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PERSPECTIVE

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Fostering human health through ocean sustainability in the 21st century

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Abstract

1. The approach of the Decade of the Ocean for Sustainable Development (2021–2030) provides a time to reflect on what we know about the complex interactions between the seas, oceans, and human health and well-being. In the past, these interactions have been seen primarily within a risk framework, for example, adverse impacts of extreme weather, chemical pollution and increasingly, climate change.
2. However, new research is expanding our concept of the 'health' of the 'Global Ocean', with a broader recognition of its essential and beneficial contribution to the current and future health and well-being of humans. The seas and coasts not only provide an essential source of food, opportunities for trade and access to sustainable energy, but also the chance for people to interact with high-quality marine environments which can lead to improvements in mental and physical health and well-being, particularly of socio-economically deprived individuals.
3. By going beyond this risk framework and a purely extractive anthropocentric point of view, we can capture the true benefits, value and importance of these resources. Articulating a vision of how humans might better interact with marine ecosystems in the future, is a key first step in identifying a range of policy and management actions that can deliver our goals of fostering health and well-being through the establishment of more sustainable interconnections with the Global Ocean.

KEYWORDS
benefits, health, oceans, planetary health, risks, wellbeing

1 | THE SEAS AND OCEANS AROUND US

The seas and oceans of the Earth are vast, covering 70% of the planet's surface, and from one perspective, forming a single unitary Ocean with global significance (National Ocean Service, 2018). This has perhaps led past generations to think that such an enormous seawater ecosystem can withstand whatever impacts human activities generate. However, around 75 years ago, the concerns of a few individuals began to raise doubts in the public consciousness. Notable pioneers such as Rachel Carson (of 'Silent Spring' fame) highlighted emerging risks including widespread global warming and the contamination of the oceans in her seminal book 'The Sea Around Us' published in 1951 (Carson, 1951).

As the World's human population has increased from 2.5 billion at that time to more than 7.6 billion today, the range and intensity of threats to human health and well-being arising in the seas and oceans, have grown. This is documented in a myriad of studies identifying marine pollution, overfishing, hypoxic dead areas, coastal

zone destruction and more recently, ocean acidification, sea level rise, coastal flooding and an increased frequency and intensity of extreme storms, all posing serious dangers to the "health" of both humans and the Global Ocean (Bowen, Depledge, Carlarne, & Fleming, 2014; Dewailly et al., 2002; Fleming et al., 2015; Halpern et al., 2012; Knap et al., 2002; Walsh, Smith, Fleming, Solo-Gabriele, & Gerwick, 2008). The fight is on to try to prevent and mitigate such impacts.

But there is another marine theme that is gaining momentum, namely the exploration of the health, well-being and socio-economic benefits that marine ecosystems can provide. Environmental managers, academics, politicians and groups of concerned citizens are currently making enormous efforts to mitigate threats while fostering the use of our coasts and open waters for the benefit of the society. It would be disastrous if these positive marine dividends are reduced or lost.

One notable constraint on our efforts is that we still lack a cohesive, holistic, and widely supported vision for the future of the seas and oceans (i.e. the 'Global Ocean') over the next 30 years and beyond. The UN's Sustainable Development Goals (SDGs) take a step in this direction by including 'Life Under Water' (Goal 14), but the other 16 goals focus almost entirely on issues to do with the great land masses despite them only covering 30% of the planet. The SGDs that do discuss ocean-related issues (e.g. sea level rise in Goal 13 Climate Action), are poorly joined up across the SDG framework, and fail to take into account the global impact of changes in the ocean on human populations worldwide. What is needed is a more coherent joined-up set of targets equivalent to something like the "Sustainable Ocean Goals" (see also 'Because of the Ocean' https://www.youtube.com/watch?v=jQ00DZUrhdI).

Specifically, we argue here that a much more comprehensive appreciation is needed of the current and future threats, risks, benefits and opportunities afforded by the ongoing interactions between humans and the marine environment, together with the promise of a more sustainable future relationship.

2 | THE STORY SO FAR….

Research on human impacts on marine ecosystems originally focused on describing and measuring the characteristics of the impacts. This illuminated the adverse effects of both chemical and microbial pollution on local coastal ecosystems and open seas (e.g. Prince William Sound oil spill) (European Marine Board (EMB), 2013; Fleming et al., 2006; National Research Council (NRC), 1999; Shin, 2017). Subsequent studies tended to concentrate on specific single issues, for example, pollution with specific chemicals (e.g. mercury, PCB, PAH, etc.), or harmful algal blooms (HABs). Adverse impacts were typically also assessed using single species as indicators (e.g. TBT and dog whelks, Gibbs, Bryan, Pascoe, & Burt, 1987; see also Dewailly, Nantel, Weber, & Meyer, 1989; Fleisher et al., 2010; Fleming et al., 2011). However, anthropogenic environmental stressors work together to exert an integrated impact on entire marine communities and ecosystems, and across regional and global scales.

Equally important was the recognition that while humans can damage the Global Ocean 'health', the oceans themselves can damage human health. This is now widely accepted as a greater understanding of the variety of complicated processes involved has emerged (e.g. pollutant bio-accumulation and bio-magnification in food webs; Depledge, Harvey, et al., 2013). Damage to coral reefs by the sunscreen ingredient oxybenzone, and the accumulation of DDT, PCB and other persistent organic pollutants in Arctic peoples, illustrate this interdependency in very different marine contexts (Weihe et al., 2016). Over recent decades, the collapse of many of the world's fisheries has been attributed to the combined effects of over-fishing, pollution, habitat destruction, ocean acidification, rising sea surface temperatures, loss of species from food webs and other physico-chemical and biological changes in the oceans (Food and Agriculture Organisation (FAO), 2018). Climate change and its influence on the Global Ocean provide a stark example of a truly planet-wide impact caused by human activities, with profound consequences for all life on Earth, including marine life (Allison & Bassett, 2015).

The relentless, progressive deterioration in marine ecosystems described above has already harmed human populations (Weihe et al., 2016). More people will be affected in the coming years. Among the direct and obvious impacts are the deaths and morbidity through drowning and injury experienced by individuals affected by flooding caused by sea level rise and storm surges arising from more extreme weather events as well as in marine occupations (Depledge, 2018; Woodhead, Abernethy, Szaboova, & Turner, 2018). Anthropogenic chemical toxicity (e.g. methyl mercury poisoning in Minamata, Japan), microbial pollution (causing infectious diseases, antimicrobial resistance) and natural toxins (e.g. from HABs) can cause illness and death by exposure through seafood consumption or via contact with seawater and even marine aerosols (Depledge, 2018; Fleming et al., 2015).

There are numerous instances of extreme weather causing not just acute effects (drowning, injury, infections), but also prolonged emotional trauma and mental health disorders in the aftermath of major weather events (Hayes, Blashki, Wiseman, Burke, & Reifels, 2018). Earlier projections of climate change infrastructure destruction (e.g. sewage and water pipes, fibre-optic cables, buildings including ports and hospitals, etc.), are now tangible and overtly visible, particularly in coastal areas with deprived populations (Keenan, Hill, & Gumber, 2018; US National Climate Assessment (NCA), 2014). The long-term effects of ocean acidification coupled with the influence of its pH change on chemical pollutant uptake in fish and shellfish and on fishery sustainability, are already resulting in seafood shortages for some human populations (Hernández-Delgado, 2015). In the future, these changes in chemical exposures may cause more chronic diseases (e.g. cancer, cardiovascular disease) and reproductive failure in human and other animal populations (Depledge, Tyrrell, Fleming, & Holgate, 2013; US Centers for Disease Control and Prevention (CDC), 2009).

From the point of view of both human and ocean 'health', integrated impacts of all the above exposures and effects may be further exacerbated by negative feedback loops (e.g. ocean microplastics carrying pathogenic bacteria, antimicrobial resistance genes and endocrine-disrupting chemicals entering the food web). This is particularly alarming

especially as researchers are only just beginning to be able to measure, understand and predict the complicated interactions of these diverse stressors (Smith, Love, Rochman, & Neff, 2018). Figure 1, the 'tangled net', illustrates selected positive and negative interconnections between human health and activities in and around the seas and ocean.

Crucially, many of the risks to human health are a direct product of the ways in which we try to exploit ocean resources. Fisheries, oil/gas/aggregate/mineral extraction, marine renewables, shipping, biotech discoveries, and tourism all have the potential to provide a wide range of benefits to people's health and well-being. However, they also have the potential to pose unintended threats, especially if ocean and coastal management is short-term, spatially short-sighted (e.g. flood protection initiatives which simply push the problem to the next district) and inherently inequitable (e.g. power inequalities may mean the benefits and risks accrue to different members of coastal communities) (Figure 1).

3 | RECOGNIZING BENEFITS AND NEW OPPORTUNITIES

To date, many of the benefits to human health and wellbeing from the Global Ocean have been implicit. More recently, over the last 10 years,

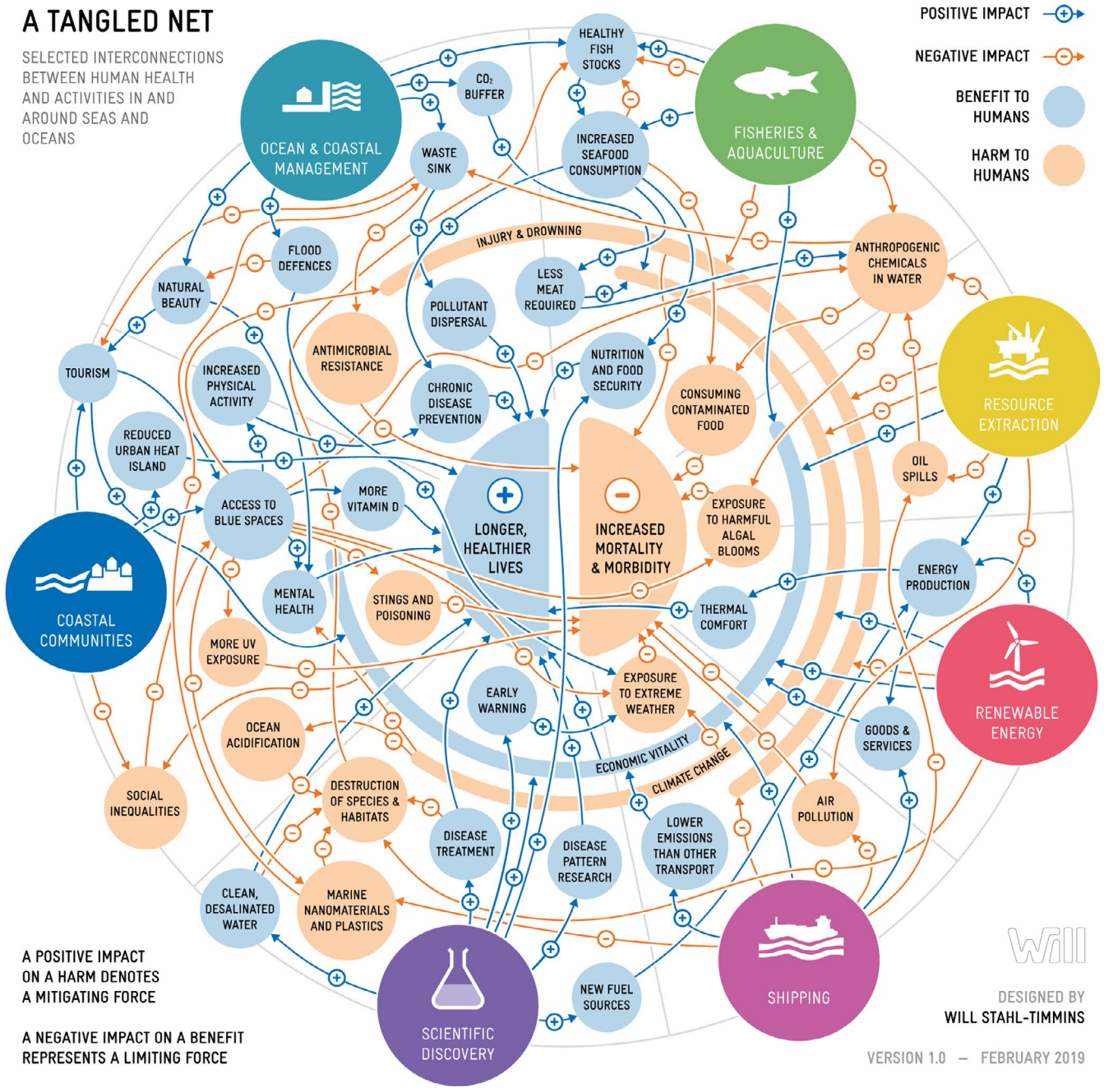

FIGURE 1 A tangled net – selected interconnections between human health and activities in and around the seas and oceans (designed by Will Stahl-Timmins)

we have made significant progress in understanding and quantifying them beyond their role as a food source and a means of enabling transport of goods and people. This broader range of benefits from coastal seas and open ocean is being codified under the ecosystem services typology and includes 'supporting' (e.g. nutrient cycling), 'regulating' (e.g. carbon sequestration) and 'provisioning' (e.g. seafood) services. As highlighted in the European Union's '5 Blue Growth areas' (e.g. aquaculture, coastal tourism, marine biotechnology, ocean energy and seabed mining), marine ecosystems are a potential source of prosperity for humans in terms of jobs, economic activity, goods and services (European Union (EU), 2017; see also Figure 1).

Seafood provides an example of both what is on offer and what is at risk. It is not only an important protein source for a significant proportion of the global population (particularly in economically depressed coastal communities), but also a provider of important micronutrients offering beneficial health effects in terms of reducing the likelihood of developing non-communicable diseases (Walsh et al., 2008). And yet, fish that could be used to sustain local coastal communities (such as herring, mackerel and anchovy) are still being processed into fish meal for use in high value aquaculture (such as salmon) to meet demand in high-income countries (Bowen et al., 2014). Other natural products harvested from the sea can directly benefit human health, for example, anti-cancer drugs and antibiotics derived from marine biota; while specific marine animals have long served as models of human physiology and disease in biomedical research (National Research Council (NRC), 1999; Walsh et al., 2008).

More recently, there is a growing weight of evidence that the direct interactions of humans, both as individuals and communities, with the seas and oceans can lead to a number of public health benefits (e.g. the 'blue gym'; Depledge & Bird, 2009) including increased physical activity and improved mental well-being (Gascon, Zijlema, Vert, White, & Nieuwenhuijsen, 2017). Many of the benefits appear to be derived from the sea's ability to encourage, particularly urbanized, populations into spending more time outdoors 'in the fresh air', engaging in activities ranging from high energy water sports to more gentle coastal walks (White, Pahl, Wheeler, Fleming, & Depledge, 2016; White, Wheeler, Herbert, Alcock & Depledge, 2014). Studies in three countries (New Zealand, Ireland and Hong Kong) even suggest that merely having a view of the ocean from home is associated with a lower risk of general and/or mental health problems, after taking into account direct coastal engagement and various socio-economic factors (Dempsey, Devine, Gillespie, Lyons, & Nolan, 2018; Garrett et al., 2019; Nutsford, Pearson, Kingham, & Reitsma, 2016).

Indeed, evidence from the UK suggests that the benefits may be greatest among lower socio-economic status groups (Wheeler, White, Stahl Timmins, & Depledge, 2012), in part because unlike other natural environments (e.g. woodlands), seas and coasts are used by all groups in society for recreation (Elliott et al., 2018). Furthermore, from the point of view of sustaining sea and oceans, people seem to derive more mental health benefits from spending time in higher quality (e.g. more biodiverse) marine environments (Wyles et al., 2017), providing a further justification for protecting the Global Ocean from damaging human activities (Figure 1).

4 | AN INTERNATIONAL PERSPECTIVE

Despite these gains in our understandings of the benefits, the history of research into the interactions between the seas, Global Ocean and human health and well-being has still predominantly focused on addressing the risks (European Marine Board (EMB), 2013; National Research Council (NRC), 1999; Knap et al., 2002). Better understanding and management of these interactions are a global priority that require a global political focus and worldwide participation. Its achievement depends upon responsible economic development administered through the dual lens of environmental sustainability and social inclusion; and, if successful, such research will contribute to attaining the ambitious UN SDGs.

The latest contemporary international perspective is provided by the UN Secretary General (2018) Report on the Sustainable Development Goals, which reviews the current state of affairs. For SDG 14 '*Conserve and sustainably use the oceans, seas and marine resources*', progress has been mixed (UN Secretary General, 2018). Investigations have documented overfishing, acidification of the oceans, coastal eutrophication, and the need to create protected areas, expand research capacity and increase ocean science funding. These matters are urgent. Ocean acidity, for example, has increased by about 26% since the industrial revolution; while coastal water pollution and eutrophication are still contributing to the deterioration of coastal water quality. On the positive side, there has been a 16% increase in marine waters under national jurisdiction that have been declared protected areas, and the coverage of key biodiversity ecosystems has increased from 30% to 44%.

The state of ocean ecosystems also strongly influences our ability to achieve other SDGs. For example, SDG 6 '*Clean water and sanitation*', SDG 12 '*Responsible consumption and production*', SDG 13 '*Climate action*', and SDG 15 '*Life on land*' (Thomson, 2017)), as well as SDG 2 '*End hunger and improved nutrition*', SDG 3 '*Good health and well-being for all people*', SDG 7 '*Energy production*' and SDG 8 '*Decent work*'. In other words, our seas and the Global Ocean are absolutely central to efforts to improve human health and well-being, and more broadly, global sustainability. This view was supported by the Heads of State and Government and high-level representatives who met in June 2017. Their report "Our Oceans, Our future: Call for Action Resolution" (UN Secretary, 2017) reiterates the importance of the oceans in achieving all the SDGs.

5 | THE WAY FORWARD……

From the perspective of human societies, moving beyond risks to capture benefits and opportunities for all is the key (Frumkin, 2001; Silva, Rogers, & Buckley, 2018). However, the challenges obviously remain. Notably, access to marine environments and their resources is often inequitable, with marginalized communities and those who might benefit most, having the least access to or say in their use. The ability of ecosystems to deliver important services is also under increased threat as critical thresholds are passed (Selkoe et al., 2015).

Much of the evidence for benefits, particularly the 'blue gym', has been explored in higher income countries, where ironically the increasing value of coastal areas is leading to decreasing accessibility for less well-off individuals (Depledge et al., 2017). Furthermore, there is a paucity of research into what benefits individuals and communities in lower and middle-income countries could gain from increasing and sustainable accessibility to high-quality 'blue' exposures in terms of their health and well-being. This is important as currently some of the poorest people live in the most highly degraded and vulnerable coastal environments (Neumann, Vafeidis, Zimmermann, & Nicholls, 2015).

Regardless of geography or socio-economic status, it is unknown whether greater exposure to high-quality blue environments, in combination with increasing 'ocean literacy' (Kelly, 2018; Lotze, Guest, O'Leary, Tuda, & Wallas, 2018), will necessarily lead to a greater appreciation of the value of the Global Ocean, and trigger more pro-environmental behaviours.

6 | WHAT ARE WE AIMING FOR?

Taking a step back, in the final analysis we have yet to fully consider what might be regarded as 'success' in our relationship with the ocean environment. How can a global population of 7.6 billion humans, whose practices make extensive use of both non-renewable and renewable marine resources (especially energy resources) and who continue to discharge vast amounts of waste materials into the seas (including persistent industrial and agricultural chemicals, plastics and pharmaceuticals) be sustainable? Clearly, current practices and approaches must change (Brown, Adger, & Cinner, 2018; Hernández-Delgado, 2015; Johnson & Panlilio, 2018; Rockström et al., 2009; Whitmee et al., 2015).

Although important research is being done in specific areas (e.g. Pauly (2018) in fisheries and the blue economy; Ban et al. (2017), Christie et al. (2017), Alleway et al. (2019) around Marine Protected Areas), it is extraordinarily difficult to find a comprehensive overview describing a common view of what we want the coastal and ocean environments to be like in the future. However, piecing together various local, national and regional management plans from around the world, it appears that only very low levels of chemical and microbial contaminants will be acceptable in coastal and ocean waters. There is a strong desire to restore fish stocks to much higher levels that can support reasonable capture fisheries; and there is a particularly widespread desire to restore biodiversity.

This latter aspiration requires some extra clarification because a general call to enhance biodiversity is both naïve and misguided. What is required is a broader appreciation of the value of restoring biodiversity to levels that are appropriate for the particular local ecosystem. As the climate changes, some species will be lost or move away, while others will arrive, establishing an ecosystem appropriate to the new circumstances, hopefully with species in the proportions and at the time appropriate for the prevailing ecological succession (Bennett et al., 2015).

As we move forward, it is essential that we neither refrain from modifying natural coastlines in ways that destroy the communities of the marine ecosystems worldwide, exacerbate coastal flooding, or increase vulnerability of human populations to storms, nor should we disturb or damage our still poorly understood deep sea ecosystems. An overarching aim must be to severely limit anthropogenic climate change, by curtailing CO_2 and other greenhouse gas emissions so that the Global Ocean does not continue to warm and acidify.

There are many other matters to consider, not the least, thinking about where we place our coastal towns and cities; where we site industrial operations and leisure activities; how we use the marine environment for sustainable energy production, etc. Establishing a list of objectives while taking trade-offs into account, and formulating policies to attain them would go a long way towards establishing and then achieving a vision of sustainable seas and Global Ocean.

Some will argue that we are already controlling pollutant inputs into the seas from land-based sources and from ocean mining, oil and gas industries, shipping, etc., through regulation. Yet, the reality is that globally the ocean is being treated as a waste sink with up to 90% of untreated wastewater and 70% of industrial waste from some developing countries entering the ocean (Cicin-Sain, Bernal, Vanderweerd, Belfiore, & Goldstein, 2002). While efforts are being directed at reducing the physical destruction of the coastal zone, reducing emissions from shipping, regulating capture fisheries and curtailing greenhouse gas emissions, the fact is that our efforts so far have been inadequate in avoiding ongoing diverse and adverse impacts of human activities on our seas and oceans, and their consequential short- and long-term effects on human health and well-being.

7 | REACHING BEYOND

Ultimately, it has not been unequivocally established that what is good for the health of humans is good for the "health" of the environment, including for the Global Ocean. The experience from the last 50–100 years indicates that what has been good for humanity in the short term (i.e. the last few centuries), based on a cycle of extractive and wasteful human activities associated with local and global inequalities, has actually been detrimental to the rest of the planet including the Global Ocean (Brown et al., 2018; Hernández-Delgado, 2015; Johnson & Panlilio, 2018; Rockström et al., 2009; Whitmee et al., 2015).

Future research on the seas, ocean and human health, must provide greater understanding of how to better manage interacting stressors, as well as exposures to actual mixtures, while capturing the potential for co-benefits available through intelligent management. (Depietri & McPhearson, 2017) This will necessitate collaborations by individuals and institutions working across sectors, and responsible economic development administered through the dual lens of environmental sustainability and social inclusion to ensure the voice of those most affected is heard. A greater focus on truly transdisciplinary research and training will be especially valuable,

involving collaborations between marine and terrestrial natural scientists, social scientists and biomedical/public health researchers and many others (Phoenix et al., 2013). Inherent in this approach should be the issue of social inclusion, to ensure that those least able to influence the process but often most affected are heard, necessarily involving the co-creation of research plans with diverse communities (including indigenous communities).

As we near the Decade of the Ocean for Sustainable Development (2021–2030), one thought would be to establish a panel similar to the 'Intergovernmental Panel for Climate Change (IPCC)', to gather global evidence and to promote collaborative action on behalf of the 'Global Ocean and Human Health and Well-being'. This effort must go beyond climate change to embrace all environmental change. This should include ongoing assessments of both benefits and the risks, involving and engaging affected, diverse communities (i.e. social inclusion), as well as being evidenced by truly transdisciplinary science. Pertinent issues to humans such as the rapidly changing ageing demographics and increasing non-communicable disease profile of human populations around the world, as well as the increasing and mixed exposures from contaminated environments of anthropogenic chemicals and other pollution, coupled with climate change, biodiversity loss and ecosystem degradation of the seas and the Global Ocean—all need to be considered to understand the complexity of Ocean and Human Health (Figure 1).

At its core, there must be a well thought out and clearly articulated vision of what would be an acceptable relationship between humans and the ocean in the future. This means accepting and embracing the fact that the current and future state of the Global Ocean will in large part determine the current and future sustainability, health and well-being of all humans on Earth.

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CONFLICT OF INTEREST

No authors have any known conflicts of interest for this paper.

AUTHORS' CONTRIBUTIONS

All authors conceived the ideas and contributed to the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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- The work is original and all necessary acknowledgements have been made.
- The work conforms to the legal requirements of the country in which it was carried out, including those relating to conservation and welfare, and to the journal's policy on these matters.

DATA ACCESSIBILITY

No data were collected for this paper.

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SUPPORTING INFORMATION

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

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