocean, we protect ourselves; (4) humans, the ocean, biodiversity, and climate are inextricably linked; (5) ocean and climate action must be undertaken together; and (6) reversing ocean change needs action now.
4. This narrative adopts a 'One Health' approach to protecting the ocean, addressing the whole Earth ocean system for better and more equitable social, cultural, economic, and environmental outcomes at its core. Speaking with one voice through a narrative that captures the latest science, concerns, and linkages to humanity is a precondition to action, by elevating humankind's understanding of our relationship with 'planet Ocean' and why it needs to become a central theme to everyone's lives. We have only one ocean, we must protect it, now. There is no 'Ocean B'.

KEYWORDS
COVID-19, global change, ocean literacy, protection, social norms, sustainability

1 | INTRODUCTION

When the British Prime Minister Harold Macmillan was asked what made his job difficult, he is alleged to have replied ‘Events, dear boy, events’. As it is with politics, so it is with the world. Rare though they are, some events shape the way everyone sees, relates to, and responds to the world around them. The COVID-19 pandemic is one of those events. It has altered the way much of the global population thinks, lives, and behaves. The pandemic has been a violent rupture of our experience of normality, and for many it has led to profound suffering and loss, and at the same time directly or indirectly affecting the lives of ocean-dependent coastal communities (Bennett et al., 2020). Though the outbreak of the virus has caused huge global disruption of social and economic activity and either the cancellation or postponement of key ocean protection events, it has shown that large-scale urgent change is possible, but not without challenges (Bavel et al., 2020).

Some of the changes that have happened as a result of COVID-19, at least in the short term, have been positive for the environment, such as the rapid decrease in atmospheric pollutants (and associated deaths) arising from decreased transportation, cleaner beaches, and reduced environmental noise levels (Chen et al., 2020; Zambrano-Monserrate, Ruano & Sanchez-Alcade, 2020). On the negative side, however, many have been very damaging for the ocean, such as the increase in generation of plastic waste, a decrease in waste recycling (Klemeš et al., 2020; Zambrano-Monserrate, Ruano & Sanchez-Alcade, 2020), major disruptions to the blue economy, and significant impacts worldwide on the management of protected areas due to a lack of tourist funding, amongst other issues (Hockings et al., 2020).

During the recovery phase of COVID-19, the challenge will be how to sustain a green recovery and effectively communicate the need to address other crises, such as the climate emergency and the rapidly degrading ocean, and to manage the pressure for rapid economic recovery by directing it at a more sustainable path (Rosenbloom & Markard, 2020). As we move into a post-COVID-19 world, new policy decisions will need to be made. Some, especially those that were being developed prior to the pandemic, will require changes to their trajectories; others will emerge as a response to this global event. For ocean conservation, this is an opportunity to set out what should follow.

There is a growing general sentiment that what went before is not what should continue as world economies reboot and the global population re-emerges from their nationally imposed lockdowns. An example of this is the EU's Green Deal (EU, 2019), which has now been supplemented by a Green Recovery Plan (EU, 2020). However, at the same time, there is evidence that some governments have used COVID-19 as an opportunity to roll back environmental legislation (e.g. Tollefson, 2020). A change of paradigm is needed to help develop new social norms that will in turn create new incentives for governments, the private sector, and individuals to practise more sustainable behaviour (Claudet et al., 2020a). This paper is therefore not, as such, directly about COVID-19, but it is about what that paradigm means and what needs to follow the global pandemic. The narrative it proposes to connect, inspire, and act for the ocean is a contribution to the green recovery process that many are now focused on seeing happen (e.g. Bleischwitz, 2020).

By exploring the issues from an ocean perspective that have led us to this precarious position with nature and the planet in the first place, this paper sets out an evolution of the narrative to put the ocean centre stage in such recovery processes. As the author and entrepreneur Mohith Agadi once said, ‘Environment is no one's property to destroy; it's everyone's responsibility to protect’. We hope that this paper will therefore be a valuable information source to policy advisers and decision-makers and for all engaged stakeholders, including civil society, as we inch slowly towards a post-COVID-19 world, where we all need to try harder to live much more in harmony with nature than we did before the pandemic took hold.

2 | APPRECIATING OCEAN VALUES, AND WHY WORDS MATTER

The ocean is the linchpin supporting global health and well-being. Despite the ocean being considered ‘remote’ and largely inaccessible, this has not protected it from many impacts of human activities (Stoknes, 2015; Lubchenco & Gaines, 2019). Only 3% is now recognized by researchers mapping ocean impacts as having no discernible human impact (Halpern et al., 2015). As the human footprint of exploitation has spread over and throughout the whole ocean, driven by the demands of an expanding world population and the consequences of climate change, nowhere is now beyond reach and shielded from human impacts. The ‘distance’ issue remains in the minds of many of the world's citizens, where lack of personal direct experience of the ocean and its degradation leads to low awareness and concern of the scale and significance of the problem—see Stoknes (2015) for a similar phenomenon with climate change.

Set starkly against this lack of awareness is the fact that the ocean's vast size means it has a major influence on the functioning of the entire planet (Steffen et al., 2020). The ocean provides benefits that can be individually seen, tasted, and experienced. Seafood and aquaculture from the ocean are critical for global food security, as they provide around 20% of the animal protein and 6.7% of all protein consumed worldwide (Food and Agriculture Organization of the United Nations, 2018; Costello et al., 2019). Diverse cultures, societies, and knowledge bases are integrally linked to marine and coastal biodiversity and the social–ecological systems they support. For example, communities and infrastructure benefit through mangroves, seagrasses, and saltmarshes that provide coastal protection from storms and erosion. There is also increasing evidence that humans can derive increased fitness and mental health because of proximity to the ocean (Fleming et al., 2014; Fleming et al., 2019).

In the context of COVID-19 and human health more generally, the diversity of ocean life also provides a genetic storehouse of adaptive potential in the face of a changing climate (Blasiak et al., 2020). It is the source of new pharmaceutical products, which have been discovered at rates of up to 2.5 times the industry average

(Blasiak et al., 2020). To date, over 34,000 marine natural products have been discovered (MarinLit, 2020), holding great potential to improve human life and health. Some hold high potential to provide cures (Sagar, Kaur & Minneman, 2010; Gentile et al., 2020), such as the sponge, *Aplysina*, which when damaged produces chemicals known as bromotyrosines (Binnewerg et al., 2020). Bromotyrosines are responsible for the antiviral, antibacterial, and antiparasitic properties of the sponge. Of more recent relevance regarding COVID-19 are the unusual nucleoside properties of sponges (nucleosides are best known as the four building blocks of DNA). Unlike DNA, a sponge can fill its body with just a single nucleoside, which has been found to be powerful in halting viral infections by mimicking DNA to trick the virus. Single sponge nucleosides cannot be linked in a complex intertwined chain like human DNA, and so, as the viral body tries to replicate, the single nucleosides will not react in the expected manner and DNA construction is terminated (Bergmann & Feeney, 1951; Hall, 2019). Antiviral drugs have since been developed that harness the mimicking qualities of nucleosides, and one of these, Remdesivir, is on trial as a treatment for COVID-19 (Seley-Radtke & Yates, 2018; Eastman et al., 2020; Seley-Radtke, 2020).

Infectious diseases have shaped the course of human history (Diamond, 2005). Over the last three decades, 75% of emerging human infectious diseases have involved a jump between species (One Health Initiative Task Force, 2008; Parvez & Parveen, 2017). Likewise, the increasing frequency of massive ocean-scale changes is driven by human activities, the speed and scale of which are unprecedented in recent Earth history. The current pandemic, driven from the consequences of our now unnaturally close association with nature, shows that we ignore planetary changes at our peril. Pandemics represent an existential risk to human civilization (Ord, 2020). Pandemics such as COVID-19, alongside all the human suffering and loss, may have brought a small pause to human activity, but this is still outweighed by the human footprint of exploitation and destruction. Although the risks posed by damage to the ocean from the direct and indirect impacts arising from human activities may be less clear to many people, that damage is resulting in increasingly severe climate disruption and sustained loss and degradation of ecosystem functions.

Action must be taken to heed the warning signs before it becomes too late. Earth's history shows that if the ocean rapidly or appreciably departs from the status quo sustained through feedback and self-regulatory processes over hundreds or thousands of years (exemplified by changes in temperature, acidity, and oxygen), such major environmental perturbations have always resulted in incredibly challenging times for life on Earth, often leading to mass extinctions (Barnosky et al., 2011), such as the Permian mass extinction (the Great Dying) that saw ~90% of all marine taxa go extinct (Payne & Clapham, 2012; Burger, Estrada & Gustin, 2019; Shen et al., 2019). There are real and mounting dangers that we may win battles but ultimately lose the war on decline and degradation of the ocean by simply not using the right narratives to connect us to the importance of the ocean, the realities of a post-COVID world, and the need to alter our course (Lubchenco & Gaines, 2019; Claudet et al., 2020a).

3 | WHY A BETTER, MORE PRECISE, AND UPDATED OCEAN NARRATIVE IS NEEDED

To succeed post-COVID-19 in a collective vision of a healthy, thriving, and more effectively managed and protected ocean, we need to further evolve the ocean narrative (Lubchenco & Gaines, 2019). Unfortunately, most of the world's population lacks a basic understanding of our total dependence on the systems that sustain us and all other life on Earth. Reconnecting with nature, therefore, and specifically with the ocean which is the lifeblood of planet Earth, will take more than good intent and wishful thinking. Put simply, people do not understand how deeply 'embedded' we all are in the systems that sustain life on Earth, how those systems exert a huge influence on human well-being, and how humans now, in turn, exert such a huge influence on the functioning and viability of such an Earth system.

The reality is that the ocean is still a largely ignored part of the Earth system, with insufficient protection and management. There are real problems and issues around agreeing solutions and then failing to implement them, examples being some of the many international treaties, agreements, and codes of conduct set up to protect the ocean and its biodiversity (Rogers et al., 2020). Another issue is that the current rules are so poorly observed and enforced that full protection is not achievable; for example, the difference between 'paper parks' and fully protected well-enforced marine protected areas (MPAs; Lubchenco & Grorud-Colvert, 2015; Gill et al., 2017; Rogers et al., 2020). There is a growing feeling of disquiet by those who want real actions to protect nature and the systems that keep us alive, versus those who simply wish to maintain the status quo for short-term gain, with all the associated and increasing environmental, economic, and social challenges the latter holds.

Beneath the surface, there have been notable conservation successes (e.g. Duarte et al., 2020; Knowlton, 2020), but overall, despite the grand pronouncements, it is fair to say we continue to increase extraction of resources and add more pollutants, discounting the damage to the ocean as minor problems or acceptable losses, against perceived 'essential' exploitative gain. The growing global population is increasingly used by sectors, such as fisheries, as justification of ever greater levels of exploitation at the clear sacrifice of nature (Steneck & Pauly, 2019). These attempts are increasingly 'dressed up' by affiliating them to the conservation flag. This behaviour is self-destructive. Cutting through the rhetoric and realizing that we are continuing on the same path with no reprieve for the ocean from the pressures of exploitation and climate breakdown *and* expecting a different—more positive outcome—was used by Einstein as the definition of madness.

Whilst some inroads have been made in policy dialogues over the last decades to link human well-being to a stable climate in an attempt to control our carbon emissions (not entirely successfully; Stoknes, 2015), the same cannot be said about connecting human well-being with the health of the ocean. We use 'our' in this paper in respect of the ocean and planet simply to point out that it is humankind's responsibility to sort out the problems that we have created. This is to allow the ocean to contribute maximally to human well-being by restoring it to full health, and in so doing to take the opportunity to do better for ourselves, the ocean, and the planet.

Words, and how we express our connection to the ocean, clearly matter now more than ever before. We must acknowledge the importance of the ocean and reset and reframe the discussion in the face of direct human impacts, such as overfishing and habitat destruction, as well as climate disruption. Reflections from the experience of COVID-19 show us the discussion needs to be substantive and focused. The global community faces a decision point: relaxing back into the status quo of life before the pandemic, beset with all its problems and issues, or building a green (blue) recovery to support economies within the context of a healthier planet. It is clear the latter has significant advantages to human well-being and the environment.

There is the opportunity to create a new, promising and more equitable future, where humanity can realize its full potential over the long term by utilizing nature-based solutions much more, and living in greater harmony with nature. There is also an urgent need to transform the ocean narrative and how it connects to people, policies, and priorities, as science now clearly shows the ocean is integral to the Earth system (Steffen et al., 2020). Humans are part of one unified Earth system (Schellnhuber, 1999), and through that realization it is clear the ocean is central to human well-being (and vice versa). The current narrative, however, does not connect people with actions in the way that is needed; if it did, we would have made more progress by now. This statement applies equally to the global climate crisis.

Experience has shown the importance of getting the narrative right, and the ocean conservation community itself has a key role, first and foremost, in delivering consistent facts through the diversity of communication routes at its disposal. If we are inconsistent, then others will be too. Some may even exploit such weaknesses in approach to justify their own ends, which usually relates to sustaining the status quo or increasing exploitation and exploration pressures on an already fragile, damaged ocean system. We already know—for example, from the works of Aristotle and Copernicus in ancient human history, to the impressive modern technology displayed by the USA, Russia, China, and other space-faring nations in more recent times—that we live on a blue planet with water covering 71% of its surface. The ocean efficiently absorbs infrared, red, and other wavelengths of light from the sun that penetrate its surface, leaving only blue to be reflected into space. In an effort to satisfy the human psyche's quest for order, hydrographers have overlain wholly artificial hydrographic boundaries to create the defined spaces of the Atlantic, Pacific, Indian and Arctic Oceans (International Hydrographic Organization, 1986), with the fifth basin, the Southern Ocean, even now still not recognized by all countries. Look more closely and there is only one ocean (Figure 1).

FIGURE 1 There is only one ocean. The ocean is an immense interconnected and heterogeneous whole that provides immeasurable benefits to humanity and the planet

The ocean is an immense interconnected and heterogeneous whole that provides immeasurable benefits to humanity and the planet. It is modulated by a range of physical oceanographic processes, as well as by wind, solar heating, and precipitation. These processes include the thermohaline circulation system on a large scale and more localized coastal currents that are influenced by geomorphology, weather, and tidal conditions. The ocean also comprises a vast array of seabed and water column habitats, each home to different communities of animals, plants, algae, and micro-organisms. Some habitats are connected through their use by marine species at different stages of their life cycle; for example, reef fish that use coral reefs as adults and mangroves as juveniles, or seafloor animals whose early life stages (larvae) reside in surface waters (e.g. Nagelkerken et al., 2002; Cowan & Sponaugle, 2009; Nagelkerken et al., 2017). This variation across local to large scales increases the resilience of the ocean, and the need to transcend jurisdictional boundaries is an important consideration in the application of area-based management tools.

The political behaviour of governments over the past decades shows that referring to the 'basins' as 'oceans' makes it justifiable to apply different management standards in different regions (e.g. with different regional fisheries management bodies; Pretlove & Blasiak, 2018). The Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization has long campaigned for the need to use the singular form 'ocean' rather than the commonly used plural 'oceans'. More recently, campaigning to drop the 's' from ocean[1] has been seen as a further step towards improving 'ocean literacy' amongst policymakers, the media, teachers, the public, and scientists. This has helped recognize the importance of the ocean to the health of the planet and humanity and helped strengthen marine governance for the benefit of present and future generations.[2] We refer to the atmosphere in the singular, and so we should do the same and refer to the ocean in the same

[1] https://www.oceanprotect.org/
[2] https://oceanliteracy.unesco.org/home/

way. It is very unfortunate, therefore, that key individuals and organizations leading ocean conservation efforts, scientists, and donors supporting the ocean community so consistently get this wrong and keep still referring to 'oceans'. The wording matters, especially if we wish to drive protection and management forward with a single voice and in a more consistent way. World Oceans Day should more correctly and impactfully be referred to as World Ocean Day. The ocean conservation community must shoulder more responsibility to get the narrative right: we have only one ocean, we must protect it, there is no 'Ocean B'.

Another narrative issue that the ocean community has a prominent role in correcting relates to statements about 'managing the ocean'. No! The ocean cannot be directly 'managed', but our activities can be managed, and in this way reduce impacts on the ocean. Similarly, precision is lacking in other related areas. The new target of 'at least 30%' as a global target for coverage of the ocean by fully or highly protected MPAs (Horta e Costa et al., 2016)—the level of protection that will most benefit biodiversity (Zupan et al., 2018a)—is clearly and specifically worded, yet time and time again the ocean conservation community refers to the target as '30%'. The phrase 'at least 30%' is a direction, whereas '30%' is a definitive destination.

There is a scientific reason for using 'at least'; this refers to at least 30% of representative ecosystems; and because these ecosystems are differently distributed, this results in a need for more than 30% of the ocean area to be protected (O'Leary et al., 2019). Also, because knowledge and analytical powers are increasing year on year and it takes years for the global conservation community to agree on things, we now know that stating exactly '30%' is already outdated. The target was developed and agreed at the International Union for Conservation of Nature (IUCN) World Parks Congress in Sydney, Australia, in 2014, and since then much more is known about the scale and nature of the impacts and challenges that we face. In fact, the latest scientific analysis shows that at least 30% is now the barest minimum needed to properly protect the ocean (Woodley et al., 2019). Besides, this percentage only accounts for present threats on the ocean, whereas they are increasing at an unprecedented pace (Jouffray et al., 2020).

It is also important to prevent the science-based narrative around 'at least 30%' from being diluted by current challenges and distractions. It is evident that, in discussions related to 'at least 30%', there are two things going on, and a clear tension between them. First, there is the narrative around science-backed facts of what it will take to put the ocean back on track, delivered through joined-up mitigation of climate disruption (Intergovernmental Panel on Climate Change (IPCC), 2019) and ocean biodiversity protection action (Rogers et al., 2020). Second, there is the conflict with the current position of what some countries feel is possible right now, based on business as usual and the option of 'least cost and pain', shielding vested interests from the reality of delivering significant change now—see Claudet et al. (2020b) and Rogers et al. (2020) for examples of the variation in effort of different countries in biodiversity protection.

It is also important to specify that the 'at least 30%' target is for fully or highly protected MPAs (Horta e Costa et al., 2016). Experience has already demonstrated that a high proportion of existing MPAs lack management plans (Rogers et al., 2020), are often weakly enforced (Edgar et al., 2014; Gill et al., 2017), or permit activities that damage biodiversity (Dureuil et al., 2018; Zupan et al., 2018b).

In taking forward a fit-for-purpose ocean narrative, it is critically important that the differences between these two discussion threads are recognized and understood (i.e. the amount of ocean we actually need to protect versus the lesser amount of ocean nations feel they can protect), otherwise current political pressures and sectoral interests will deprive the world of the opportunity to state goals for sustainable development and the actual level of action needed for a better tomorrow. There is a clear choice here between the debate and decisions being led by what people 'think they can do', rather than what all the science and evidence says we 'must do' now. Future generations looking back at our pandemic-compromised world with an ocean full of warning signs may characterize the former as 'reckless and self-centred' and the latter as 'wise and enlightened' leadership. This issue of consistency and accuracy in the ocean narrative, therefore, is not just about particular phrases, but also about how the ocean community ensures they are founded in science. They need to be based on facts and experience, so the overall approach to ocean conservation holds together, makes sense, and has the right degree of ambition.

Alongside direct, often local, management issues, such as overfishing, pollution, and habitat destruction, a new range of global climate-related drivers are significantly increasing pressure on the ocean. In the last 15 years, six major areas of concern have been documented in the scientific literature, which are now widely recognized as issues of global concern (e.g. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019; see Appendix 1 for details):

- Significant and accelerating heating of the ocean and associated oxygen loss (Laffoley & Baxter, 2016; Laffoley & Baxter, 2019).
- Significant sea-level rise and linked loss of coastal natural protection (Li et al., 2020).
- Significant regional acidification with a worsening trend (Ono et al., 2019; Terhaar, Kwiatowski & Bopp, 2020)
- Significant alterations to wind regimes and perturbations to major ocean currents and upwelling systems, which shape ocean ecosystems and human societies (Hu et al., 2020).
- Significant changes in patterns of ocean primary production, ecosystems, and species distribution resulting from increased warming and stratification at low to mid latitudes and decline of sea ice (Lotze et al., 2019).
- Significant impact on marine fisheries (Thiault et al., 2019).

These new issues are significant at the Earth/ocean system scale, and they interact with one another to greatly exacerbate the scale of concern and impacts. It is these combined issues that are driving a much greater urgency and need for ambition to recover and restore the ocean state. A clear updated ocean narrative needs to lie at the heart of such a process.

4 | RESETTING THE OCEAN NARRATIVE POST-COVID-19

The COVID-19 pandemic has provided an opportunity to reflect on our relationship with nature, but the overriding climate and biodiversity crises have not gone away. Emissions continue to rise, and climate impact problems continue to escalate and develop (IPCC, 2019). The same is true of serious losses of ecosystems and associated biodiversity driven by overfishing, habitat destruction, and pollution (IPBES, 2019; Rogers et al., 2020). Resetting the narrative requires better navigation of these driving forces and a need to remind ourselves of our place in the world, our links to nature, and our dependence on a healthy, functioning ocean.

If we are to reconnect the dots in an orderly manner to lead us to better actions and conclusions, a joined-up narrative is needed to stimulate integrated action. Politically, the world agreed to look at linking climate and biodiversity in 2014 at COP21 in Paris, but there has been limited progress to put such words into practice. Notably, the decision text at COP25 in 2019 recognizes the ocean as an 'integral part of the Earth's climate system', highlights the need to ensure 'the integrity of ocean and coastal ecosystems', and requests the Subsidiary Body for Scientific and Technological Advice, a United Nations (UN) climate change advisory group, to open a dialogue on the ocean and climate. The 44 submissions to the UN addressing content and format of this dialogue make clear the urgency of implementing the Paris commitments, informed by a clear ocean narrative.

Through a workshop held in London, but conducted mainly virtually, the International Programme on the State of the Ocean drew together leading marine scientists to pose them this very challenge. Their response was to create a six-point post-COVID-19 narrative (Table 1) together with a list of the fundamental services the ocean provides to humankind (Appendix 1) and the case for urgent action (Supporting Information Data S1).

TABLE 1 Narrative themes

1. All life is dependent on the ocean We depend on the ocean for all life on Earth; it nurtures us, but we have done woefully little to nurture it
2. By harming the ocean, we harm ourselves All ocean activities need to be carried out more responsibly with the curtailment of damaging actions that affect current and future values
3. By protecting the ocean, we protect ourselves Humanity's reliance on the ocean means we must protect it to protect ourselves
4. Humans, the ocean, biodiversity and climate are inextricably linked The ocean modulates the climate and humans influence the state of the ocean and its biodiversity—what is needed is joined-up action and solutions
5. Ocean and climate action must be undertaken together If you are not factoring in ocean impacts and solutions, you are not effectively addressing climate breakdown
6. The degree of ocean change requires action now We have no choice. We need to act now or risk closing off future options for action

4.1 | Narrative themes

4.1.1 | All life is dependent on the ocean

Nurturing the ocean is essential to safeguard our future as it provides valuable and vital ecosystem services, such as oxygen production and climate regulation, as well as food, energy, mineral, genetic, and cultural and recreational services (Figure 2; Barbier, 2017). Coastal communities and economies are reliant on these services for their sustenance and persistence, which have also been challenged by the COVID-19 pandemic. The provision of these services and access to appropriately managed resources are critical to accomplishing the sustainable development goals adopted by all member states of the UN to eliminate poverty and promote sustainable development (Singh et al., 2018; Claudet et al., 2020a). Our survival is accordingly dependent on a healthy ocean, but from afar it may seem to some more akin to a parasitic relationship, where resources are being extracted well beyond safe, sustainable levels, with little thought for ocean health or for the plight of future generations. If we are alert to the problems, we often simply shift our baselines (Pauly, 1995; Jackson et al., 2001), forgetting how the ocean was and instead use more recent data on partly depleted resources to justify our actions.

Humankind's relationship with the ocean is no longer sustainable; we are affecting ocean ecosystems and resources on a global scale through our overexploitation of the ocean for food and energy production, tourism, and transportation, and through land-based activities such as atmospheric emissions and discharge of waste (Halpern et al., 2015). Additionally, the cumulative effects of human uses are further changing the ocean's properties, destroying habitats (Rogers et al., 2020), altering species distributions (e.g. Poloczanska et al., 2013; Poloczanska et al., 2016), food webs (e.g. Pauly et al., 1998; du Pontavice et al., 2019), and ocean circulation and biochemistry (e.g. Doney et al., 2009; Levin, 2018; Hu et al., 2020), thus altering the capacity of the ocean to provide ecosystem services to humankind, such as climate regulation or food production (e.g. Costanza et al., 2014; Cheung, 2018). The problems we face are now so big that they are manifest at the whole ocean/world scale, and so the solutions need to have similar scale and ambition if they are to be successful. A systemic view of the ocean can promote mutually beneficial solutions for reaching humanity's full potential within safe sustainable limits, whilst still achieving the goal of a healthy global ocean (Singh et al., 2018; Claudet et al., 2020a). This is not without precedent, and numerous examples of success in conservation

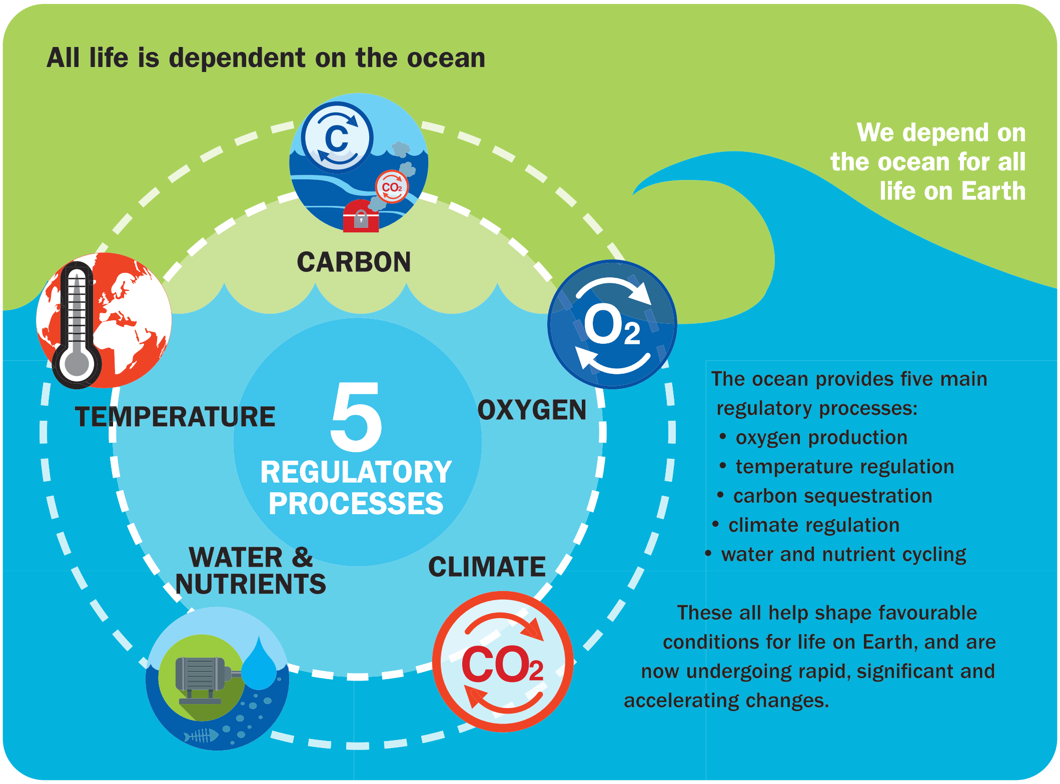

FIGURE 2 All life is dependent on the ocean. The ocean provides five main regulatory processes: oxygen production, temperature regulation, carbon sequestration, climate regulation, and water and nutrient cycling

coupled with sustainable management of marine living resources to the benefit of both industry and local communities give grounds for ocean optimism (Knowlton, 2020).

Despite all the political words, pledges, and calls to action in the name of nurture and protection, the vast open ocean referred to as the High Seas, which accounts for nearly half the surface area of the planet, still has no coherent legal framework for sustainable management of biodiversity, effective or otherwise (Rogers et al., 2020). For the remaining 21% of waters within the territories and jurisdictions of countries more has been done, but even here actions fall well behind political words and aspirations (Rogers et al., 2020). The political target of 10% protection may be met by the end of 2020 from a numerical basis, but not in terms of effective measures that demonstrably protect nature (Rogers et al., 2020; Claudet et al., 2020b). The 10% target was formatted at the third World Parks Congress in 1983, and though the conservation world is now demanding at least 30% in strict protection through MPAs, the political world has stuck for the ocean to that original 10% idea. The 10% target includes any and all types of conservation measures with only a small fraction of that 10% now in fully or highly protected MPAs (Claudet, 2018; Sala et al., 2018). Over a similar period of time, global-scale substantial changes in ocean health have been identified, whether that be warming, deoxygenation, sea-level rise, acidification, or, more recently, the conclusion that the speed of the major current systems has altered since the 1990s (Hu et al., 2020). Policy over the decades has simply failed to keep up with the science, and to respond with the additional ambition that is clearly needed to protect the ocean and address the issues involved.

As a result, ocean extremes (cyclones, hurricanes and typhoons, flooding, and heat waves), species redistributions, and biodiversity loss will increasingly and disproportionately now affect small islands and less wealthy coastal nations. Prevention is far better and less costly than cure, and more likely to succeed if carried out now. Indeed, a recent study by the World Economic Forum showed that, by embedding ‘net-positive’ nature requirements into their COVID-19 recovery strategies, governments and businesses could collectively realize US$10 trillion (£7.9 trillion) economic growth alongside creating 395 million new jobs within a decade (World Economic Forum, 2020). Set against these projected benefits, COVID-19 is disrupting the ‘blue economy’—a mix of marine jobs, products, and services that have been valued at US$2.5 trillion a year. If the ocean were a nation, it would rank as the seventh largest economy in the world (McCauley, Teleki & Fluxà Thienemann, 2020). Alongside rebuilding a sustainable ocean economy, another recent study showed that the benefits of protecting at least 30% of the world's land and ocean outweigh the costs by a ratio of at least 5:1 (Waldron et al., 2020). Much more on-the-water action is therefore needed right now if we are to make such returns on investments and nurture this ocean-dominated world back towards good health before any such interventions become less, or completely, ineffective, or impossible.

4.1.2 | By harming the ocean, we harm ourselves

We have ample scientific data that confirm certain large-scale human activities are damaging to the current and future state and condition of the ocean, from which humankind derives the very benefits we value, and yet there is little action to cease these practices. Out of sight and out of mind can no longer be the excuse when marine species, habitats, and ecosystem structure and functions are being impacted and lost. In some cases, such as unsustainable fisheries, activities are even subsidised with taxpayers' money (Sumaila et al., 2016). Although there is a process of environmental impact assessments in place in most nations, they have not been effective in many cases, in part because of stakeholder manipulation (Enríquez-de-Salamanca, 2018).

Intertidal and subtidal habitats are closest to human populations and, therefore, have arguably been most impacted by anthropogenic activities. For example, global mangrove cover decreased by 0.2–0.7% annually between 2000 and 2012, with some countries suffering significantly greater decreases (Hamilton & Casey, 2016); coastal development is a primary cause of this decline. These activities have many impacts on ecosystems, including direct (e.g. building on habitats) and indirect impacts (e.g. increased erosion and sedimentation from land clearance and forestry that increases water turbidity), alongside the loss of appreciable carbon storage that such ecosystems provide.

More broadly, coastal reclamation, land-use change, pollution, and climate breakdown have led to a loss of 30–50% of coastal ecosystems (Pandolfi et al., 2003; Waycott et al., 2009; Polidoro et al., 2010; Barbier, 2017; Duarte et al., 2020; Rogers et al., 2020). The value of ecosystem services provided by such ecosystems is considerable; coastal wetlands in the USA, for example, are thought to confer a value of US$23.2 billion a year in storm protection damage (Costanza et al., 2008). Recent estimates of damage from 88 tropical storms and hurricanes hitting the USA between 1996 and 2016 suggest the economic value of the protective effects of wetlands has an average value of about US$1.8 million/km^2 per year and a median value of US$91,000/km^2 (Sun & Carson, 2020).

Land-based pollution, including nutrients, chemicals, and debris, enters the ocean especially via riverine input, damaging marine life, changing productivity cycles, and creating deoxygenated zones (Stemmler & Lammel, 2009; Doney, 2010; Lammel et al., 2016; Breitburg et al., 2018; Chiba et al., 2018). Oil and gas exploration and exploitation are known to cause local and regional impacts from the sea surface to the deep seabed (Gomez & Green, 2013; Chang et al., 2014; Cordes et al., 2016). However, the most significant direct threats to biodiversity in the ocean, both within national jurisdictions and beyond, are from global fisheries (Lascelles et al., 2014; O'Leary et al., 2020; Rogers et al., 2020) and now exacerbated by accelerating ocean warming and deoxygenation (Laffoley & Baxter, 2016; Breitburg et al., 2018; Laffoley & Baxter, 2019). Impacts from fishing are not only from overexploitation but also from the environmental impacts of current fishing methods (Rogers et al., 2020). For example, bottom trawling occurring in both the shallow and deep ocean can have long-lasting impacts on vulnerable marine ecosystems (Food and Agriculture Organization of the United Nations, 2018; Victorero et al., 2018; Clark et al., 2019).

Coral reefs have been estimated to reduce damage to terrestrial assets by US$4 billion annually through coastal protection (Beck et al., 2018). Yet, these very same coral-reef ecosystems are predicted to be reduced to 10–30% of their area of extent with a 1.5°C increase in temperature resulting from climate disruption. If the temperature is allowed to increase by 2°C then the remaining area shrinks to just 1% (IPCC, 2019). Such a narrow window of change in environmental conditions demonstrates the linkages between climate and biodiversity, and the importance of acting quickly to mitigate climate breakdown to prevent the large-scale transformation of a habitat already at high risk of impact from sea-surface temperature rise (Gattuso et al., 2015). Rapid and sustained reduction in the emissions of carbon dioxide (CO_2) and other powerful greenhouse gases, such as methane, is the only way of mitigating climate breakdown impacts on coral reefs. Other conservation, adaptation, and restoration options will progressively narrow and become more expensive to society as time progresses and as the effects of ocean warming, acidification, and deoxygenation become more intense (Gattuso et al., 2015).

Additionally, it is unconscionable that new major industrial activities go ahead despite a lack of informative data and/or mitigation considerations. For instance, it is expected that deep-seabed mining for metals, such as cobalt and nickel, will begin within the next decade, justified on the basis of a need for renewable energy technologies, despite the potential wide-ranging and long-lasting impacts, including inevitable biodiversity loss (Niner et al., 2018; Jones, Amon & Chapman, 2018), with recovery on human timescales an impossibility in the abyssal ocean (Jones et al., 2017; Simon-Lledó et al., 2019). The money required for successful deep-seabed mining would be better invested in the development of technologies that use alternative metals and other materials, recycling of metals and rare earth elements, and forcing compliance with such measures, rather than driving more and more unsustainable extraction of finite resources (Levin, Amon & Lily, 2020).

Given the global scale of ocean challenges, many large-scale geoengineering solutions have also been suggested: marine cloud brightening (to increase ocean reflectivity), artificial upwelling (energy and fish production), downwelling (hurricane diversion), mineralization of CO_2 in rock under the sea floor (carbon storage), and adding carbonate minerals to the ocean (to enhance alkalinity). Several assessments, however, have identified significant risks associated with such projects, so any possible geoengineering solutions to climate disruption require a lot more investigation (Shepherd, 2012; Hoegh-Guldberg et al., 2019). In any such endeavours, the precautionary principle is the only sensible approach when considering future activities.

4.1.3 | By protecting the ocean, we protect ourselves

In the past, obtaining provisions from the ocean was too easily taken for granted; the ocean seemed 'too big to fail' until it became increasingly clear that human impacts were, and are, threatening the ocean's functionality and capacity to provide these services (Lubchenco & Gaines, 2019). These issues are now too large to ignore. It is abundantly clear that we protect ourselves by protecting the ocean.

MPAs have been widely documented and actively tracked for decades (Lubchenco & Grorud-Colvert, 2015), such that the current estimate of ocean area within MPAs is approximately 7% (UN Environment Programme World Conservation Monitoring Centre, 2020). This single number includes multiple layers. There is a wide range of activities that are allowed or disallowed in any given MPA (Zupan et al., 2018b), leading to different outcomes from different types of MPAs (Zupan et al., 2018a). Fully protected areas are MPAs where all extractive and destructive activities are prohibited (Horta e Costa et al., 2016; Oregon State University et al., 2019) and have been widely shown to return significant ecological benefits (Claudet et al., 2008; Lester et al., 2009; Roberts et al., 2017; Zupan et al., 2018b), with the capacity to benefit local communities (Sala et al., 2013; Ban et al., 2019). Highly protected MPAs achieve conservation outcomes but may also allow human use with the lowest possible impact (e.g. providing a means to balance rights and tenure of indigenous communities whose harvesting practices preserve biodiversity). Other minimally or lightly protected MPAs might still allow destructive activities, balancing human use but achieving fewer conservation benefits, if any (Zupan et al., 2018a; Oregon State University et al., 2019). Minimally protected MPAs would be expected to result in little to no progress towards meeting global conservation goals, but ironically are the main type of MPA used by many countries to increase the area in MPAs whilst avoiding the challenges and costs of changing ocean uses (Rogers et al., 2020; Claudet et al., 2020b). Thus, the ∼7% protection does not depict full ocean protection as it includes different levels of protection with varying conservation outcomes (Rogers et al., 2020).

The second challenge to MPA accounting is the fact that not all MPAs are managed and enforced on the water (Gill et al., 2017). It can take many steps from the moment the intent to create an MPA is announced, to the point it is designated (legally binding), implemented (regulations are in force on the water), and management is enforced (where monitoring and regular reviews occur to ensure that conservation goals are being met; Sala et al., 2018; Oregon State University et al., 2019). Many MPAs in the current global tally are designated but not yet actively managed. Thus, taking into account these so called ‘paper parks’, a closer examination shows that nearer to 5.3% of the ocean is currently in MPAs that are implemented (Marine Conservation Institute, 2020). This means that Aichi Biodiversity Target 11 of the Convention on Biological Diversity where 10% of representative habitats of the ocean are well protected is still a remote target (Klein et al., 2015; Jenkins & Van Houten, 2016; Sala et al., 2018; Jones et al., 2020; Rogers et al., 2020).

The discrepancy that arises from assuming that all MPAs have the same conservation outcomes leads to confusion, partly because different assessments are tallying different numbers and percentages (Sala et al., 2018). Furthermore, analyses show the 10% target is likely insufficient; the more appropriate goal to achieve effective biodiversity conservation in functioning ocean systems is for at least 30% of the ocean to be fully to highly protected (O'Leary et al., 2016; Rogers et al., 2020).

If we are to protect ourselves and the many services the ocean provides, it is critical that a clear accounting of MPAs and other forms of effective area-based conservation measures is carried out as we work towards achieving more appropriate targets. In addition, an adequate level of protection needs to be implemented and effectively managed; MPAs need to be climate smart and resilient in the face of global change (Tittensor et al., 2019).

Though we have stressed the importance of spatial conservation measures here, it is important to emphasize that this does not mean the rest of the ocean is left to business-as-usual exploitation. For example, marine reserves in themselves do not necessarily reduce overfishing and may even displace fishing activity to areas where it has previously been low (e.g. Kaiser, 2005; Agardy, Notarbartolo di Sciara & Christie, 2011). They also provide little protection from issues such as long-range pollutants or invasive species (Agardy et al., 2011; Burfeind et al., 2013). It is therefore of great importance to manage the entire ocean for all activities so that they are sustainable and maximize ocean and human health (Rogers et al., 2020).

4.1.4 | Humans, the ocean, biodiversity, and climate are inextricably linked

The ocean forms a critical part of the Earth's life-support system through its modulation of climate (Figure 3; Stocker, 2015). It also directly controls the habitability of the coastal zone, the provision of food, recreation, livelihoods, transport of goods (shipping), and information (internet cables) (Bindoff et al., 2019). The ocean, from the surface to its greatest depths, is a vast reservoir of heat. Water can hold approximately 4,000 times as much heat as air. By taking up 93% of the excess heat from global warming (Levitus et al., 2012; Reid, 2016), and by absorbing more than a quarter of the excess CO_2 associated with anthropogenic greenhouse gas emissions over the past half century (Laffoley & Baxter, 2019), the ocean has protected the planet from more extreme heating (Houghton, 2007; McKinley et al., 2017). The ocean is also the largest body of water on Earth, controlling the water cycle by regulating evaporation, rainfall, terrestrial runoff, and sea ice formation. These, in turn, influence ocean circulation, which modulates the ocean carbon, heat, and salt budgets.

But this overwhelming influence comes with a cost for ocean ecosystems, and for people (Pörtner et al., 2014; Bindoff et al., 2019). The ocean has buffered climate breakdown over the last century by absorbing ever greater amounts of heat and carbon, but there are indications that the role it has played until now is changing. Both the rate of warming (Cheng et al., 2019) and the global mean circulation that transports heat by currents towards the poles from warm equatorial regions has accelerated (Hu et al., 2020). Based on the work of Cheng and colleagues, it is estimated that the ocean is warming up to

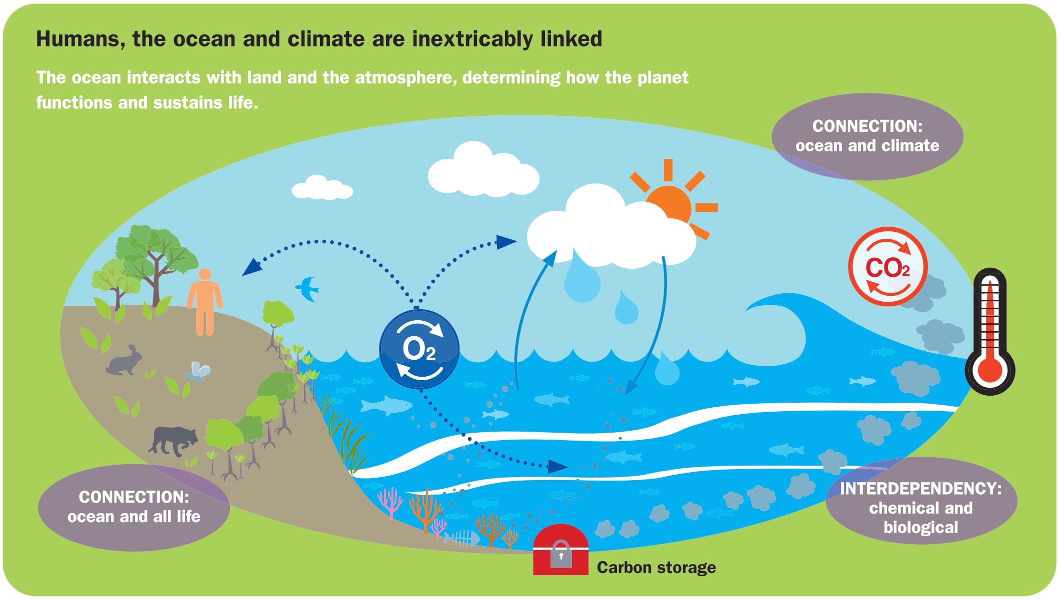

FIGURE 3 Human, the ocean, and climate are inextricably linked

40% faster than was estimated by the IPCC (2013) report. The two main sinks (ocean and land) for greenhouse gas CO_2, which are the major pathways for lowering concentrations in the atmosphere, appear also to be declining in their ability to do this at a fast rate, 0.54% per annum (Bennedsen, Hillebrand & Koopman, 2019). When combined, these two factors mean that climate disruption, as represented by a changing ocean, is possibly happening at a much faster rate than climate models have been predicting.

The consequences for climate and ecosystems have been enormous, with increases in ocean heat waves and other extreme events around the world (Holbrook et al., 2019; IPCC, 2019; Ainsworth et al., 2020; Cheung & Frölicher, 2020) and a much greater contribution of melting ice and snow to sea-level rise than expected. Accelerating declines in sea ice, glaciers, ice sheets, and permafrost, as well as reductions in snow (Baxter et al., 2019; Connolly et al., 2019; Farquharson et al., 2019; Golledge et al., 2019; Maurer et al., 2019), together are contributing to accelerating sea-level rise (Dieng et al., 2017; Nerem et al., 2018), threatening coastal and island habitability, ports and infrastructure, tourism, and coastal archaeology and food production (IPCC, 2019; Kulp & Strauss, 2019; Dawson et al., 2020). Ocean warming is causing poleward movement of species, loss of biodiversity (e.g. coral bleaching), and reduced productivity and integrity in tropical and temperate waters (Beaugrand et al., 2002; Chivers, Walne & Hays, 2017; Beaugrand et al., 2019; Skirving et al., 2019; Smith, Dowling & Brown, 2019).

Sea-level rise is expected to reduce wetland cover and the potential for both carbon and nutrient sequestration. A warming ocean is also losing oxygen due to reduced solubility of gases and reduced ventilation (vertical mixing) as stratification intensifies. Animals and microbes in a warmer ocean require more oxygen to survive and thus 'use it up' as they respire in the ocean interior. Warming is expanding low-oxygen zones (Stramma et al., 2008; Stramma et al., 2010) and tipping estuaries and coastal waters subject to eutrophication into oxygen-depleted dead zones (Altieri & Gedan, 2015). This phenomenon, referred to as hypoxia or deoxygenation, can manifest in the redistribution of species (vertically and horizontally), loss of biodiversity, altered food webs, reductions in body size, and changes in productivity (Laffoley & Baxter, 2019). As the ocean absorbs carbon from the atmosphere, the resulting rise in acidity and undersaturation of carbonate ions challenges the ability of calcifying species to thrive, form habitat, and function properly (Gattuso et al., 2015; Doney et al., 2020). Effects are particularly severe at high latitudes and in tropical warm-water corals (Pandolfi et al., 2011; Foster et al., 2016). Together, warming, acidification, deoxygenation, sea-level rise, and changes in circulation impose multiple stresses on ocean ecosystems that interact cumulatively with direct disturbance in the form of overfishing, habitat loss or disruption, species invasions, contamination, and pollution.

The solution to the aforementioned issues is to first recognize the essential values that the ocean provides for all life on Earth and then, in joined-up actions across all sectors of society, to strengthen existing and discover new solutions to overcome the challenges everyone now faces. Some are straightforward, such as taking the pressures off the system to enable the ocean to recover and become healthier into the future. This should be a multi-pronged strategy, combining drastic cuts in anthropogenic emissions of CO_2 and other potent greenhouse gases with dramatic scaling-up of full and effective protection for ecosystems in the ocean, better provisions to protect mobile species, and a return to recognizable, demonstrable, and accountable sustainability for all activities conducted anywhere in the ocean.

Other strategies across society to join up actions will need to be stronger and more inventive. They will need to include more help to protect wide-ranging marine species whose conservation is dependent on wider measures rather than just MPAs, as well as new innovative private–public partnerships. An example of this is the rapidly growing cuboid satellite industry and all the new technology they have to observe the Earth and ocean in hitherto unimaginable detail, and thus revolutionize surveillance and monitoring capabilities, and the prosecution of those individuals and nations who undermine everyone else's efforts to do the right thing and protect the ocean.

4.1.5 | Ocean and climate action must be undertaken together

Humans reside at the heart of the climate problem and must wholeheartedly embrace the ocean as part of the climate solution. Feedbacks from human influence on ocean temperature may reinforce and exacerbate global warming. Solutions to these problems must be ambitious and wide-reaching. Protecting the ocean will require more than achieving the Paris Agreement greenhouse gas emission targets. Even if they are achieved, some parts of the ocean and dependent people in coastal cities and regions and small island states will still suffer (IPCC, 2018; Laffoley & Baxter, 2018).

The Paris Agreement only considers national emissions. It does not include, for example, aircraft and shipping emissions, which in the case of the pre-COVID-19UK, for example, added a further 57% on top of the current national emissions (Committee on Climate Change, 2019). Given the importance, and until very recently unrecognized key role, that the ocean plays in mitigating climate breakdown, much greater resources need to be allocated to understanding the ocean and its climate role so that humanity is in a better position to predict and adapt to the speed and scale of change in the future. This applies to addressing potential changes in the ocean that may initiate tipping points/regime shifts in global climate (e.g. Lenton, 2020). Short of yet-to-be developed innovations and geoengineering solutions, achieving the required reduction in carbon emissions will require dramatic changes in current approaches to ensure a habitable world for future generations. Though such benefits may not be immediately obvious, they are essential as they will ultimately lead to cleaner air, less acidic water, and so on. This new narrative is therefore formulated and focused on the opportunity for humanity to live within its means and to achieve its full potential in that context, both now *and* in the future, whilst preventing our current actions from reducing our future potential or even destroying it. Most people's actions are driven by personal gain, not community or future community gain. Yet time is not on our side to address these shortcomings, as the decadal timescale to effect changes such as these is rapidly reducing with little sign of the serious at-scale responses that will be required from governments.

Direct ocean-based mitigation actions include increasing the generation of renewable energy (solar and wind) from the ocean, the greening of ocean industries (to achieve carbon neutrality), and enhancement of the natural carbon sequestration capabilities of blue carbon ecosystems through expansion and restoration of coastal mangroves, seagrasses, and saltmarshes, and carbon storage in seabed sediments and biogenic reefs. Hoegh-Guldberg et al. (2019), based on the aforementioned options, plus possible sub-seabed (geological) carbon storage, calculate that these initiatives could reduce global carbon emissions by 4 Gt of CO_2 equivalent per annum by 2030 relative to projected business-as-usual emissions. During the COVID-19 pandemic it is estimated that CO_2 emissions fell by around 17 Mt per day, equivalent to 6.2 Gt per annum (Le Quéré et al., 2020). 'A sustainable ocean-based economy can play an essential role in much needed emissions reduction, while providing jobs, supporting food security, sustaining biological diversity and enhancing resilience' (Hoegh-Guldberg et al., 2019).

However, societal adaptation can and must go further to build ocean resilience to climate stress. From spatial planning and the designation of MPAs to improved fishing and aquaculture practices, new ocean science and ecosystem-based management, climate consideration must become integral to how we study, perceive, protect, and use the ocean. The benefits will accrue to the ocean economy (Gaines et al., 2019), to the whole of society, and to the health of the planet (Gattuso et al., 2015).

4.1.6 | Reversing ocean change needs action now

In many respects, the ocean has been treated as a frontier with open access to its resources, relatively few rules to constrain human activities, and competition to exploit its resources. This has resulted in wasteful exploitation of species, habitats, and ecosystems (Norse, 2005).

Fishing is the best-known example where technological advances since World War II have allowed expansion of such activities across the entire ocean (Swartz et al., 2010) and to increasing depths (Watson & Morato, 2013). Despite a decline in global catches (Pauly & Zeller, 2016), and evidence of an ocean-wide declining catch per unit effort, the size and power of the international fishing fleet, including both industrial and small-scale fisheries, has been allowed to continue to increase (Rousseau et al., 2019). Not only has this resulted in the depletion of many populations of target fish species, but it has also become the current number one driver of extinction risk in the ocean (IPBES, 2019; Rogers et al., 2020). It is also economically wasteful; the World Bank has estimated that overfishing causes a loss in annual revenues of US$83 billion per year (World Bank, 2017). The combination of direct fishing impacts and indirect effects of global climate disruption on exploited ecosystems is also making fisheries themselves vulnerable (Thiault et al., 2019).

Poor profitability of fisheries coupled with lack of regulation has led to other undesirable consequences in the industry, particularly human rights abuses, such as slavery, child labour, and violence (Ratner, Åsgård & Allison, 2014; Tickler et al., 2018; Vandergeest, 2019). Efforts to reduce fishing capacity and to regulate catches have allowed fish stocks to stabilize in developed countries, such as in Europe, Canada, and the USA (Fernandes & Cook, 2013; Fernandes et al., 2017; Hilborn et al., 2020), and there has also been a gradual increase in the incorporation of biodiversity considerations into fisheries management (Friedman, Garcia & Rice, 2018). However, despite an increasing number of international and regional conventions, agreements, guidelines, codes of practice, and plans of action, as well as national regulation, measures both to reform fisheries to make them sustainable and to conserve biodiversity from the impacts of fishing have been fragmented and too slow at a global scale.

The solution to the problems leading to a degradation of marine ecosystems, the services they provide, and their predicted sustained and accelerated decline for the foreseeable future is immediate concerted global action. Such action is not unprecedented at a global scale. The discovery of the ozone hole in Antarctica in 1985 (Farman, Gardiner & Shanklin, 1985) triggered the creation of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and the subsequent regulation of chlorofluorocarbons (CFCs) and other halogenated ozone-depleting substances that stimulated the opening of the hole in the first place. Evidence since then suggests that this multilateral agreement has largely succeeded, with evidence that the ozone hole is reducing in size (Banerjee et al., 2020). Vigilance is still required to ensure that CFC production does not increase again, as the expected rate of reduction has slowed, suggesting that unreported new production is occurring that is inconsistent with the protocol (Montzka et al., 2018; Dhomse et al., 2019).

In contrast to how we have dealt with CFCs, the sectoral and fragmented approach to ocean governance underlies our inability to tackle the drivers of degradation of marine ecosystems and, at a broader scale, the Earth system. Failure to recognize the connections between the state of the ocean, human health, and societal well-being is symptomatic of an archaic view of management of resources for the benefit of a limited number of actors, such as private industry or states.

The connectivity between marine ecosystems (e.g. O'Leary & Roberts, 2016; Popova et al., 2019) means that negative impacts in one place, or on one species, habitat, or ecosystem, inevitably have broader consequences for the ocean. What has not been fully recognized is that they also impact humans at local to global scales.

5 | DISCUSSION: THE URGENCY TO TRANSFORM WORDS INTO ACTIONS

The global response to the COVID-19 pandemic is an example of a rapid and coordinated response to the emergence of a threat to human health, despite its deficiencies (Gates, 2020; Jacobsen, 2020). Preventing, detecting, and controlling such diseases has given rise to the 'One Health' concept (One Health Initiative Task Force, 2008; Annelli et al., 2011), which highlights the transdisciplinary approaches required to address a complex problem that spans humans, animals, and ecosystems (Jacobsen, 2020). The ocean narrative set out in this paper has adopted a 'One Health' approach to protecting the ocean, considering all aspects of ocean problems, including the cultural and economic drivers of degradation and recognizing the broadscale consequences on ecosystems and human health. The intent of this further evolution of the ocean narrative is to raise the ocean on the global agenda and garner the concerted global action required to change the current trajectory of biodiversity loss and decline in ecosystem services and to allow humanity to achieve its full potential (Ord, 2020).

At the core of the narrative is recognition of the need to address the whole Earth-ocean system for better and more equitable social, cultural, economic, and environmental outcomes. Our 'legacy of inaction' combined with new climate impacts has caught up with us to create an increasingly dangerous mix of changes that threaten current and future ocean functions, values, and benefits. To move forward we need to deal once and for all with the political mismatch between acting now to invest for the future, and not the often-encountered strategy of political short-termism to garner re-election. Though the latter may play out to good effect for individual politicians and their aspirations at national scales, it does little to secure the changes needed at a world scale.

Addressing the needs to respond to the ocean problems, which are now manifest at the global scale, will not only stand a better chance of halting the decline and negative changes now being seen across the whole ocean, but it also represents the best strategy to achieving success in other related areas, such as delivering a 'sustainable ocean economy'. Fundamentally, as was achieved with tackling CFCs, we need to remove the problems associated with 'mind the gap(s)' and recognize the importance of delivering joined-up sectoral policy development and implementation. If this is not achieved, then the positive actions in one sector can easily be wiped out by other sectors ignoring the ocean warning signs and continuing with business as usual.

Such a strategy and the actions that emerge from it must be guided by recognition of and investment in baselines, which can be used to guide ambition and the creation of successful solutions. We have lost measurable and significant value and benefits from the ocean over the decades, and longer, by not recognizing the opportunities that investment in the ocean can bring, coupled with not internalizing the costs of current activities that damage the ocean, such as overfishing. As it is, such existing industries, coupled with the potential of new damaging ones like deep-sea mining, take the profits and seldom pay for the damage and consequences of their actions to broader society, and indeed often taxpayers subsidize their endeavours to the tune of billions of pounds. As with climate change impacts, it is predominantly the poor and those least able to pay who shoulder the impacts and costs of such discounting, and so the issue of environmental rights and justice will also need to be central in developing a new ocean agenda in order to address the problems that we are both creating today and have inherited from malpractices in the past.

There is fundamentally, in the middle of all this, the fact that the ocean, as the lifeblood of the planet, merits protection in its own right. The wonder it instils in individuals, its sheer beauty, and the feeling of calm it injects into the soul, all of which benefit human well-being, must never be forgotten against the base arguments of pounds spent or invested. Sustaining and recovering the ocean is no doubt a key part of intergenerational equity, and actions must now deliver on the ideals that we are merely custodians of the ocean and should pass it on to future generations in no worse shape, and ideally in much better health, than it was passed to us.

The COVID-19 pandemic is both a wake-up call and a stark reminder about how all our fates are intrinsically linked. Just as the COVID-19 pandemic has taught us all about what we now know can happen when people are forced into unnaturally close association with nature, so most people still do not realize just how dependent humanity is on a healthy ocean and its well-being. We can and need to make clearer the links between human health, our well-being, and the ocean's fate, whether this be through food, weather, or the oxygen we breathe. We need to rapidly build a greater understanding and appreciation of what that relationship is, why we should value it more, and what we must do to protect it.

Most people still do not appreciate how all our futures are in some way and at some point tied not just to the ocean but to individual species; for example, the horseshoe crab. Few people know that all pharmaceutical companies in the world rely on a particular horseshoe crab species, *Limulus polyphemus*. This is because the horseshoe crab's milky-blue blood provides the only known natural source of limulus amoebocyte lysate (e.g. Mehmood, 2019). This is a substance that is extremely sensitive for detecting a contaminant called endotoxin, which is created by bacteria. If even a tiny amount of endotoxin makes its way into vaccines, injectable drugs, or other sterile pharmaceuticals, such as artificial knees and hips, the results can be deadly. Across health care, our well-being and trust in those very medicines and medical procedures comes down to a reliance on this primitive marine creature. Without this species, medicine as we know it would not exist.

As economies around the world struggle to cope with the COVID-19 virus, living in the hope of a vaccine so some day we can return to some form of normality, we will owe that (hopefully imminent) success, and the safety of such vaccines, in a large part to the ocean and one of the species that lives in it. This is a stark reminder that it is in all our interests to act now while there is still time to better protect the ocean and recover its health, for our health as a species is absolutely tied to the ocean's health. It is true to say that whether we act or not will depend on widespread recognition of the warning signs we now see at a whole ocean scale. We must heed the warning signs and act with new ambition and at scale to counter and overcome them, because what we do today will without a doubt define all our tomorrows.

6 | RECOMMENDATIONS

The COVID-19 pandemic and the opportunity to reflect on what is happening around that provide an opportunity through a new narrative to improve human well-being and create a more equitable society and a healthier ocean. The health of the ocean is so closely intertwined with humanity's health that failure is not an option; early action will be more successful and will be less costly. In particular:

- We must act now on the science and trends we see and not wait for a perfect solution. The scale and apparently accelerating rate of changes seen in the ocean require a joined-up, whole-ocean response to climate and biodiversity.
- Current measures proposed or agreed for ocean protection are outdated, too small, too poorly coordinated, and too piecemeal to have an impact at a whole ocean scale given the level of observed changes.
- Far more ambitious action is needed now—indecision and delay are at the cost to humanity of delivering the conditions to be able to gain greater benefits and make better choices in the future.
- Acting now should focus on developing a 'plan B for ocean recovery' based on the eventuality that downward step-changes in ocean health will dramatically start to impact humanity—a new 'Marshall-style' plan for the ocean, akin to the ambition and drive used to rebuild societies after World War II (Wikipedia Contributors, 2019)[3] is needed.

Speaking with one voice through a narrative that captures the latest science, concerns, and linkages to humanity is a precondition to action. Success, both now and in the future, can be increased by elevating everyone's understanding of our relationship with our planet's ocean and why it needs to become a central theme to everyone's lives. This includes the first, simple step of dropping the 's', recognizing the ocean as a single entity, and referring to the ocean in the singular.

ORCID

D. Laffoley https://orcid.org/0000-0001-6338-6244
J.M. Baxter https://orcid.org/0000-0002-0847-3318
J.M. Hall-Spencer https://orcid.org/0000-0002-6915-2518
N.F. Andersen https://orcid.org/0000-0003-1288-2568

REFERENCES

Agardy, T., Notarbartolo di Sciara, G. & Christie, P. (2011). Mind the gap: Addressing the shortcomings of marine protected areas through large scale marine spatial planning. *Marine Policy*, *35*(2), 226–232. https://doi.org/10.1016/j.marpol.2010.10.006

Ainsworth, T.D., Hurd, C.L., Gates, R.D. & Boyd, P.W. (2020). How do we overcome abrupt degradation of marine ecosystems and meet the challenge of heat waves and climate extremes? *Global Change Biology*, *26*, 343–354. https://doi.org/10.1111/gcb.14901

Altieri, A.H. & Gedan, K.B. (2015). Climate change and dead zones. *Global Change Biology*, *21*(4), 1395–1406. https://doi.org/10.1111/gcb.12754

Annelli, J., Black, P., Boggess, S., Conn, B., Dehove, A., Dugas, R. et al. (2011). *Expert meeting on One Health governance and global network—October 31–November 1 2011: Atlanta report 2011*. Technical Report. One Health Global Network. Retrieved from https://doi.org/10.13140/2.1.3212.1602

Arístegui, J., Gasol, J.M., Duarte, C.M. & Herndld, G.J. (2009). Microbial oceanography of the dark ocean's pelagic realm. *Limnology and Oceanography*, *54*(5), 1501–1529. https://doi.org/10.4319/lo.2009.54.5.1501

Ban, N., Gurney, G., Marshall, N., Whitney, C., Mills, M., Gelcich, S. et al. (2019). Well-being outcomes of marine protected areas. *Nature*

[3]https://en.wikipedia.org/wiki/Marshall_Plan

Sustainability, *2*(6), 524–532. https://doi.org/10.1038/s41893-019-0306-2

Banerjee, A., Fyfe, A.G., Polvani, L.M., Waugh, D. & Chang, K.-L. (2020). A pause in Southern Hemisphere circulation trends due to the Montreal Protocol. *Nature*, *579*, 544–548. https://doi.org/10.1038/s41586-020-2120-4

Barbier, E.B. (2017). Marine ecosystem services. *Current Biology*, *27*(11), R507–R510. https://doi.org/10.1016/j.cub.2017.03.020

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O.U., Swartz, B., Quental, T.D. et al. (2011). Earth's sixth mass extinction already arrived? *Nature*, *417*, 51–57. https://doi.org/10.1038/nature09678

Baumgartner, A. & Reichel, E. (1975). *The world water balance*. New York, NY: Elsevier.

Bavel, J., Boggio, P., Capraro, V., Cichocka, A., Cikara, M., Crockett, M. et al. (2020). Using social and behavioural science to support COVID-19 pandemic response. *Nature Human Behaviour*, *4*(5), 460–471. https://doi.org/10.31234/osf.io/y38m9

Baxter, I., Ding, Q., Schweiger, A., L'Heureux, M., Baxter, S., Wang, T. et al. (2019). How tropical Pacific surface cooling contributed to accelerated sea ice melt from 2007 to 2012 as ice is thinned by anthropogenic forcing. *Journal of Climate*, *32*(24), 8583–8602. https://doi.org/10.1175/jcli-d-18-0783.1

Beaugrand, G., Conversi, A., Atkinson, A., Cloern, J., Chiba, S., Fonda-Umani, S. et al. (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

Beaugrand, G., Reid, P.C., Ibañez, F., Lindley, J.A. & Edwards, M. (2002). Reorganisation of North Atlantic marine copepod biodiversity and climate. *Science*, *296*(5573), 1692–1694. https://doi.org/10.1126/science.1071329

Beck, M.W., Losada, I.J., Menéndez, P., Reguero, B.G., Díaz-Simal, P. & Fernández, F. (2018). The global flood protection savings provided by coral reefs. *Nature Communications*, *9*, 2186. https://doi.org/10.1038/s41467-018-04568-z

Bennedsen, M., Hillebrand, E. & Koopman, S.J. (2019). *Modeling, forecasting and nowcasting U.S. CO_2 emissions using May macroeconomic predictors*. CREATES Research Papers 2019‐21. Department of Economics and Business Economics, Aarhus University; Aarhus, Denmark.

Bennett, N.J., Finkbeiner, E.M., Ban, N.C., Belhabib, D., Jupiter, S.D., Kittinger, J.N. et al. (2020). The COVID-19 pandemic, small-scale fisheries and coastal fishing communities. *Coastal Management*, *48*(4), 336–347. https://doi.org/10.1080/08920753.2020.1766937

Bergmann, W. & Feeney, R.J. (1951). Contributions to the study of marine products. XXXII. The nucleosides of sponges. I. *Journal of Organic Chemistry*, *16*(6), 981–987. https://doi.org/10.1021/jo01146a023

Bigg, G.R., Jickells, T.D., Liss, P.S. & Osborn, T.J. (2003). The role of the oceans in climate. *International Journal of Climatology*, *23*(10), 1127–1159. https://doi.org/10.1002/joc.926

Bindoff, N.L., Cheung, W.W.L., Kairo, J.G., Arístegui, J., Guinder, V.A. & Hallberg, R. (2019). Chapter 5: Changing ocean, marine ecosystems, and dependent communities. In: Pörtner, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., et al. (Eds.) *The ocean and cryosphere in a changing climate: A special report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Binnewerg, B., Schubert, M., Voronkina, A., Muzychka, L., Wysokowski, M., Petrenko, L. et al. (2020). Marine biomaterials: Biomimetic and pharmacological potential of cultivated *Aplysina aerophoba* marine demosponge. *Materials Science and Engineering C*, *109*, 110566. https://doi.org/10.1016/j.msec.2019.110566

Blasiak, R., Wynberg, R., Grorud-Colvert, K., Thambisetty, S., Bandarra, N., Canario, A.V.M. et al. (2020). Prospects for conservation and sustainable use of the ocean genome. *Nature Sustainability*, *3*, 588–596. https://doi.org/10.1038/s41893-020-0522-9

Bleischwitz, R. (2020). COVID-19: 5 ways to create a green recovery. *World Economic Forum/The Conversation*. Retrieved from https://www.weforum.org/agenda/2020/06/five-ways-to-kickstart-a-green-recovery/

Breitburg, D., Levin, L.A., Oschiles, A., Grégoìre, M., Chevez, F.P., Conley, D.J. et al. (2018). Declining oxygen in the global ocean and coastal waters. *Science*, *359*(6371), eaam7240. https://doi.org/10.1126/science.aam7240

Bristow, L.A., Mohr, W., Ahmerkamp, S. & Kuypers, M.M.M. (2017). Nutrients that limit growth in the ocean. *Current Biology*, *27*(11), R474–R478. https://doi.org/10.1016/jcub.2017.03.030

Burfeind, D.D., Pitt, K.A., Connolly, R.M. & Byers, J.E. (2013). Performance of non-native species within marine reserves. *Biological Invasions*, *15*, 17–28. https://doi.org/10.1007/s10530-012-0265-2

Burger, B.J., Estrada, M.V. & Gustin, M.S. (2019). What caused Earth's largest mass extinction event? New evidence from the Permian–Triassic boundary in northeastern Utah. *Global and Planetary Change*, *177*, 81–100. https://doi.org/10.1016/j.gloplacha.2019.03.013

Chang, S.E., Stone, J., Demes, K. & Piscitelli, M. (2014). Consequences of oil spills: A review and framework for informing planning. *Ecology and Society*, *19*(2), 26. https://doi.org/10.5751/ES-06406-190226

Chen, K., Wang, M., Huang, C., Kinney, P.L. & Anastas, P.T. (2020). Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. *The Lancet: Planetary Health*, *4*(6), e210–e212. https://doi.org/10.1016/s2542-5196(20)30107-8

Cheng, L., Abraham, J., Hausfather, Z. & Trenberth, K.E. (2019). How fast are the oceans warming? *Science*, *363*(6423), 128–129. https://doi.org/10.1126/science.aav7619

Cheung, W. W. L. (2018). The future of fishes and fisheries in the changing oceans. *Journal of Fish Biology*, *92*(3), 790–803. https://doi.org/10.1111/jfb.13558

Cheung, W.W.L. & Frölicher, T.L. (2020). Marine heatwaves exacerbate climate change impacts for fisheries in the northeast Pacific. *Scientific Reports*, *10*, 6678. https://doi.org/10.1038/s41598-020-63650-z

Chiba, S., Saito, H., Fleycher, R., Yogi, T., Kayo, M., Miyagi, S. et al. (2018). Human footprint in the abyss: 30-year records of deep-sea plastic debris. *Marine Policy*, *96*, 204–212. https://doi.org/10.1016/j.marpol.2018.03.022

Chislock, M.F., Doster, E., Zitomer, R.A. & Wilson, A.E. (2013). Eutrophication: Causes, consequences, and controls in aquatic ecosystems. *Nature Education Knowledge*, *4*(4), 10.

Chivers, W.J., Walne, A.W. & Hays, G.C. (2017). Mismatch between marine plankton range movements and the velocity of climate change. *Nature Communications*, *8*, 14434. https://doi.org/10.1038/ncomms14434

Clark, M.R., Bowden, D.A., Rowden, A.A. & Stewart, R. (2019). Little evidence of benthic community resilience to bottom trawling on seamounts after 15 years. *Frontiers in Marine Science*, *6*, 63. https://doi.org/10.3389/fmars.2019.00063

Claudet, J. (2018). Six conditions under which MPAs might not appear effective (when they are). *ICES Journal of Marine Science*, *75*(3), 1172–1174. https://doi.org/10.1093/icesjms/fsx074

Claudet, J., Bopp, L., Cheung, W., Devillers, R., Escobar-Briones, E., Haugan, P. et al. (2020a). A roadmap for using the UN Decade of Ocean Science for Sustainable Development in support of science, policy, and action. *One Earth*, *2*(1), 34–42. https://doi.org/10.1016/j.oneear.2019.10.012

Claudet, J., Loiseau, C., Sostres, M. & Zupan, M. (2020b). Underprotected marine protected areas in a global biodiversity hotspot. *One Earth*, *2*(4), 380–384. https://doi.org/10.1016/j.oneear.2020.03.008

Claudet, J., Osenberg, C.W., Benedetti-Cecchi, L., Domenici, P., García-Charton, J.-A., Pérez-Ruzafa, Á. et al. (2008). Marine reserves: Size and age do matter. *Ecology Letters*, *11*(5), 481–489. https://doi.org/10.1111/j.1461-0248.2008.01166.x

Committee on Climate Change. (2019). *Reducing UK emissions: 2019 progress report to Parliament*. Committee on Climate Change, London, UK, pp. 93.

Connolly, R., Connolly, M., Soon, W., Legates, D.R., Cionco, R.G. & Velasco Herrera, V.M. (2019). Northern Hemisphere snow-cover trends (1967–2018): A comparison between climate models and observations. *Geosciences*, *9*(3), 135. https://doi.org/10.3390/geosciences9030135

Cordes, E.E., Jones, D.O.B., Schlacher, T.A., Amon, D.J., Bernardino, A.F., Brooke, S. et al. (2016). Environmental impacts of the deep-water oil and gas industry: A review to guide management strategies. *Frontiers in Environmental Science*, *4*, 58. https://doi.org/10.3389/fenvs.2016.00058

Costanza, R., Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S., Kubiszewski, I. et al. (2014). Changes in the global value of ecosystem services. *Global Environmental Change*, *26*(1), 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Costanza, R., Pérez-Maqueo, O., Martinez, M.L., Sutton, P., Anderson, S.J. & Mulder, K. (2008). The value of coastal wetlands for hurricane protection. *Ambio*, *37*(4), 241–248. https://doi.org/10.1579/0044-7447

Costello, C., Cao, L., Gelcich, S., Cisneros, M.A., Free, C.M., Froehlich, H.E. et al. (2019). The future of food from the sea. Washington, DC: World Resources Institute. Retrieved from www.oceanpanel.org/sites/default/files/2019-11/19_HLP_BP1Paper.pdf

Cowan, R.K. & Sponaugle, S. (2009). Larval dispersal and marine population connectivity. *Annual Review of Marine Science*, *1*, 443–466. https://doi.org/10.1146/annurev.marine.010908.163757

Dawson, T., Hambly, J., Kelley, A., Lees, W. & Miller, S. (2020). Coastal heritage, global climate change, public engagement, and citizen science. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(15), 8280–8286. https://doi.org/10.1073/pnas.1912246117

Dhomse, S.S., Feng, W., Montzka, S.A., Hossaini, R., Keeble, J., Pyle, J.A. et al. (2019). Delay in recovery of the Antarctic ozone hole from unexpected CFC-11 emissions. *Nature Communications*, *10*, 5781. https://doi.org/10.1038/s41467-019-13717-x

Diamond, J. (2005). *Guns, germs and steel: A short history of everybody for the last 13,000 years*. London, UK: Vintage. https://doi.org/10.1007/11566489_80

Dieng, H.B., Cazenave, A., Meyssignac, B. & Ablain, M. (2017). New estimate of the current rate of sea level rise from a sea level budget approach. *Geophysical Research Letters*, *44*(8), 3744–3751. https://doi.org/10.1002/2017gl073308

Doney, S.C. (2010). The growing human footprint on coastal and open-ocean biogeochemistry. *Science*, *328*(5985), 1512–1516. https://doi.org/10.1126/science.1185198

Doney, S.C., Busch, D.S., Cooley, S.R. & Kroeker, K.J. (2020). The impacts of ocean acidification on marine ecosystems and reliant human communities. *Annual Review of Environment and Resources*, *45*, 83–112. https://doi.org/10.1146/annurev-environ-012320-083019

Doney, S.C., Fabry, V.J., Feely, R.A. & Kleypas, J.A. (2009). Ocean acidification: The other CO_2 problem. *Annual Review of Marine Science*, *1*, 169–192. https://doi.org/10.1146/annurev.marine.010908.163834

du Pontavice, H., Gascuel, D., Reygondeau, G., Maureaud, A. & Cheung, W.W.L. (2019). Climate change undermines the global functioning of marine food webs. *Global Change Biology*, *26*(3), 1306–1318. https://doi.org/10.1111/gcb.14944

Duarte, C.M., Agusti, S., Barbier, E., Britten, G.L., Castilla, J.C., Gattuso, J.-P. et al. (2020). Rebuilding marine life. *Nature*, *580*(7801), 39–51. https://doi.org/10.1038/s41586-020-2146-7

Ducklow, H.W., Steinberg, D.K. & Buesseler, K.O. (2015). Upper ocean carbon export and the biological pump. *Oceanography*, *14*(4), 50–58. https://doi.org/10.5670/oceanog.2001.06

Durack, P.J., Wijffels, S.E. & Matear, R.J. (2012). Ocean salinities reveal strong global water cycle intensification during 1950 to 2000. *Science*, *336*(6080), 455–458. https://doi.org/10.1126/science.1212222

Dureuil, M., Boerder, K., Burnett, K.A., Froese, R. & Worm, B. (2018). Elevated trawling inside protected areas undermines conservation outcomes in a global fishing hot spot. *Science*, *362*(6421), 1403–1407. https://doi.org/10.1126/science.aau0561

Eastman, R., Roth, J., Brimacombe, K., Simeonov, A., Shen, M., Patnaik, S. & Hall, M. (2020). Remdesivir: A review of its discovery and development leading to emergency use authorization for treatment of COVID-19. *ACS Central Science*, *6*(5), 672–683. https://doi.org/10.1021/acscentsci.0c00489

Edgar, G.J., Stuart-Smith, R.D., Willis, T.J., Kininmonth, S., Baker, S.C., Banks, S. et al. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature*, *506*(7487), 216–220. https://doi.org/10.1038/nature13022

Enríquez-de-Salamanca, Á. (2018). Stakeholders' manipulation of environmental impact assessment. *Environmental Impact Assessment Review*, *68*, 10–18. https://doi.org/10.1016/j.eiar.2017.10.003

EU. (2019). A *European green deal: Striving to be the first climate-neutral continent*. Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

EU. (2020). *The EU budget powering the recovery plan for Europe*. Retrieved from https://ec.europa.eu/info/files/eu-budget-powering-recovery-plan-europe_en

Faizal, M. & Ahmed, M.R. (2011). On the ocean heat budget and ocean thermal energy conversion. *International Journal of Energy Conversion*, *35*(13), 1119–1144. https://doi.org/10.1002/er.1885

Falkowski, P.G., Barber, R.T. & Smetacek, V. (1998). Biogeochemical controls and feedbacks on ocean primary production. *Science*, *281*(5374), 200–206. https://doi.org/10.1126/science.281.5374.200

Falkowski, P.G. & Raven, J.A. (2013). *Aquatic photosynthesis*. Princeton, NJ: Princeton University Press.

Food and Agriculture Organization of the United Nations. (2018). *The state of the world fisheries and aquaculture 2018: Meeting the sustainable development goals*. Rome, Italy: FAO.

Farman, J.C., Gardiner, B.G. & Shanklin, J.D. (1985). Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction. *Nature*, *315*, 207–210. https://doi.org/10.1038/315207a0

Farquharson, L.M., Romanovsky, V.E., Cable, W.L., Walker, D.A., Kokelj, S.V. & Nicolsky, D. (2019). Climate change drives widespread and rapid thermokarst development in very cold permafrost in the Canadian High Arctic. *Geophysical Research Letters*, *46*, 6681–6689. https://doi.org/10.1029/2019GL082187

Fernandes, P.G. & Cook, R.M. (2013). Reversal of fish stock decline in the Northeast Atlantic. *Current Biology*, *23*(15), 1432–1437. https://doi.org/10.1016/j.cub.2013.06.016

Fernandes, P.G., Ralph, G.M., Nieto, A., Criado, M.G., Vasilakopoulos, P., Maravelias, C.D. et al. (2017). Coherent assessments of Europe's marine fishes show regional divergence and megafauna loss. *Nature Ecology and Evolution*, *1*, 0170. https://doi.org/10.1038/s41559-017-0170

Fleming, L.E., Maycock, B., White, M.P. & Depledge, M.H. (2019). Fostering human health through ocean sustainability in the 21st century. *People and Nature*, *1*(3), 276–283. https://doi.org/10.1002/pan3.10038

Fleming, L.E., McDonough, N., Austen, M., Mee, L., Moore, M., Hess, P. et al. (2014). Oceans and human health: A rising tide of challenges and opportunities for Europe. *Marine Environmental Research*, *99*, 16–19. https://doi.org/10.1016/j.marenvres.2014.05.010

Foster, T., Falter, J.L., McCulloch, M.T. & Clode, P.L. (2016). Ocean acidification causes structural deformities in juvenile coral skeletons. *Science Advances*, *2*(2), e1501130. https://doi.org/10.1126/sciadv.1501130

Friedman, K., Garcia, S.M. & Rice, J. (2018). Mainstreaming biodiversity in fisheries. *Marine Policy*, *95*, 209–220. https://doi.org/10.1016/j.marpol.2018.03.001

Gaines, S., Cabral, R., Free, C., Golbuu, Y., Arnason, R., Battista, W. et al. (2019). *The expected impacts of climate change on the ocean economy*. Washington, DC: World Resources Institute. Retrieved from https://

www.oceanpanel.org/sites/default/files/2019-12/expected-impacts-climate-change-on-the-ocean-economy-executive-summary.pdf

Gao, K., Beardall, J., Häder, D.-P., Hall-Spencer, J.M., Gao, G. & Hutchins, D.A. (2019). Effects of ocean acidification on marine photosynthetic organisms under the concurrent influences of warming, UV radiation, and deoxygenation. *Frontiers in Marine Science*, *6*(June), 322. https://doi.org/10.3389/fmars.2019.00322

Gates, B. (2020). Responding to COVID-19—A once-in-a-century pandemic? *The New England Journal of Medicine*, *382*, 1677–1679. https://doi.org/10.1056/NEJMp2003762

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

Gentile, D., Patamia, V., Scala, A., Sciortino, M., Piperno, A. & Rescifina, A. (2020). Putative inhibitors of SARS-CoV-2 main protease from a library of marine natural products: A virtual screening and molecular modeling study. *Marine Drugs*, *18*(4), 225. https://doi.org/10.3390/md18040225

Gill, D.A., Mascia, M.B., Ahmadia, G.N., Glew, L., Lester, S.E., Barnes, M. et al. (2017). Capacity shortfalls hinder the performance of marine protected areas globally. *Nature*, *543*(7647), 665–669. https://doi.org/10.1038/nature21708

Golledge, N.R., Keller, E.D., Gomez, N., Naughten, K.A., Bernales, J., Trusel, L.D. et al. (2019). Global environmental consequences of twenty-first-century ice-sheet melt. *Nature*, *566*(7742), 65–72. https://doi.org/10.1038/s41586-019-0889-9

Gomez, C. & Green, D.R. (2013). *The impact of oil and gas drilling accidents on EU fisheries*. Brussels, Belgium: EU-Directorate General for Internal Policies.

Grover, V.I. (2015). Impact of climate change on the water cycle. In: Shrestha, S., Anal, A., Salam, P. and van der Valk, M. (Eds.) *Managing water resources under climate uncertainty: Examples from Asia, Europe, Latin America, and Australia*. Cham, Switzerland: Springer.

Hall, D. (2019). Sea sponges: Pharmacies of the sea. Retrieved from https://ocean.si.edu/ocean-life/invertebrates/sea-sponges-pharmacies-sea

Halpern, B., Frazier, M., Potapenko, J., Casey, K., Koenig, K., Longo, C. et al. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nature Communications*, *6*(1), 7615. https://doi.org/10.1038/ncomms8615

Hamilton, S.E. & Casey, D. (2016). Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Global Ecology and Biogeography*, *25*(6), 729–738. https://doi.org/10.1111/geb.12449

Hilborn, R., Amoroso, R.O., Anderson, C.M., Baum, J.K., Branch, T.A., Costello, C. et al. (2020). Effective fisheries management instrumental in improving fish stock status. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(4), 2218–2224. https://doi.org/10.1073/pnas.1909726116

Hockings, M., Dudley, N., Ellio, W., Ferreira, M., Mackinnon, K., Pasha, M. et al. (2020). COVID-19 and protected and conserved areas. *Parks*, *26*, 7–24. https://doi.org/10.2305/IUCN.CH.2020.PARKS-26-1MH.en

Hoegh-Guldberg, O., Caldeira, K., Chopin, T., Gaines, S., Haugan, P., Hemer, M. et al. (2019). *The ocean as a solution to climate change: Five opportunities for action*. Washington, DC: World Resources Institute. Retrieved from https://oceanpanel.org/sites/default/files/2019-10/HLP_Report_Ocean_Solution_Climate_Change_final.pdf

Holbrook, N.J., Scannell, H.A., Sen Gupta, A., Benthuysen, J.A., Feng, M., Oliver, E.C.J. et al. (2019). A global assessment of marine heatwaves and their drivers. *Nature Communications*, *10*, 2624. https://doi.org/10.1038/s41467-019-10206-z

Honjo, S., Eglinton, T.I., Taylor, C.D., Ulmer, K.M., Sievert, S.M., Bracher, A. et al. (2014). Understanding the role of the biological pump in the global carbon cycle: An imperative for ocean science. *Oceanography*, *27*(3), 10–16. https://doi.org/10.5670/oceanog.2014.78

Horta e Costa, B., Claudet, J., Franco, G., Erzini, K., Caro, A. & Gonçalves, E. (2016). A regulation-based classification system for marine protected areas (MPAs). *Marine Policy*, *72*, 192–198. https://doi.org/10.1016/j.marpol.2016.06.021

Houghton, R.A. (2007). Balancing the global carbon budget. *Annual Review of Earth and Planetary Science*, *35*(1), 313–347. https://doi.org/10.1146/annurev.earth.35.031306.140057

Hu, S., Sprintall, J., Guan, C., McPhaden, M.J., Wang, F., Hu, D. & Cai, W. (2020). Deep-reaching acceleration of global mean ocean circulation over the past two decades. *Science Advances*, *6*(6), eaax7727. https://doi.org/10.1111/tpj.15043

International Hydrographic Organization. (1986). *Limits of oceans and seas*, Special Publication No. 23. Monaco: International Hydrographic Organization.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019). In: Díaz, S., Settele, J., Brondízio, E.S., Ngo, H.T., Guèze, M., Agard, J., et al. (Eds.) *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn, Germany: IPBES Secretariat Retrieced from https://ipbes.net/sites/default/files/2020-02/ipbes_global_assessment_report_summary_for_policymakers_en.pdf

Intergovernmental Panel on Climate Change. (2018). In: Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., 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*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change. (2019). In: Pörtner, H.O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., et al. (Eds.) *The ocean and cryosphere in a changing climate: A special report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2013). *Climate change 2013: The physical science basis. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change* (eds) T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P.M. Midgley. Cambridge, UK/-New York, NY; Cambridge University Press

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J. et al. (2001). Historical overfishing and the recent collapse of coastal ecosystems. *Science*, *293*(5530), 629–638. https://doi.org/10.1126/science.1059199

Jacobsen, K.H. (2020). Will COVID-19 generate global preparedness? *The Lancet*, *395*(10229), 1013–1014. https://doi.org/10.1016/S0140-6736(20)30559-6

Jenkins, C.N. & Van Houten, K.S. (2016). Global and regional priorities for marine biodiversity protection. *Biological Conservation*, *204*, 333–339. https://doi.org/10.1016/j.biocon.2016.10.005

Jones, D.O., Amon, D.J. & Chapman, A.S. (2018). Mining deep-ocean mineral deposits: What are the ecological risks? *Elements: An International Magazine of Mineralogy, Geochemistry, and Petrology*, *14*(5), 325–330. https://doi.org/10.2138/gselements.14.5.325

Jones, D.O.B., Kaiser, S., Sweetman, A.K., Smith, C.R., Menot, L., Vink, A. et al. (2017). Biological responses to disturbance from simulated deep-sea polymetallic nodule mining. *PLoS ONE*, *12*(2), e0171750. https://doi.org/10.1371/journal.pone.0171750

Jones, K.R., Klein, C.J., Grantham, H.S., Possingham, H.P., Halpern, B.S., Burgess, N.D. et al. (2020). Area requirements to safeguard Earth's marine species. *One Earth*, *2*(2), 188–196. https://doi.org/10.1016/j.oneear.2020.01.010

Jouffray, J.-B., Blasiak, R., Norström, A., Österblom, H. & Nyström, M. (2020). The blue acceleration: The trajectory of human expansion into the ocean. *One Earth*, *2*(1), 43–54. https://doi.org/10.1016/j.oneear.2019.12.016

Kaiser, M.J. (2005). Are marine protected areas a red herring or fisheries panacea? *Canadian Journal of Fisheries and Aquatic Sciences*, *62*(5), 1194–1199. https://doi.org/10.1139/f05-056

Keeling, R.F., Körtzinger, A. & Gruber, N. (2010). Ocean deoxygenation in a warming world. *Annual Review of Marine Science*, *2*, 199–229. https://doi.org/10.1146/annurev.marine.010908.163855

Kim, I.-N., Lee, K., Gruber, N., Karl, D.M., Bullister, J.L., Yang, S. & Kim, T.-W. (2014). Increasing anthropogenic nitrogen in the North Pacific Ocean. *Science*, *346*(6213), 1102. https://doi.org/10.1126/science.1258396

Klein, C.J., Brown, C.J., Halpern, B.S., Segan, D.B., McGowan, J., Beger, M. et al. (2015). Shortfalls in the global protected area network at representing marine biodiversity. *Scientific Reports*, *5*, 17539. https://doi.org/10.1038/srep17539

Klemeš, J.J., Fan, Y.V., Tan, R.R. & Jiang, P. (2020). Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. *Renewable and Sustainable Energy Reviews*, *127*(C), 109883. https://doi.org/10.1016/j.rser.2020.109883

Knowlton, N. (2020). Ocean optimism: Moving beyond obituaries in marine conservation. *Annual Review of Marine Science*, *13*, 2.1–2.21. https://doi.org/10.1146/annurev-marine-040220-101608

Kulp, S.A. & Strauss, B.H. (2019). New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nature Communications*, *10*(1), 4844. https://doi.org/10.1038/s41467-019-12808-z

Laffoley, D. and Baxter, J.M. (Eds). (2016). *Explaining ocean warming: Causes, scale, effects and consequences*. Gland, Switzerland: IUCN. https://doi.org/10.2305/IUCN.CH.2016.08.en

Laffoley, D. & Baxter, J. M. (2018). *Ocean connections. An introduction to rising risks from a warming, changing ocean*. Gland, Switzerland: IUCN. https://doi.org/10.2305/IUCN.CH.2018.09.en

Laffoley, D. & Baxter, J.M. (2019). *Ocean deoxygenation: Everyone's problem. Causes, impacts, consequences, and solutions*. Gland, Switzerland: IUCN.

Lal, R. (2008). Carbon sequestration. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1492), 815–830. https://doi.org/10.1098/rstb.2007.2185

Lammel, G., Spitzy, A., Audy, O., Beckmann, S., Codling, G.P. & Kretzschmann, L. (2016). Organochlorine pesticides and polychlorinated biphenyls along an east-to-west gradient in subtropical North Atlantic surface water. *Environmental Science and Pollution Research*, *24*, 11045–11052. https://doi.org/10.1007/s11356-016-7429-z

Lascelles, B., Notarbartolo di Sciara, G., Agardy, T., Cuttelod, A., Eckert, S., Glowka, L. et al. (2014). Migratory marine species: Their status, threats and conservation management needs. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *24*(S2), 111–127. https://doi.org/10.1002/aqc.2512

Lenton, T.M. (2020). Tipping positive change. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1794), 20190123. https://doi.org/10.1098/rstb.2019.0123

Lester, S.E., Halpern, B.S., Grorud-Colvert, K., Lubchenco, J., Ruttenberg, B.I., Gaines, S.D. et al. (2009). Biological effects within no-take marine reserves: A global synthesis. *Marine Ecology Progress Series*, *384*, 33–46. https://doi.org/10.3354/meps08029

Levin, L.A. (2018). Manifestation, drivers, and emergence of open ocean deoxygenation. *Annual Review of Marine Science*, *10*, 229–260. https://doi.org/10.1146/annurev-marine-121916-063359

Levin, L.A., Amon, D.J. & Lily, H. (2020). Challenges to the sustainability of deep-seabed mining. *Nature Sustainability*, *3*, 784–794. https://doi.org/10.1038/S41893-020-0558-X

Levitus, S., Antonov, J.I., Boyer, T.P., Baranova, O.K., Garcia, H.E., Locarnini, R.A. et al. (2012). World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010. *Geophysical Research Letters*, *39*(10), L10603. https://doi.org/10.1029/2012gl051106

Li, C., Held, H., Hokamp, S. & Marotzke, J. (2020). Optimal temperature overshoot profile found by limiting global sea level rise as a lower-cost climate target. *Science Advances*, *6*(2), eaaw9490. https://doi.org/10.1002/sctm.20-0193

Lin, I., Liu, W.T., Wu, C., Wong, G.T.F., Hu, C., Chen, Z. et al. (2003). New evidence for enhanced ocean primary production triggered by tropical cyclone. *Geophysical Research Letters*, *30*(13), 1718. https://doi.org/10.1029/2003gl017141

Link, P.M. & Tol, R.S.J. (2004). Possible economic impacts of a shutdown on the thermohaline circulation: An application of FUND. *Portuguese Economic Journal*, *3*(2), 99–114. https://doi.org/10.1007/s10258-004-0033-z

Lotze, H.K., Tittensor, D.P., Bryndum-Buchholz, A., Eddy, T.D., Cheung, W.W.L., Galbraith, E.D. et al. (2019). Global ensemble projections reveal trophic amplification of ocean biomass declines with climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(26), 12907–12912. https://doi.org/10.1073/pnas.1900194116

Lubchenco, J. & Gaines, S.D. (2019). A new narrative for the ocean. *Science*, *364*(6444), 911–911. https://doi.org/10.1126/science.aay2241

Lubchenco, J. & Grorud-Colvert, K. (2015). Making waves: The science and politics of ocean protection. *Science*, *350*(6259), 382–383. https://doi.org/10.1126/science.aad5443

Le Quéré, C., Jackson, R.B., Jones, M.W., Smith, A.J.P., Abernethy, S., Andrew, R.M., De-Gol, A.J., Willis, D.R., Shan, Y., Canadel, J.G., Friedlingstein, P., Creutzig, F., & Peters, G.P. (2020).. Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. *Nature Climate Change 10*, 647–653.

Marine Conservation Institute. (2020). MPAtlas. Retrieved from http://mpatlas.org/

MarinLit. (2020). A database of marine natural products literature. Retrieved from http://pubs.rsc.org/marinlit/

Marotzke, J. (2000). Abrupt climate change and thermohaline circulation: Mechanisms and predictability. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(4), 1347–1350. https://doi.org/10.1073/pnas.97.4.1347

Maurer, J.M., Schaefer, J.M., Rupper, S. & Corley, A. (2019). Acceleration of ice loss across the Himalayas over the past 40 years. *Science Advances*, *5*(6), eaav7266. https://doi.org/10.1177/1756286419892077

McKinley, G.A., Fay, A.R., Lovenduski, N.S. & Pilcher, D.J. (2017). Natural variability and anthropogenic trends in the ocean carbon sink. *Annual Review of Marine Science*, *9*(1), 125–150. https://doi.org/10.1146/annurev-marine-010816-060529

McCauley, D., Teleki, K., Fluxà Thienemann, G. (2020). *8 ways to rebuild a stronger ocean economy after COVID-19*. Geneva, Switzerland: World Economic Forum. Retrieved from https://www.weforum.org/agenda/2020/05/how-to-build-a-bluer-ocean-economy-after-cobid-19/

Mehmood, Y. (2019). What is *Limulus* amebocyte lysate (LAL) and its applicability in endotoxin quantification of pharma products. In: *Growing and handling of bacterial cultures*. London, UK: IntechOpen https://doi.org/10.5772/intechopen.81331.

Montzka, S.A., Dutton, G.S., Yu, P., Ray, E., Portmann, R.W., Daniel, J.S. et al. (2018). An unexpected and persistent increase in global emissions of ozone-depleting CFC-11. *Nature*, *557*(7705), 413–417. https://doi.org/10.1038/s41586-018-0106-2

Nagelkerken, I., Huelbert, K.B., Serafy, J.E., Grol, M.G.G., Dorenbosch, M. & Bradshaw, C.J.A. (2017). Highly localized replenishment of coral reef fish populations near nursery habitats. *Marine Ecology Progress Series*, *568*, 137–150. https://doi.org/10.3354/meps12062

Nagelkerken, I., Roberts, C.M., van der Velde, G., Dorenbosch, M., van Riel, M.C., Cocheret de la Morinière, E. et al. (2002). How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. *Marine Ecology Progress Series*, *244*, 299–305. https://doi.org/10.3354/meps244299

Nerem, R.S., Beckley, B.D., Fasullo, J.T., Hamlington, B.D., Masters, D. & Mitchum, G.T. (2018). Climate-change-driven accelerated sea-level rise detected in the altimeter era. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(9), 2022–2025. https://doi.org/10.1073/pnas.1717312115

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

Norse, E.A. (2005). Ending the range wars on the last frontier: Zoning the sea. In: Norse, E.A. and Crowder, L.B. (Eds.) *Marine conservation biology: The science of maintaining the sea's biodiversity*. Washington, DC: Island Press. pp. 422–443.

O'Leary, B.C., Allen, H.L., Yates, K.L., Page, R.W., Tudhope, A.W., McClean, C. et al. (2019). *30×30: A blueprint for ocean protection—How we can protect 30% of our oceans by 2030*. London, UK: Greenpeace UK.

O'Leary, B.C. & Roberts, C.M. (2016). Ecological connectivity across ocean depths: Implications for protected area design. *Global Ecology and Conservation*, *15*, e00431. https://doi.org/10.1016/j.gecco.2018.e00431

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*(6), 398–404. https://doi.org/10.1111/conl.12247

O'Leary, B.C., Hoppit, G., Townley, A., Allen, H.L., McIntyre, C.J. & Roberts, C.M. (2020). Options for managing human threats to high seas biodiversity. *Ocean & Coastal Management*, *187*, 105110. https://doi.org/10.1016/j.ocecoaman.2020.105110

One Health Initiative Task Force. (2008). *One Health: A new professional imperative*. Schaumberg, IL: American Veterinary Medical Association Retrieved from https://www.avma.org/sites/default/files/resources/onehealth_final.pdf

Ono, H., Kosugi, N., Toyama, K., Tsujino, H., Kojima, A., Enyo, K. et al. (2019). Acceleration of ocean acidification in the western North Pacific. *Geophysical Research Letters*, *46*, 13161–13169. https://doi.org/10.1029/2019gl085121

Ord, T. (2020). *The precipice: Existential risk and the future of humanity*. London, UK: Bloomsbury Publishing.

Oregon State University, IUCN World Commission on Protected Areas, Marine Conservation Institute, National Geographic Society, & UNEP World Conservation Monitoring Centre. (2019). *An introduction to the MPA guide*. Retrieved from https://www.protectedplanet.net/c/mpa-guide?

Pandolfi, J.M., Bradbury, R.H., Sala, E., Hughes, T.P., Bjorndal, K.A., Cooke, R.G. et al. (2003). Global trajectories of the long-term decline of coral reef ecosystems. *Science*, *301*(5635), 955–958. https://doi.org/10.1126/science.1085706

Pandolfi, J.M., Connolly, S.R., Marshall, D.J. & Cohen, A.L. (2011). Projecting coral reef futures under global warming and ocean acidification. *Science*, *333*(6041), 418–422. https://doi.org/10.1126/science.1204794

Parvez, M.K. & Parveen, S. (2017). Evolution and emergence of pathogenic viruses: Past, present, and future. *Intervirology*, *60*(1-2), 1–7. https://doi.org/10.1159/000478729

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology and Evolution*, *10*(10), 430. https://doi.org/10.1016/S0169-5347(00)89171-5

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. & Torres, F., Jr. (1998). Fishing down marine food webs. *Science*, *279*(5352), 860–863. https://doi.org/10.1126/science.279.5352.860

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

Payne, J.L. & Clapham, M.E. (2012). End-Permian mass extinction in the oceans: An ancient analog for the twenty-first century? *Annual Review of Earth and Planetary Sciences*, *40*, 89–111. https://doi.org/10.1146/annurev-earth-042711-105329

Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A.M., Ellison, J.C. et al. (2010). The loss of species: Mangrove extinction risk and geographic areas of global concern. *PLoS ONE*, *5*(4), e10095. https://doi.org/10.1371/journal.pone.0010095

Poloczanska, E.S., Brown, C.J., Sydeman, W.J., Kiessling, W., Schoeman, D.S., Moore, P.J. et al. (2013). Global imprint of climate change on marine life. *Nature Climate Change*, *3*(10), 919–925. https://doi.org/10.1038/nclimate1958

Poloczanska, E.S., Burrows, M.T., Brown, C.J., García Molinos, J., Halpern, B.S., Hoegh-Guldberg, O. et al. (2016). Responses of marine organisms to climate change across oceans. *Frontiers in Marine Science*, *3*, 62. https://doi.org/10.3389/fmars.2016.00062

Popova, E., Vousden, D., Sauer, W.H.H., Mohammed, E.Y., Allain, V., Downey-Breedt, N. et al. (2019). Ecological connectivity between the areas beyond national jurisdiction and coastal waters: Safeguarding interests of coastal communities in developing countries. *Marine Policy*, *104*, 90–102. https://doi.org/10.1016/j.marpol.2019.02.050

Pörtner, H.-O., Karl, D.M., Boyd, P.W., Cheung, W.W.L., Lluch-Cota, S.E., Nojiri, Y. et al. (2014). Ocean systems. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.F., et al. (Eds.) *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change*. New York, NY: Cambridge University Press. pp. 411–484.

Pretlove, B. & Blasiak, R. (2018). Mapping ocean governance and regulation. Working paper for consultation for UN Global Compact Action Platform for Sustainable Ocean Business.

Ratner, B.D., Åsgård, B. & Allison, E.H. (2014). Fishing for justice: Human rights, development, and fisheries sector reform. *Global Environmental Change*, *27*, 120–130. https://doi.org/10.1016/j.gloenvcha.2014.05.006

Reid, P.C. (2016). Ocean warming: Setting the scene. In: Laffoley, D. and Baxter, J.M. (Eds.) *Explaining ocean warming: Causes, scale, effects and consequences*. Gland, Switzerland: IUCN. pp. 17–45.

Reid, P., Fischer, A., Lewis-Brown, E., Meredith, M., Sparrow, M., Andersson, A. et al. (2009). Chapter 1 impacts of the oceans on climate change. *Advances in Marine Biology*, *56*, 1–150. https://doi.org/10.1016/S0065-2881(09)56001-4

Ren, H., Chen, Y., Wang, X.T., Wong, G.T.F., Cohen, A.L., DeCarlo, T.M. et al. (2017). 21st-century rise in anthropogenic nitrogen deposition on a remote coral reef. *Science*, *356*(6339), 749–752. https://doi.org/10.1126/science.aal3869

Roberts, C.M., O'Leary, B.C., McCauley, D.J., Cury, P.M., Duarte, C.M., Lubchenco, J. et al. (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*(24), 6167–6175. https://doi.org/10.1073/pnas.1701262114

Rogers, A., Aburto-Oropeza, O., Appeltans, W., Assis, J., Balance, L.T., Cury, P. et al. (2020). Critical habitats and biodiversity: Inventory, thresholds and governance. Blue Paper 10. Report prepared for the (Norwegian) Prime Minister's High Level Panel on a Sustainable Ocean Economy. Retrieved from https://www.oceanpanel.org/blue-papers/critical-habitats-and-biodiversity-inventory-thresholds-and-governance

Rosenbloom, D. & Markard, J. (2020). A COVID-19 recovery for climate. *Science*, *368*(6490), 447. https://doi.org/10.1126/science.abc4887

Rost, B. & Riebesell, U. (2004). In: Thierstein, H. and Young, J. (Eds.) *Coccolithophores and the biological pump: Responses to environment changes*. New York, NY: Springer Verlag.

Rousseau, Y., Watson, R.A., Blanchard, J.L. & Fulton, E.A. (2019). Evolution of global marine fishing fleets and the response of fished resources. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(25), 12238–12243. https://doi.org/10.1073/pnas.1820344116

Sabine, C.I., Feely, R.A., Gruber, N., Key, R.M., Lee, K., Bullister, J.L. et al. (2004). The oceanic sink for anthropogenic CO_2. *Science*, *305*(5682), 367–371. https://doi.org/10.1126/science.1097403

Sagar, S., Kaur, M. & Minneman, K. (2010). Antiviral lead compounds from marine sponges. *Marine Drugs*, *8*(10), 2619–2638. https://doi.org/10.3390/md8102619

Sala, E., Costello, C., Dougherty, D., Heal, G., Kelleher, K., Murray, J.H. et al. (2013). A general business model for marine reserves. *PLoS ONE*, *8*(4), e58799. https://doi.org/10.1371/journal.pone.0058799

Sala, E., Lubchenco, J., Grorud-Colvert, K., Novelli, C., Roberts, C. & Sumaila, U.R. (2018). Assessing real progress towards effective ocean protection. *Marine Policy*, *91*, 11–13. https://doi.org/10.1016/j.marpol.2018.02.004

Schellnhuber, H.J. (1999). 'Earth system' analysis and the second Copernican revolution. *Nature*, *402*(S6761), C19–C23. https://doi.org/10.1038/35011515

Schmidtko, S., Stramma, L. & Visbeck, M. (2017). Decline in global oceanic oxygen content during the past five decades. *Nature*, *542*(7641), 335–339. https://doi.org/10.1038/nature21399

Schmitt, R.W. (2008). Salinity and the global water cycle. *Oceanography*, *21*(1), 12–19. https://doi.org/10.5670/oceanog.2008.63

Sekerci, Y. & Petrovskii, S. (2015). Mathematical modelling of plankton–oxygen dynamics under the climate change. *Bulletin of Mathematical Biology*, *77*(12), 2325–2353. https://doi.org/10.1007/s11538-015-0126-0

Seley-Radtke, K. (2020). Remdesivir explained—What makes this drug work against viruses? *The Conversation*. Retrieved from https://theconversation.com/remdesivir-explained-what-makes-this-drug-work-against-viruses-137751

Seley-Radtke, K. & Yates, M. (2018). The evolution of nucleoside analogue antivirals: A review for chemists and non-chemists. Part 1: Early structural modifications to the nucleoside scaffold. *Antiviral Research*, *154*, 66–86. https://doi.org/10.1016/j.antiviral.2018.04.004

Shen, J., Jiubin Chen, J., Algeo, T.J., Yuan, S., Feng, Q., Yu, J. et al. (2019). Evidence for a prolonged Permian–Triassic extinction interval from global marine mercury records. *Nature Communications*, *10*, 1563. https://doi.org/10.1038/s41467-019-09620-0

Shepherd, J.G. (2012). Geoengineering the climate: An overview and update. *Philosophical Transactions of the Royal Society A*, *370*(1974), 4166–4175. https://doi.org/10.1098/rsta.2012.0186

Simon-Lledó, E., Bett, B.J., Huvenne, V.A., Köser, K., Schoening, T., Greinert, J. et al. (2019). Biological effects 26 years after simulated deep-sea mining. *Scientific Reports*, *9*, 8040. https://doi.org/10.1038/s41598-019-44492-w

Singh, G., Cisneros-Montemayor, A., Swartz, W., Cheung, W., Guy, A., Kenny, T.-A. et al. (2018). A rapid assessment of co-benefits and trade-offs among sustainable development goals. *Marine Policy*, *93*, 223–231. https://doi.org/10.1016/j.marpol.2017.05.030

Skirving, W.J., Heron, S.F., Marsh, B.L., Liu, G., De La Cour, J.L., Geiger, E.F. et al. (2019). The relentless march of mass coral bleaching: A global perspective of changing heat stress. *Coral Reefs*, *38*, 547–557. https://doi.org/10.1007/s00338-019-01799-4

Smith, K.A., Dowling, C.E. & Brown, J. (2019). Simmered then boiled: Multi-decadal poleward shift in distribution by a temperate fish accelerates during marine heatwave. *Frontiers in Marine Science*, *6*, 407. https://doi.org/10.3389/fmars.2019.00407

Smith, K.L., Jr., Ruhl, H.A., Bett, J., Billett, D.S.M., Lampitt, R.S. & Kaufmann, R.S. (2009). Climate, carbon cycling, and deep-ocean ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(46), 19211–19218. https://doi.org/10.1073/pnas.0908322106

Steffen, W., Richardson, K., Rockström, J., Schellnhuber, H.J., Dube, O.P., Dutreuil, S. et al. (2020). The emergence and evolution of Earth system science. *Nature Reviews: Earth and Environment*, *1*(1), 54–63. https://doi.org/10.1038/s43017-019-0005-6

Stemmler, I. & Lammel, G. (2009). Cycling of DDT in the global environment 1950–2002: World ocean returns the pollutant. *Geophysical Research Letters*, *36*, L24602. https://doi.org/10.1029/2009GL041340

Steneck, R.S. & Pauly, D. (2019). Fishing through the Anthropocene. *Current Biology*, *29*(19), 987–992. https://doi.org/10.1016/j.cub.2019.07.081

Stocker, T.F. (2015). The silent services of the world ocean. *Science*, *350*(6262), 764–765. https://doi.org/10.1126/science.aac8720

Stoknes, P.E. (2015). *What we think about when we try not to think about global warming*. White River Junction, VT: Chelsea Green. https://doi.org/10.1016/j.ejpn.2014.12.017.

Stramma, L., Johnson, G.C., Sprintall, S. & Mohrholz, V. (2008). Expanding oxygen-minimum zones in the tropical oceans. *Science*, *320*(5876), 655–658. https://doi.org/10.1126/science.1153847

Stramma, L., Schmidtko, S., Levin, L.A. & Johnson, G.C. (2010). Ocean oxygen minima expansions and their biological impacts. *Deep Sea Research Part I: Oceanographic Research Papers*, *57*(4), 587–595. https://doi.org/10.1016/j.dsr.2010.01.005

Sumaila, U.R., Lam, V., Le Manach, F., Swartz, W. & Pauly, D. (2016). Global fisheries subsidies: An updated estimate. *Marine Policy*, *69*, 189–193. https://doi.org/10.1016/j.marpol.2015.12.026

Sun, F. & Carson, R.T. (2020). Coastal wetlands reduce property damage during tropical cyclones. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(11), 5719–5725. https://doi.org/10.1073/pnas.1915169117

Swartz, W., Sala, E., Tracey, S., Watson, R. & Pauly, D. (2010). The spatial expansion and ecological footprint of fisheries (1950 to present). *PLoS ONE*, *5*(12), e15143. https://doi.org/10.1371/journal.pone.0015143

Terhaar, J., Kwiatkowski, L. & Bopp, L. (2020). Emergent constraint on Arctic Ocean acidification in the twenty-first century. *Nature*, *582*(7812), 379–383. https://doi.org/10.1038/s41586-020-2360-3

The Royal Society. (2005). *Ocean acidification due to increasing atmospheric carbon dioxide*, Policy Document 12/05. London, UK: The Royal Society.

Thiault, L., Mora, C., Cinner, J.E., Cheung, W.W.L., Graham, N.A.J., Januchowski-Hartley, F.A. et al. (2019). Escaping the perfect storm of simultaneous climate change impacts on agriculture and marine fisheries. *Sciences Advances*, *5*(11), eaaw9976. https://doi.org/10.1126/sciadv.aaw9976

Thurber, A.R., Sweetman, A.K., Narayanaswamy, B.E., Jones, D.O.B., Ingels, J. & Hansman, R.L. (2014). Ecosystem function and services provided by the deep sea. *Biogeosciences*, *11*(14), 3941–3963. https://doi.org/10.5194/bg-11-3941-2014

Tickler, D., Meeuwig, J.J., Bryant, K., David, F., Forrest, J.A.H., Gordon, E. et al. (2018). Modern slavery and the race to fish. *Nature Communications*, *9*(1), 4643. https://doi.org/10.1038/s41467-018-07118-9

Tittensor, D.P., Beger, M., Boerder, K., Boyce, D.G., Cavanagh, R.D., Cosandey-Godin, A. et al. (2019). Integrating climate adaptation and biodiversity conservation in the global ocean. *Science Advances*, *5*(11), eaay9969. https://doi.org/10.1126/sciadv.aay9969

Tollefson, J. (2020). Five ways Trump is undermining environmental health. *Nature*, *581*(7806), 17–18. https://doi.org/10.1038/d41586-020-01261-4

Trenberth, K.E., Cheng, L., Jacobs, P., Zhang, Y. & Fasullo, J. (2018). Hurricane Harvey links to ocean heat content and climate change adaptation. *Earth's Future*, *6*(5), 730–744. https://doi.org/10.1029/2018EF000825

UN Environment Programme World Conservation Monitoring Centre. (2020). World database on protected areas. *Protected Planet*. Retrieved from https://www.protectedplanet.net/marine

Vandergeest, P. (2019). Law and lawlessness in industrial fishing: Frontiers in regulating labour relations in Asia. *International Social Science Journal*, *68*(229-230), 325–341. https://doi.org/10.1111/issj.12195

Victorero, L., Watling, L., Deng Palomares, M.L. & Nouvian, C. (2018). Out of sight, but within reach: A global history of bottom-trawled deep-sea fisheries from> 400 m depth. *Frontiers in Marine Science*, *5*, 98. https://doi.org/10.3389/fmars.2018.00098

Voozen, P. (2020). Climate change spurs global speedup of ocean currents. *Science*, *367*(6478), 612–613. https://doi.org/10.1126/science.367.6478.612

Waldron, A., Adams, V., Allan, J., Arnell, A., Anser, G., Atkinson, S. et al. (2020). Protecting 30% of the planet for nature: Costs, benefits and economic implications. Campaign for Nature. Retrieved from https://www.campaignfornature.org/protecting-30-of-the-planet-for-nature-economic-analysis

Watson, R.A. & Morato, T. (2013). Fishing down the deep: Accounting for within-species changes in depth of fishing. *Fisheries Research*, *140*, 63–65. https://doi.org/10.1016/j.fishres.2012.12.004

Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S.A. et al. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(30), 12377–12381. https://doi.org/10.1073/pnas.0905620106

Wentz, F.J., Ricciardulli, L., Hilburn, K. & Mears, C. (2007). How much more rain will global warming bring? *Science*, *317*(5835), 233–235. https://doi.org/10.1126/science.1140746

Wenzhöfer, F., Adler, M., Kohls, O., Hensen, C., Strotmann, B., Boehme, S. et al. (2001). Calcite dissolution driven by benthic mineralization in the deep-sea: In situ measurements of Ca^{2+}, pH, pCO_2 and O_2. *Geochimica et Cosmochimica Acta*, *65*, 2677–2690. https://doi.org/10.1016/S0016-7037(01)00620-2

World Economic Forum. (2020).. *The future of nature and business*. Geneva, Switzerland: World Economic Forum/AlphaBeta. Retrieved from http://www3.weforum.org/docs/WEF_The_Future_Of_Nature_And_Business_2020.pdf

Woodley, S., Locke, H., Laffoley, D., MacKinnon, K., Sandwith, T. & Smart, J. (2019). A review of evidence for area-based conservation targets for the post-2020 global biodiversity framework. *Parks*, *25*, 31–46. https://doi.org/10.2305/IUCN.CH.2019.PARKS-25-2SW2.en

World Bank. (2017). *The sunken billions revisited: Progress and challenges in global marine fisheries*. Washington, DC: World Bank. Retrieved from https://openknowledge.worldbank.org/handle/10986/24056

Wikipedia Contributors. (2019, January 30). *Marshall Plan*. Wikipedia; Wikimedia Foundation. Retrieved from https://en.wikipedia.org/wiki/Marshall_Plan

Yu, L. (2011). A global relationship between the ocean water cycle and near-surface salinity. *Journal of Geophysical Research*, *116*(C10), C10025. https://doi.org/10.1029/2010JC006937

Zambrano-Monserrate, M.A., Ruano, M.A. & Sanchez-Alcade, L. (2020). Indirect effects of COVID-19 on the environment. *Science of the Total Environment*, *728*, 138813. https://doi.org/10.1016/j.scitotenv.2020.138813

Zupan, M., Bulleri, F., Evans, J., Fraschetti, S., Guidetti, P., Garcia-Rubies, A. et al. (2018a). How good is your marine protected area at curbing threats? Operationalizing a local threat assessment framework. *Biological Conservation*, *221*, 237–245. https://doi.org/10.1016/j.biocon.2018.03.013

Zupan, M., Fragkopoulou, E., Claudet, J., Erzini, K., Horta e Costa, B. & Gonçalves, E. (2018b). Marine partially protected areas: Drivers of ecological effectiveness. *Frontiers in Ecology and the Environment*, *16*(7), 381–387. https://doi.org/10.1002/fee.1934

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Laffoley D, Baxter JM, Amon DJ, et al. Evolving the narrative for protecting a rapidly changing ocean, post-COVID-19. *Aquatic Conserv: Mar Freshw Ecosyst*. 2020; 1–23. https://doi.org/10.1002/aqc.3512

APPENDIX: FUNDAMENTAL FACTS ON WHAT THE OCEAN DOES FOR HUMANKIND

BACKGROUND

The healthy functioning of the ocean makes all life on Earth possible. It is essential to human existence and well-being, providing vital regulating and functioning services. Our planet will not be able to sustain life as we know it if the state of the ocean continues to deteriorate because of human-induced stressors.

As part of the preparations for the International Programme on the State of the Ocean[4] workshop a survey of the authors was undertaken, and a backing paper was prepared on ocean facts to help inform and ensure that people understand the fundamentals of what the ocean does for humankind. This appendix extracts key points from that paper to explain the role of the ocean, why it matters, and to underpin the urgency of action and the need for a new narrative. It represents the key areas identified by the authors for wider understanding.

SCALE

Physical scale of the ocean

Although water masses across the world are differentiated and habitats are diverse, they are all connected. There is only one ocean and it works at the Earth system level to make life on our planet possible. Damage to any part of the ocean can affect us all. The ocean covers 71% of the surface of the planet, extending vertically to 11,000 m deep in the Mariana Trench and contains close to $1{,}335 \times 10^6$ km^3 of water that comprises 97% of all water on Earth (Reid, 2016).

Temporal scale of the ocean

Ocean ecosystems have dynamics that work at vastly different timescales from millions of years to daily cycles. For example, every day the largest migration on Earth occurs as gelatinous zooplankton, crustaceans, cephalopods, and fish rise to the ocean surface to feed, and

[4] http://www.stateoftheocean.org/

then sink back to the deep ocean, transporting organic material through the water column and contributing to carbon cycling and storage in the ocean.

In comparison, it is estimated that it takes up to 1,000 years for any 1 m^3 of water to complete its journey through the thermohaline cycle (Bigg et al., 2003) transporting cold waters from the poles to the tropics and warm waters from the equator to the poles, a process that is essential in regulating Earth's temperature. It takes millions of years to form polymetallic nodules, now targeted for mining, in the abyss. Some of the changes occurring today will be impossible to reverse in human timescales; for example, those now being seen in changes to ocean circulation.

ROLE OF THE OCEAN

Oxygen

Oxygen is fundamental to life on Earth, and the ocean plays a vital role its production. Some 40–50% of the oxygen in our atmosphere was produced in the past by the ocean; thus, it is true to say that every second breath taken has come from the ocean.

In the top 50–150 m of the water column, phytoplankton produce over half of all atmospheric oxygen via photosynthesis as part of the biological pump (Lin et al., 2003; Sekerci & Petrovskii, 2015). The oxygen produced by phytoplankton is dissolved in seawater and is consumed by animals and microbes or eventually enters the atmosphere via the sea surface, where it contributes to the total oxygen budget (Sekerci & Petrovskii, 2015).

Change

Recent research suggests the ocean is losing oxygen at an unprecedented rate; the overall level of oxygen in the ocean has decreased by approximately 2% since 1960 (Schmidtko, Stramma & Visbeck, 2017; Laffoley & Baxter, 2019). Some areas have lost much more oxygen over the few decades (up to 40%), but even very small declines can be catastrophic when oxygen availability is already low (Breitburg et al., 2018; Levin, 2018). A further decline in dissolved oxygen of between 1% and 7% is predicted by the end of the century, caused by a combination of reduced oxygen solubility and reduced mixing of deep waters (Laffoley & Baxter, 2019). Oxygen becomes less soluble at warmer water temperatures, which means that, as sea temperatures increase, dissolved oxygen content in the ocean decreases (Keeling, Körtzinger & Gruber, 2010; Gao et al., 2019).

Biological pump, carbon cycle, and storage

The oceanic biological pump is a key mechanism for removing CO_2 from the atmosphere and involves a complex suite of processes that absorb CO_2 from the atmosphere and then transfer it as carbon from the surface of the ocean to its depths (Honjo et al., 2014). During oceanic cycling of carbon, photosynthesis by marine plants and phytoplankton removes CO_2 from surface waters and produces oxygen as a by-product. Over 50% of global photosynthetic carbon fixation is undertaken by marine photosynthetic organisms (Falkowski & Raven, 2013).

Marine organisms that use CO_2 to build calcium carbonate skeletons and structures—such as shellfish, coral, and some phytoplankton—also form a major component of the biological pump. Some key functional groups include phytoplankton such as coccolithophores and diatoms, which build calcareous or siliceous shells respectively (Rost & Riebesell, 2004). When these organisms die, they sink downwards to the seabed ballasted by their shells, where the organic carbon becomes buried at depth in marine sediments and is stored for millions of years (Ducklow, Steinberg & Buesseler, 2015). Zooplankton also play a vital role in the biological pump by feeding on phytoplankton and producing sinking faecal pellets. The diel (24 hr) migration of some species of zooplankton and micronekton between shallower and deeper ocean waters also contributes to the active transport of carbon; as these organisms migrate through the water column, they influence the pattern and magnitude of fluctuations of carbon (Ducklow, Steinberg & Buesseler, 2015). Through the removal of carbon from surface waters and the subsequent transport to the deep sea, the biological pump increases the capacity of the ocean to act as a sink for atmospheric CO_2 (The Royal Society, 2005; Reid et al., 2009).

The deep sea of greater than 200 m depth occupies approximately 60% of the Earth's surface and plays a major role in carbon cycling; below 2,000 m it contributes to long-term biological carbon storage and burial in the biosphere (Arístegui et al., 2009; Smith et al., 2009). When organic material settles on the deep-sea floor it is becomes buried in ocean sediments by a series of biogeochemical processes (Wenzhöfer et al., 2001), thus removing the carbon from the atmosphere on geological timescales, which span thousands to millions of years (Thurber et al., 2014).

The sheer size of the ocean's carbon reserves and the high rate of uptake make the ocean a vital component in regulating excess CO_2 in our atmosphere, and thus mitigating climate breakdown. The ocean is our planet's largest store of carbon (Lal, 2008), removing over 1×10^6 tons of human-made CO_2 from the atmosphere every hour (Sabine et al., 2004) and having absorbed 28% of all human-made CO_2 emissions since 1750 (Gattuso et al., 2015).

Change

Without human interference, the natural flow of carbon between the sinks (oceanic, soil, and vegetation) would be roughly stable; however, disruption to the strength of the biological pump has significant consequences for the carbon sequestration capacity of the ocean, and therefore the amount of CO_2 removed from the atmosphere (The Royal Society, 2005). Climate-induced impacts, including ocean acidification, rising sea surface temperatures, and changes in light and nutrient availability, will affect the structure and composition of marine ecosystems, resulting in a knock-on effect on the natural function of the biological pump (Rost & Riebesell, 2004).

Water

Fresh water is crucial to humankind, and the vast majority (97%) is cycled through the ocean.

It is the source of 86% of global evaporation, and 78% of all rain on Earth falls on the ocean (Baumgartner & Reichel, 1975), and these processes are fundamental components of the global water cycle (Yu, 2011). Evaporated moisture from the surface of the ocean is transported to land, where it falls as rain and is eventually returned to the ocean by rivers, groundwater flow, and the melting and discharge from glaciers and ice sheets, completing the water cycle (IPCC, 2019). Evaporation and precipitation govern the loss and gain of fresh water respectively, and the balance between these two processes determines the surface salinity of the ocean (Schmitt, 2008). Salinity, in turn, plays a key role in thermohaline circulation, as it influences water density; combined with water temperature, this leads to the sinking of cold, dense seawater near the poles, driving the global conveyor belt.

Change

As a result of increases in anthropogenic greenhouse gas emissions, a 16–24% intensification of the global water cycle is predicted to occur in a 2–3°C warmer world (Durack, Wijffels & Matear, 2012). This change is already occurring and is causing fresh-water regions to become fresher and salty regions to become saltier (Durack, Wijffels & Matear, 2012). The changes brought about by the intensification of the global water cycle and the corresponding redistribution of rainfall will have widespread impacts on ecosystems and societies (Durack, Wijffels & Matear, 2012), including changes in water quality and availability, food security, health and sanitation, and biodiversity (Grover, 2015). Increased rainfall also reduces the salinity, and therefore density, of ocean surface waters. This, combined with human-induced warming, causes a weakening of thermohaline circulation, a key element of the global climate system (Marotzke, 2000). A significant reduction in the strength of the thermohaline cycle would lead to cooling in the North Atlantic, with northern and western Europe particularly affected (Link & Tol, 2004).

Nutrients

Nutrients are essential for the growth and health of all plants, including phytoplankton; and in locations where necessary nutrients are limited, the ability of a plant to photosynthesize can be reduced. Phosphorus, nitrogen, iron, and silica are present in the ocean in small quantities, and these nutrients can affect the rate of primary productivity, and ultimately the capacity of the ocean to sequester CO_2 from the atmosphere (Falkowski, Barber & Smetacek, 1998; Bristow et al., 2017). Although these nutrients are supplied from external sources, namely atmospheric deposition and riverine input, the main source during photosynthesis is the recycling of nutrients through decomposition and deep water upwellings; approximately 80% of primary productivity in surface waters is supported through nitrogen recycling (Bristow et al., 2017).

Change

The enrichment of surface waters with nutrients from human development causes eutrophication, which contributes to oxygen depletion in the ocean (Breitburg et al., 2018) and can lead to deoxygenation and hypoxia, causing deterioration of water quality (Chislock et al., 2013). Increasing concentrations of nitrogen oxide, nitrous oxides, and ammonia have been released into the atmosphere as a result of industrial activity, leading to increased nitrogen deposition in the ocean. These additional inputs of nitrogen have changed the ratio of phosphorus to nitrogen in some regions, particularly the North Pacific, causing disruption to open ocean nutrient cycles, especially in nutrient-limited areas (Kim et al., 2014; Ren et al., 2017). Ocean warming and increased stratification are also altering nutrient availability and, as a result, primary productivity, particularly in low-latitude upwelling regions (Bindoff et al., 2019).

Weather

The ocean regulates global weather and climate through the storage and transport of heat around the planet, via the conveyor belt-like system known as thermohaline circulation, in which deep ocean currents transport cold waters from the poles to the tropics and warm waters from the equator to the poles. As warmer waters evaporate, the temperature and humidity of the surrounding air increases, forming storms and clouds that are carried around the Earth by prevailing winds, known as trade winds. These trade winds are part of a complex global wind system that drives surface ocean-circling currents called gyres, which transfer heat from the tropics to the polar regions. The ocean also causes the formation of tropical cyclones, known as hurricanes or typhoons depending on the region in which they occur. These intense storm systems form almost exclusively over areas of tropical ocean where sea surface temperatures exceed 26°C (Trenberth et al., 2018). A resulting rise of warm air generates changes in air pressure and the formation of clouds to force the high and damaging winds of these storms.

Change

The warming of the ocean as a result of climate breakdown now being observed is already contributing to an increase in the intensity and duration of extreme weather events, such as tropical cyclones, flooding, heatwaves, and droughts (Trenberth et al., 2018). A recent study found that an intensification of sea surface winds since the 1990s, likely caused by changes in atmospheric circulation as a result of greenhouse gas warming, has resulted in a speeding up of ocean currents, equivalent to a 15% increase per decade in the energy of currents (Hu et al., 2020). This acceleration could have effects that will be felt around the planet, with changes to ocean heat storage, CO_2 uptake, and weather patterns (Voozen, 2020).

Climate-induced changes to the intensity and spatial distribution of rainfall, if substantial, pose one of the greatest risks associated with climate change (Wentz et al., 2007). It is anticipated that for every degree Celsius of warming in the Earth's lower atmosphere there will be a 7% increase in the atmospheric moisture content as a result of the ability of warmer air to hold more water vapour (Schmitt, 2008). This will cause an intensification of existing patterns of ocean evaporation and precipitation, leading to extreme weather events such as floods and droughts, with wet regions becoming wetter and dry regions becoming drier in response to global warming (Durack et al., 2012).

Climate

The ocean is a vital component of the planet's climate system and is continuously exchanging large quantities of heat, gases, and water with the atmosphere (Bigg et al., 2003). Without the ocean, our climate would be vastly different. Seawater has the greatest heat capacity of any component of Earth's climate system, which allows vast quantities of solar energy to be stored in the ocean and prevents the Earth's surface from overheating (Faizal & Ahmed, 2011). In fact, the ocean can absorb as much as 97% of solar radiation that hits its surface (Bigg et al., 2003), and this high heat capacity, relative to land, and the ability of the ocean to transport heat from one location to another via the circulation of currents makes the ocean a critical part of the of the Earth's temperature regulation.

Change

If the amount of thermal energy entering the ocean is greater than the thermal energy leaving, the average temperature will increase (Faizal & Ahmed, 2011). This change is already seen to be happening, as in the past 50 years the ocean has absorbed 93% of the excess heat generated by greenhouse gas emissions (Levitus et al., 2012). The average global sea surface temperature has increased by approximately 0.11°C every decade since the 1970s and by an estimated 1°C since the Industrial Revolution (IPCC, 2019).

Because the ocean plays such a critical role in regulating Earth's climate, a rise in sea temperature will also result in potentially significant changes to the climate system.