Commissioned by

HIGH LEVEL PANEL *for*
A SUSTAINABLE
OCEAN ECONOMY

Blue Paper

How can a healthy ocean improve human health and enhance wellbeing on a rapidly changing planet?

LEAD COORDINATING AUTHORS | Lora E. Fleming and Philip J. Landrigan

LEAD AUTHORS | William Gerwick, Johanna J. Heymans, Christina C. Hicks, Karyn Morrissey and Mathew P. White

CONTRIBUTING AUTHORS | Lota Alcantara-Creencia, Karen A. Alexander, Oliver S. Ashford, Thomas Astell-Burt, Roberto G.S. Berlinck, Philippa J. Cohen, Richard Hixson, Mohammad Mahmudul Islam, Arihiro Iwasaki, Radisti A. Praptiwi, Hervé Raps, Jan Yves Remy, Georgina Sowman, Amy Swift, Eva Ternon, Torsten Thiele, Shakuntala H. Thilsted and Ella M. Whitman

oceanpanel.org

About the Ocean Panel

Established in 2018, the High Level Panel for a Sustainable Ocean Economy (Ocean Panel) is a unique initiative made up of serving world leaders who are building momentum for a sustainable ocean economy in which effective protection, sustainable production and equitable prosperity go hand in hand. By working collaboratively with a wide array of stakeholders, the Ocean Panel aims to identify bold solutions that bridge ocean health, wealth and equity and accelerate and scale responsive action worldwide.

This Blue Paper was prepared in support of the work of the Ocean Panel to provide a robust science and knowledge base and practical opportunities for action across issues central to the attainment of a sustainable ocean economy. The arguments, findings and opportunities outlined in this Blue Paper represent the views of the authors alone. Ocean Panel members have not been asked to formally endorse the Blue Paper and should not be taken as having done so.

Suggested Citation: Fleming, L.E., P. J. Landrigan et al. 2024. *How can a healthy ocean improve human health and enhance wellbeing on a rapidly changing planet?*. Washington, DC: World Resources Institute. Available online at https://oceanpanel.org/publications/ocean-human-health/.

Table of Contents

Foreword

This Blue Paper commissioned by The High Level Panel for a Sustainable Ocean Economy (the 'Ocean Panel') is the first in the series to explore the topic of human health and its relationship with the ocean. It demonstrates that the health of the ocean and human health are inextricably linked.

Traditionally, conversations about ocean and human health relationships have focused on risks and threats. Hotter ocean temperatures, coastal urbanisation and nutrient and microbial pollution affect health by encouraging harmful algal blooms. Mercury, lead, chemicals leaching out of plastic polymers, persistent organic pollutants, pharmaceuticals and others can enter food chains and increase the risk of some cancers, infertility and birth defects, neuro-behavioural toxicity and endocrine disruption. Flooding, land erosion, rising sea levels and more frequent and violent storms pose a growing threat to the physical and mental health of coastal communities.

What is communicated much less often are the enormous opportunities for improving human health, supporting mental health and wellbeing, creating economic opportunities and advancing social justice and wellbeing that the ocean offers. Ocean biodiversity can provide new medicines to fight disease, inspiration for new technologies, new materials and energy sources. Sustainable production of blue food holds promise for ending hunger and malnutrition. Access to healthy marine environments supports recreation and promotes mental health.

The authors of this Blue Paper are international and interdisciplinary experts with diverse backgrounds and broad experiences. They present a menu of actions to promote equity, sustainability, biodiversity and human flourishing. They also emphasise that healthcare professionals, as expert communicators and trusted members of society, are uniquely well positioned to advocate for change, advance equity and promote sustained global action to protect both ocean health and human health. Yet they are an underutilised ally at present.

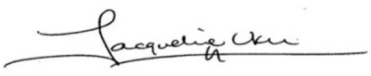
The UN Decade of Ocean Science for Sustainable Development strives to promote the science we need for the ocean we want. However, little emphasis has been placed by the Ocean Decade to date on understanding the relationships between ocean health and human health. Similarly, the World Health Organization's draft fourteenth general programme of work makes no mention of the ocean. We hope that the publication of this Blue Paper ultimately creates an inflection point in the mainstreaming of ocean health and human health research and understanding.

As the Lead Experts of the Ocean Panel Expert Group, we would like to warmly thank the authors, the reviewers and the Ocean Panel Secretariat at World Resources Institute for supporting the production of this resource. We are also grateful for the continued enthusiasm of Ocean Panel member states in their work towards realising a global sustainable ocean economy.

Humans cannot thrive when the ocean is sick. Acting on the opportunities identified in this report will help inspire the world towards a new vision of universal ocean citizenship and planetary stewardship with sustainability, equity and inclusion at the core.

Prof. Peter Haugan, Ph.D.
Institute of Marine Research,
Norway

Dr Judith Kildow, Ph.D.
Director Emeritus of the National
Ocean Economics Program
USA



Dr Jacqueline Uku, Ph.D.
Senior Research Scientist,
Kenya Marine and Fisheries
Research Institute (KMFRI)

Highlights

- The ocean holds great, though still largely unrecognised and unrealised, potential to improve human health, support mental health and wellbeing, create economic opportunity and advance social justice.
- These opportunities include new medicines to fight disease; new materials; inspiration for new technologies to support societal development; new ocean-based energy sources; blue food resources that hold promise for ending hunger and reducing food insecurity; and access to nature to support recreation and promote mental health.
- But the ocean's potential to benefit humanity is threatened by climate change, pollution, biodiversity loss, inequitable and unsustainable patterns of consumption, and marginalisation of Indigenous Peoples, local communities and other coastal populations. These threats are the result of improper ocean governance. They are driven by a relentless quest for short-term economic gain without concern for human health, natural capital or environmental consequence.
- Fully realising the ocean's benefits for human health and wellbeing and safeguarding our common future will require confronting these threats by meeting the commitments of global laws, treaties, conventions and guidelines; building global partnerships and promoting a greater focus on equity and the protection of human rights for all people, including the right to health and a healthy environment.
- Here, we identify three actions of overarching importance to both ocean and human health:
  - **Collaboratively protect, restore and sustainably manage ocean biodiversity, including by ratifying and implementing key international agreements.** This will ensure that the great potential of ocean medicines and biotechnology, ocean food sources and access to natural ocean spaces for human health is preserved.
  - **Combat climate change and eliminate pollution, including by upholding commitments to the UN Framework Convention on Climate Change Paris Agreement, the COP28 outcomes, and the UN Global Plastics Treaty.** This will benefit human health by slowing climate change, reducing the frequency of extreme weather events, limiting sea level rise, and preserving healthy marine food sources.
  - **Improve human health and equity measurement by incorporating evidence and linked indicators of both ocean health and human health and wellbeing into relevant policies and decision-making.** This will promote human health by ensuring that measures of both ocean and human health are integrated into broader health monitoring, prevention and evaluation programmes.
- The following additional actions should be taken across a wide range of sectors and actors to realise the ocean's potential to benefit human health:
  - Foster the production of new medicines and biotechnology from the ocean by supporting research and development, creating digital DNA libraries and developing biotechnological processes and products that are socially relevant, economically sustainable and environmentally friendly.
  - Build and sustain food security from the ocean by supporting sustainable seafood cultivation and harvest, promoting nutrition-sensitive fisheries management, supporting marine tenure of local communities and Indigenous Peoples, and ensuring community co-creation and genuine involvement in marine planning.
  - Enhance physical and mental health and societal wellbeing by upscaling blue prescription (nature-based health intervention) programmes and developing policies to increase ocean literacy.
  - Enhance the ocean's contributions to economic growth and equity by scaling up investment in a sustainable ocean economy, incorporating metrics of natural capital and human capital into all benefits evaluations, reforming global finance and trade to provide more equitable access to marine resources, and creating cross-sectoral linkages to encourage co-creation.
- Achieving these actions will necessitate empowering marginalised voices and creating a sustainable, more equitable economy that benefits all of humanity. Healthcare professionals and the global health sector are uniquely well positioned to advocate for change, advance equity and promote sustained global action to protect both ocean health and human health. Yet at present are they are underutilised in this capacity.
- We must act now to address this global ocean and human health emergency.

Executive summary

Prior Ocean Panel Blue Papers have explored such topics as environmental threats to the ocean, ocean-based advances in renewable energy, coastal restoration, sustainable practices within fisheries and marine transportation. This Blue Paper examines the links between the ocean and human health. Its purpose is to provide heads of government and global leaders with robust evidence on the connections between ocean health, human health, societal wellbeing and the global economy as these leaders look to chart the next urgent actions to attain all the Sustainable Development Goals (SDGs) and realise the least funded of them, SDG 14, on 'life below water' (WEF 2022). This Blue Paper identifies opportunities for sustaining and protecting the ocean in ways that improve human health and support just, equitable economic development.

The specific goals of this Blue Paper are two. First, it seeks to systematically catalogue ocean-based opportunities for enhancing human health and wellbeing. Second, it endeavours to present regional, national and international policymakers with an evidence-based menu of achievable actions for improving human health and wellbeing by equitably realising the ocean's great benefits, while effectively conserving and managing its beauty and bounty for future generations (Figure ES-1, Table ES-1).

Throughout this Blue Paper we emphasise the importance of cross-sectoral, cross-national partnerships and of a global structure of laws, treaties, guidelines and organisational entities that harness our collective creativity and intelligence, curb humanity's appetite for short-term gain, move the world towards greater sustainability and create a sustainable, more equitable economy that prioritises human health and wellbeing (Pope Francis 2015; Abbasi et al. 2023; Fleming et al. 2023). We argue that preservation of ocean and human health will require metrics and governance structures that look beyond measures of short-term productivity such as gross domestic product (GDP) and explicitly value human and natural capital; address the underlying political, economic and ethical causes of the current planetary crisis; and centre justice and equity, particularly with respect to previously marginalised communities such as Indigenous Peoples and local communities.

A recent article published in over 200 health journals simultaneously underscores the current urgency for action on ocean and human health now:

> *Over 200 health journals call on the United Nations, political leaders, and health professionals to recognise that climate change and biodiversity loss are one indivisible crisis and must be tackled together to preserve health and avoid catastrophe. This overall environmental crisis is now so severe as to be a global health emergency. (Abbasi et al. 2023)*

Critically, because healthcare professionals are tasked with maintaining and restoring health, are expert communicators and are trusted members of societies in their role as advocates for their patients, the health sector is uniquely well positioned to lead in safeguarding human health by protecting the health of the ocean (Depledge et al. 2019; Romanello et al. 2023). Yet at present they are not sufficiently educated about the need for this work or engaged in it. Involving health professionals and the health sector in protecting ocean health will require innovative efforts across multiple areas, including reducing the health sector's carbon footprint, reducing medical waste and pollution, supporting greater ocean literacy to promote science-based advocacy on behalf of patients and emphasising population health and prevention. These efforts will extend into many areas, including energy, transport, supply chains, food and education. The entire health sector must be involved, including hospitals, healthcare systems, public health, biotechnology, pharmaceuticals, social care and Indigenous health.

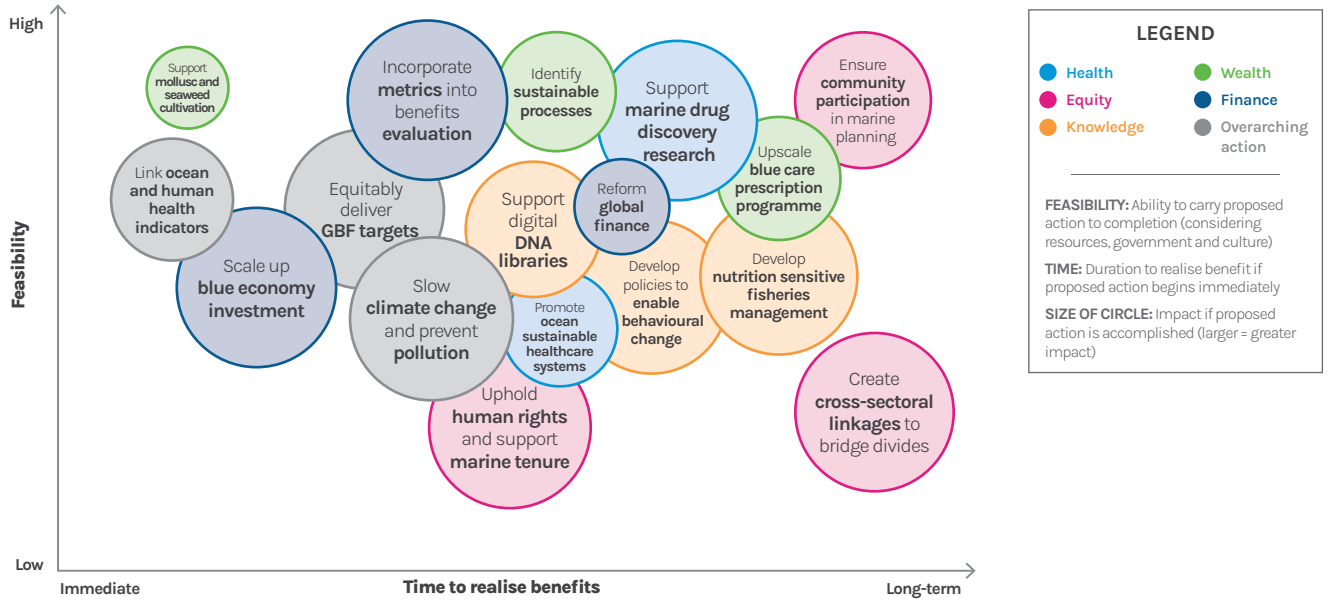
This Blue Paper actively presents a series of actions and opportunities that can and must begin immediately to sustain, protect and expand both ocean and human health (Figure ES-1; Table ES-1).

It identifies three key actions of overarching importance to both ocean and human health:

- **Protect, restore and manage ocean biodiversity.** The great potential for marine medicines and biotechnology and marine food sources depends on collaboratively and effectively protecting and sustainably managing marine biodiversity. To that end, it is essential that the world's nations ratify and implement—with genuine commitment to effective management for biodiversity protection, equity and human wellbeing—the UN Convention on Biological Diversity (CBD) Global Biodiversity Framework, the World Trade Organisation (WTO) Fisheries Subsidies Agreement and the Agreement under the UN Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ).
- **Combat climate change and eliminate pollution.** The health of coastal populations depends on slowing climate change to prevent extreme weather events and limit sea level rise, and preventing to the greatest degree possible all forms of pollution from reaching the ocean to conserve healthy marine food sources, with particular focus on reducing greenhouse gas emissions from fossil fuels to net zero by 2050 and eliminating plastic pollution. To that end, the world's nations must uphold their commitments to the UN Framework Convention on Climate Change Paris Agreement, the COP28 outcomes and the UN Global Plastics Treaty.
- **Improve measurement and support equity.** Indicators of both ocean and human health must be integrated into ongoing monitoring, prevention and evaluation programmes, and these data must be made publicly and freely accessible. To that end, evidence and linked indicators of ocean health and human health and wellbeing must be incorporated into all policies and decision-making around ocean-human interactions, and this information must be made publicly available.

We must act now to inspire and work collaboratively with individuals, communities, businesses, policymakers, the healthcare sector and governments around the world to engage in a new vision of ocean citizenship and planetary stewardship.

FIGURE ES-1. **Opportunities for action to support both ocean health and human health and wellbeing in a changing planetary environment**



Notes: GBF = Global Biodiversity Framework. Circles are plotted by feasibility (y-axis—ability to carry proposed action to completion considering resources, government and culture) and time to realise benefits (x-axis—the duration required to realise benefits of proposed action). The relative size of the circle reflects the magnitude of impact of the action (in terms of overall benefit to ocean and human health globally). All actions need to be initiated immediately. This figure is included primarily as a visual aid for readers. It is based on the authors' interpretation of best available evidence, not a quantitative analysis of all available information.

Source: Authors.

TABLE ES-1. **Tabulation of opportunities for action to support both ocean health and human health and wellbeing in a changing planetary environment**

OPPORTUNITY/ACTION IDENTIFIED	THEME	PILLAR OF TRANSFORMATIONS AGENDA (OCEAN PANEL 2020)	ACTOR
Deliver the Global Biodiversity Framework targets, the WTO Fisheries Subsidies Agreement and the Agreement under the UN Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ) with genuine commitment to equity and human wellbeing	Overarching actions	Overarching actions	Government
Protect human health by slowing climate change and preventing all pollution from reaching the ocean			Government and private sector
Incorporate indicators of both ocean and human health into all ocean-human policies and ongoing monitoring, prevention and evaluation; and make these data freely available			Government
Support equitable and sustainable research for discovery of new marine medicines and ocean-based technologies	Medicine and biotechnology	Health	Government and private sector
Identify and foster development of biotechnological processes and products that are socially relevant, economically sustainable and environmentally friendly		Wealth	Government and private sector
Create and support digital DNA libraries containing the genetic blueprints for most marine life		Knowledge	Government and private sector
Uphold human rights and support marine tenure of local communities and Indigenous Peoples	Building and sustaining food security	Equity	Government
Promote nutrition-sensitive fisheries management and sustainable mariculture production		Knowledge	Government and private sector
Ensure community co-creation and genuine involvement in marine planning		Equity	Government
Support sustainable seafood cultivation and harvest		Wealth	Government and private sector
Promote sustainable healthcare systems and practices that protect ocean health	Enhancing physical health, mental health and societal wellbeing	Health	Government and healthcare sector
Upscale existing blue prescription programmes for promoting physical health and mental wellbeing and create new programmes		Wealth	Government and healthcare sector
Develop policies to increase ocean literacy and enable behavioural change to foster pro-environmental behaviour		Knowledge	Government
Reform global finance and trade to provide more equitable access to marine resources	Growing the economy and improving health by addressing inequity	Finance	Government
Scale up investment in a sustainable and equitable ocean economy		Finance	Government, private sector and philanthropy
Create cross-sectoral linkages to bridge divides and encourage co-creation, with deliberate attention to levelling the playing field		Equity	Government and private sector
Incorporate metrics of natural capital and human capital into all benefits evaluations		Finance	Government

Note: Actions are categorised by the themes of this Blue Paper, and also by the themes of the Transformations Agenda (Ocean Panel 2020). All actions need to be initiated immediately. The broad delivering party for each action is also indicated.

Introduction

Human health and the health of the ocean are inextricably linked. The ocean is a source of joy, peace, recreation and restoration. Interactions with blue spaces—coasts, salt marshes, beaches and the ocean itself—enhance the physical health, mental health and wellbeing of humans from infancy to old age (White et al. 2020). For billions of people, the ocean is an essential source of food, micronutrients, livelihoods and traditions. The ocean economy generates more than US$1.5 to $2.5 trillion per year and provides over 30 million formal jobs (OECD 2016), with millions more people informally employed in artisanal and small-scale fisheries. Ocean species have provided multiple essential medicines, some of the world's strongest adhesives, and inspired new visions in architecture and engineering (Fleming et al. 2019; Fleming et al. 2021).

The ocean is an essential component of the planetary systems that sustain all life on Earth. It holds most of the planet's water, produces much of its oxygen and is responsible for almost half of all primary biological production. By absorbing 25 percent of all carbon dioxide (CO_2) emissions and more than 90 percent of excess atmospheric heat, the ocean stabilises the global climate and slows global warming (Friedlingstein et al. 2019; Hoegh-Guldberg et al. 2023).

However, the health of the ocean is increasingly under threat, and the current threats to ocean health are largely of human origin. They range from the growing impacts of climate change (e.g. extreme weather events, ocean warming, melting polar ice, sea level rise, ocean acidification and ocean deoxygenation), to industrial fishing practices that damage ocean ecosystems and deplete fisheries, to oil and gas extraction, deep-sea mining and pollution (Nash et al. 2017; Landrigan et al. 2020). For example, coastal urbanisation and nutrient and microbial pollution increase the frequency of harmful algal blooms, and these endanger coastal photosynthetic species (e.g. seagrasses and seaweeds) worldwide (Berdalet et al. 2016). Declines in the biomass of photosynthetic species reduce the ocean's capacity to store CO_2 (Filbee-Dexter et al. 2023) and its ability to generate oxygen. Plastic pollution (including large macro-plastics and chemical-laden microplastic particles) derived from fossil fuels is pervasive and rapidly worsening (Landrigan et al. 2023). Harmful chemicals that leach out of plastic polymers bioaccumulate in the tissue of aquatic species and contaminate food chains (Landrigan et al. 2023). All these threats to ocean health can harm human health, leading to malnutrition, acute gastrointestinal illnesses, paralytic neurotoxicity or chronic diseases such cardiovascular disease and cancer (Figure 1).

Since the Industrial Revolution, the marine environment has experienced a significant decline in biodiversity. Some marine species have already become extinct, and many more are threatened (Roberts 2007; McCauley et al. 2015). Unless humanity takes urgent action to protect the ocean's biological diversity, more species will be lost, the genetic and

OCEAN

The terms 'ocean' and 'global ocean' (both in the singular) are increasingly used to express the concept that the worlds' coasts, seas and ocean are, in fact, one ocean, which contains unique ecosystems within specific regional seas and ocean areas, and for which all humans have a shared responsibility. (Fleming et al. 2023)

SUSTAINABLE OCEAN ECONOMY

The sustainable use of ocean resources for economic growth, improved livelihoods and jobs while preserving the health of ocean ecosystems. (World Bank and UNDESA 2017)

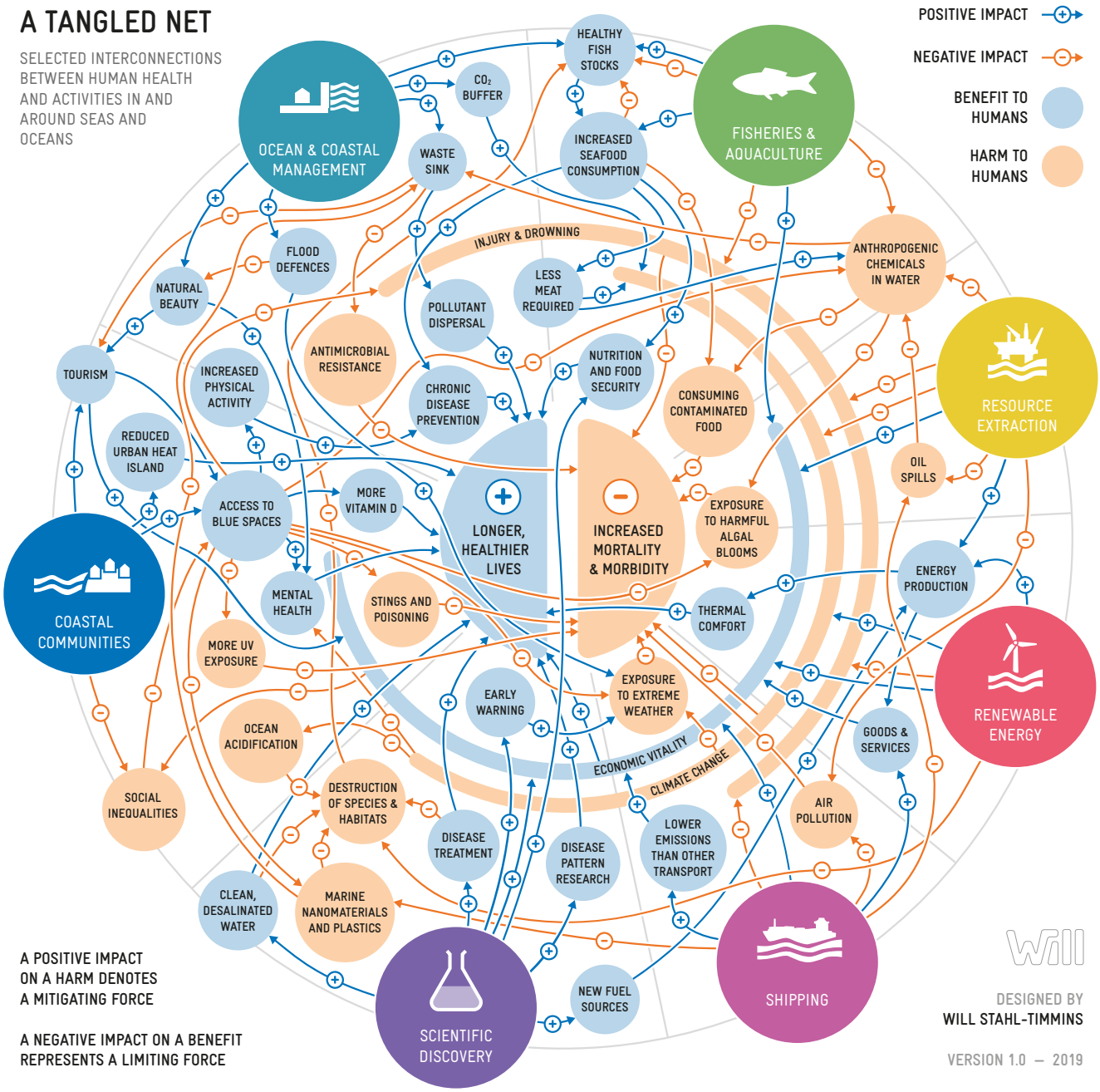
OCEAN 'HEALTH'

The seas, coasts and ocean are 'healthy' when they are resilient, productive and diverse. (Franke et al. 2020)

biological secrets these organisms hold will be gone forever, and their potential benefits for human health and wellbeing will never be realised.

If the ocean economy is to grow sustainably, and if new products, medicines and other opportunities are to continue to come from the ocean, we must effectively conserve and manage the rich biological diversity of the ocean and ensure all people's use of marine resources by creating a sustainable and equitable ocean economy. Cross-sectoral, cross-national partnerships, a global network of laws and treaties, and metrics of national and global economic wellbeing that look beyond measures of short-term productivity such as gross domestic

FIGURE 1. **Selected interconnections between human health and activities in and around the ocean**



Source: Designed by Will Stahl-Timmins, first published in Fleming et al. 2019.

ECONOMIC METRICS

Gross domestic product (GDP), the most widely used economic metric, measures the monetary value of all goods and services produced in a country in a given time. While a useful measure of productivity, GDP does not measure national wealth, which includes the economic worth of a country's natural, human and social resources. GDP thus fails to account for resource losses resulting from production. More comprehensive economic assessment includes GDP as well as valuations of natural, human and social capital. (Kubiszewski et al. 2013)

product (GDP) and include explicit assessment of natural and human capital will be essential to achieving these goals.

Conversations about the relationships between the ocean and human health have typically focused on risks and threats. They are part of growing discussions around humanity's negative impacts on planetary health. But that is only one side of the story. The good news is that the ocean offers enormous opportunities for improving human health and wellbeing (Figure 1).

This Ocean Panel Blue Paper explores these opportunities. To provide context, the paper first details the risks and threats that are the consequence of current interactions between humans and the ocean. However, our main focus is on the opportunities and the many still incompletely realised benefits that the ocean holds for humankind. In particular, we focus on actions that can be taken now to benefit both ocean health and the health and wellbeing of all people now and in future generations.

This Blue Paper reviews current knowledge and the best available evidence for ocean and human health in four key areas:

- Medicine and biotechnology
- Building and sustaining food security
- Enhancing physical health, mental health and societal wellbeing
- Growing the economy and improving health by addressing inequity

Each section identifies specific opportunities for individual and collective action by local, regional and international policymakers. The result is a collation of local, national and transnational opportunities for action and investment, which include governmental policies, international agreements and opportunities for sustainable investment. In a final section, we rank these actions by feasibility and impact; and we distinguish those that will produce immediate benefit from those whose benefits will accrue mainly to future generations. We recommend that all these actions begin now.

Throughout this Blue Paper, we stress the need for actions that are just, inclusive and designed to ensure that all members of society benefit maximally. We emphasise the need to fully involve representatives of Indigenous Peoples, marginalised coastal communities, small-scale fishers, small island developing states (SIDS; also known as 'large ocean states') and populations who live in and around marine protected areas (MPAs) and other areas designated as 'protected' in all decision-

making and action to protect or develop the ocean (Bennett et al. 2018; Blythe et al. 2023; Villasante et al. 2023). These communities are at disproportionate risk from disruptions of planetary and ocean health, but they are also long-time stewards of the ocean and curators of hard-won, empirical knowledge that can guide local and global efforts to mitigate and adapt to climate change and preserve biodiversity (Berkes et al. 2000).

In each section, we emphasise the need for continued monitoring and evaluation of all interventions, as well as the establishment of collaborative programmes for prevention, intervention and adaptation. This is especially important given the rapidly evolving nature of climate change and its consequences. Only through continued measurement and transparent dissemination of shared data can effectiveness be assessed, unintended consequences detected, policies improved and course corrections made.

Throughout this Blue Paper, we employ a variety of frameworks to envision threats, benefits and opportunities for intervention. These range from consideration of ecosystem services and planetary boundaries, to the Planetary Health and One Health constructs, to the UN Sustainable Development Goals (SDGs), the 10 UN Ocean Decade Challenges (Villasante et al. 2023) and the Ocean Panel Transformations Agenda (Ocean Panel 2020).

We also focus on the global health sector. Hospitals, clinics, public health systems and the entire health sector inflict harm on ocean health through their greenhouse gas emissions (e.g. 8.5 percent of U.S. greenhouse gas emissions, and 4.5 percent worldwide), the pollution caused by their extensive global shipping and supply chains, and because they release pharmaceuticals, other chemicals and plastic wastes that pollute the environment and enter the ocean (Steenmeijer et al. 2022; Healthcare Ocean n.d.; Senay et al. 2023).

WELLBEING

A positive state experienced by individuals and societies. Wellbeing encompasses both physical and mental health and is determined by social, racial, political, economic, environmental and historical conditions. (WHO 2021)

HEALTHCARE SECTOR

All organisations, people and actions whose primary intent is to promote, restore or maintain health. (WHO 2007)

But the health sector can also model positive change. Health professionals are tasked with maintaining and restoring health, are expert communicators and are respected, trusted members of their societies (Depledge et al. 2019; Patel 2023). Once educated in ocean and human health, they are uniquely well positioned to influence opinion, lead by example and offer science-based guidance to policymakers—all of which will enable greater protection of the patients and communities they serve.

The authors of this Blue Paper are international and interdisciplinary experts with intentionally diverse backgrounds and broad experiences enabling them to provide a global perspective and present innovative insights for the future of both ocean and human health (please see 'About the authors'). The authors present an expert review of the current state of scientific evidence and other forms of information and knowledge; this Blue Paper is not intended to be an in-depth formal systematic evidence review. We also include several illustrative case studies throughout the document.

Our goal is to present a menu of opportunities and actions that will promote equity, sustainability, biodiversity and human flourishing and inspire individuals, communities, businesses, policymakers, the health sector and governments from around the world towards a new vision of ocean citizenship and planetary stewardship.

1. Ocean opportunities for medicine and biotechnology

The rich biodiversity of the ocean holds enormous opportunities for enhancing human health and wellbeing through providing new medicines and new biotechnologies. Our ability to realise these opportunities is, however, entirely dependent on the health of the ocean.

The biodiversity of the ocean is currently under threat. Unless humanity takes urgent action to protect this biological diversity, more marine species will be lost, the genetic and biological secrets these organisms hold will be gone forever, and their potential benefits for human health and wellbeing will never be realised.

Actions to sustainably, ethically and equitably explore, preserve, and manage marine biodiversity have high potential to yield new medicines and novel biotechnologies to the benefit of human health and wellbeing.

Benefits of marine biodiversity for human health

The ocean is home to an incredible diversity of life. Of the 42 currently recognised biological phyla (major groupings of living organisms), over 80 percent exist only in the ocean (Katona et al. 2023). These species dwell in an astonishing variety of ecosystems. The organisms that live in the ocean have evolved unique chemical, physical and behavioural adaptations that are seen nowhere else on Earth and hold enormous promise for humanity.

Marine organisms have had far more time to adapt to their environment than most terrestrial species, and thus have had more opportunity to acquire unique genetic traits and develop a wide array of metabolic and chemical adaptations (Voser et al. 2022). There is great likelihood that biotechnological remedies for a wide range of problems can be found within the traits expressed by marine organisms (Carroll et al. 2023).

Study of the distinctive features of marine life has already resulted in scientific breakthroughs, new knowledge and a range of useful products that have improved human health and wellbeing (from alternative pain medications to micronutrients that can prevent chronic diseases to super-strong composite materials) (see Rotter et al. 2021 for a comprehensive list). These advances have translated into thousands of new jobs in marine biotechnology, biomedicine and drug discovery. They have generated many millions of dollars per year in revenue; the market for marine-derived pharmaceuticals alone is currently valued at $4.1 billion and is anticipated to reach $9.1 billion by 2033 (Fact.MR 2023). Until now, these advances have primarily benefitted those living in the Global North (in particular multinational corporations), and little benefit has been returned to the low- and middle-income countries (LMICs) where many of these discoveries originated (Blasiak et al. 2018).

If new biotechnology, medical and pharmaceutical products are to continue to come from the ocean and the ocean economy is to continue to grow, we must have the wisdom and the courage to build cross-sectoral, cross-national partnerships that preserve the ocean and prioritise human health and wellbeing. These collaborations will effectively conserve and manage the rich biological diversity of the ocean and ensure the sustainable and equitable use of marine resources by all people and for future generations.

Key opportunities for human health

Medicines from the sea

An estimated 30,000 unique molecules, about 10 percent of all currently known natural products, have been discovered in marine life (including marine bacteria, fungi, fish and invertebrates) (Lindequist 2016). These materials have myriad potential applications in biomedicine and biotechnology. To date, 23 approved pharmaceutical agents have been developed from marine molecules, and an additional 33 are in clinical trials and development (Antunes et al. 2023). They have been used already for treatment of inflammation, immune system disorders, skin pathologies, infectious diseases and cancers (CHEMnetBASE n.d.; Pascual Alonso et al. 2023).

As an example of unique marine molecules, Plitidepsin (a molecule derived from the sea squirt, *Aplidium albicans* (Milne Edwards 1841)) has been used to treat leukaemia and lymphomas. During the COVID pandemic, it was found effective in a limited clinical trial of patients with severe COVID disease (White et al. 2021). Conotoxins (neurotoxins isolated from predatory cone snails) are the basis for the potent pain control medicine Ziconotide® (Safavi-Hemami et al. 2019). Case study 1 describes the successful development of anti-cancer medicines from marine cyanobacteria.

Tetrodotoxin is an example of a biologically active molecule derived from marine microalgae, among other organisms (Chau et al. 2011). A potent neurotoxin at high doses, tetrodotoxin in low doses is under investigation for its pain relief potential as a local anaesthetic agent and for treatment of chemotherapy-induced neuropathic pain and cancer-related pain (Cerone and Smith 2021). It may also reduce withdrawal symptoms from opioid addiction (González-Cano et al. 2021).

In the foreseeable future, we can expect many more new medicines based on marine compounds. The economic potential of these compounds is vast, but only if there is equitable, ethical and sustainable exploration.

Marine green chemistry

Marine organisms hold great promise as a source of new catalysts that can be used in 'green chemistry', which seeks to harness natural catalysts (e.g. enzymes) and their processes to produce the chemical reactions currently performed by conventional 'brown chemistry' (the latter often based on persistent and polluting chemicals derived from fossil carbon).

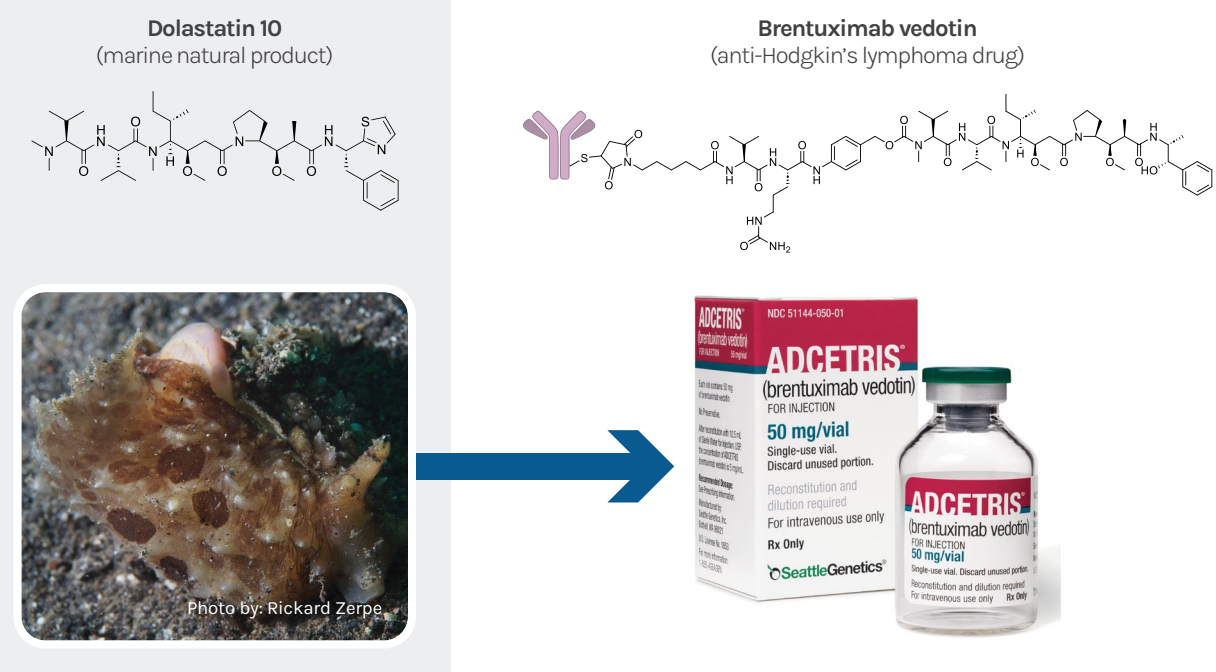
Marine catalysts include the marine cellulases, which break down cellulose (e.g. wood), the most abundant organic compound on the planet. Other marine microbial enzymes have been discovered that may be able to degrade microplastics (although the toxic plastics additives are still a challenge) (Zhai et al. 2023).

These materials are of considerable interest because of their potential to generate green bioproducts with applications in medicine, energy, food chemistry and agriculture (Navvabi et al. 2022).

CASE STUDY 1. **Anti-cancer medicines from marine cyanobacteria**

Cyanobacteria ('blue green algae') are an ancient group of organisms that arose on Earth some 2 billion years ago. Some cyanobacteria are abundant producers of biologically active substances, and some predators of cyanobacteria, such as sea slugs, are able to accumulate these biologically active compounds and use them in their own defence against predators. Several cyanobacterial compounds extracted from sea slugs show great promise for the treatment of diseases such as cancer.

FIGURE CS-1.1. **Structure and origin of dolastatin 10, and of derived drug used to treat cancer**



Source: Authors, Seattle Genetics Inc.

DISCOVERY OF DOLASTATIN 10 AND ITS APPLICATION AS AN ANTI-CANCER MEDICINE

Dolastatin 10 (Figure CS-1.1) is a natural product originally discovered in an Indian Ocean sea slug, *Dolabella auricularia* (Lightfoot 1786), and produced by a marine cyanobacterium (Pettit et al. 1987; Luesch et al. 2001). Dolastatin 10 has extremely potent anti-tumor activity. Very limited availability in nature at first delayed its development as an anti-cancer drug, but synthesis in the laboratory has provided a large supply for continued development.

Currently six different dolastatin 10–antibody drugs are being used to treat various cancers, including lymphomas and carcinomas. A further dozen related drugs are in various stages of clinical evaluation to treat other forms of cancer.

Zero-waste industry

Products such as food supplements, fuels and nanoparticles manufactured using marine resources may generate less waste and less CO_2 than those created through other manufacturing processes (Vijayan et al. 2016; Pessarrodona et al. 2023). For example, marine phytoplankton are rich sources of polyunsaturated fatty acids, especially long-chain omega-3 fatty acids (Cerone and Smith 2021). These nutritionally and economically valuable fatty acids can be harvested sustainably and can be stabilised and distributed with significantly less waste for aquacultural purposes by nanoencapsulation (Hosseini et al. 2021).

Marine microalgae have also been extensively investigated as new sources of specialty lipids, including those that can be used as energy sources (e.g. biofuels) (Maeda et al. 2018).

Biomimicry

Biomimicry is a 'nature-based solution' (NBS) strategy for creating new technologies based on the unique adaptations of organisms. In the context of marine biotechnology, its goal is to create ocean-inspired sustainable design solutions and environmentally friendly products. An example is an extremely strong and durable composite material with potentially multiple uses (e.g. airplanes, cars, medical devices), inspired by the helicoid layers of chitin present in the shell of the mantis shrimp (Figure 2) (Rivera et al. 2020; Xin et al. 2021).

The many uses of seaweeds

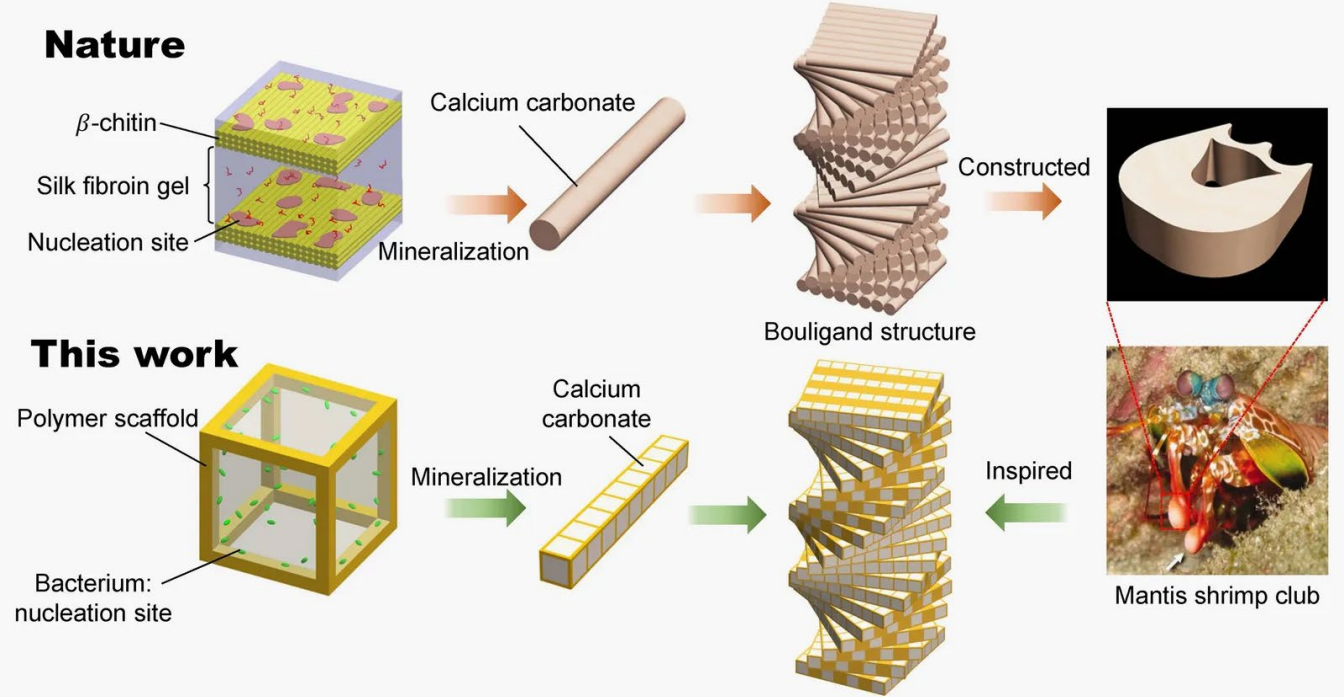
Marine seaweeds present rich opportunities for blue biotechnology. For example, Case study 2 describes the development of seaweeds into bioplastics as potentially sustainable alternatives to fossil fuel–derived plastics currently polluting the ocean (Figure 3).

Farmed seaweeds command a high value for food, cosmetic and medical purposes (Naylor et al. 2021). Marine algae are rich in essential nutrients (carotenoids, vitamins and phenolic antioxidants), and thus may help to mitigate the nutrient-poor diets of many coastal populations; these materials can be produced using socially conscious and environmentally and economically sustainable aquacultural methods, as well as through large-scale industrial production (Wells et al. 2017) (see Section 2). Large-scale seaweed production is a potential source of non-chemical agricultural fertilisers because seaweeds contain metabolites that can enhance crop growth (Nabti et al. 2017). One genus of red seaweed, *Asparagopsis* (Montagne 1840) is being explored as a supplement for dairy and beef cows, as it significantly reduces their methane emissions; methane from ruminant animals is responsible for approximately 15 percent of global anthropogenic greenhouse gas emissions (Roque et al. 2021; Hoegh-Guldberg et al. 2023).

SOCIAL, ECONOMIC AND ENVIRONMENTAL PILLARS OF SUSTAINABILITY

Sustainable development has three equally dependent dimensions— economic, social and environmental. (UNGA 2015)

FIGURE 2. **Structure of an extremely strong and durable composite material inspired by the helicoid layers of chitin present in the shell of the mantis shrimp**



Source: Adapted from Xin et al. (2021).

CASE STUDY 2. **Seaweeds into bioplastics**

Humanity's great and growing dependency on plastics affects not only the health of the ocean but also human health through the release of harmful synthetic chemicals and toxic pollutants at every stage of the plastic life cycle (Landrigan et al. 2023). Over 98 percent of all plastics are currently made from fossil carbon: coal, oil and gas. Global plastic production is increasing exponentially and is on track to double by 2040 and triple by 2060. Declining global demand for fossil fuels is an important driver of increasing plastic production as the fossil fuel industry pivots towards plastic production.

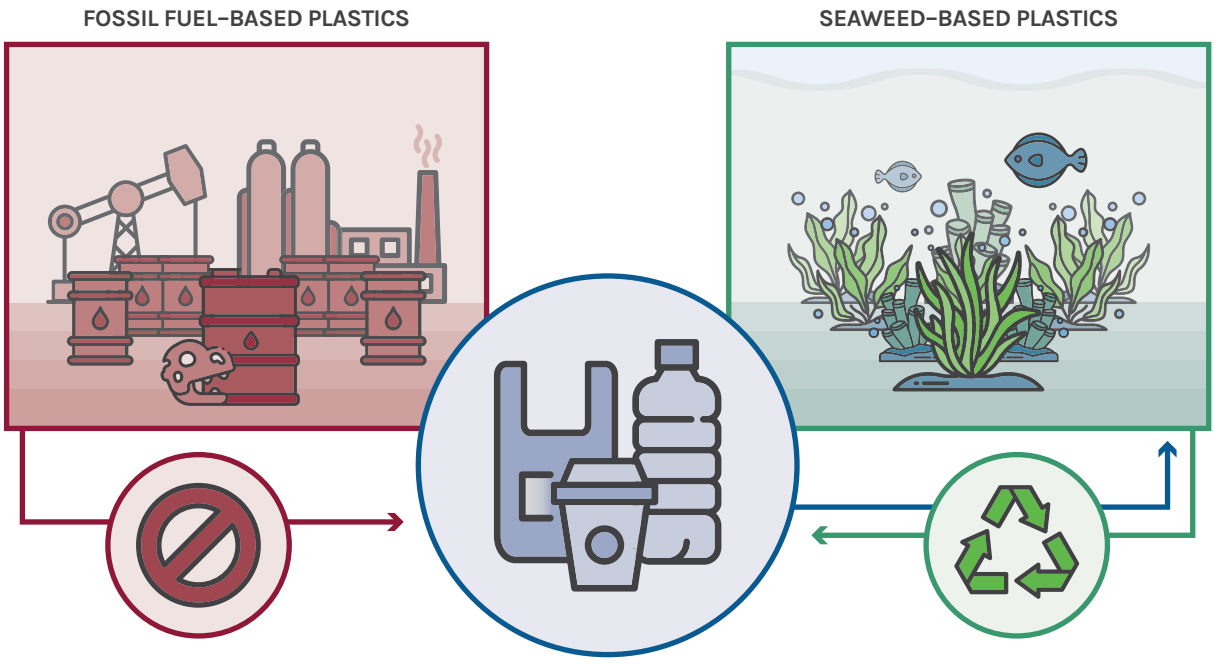
Bioplastics offer a transitional path to plastic reduction. Bioplastics are 'green materials' made with carbon-rich plant or seaweed materials that can be cultivated in a wide range of environments in many coastal regions, from the tropics to the high latitudes. Indonesia is currently a global leader in the seaweed-bioplastics industry with the recent emergence of at least two companies (EVOWARE® and Biopac®).

Bioplastics made from seaweed are potentially safer for ocean and human health than petroleum-based plastics (Figure CS-2.1). The emerging seaweed-bioplastic industry has the potential, if properly managed, to facilitate an ethical transition from harmful to environmentally friendly industrial practices (Lomartire et al. 2022).

Another approach to bioplastic production involving two French companies (ERANOVA® and Algopack®) uses two seaweed species (*Ulva* spp. and *Sargassum* spp.) that are present in huge abundance on coastal shores as a result of anthropogenic harmful practices and climate change. Harvesting them may both help resolve an emergent environmental problem and provide raw materials that replace petroleum-based plastics (Orr 2013; Orr et al. 2014).

It will be important to monitor the toxicity and the environmental fate and persistence of bioplastics to ensure that they fulfil their promise as a safer alternative to petroleum-based plastics.

FIGURE CS-2.1. **Bioplastics from seaweed as an alternative to fossil fuel–based plastics**



Source: Authors.

Limitations to current knowledge and future opportunities

As the ocean changes in response to human stressors and marine species are irretrievably lost, we are rapidly losing opportunities to develop knowledge of its incredible biodiversity. We have a profoundly inaccurate and incomplete understanding of the role that small bioactive compounds play in the ecology of the organisms that produce them, of how their production is controlled, and of how they might benefit humanity (Karthikeyan et al. 2022). We also have little insight into how species will adapt and potentially survive these changing conditions, which species will be lost, and which can be saved.

We have even less information concerning the DNA blueprints underlying the exceptional biodiversity of marine life. For example, only 3,300 of the 1.5 million known animal species on planet Earth, and about 220 of the approximately 27,000 known species of algae, have had the DNA of their genomes fully sequenced (Hanschen and Starkenburg 2020; Hotaling et al. 2021). There is urgent need to undertake periodic biodiversity inventories, conduct detailed biochemical investigations of adaptive traits and initiate studies of accelerated evolution, all ideally through ethical public-private partnerships. Open access to these data is essential to provide equitable, sustainable and creative development and use by all, not ownership and use by the few (Blasiak et al. 2018).

Exploration of the unanswered questions is essential if we are to be good stewards of the natural world and if we are to discover and produce adequate supplies of useful green pharmaceuticals and green chemicals to meet the needs of human society. It is not sufficient to discover new potential medicines from the ocean. We must also devise strategies to provide these medicines equitably and ethically in the amounts needed, using sustainable and cost-effective methodologies.

To ensure that humanity can realise the full benefit from marine genetic resources now and in the future, we must secure sustainable access to this rich diversity of species.

A key challenge to the development of biomedical (and other marine biotechnology) products from marine organisms is the substantial time required for their development; for example, the discovery and characterisation of a potent anti-cancer compound from the Caribbean tunicate, *Ecteinascidia turbinata* (Herdman 1880), took more than 20 years of concentrated study. Since many of the most biodiverse places, such as the Malay Archipelago, are in the Global South, a further key challenge is the equitable, sustainable and ethical co-development of these products with local communities and countries.

FIGURE 3. **Seaweed-based biomaterial used to 3D print an inhaler prototype**

Source: SymbioTex n.d., with permission.

Cataloguing biodiversity and measuring biodiversity loss for adaptive and sustainable management of MPAs

Climate and other environmental change threatens the biodiversity of all life in the sea, including in biodiverse-rich areas such as many MPAs, and other

areas designated as protected (Bruno et al. 2018). To ensure the effectiveness of current and future MPAs, their biodiversity must be fully characterised and high-quality monitoring data collected across both space and time (Bates et al. 2019). Adaptation strategies need to be incorporated into MPA design and management plans (including working with local communities and incorporating other effective conservation measures, or OECMs) (Gurney et al. 2021) in all ecosystems and habitat types (Wilson et al. 2020), including areas beyond national jurisdiction (Maestro et al. 2019).

Medicine discovery

Because the success rate of medicine discovery from marine life is up to four times higher than that of natural product discovery from other sources (Sigwart et al. 2021), research into the pharmaceutical properties of natural products, including medicines, from marine organisms should be intensified.

Green chemistry and zero-waste approaches

'Green chemistry' is nascent in its development. Bringing it to scale in industry will require investigation into the chemical processes of marine life and their ability to make bioactive compounds using enzymes.

Biorefineries utilise biomass conversion processes to produce value-added chemicals from side-stream biomass (i.e. not the main product) (Rotter et al. 2021). For instance, unused oyster shells from aquaculture facilities can be used to make building materials and biomedical scaffolds (Gheysari et al. 2019). They can also be ground up and reinjected locally into the ocean, at a small scale, to stabilise pH in aquaculture (Chilakala et al. 2019).

Transdisciplinary research and fair, sustainable development of blue biotechnologies

The innovation potential of marine resources is vast, but the realisation of this potential will require transdisciplinary international research, ranging from discovery in marine ecosystems to laboratory and industrial development to clinical and other applications (Schneider et al. 2022). To ensure that marine resources are not exploited in ways that endanger fragile ecosystems or deprive local communities and lower-income countries of resources, research in the social sciences and ethics and communication efforts to engage and involve the general public will be needed (Rotter et al. 2021).

Actions and opportunities

The challenges above can be addressed through the following five actions and opportunities.

Create governance policies to ensure sustainable use of and equitable access to ocean resources. Sustainable use of marine genetic resources in blue biotechnology will require governance policies tailored to the intricate social-ecological systems that surround the ocean. These policies must comply with ethical inter- and transdisciplinary scientific approaches, such as responsible research and innovation, and seek explicitly to protect human health and wellbeing.

Undiscovered marine genetic resources must be developed in ways that ensure fair access and equitable benefit, whether they are located in exclusive economic zones or in areas beyond national jurisdiction, consistent with the UN Agreement under the UN Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction. These resources should not be concentrated in the hands of a small group of global corporations or nations (Blasiak et al. 2020). New collaborative policies will be needed that facilitate equitable access of LMICs to expensive equipment (e.g. research vessels), marine collections of various types, open-access scientific data (e.g. databases) and expertise.

Create and support digital DNA libraries containing the genetic blueprints for most marine life. Several national and international collaborative projects are undertaking the enormous task of developing digital knowledge of the underlying genetic blueprint for all life on the planet. As noted by the Earth BioGenome Project (n.d.), the compelling rationale for these endeavours is 'to revolutionise our understanding of biology and evolution; to conserve, protect and restore biodiversity; [and] to create new benefits for society and human welfare.'

These coordinated and collective global efforts, such as the Earth BioGenome Project (n.d.), the International Barcode of Life Consortium (n.d.) and the Darwin Tree of Life Project (n.d.), need stable international funding by a consortium of nation-states. It is conceivable that the DNA blueprints saved by these projects could even be used to 'resurrect' species that go extinct.

Support ethical startup companies making equitable and sustainable marine-based biotechnology products. To move ocean-inspired discoveries from the beach and the lab bench to the marketplace requires transdisciplinary expertise and significant capital. Government incentives and programmes are needed to support and encourage the funding of marine biotechnology start-up companies and other coordinated collective efforts that embrace ethical, equitable and sustainability policies. The amounts of these investments will be dwarfed by the societal and economic benefits procured: long-term growth potential, job creation and valuation of marine species and the environment.

Improve funding for equitable and sustainable marine medicine discovery research that connects biodiverse low-income countries with wealthy ones. Much marine life remains unstudied for its potential to yield valuable resources, especially in regions where scientific infrastructure is not well developed. Equitable and ethical international research partnerships should connect biodiversity-rich regions with those having high scientific capacity, promote scientific training, build capacity, follow good stewardship practices and abide by international standards recognising the inherent rights of all countries and all their people to their genetic resources. These should receive broad financial support. Such investments have the potential to advance both the scientific development in LMICs and the attainment of the UN SDGs.

Prioritise development of marine-based processes and products that are socially relevant, economically sustainable and environmentally friendly. Assessment of the published literature by expert bodies can identify promising processes and products (e.g. new antibiotics). Impacts of such products must be considered in a balanced way, taking into full account policies, needs and negative results and unintended consequences.

2. Ocean opportunities for building and sustaining food security

Fish and other aquatic foods feed more than 3 billion people—nearly 40 percent of the world's population (FAO 2022). Properly managed, the ocean could produce enough food to nourish all of humanity (Golden et al. 2021b; FAO et al. 2022; Tigchelaar et al. 2022).

The production of food from the sea is a major source of employment and income. Wild fisheries, aquaculture operations and the fishery supply chain support the work of more than 500 million people worldwide, most engaged in small-scale fisheries in LMICs (Golden et al. 2021b; FAO et al. 2022; Tigchelaar et al. 2022). They provide livelihood and food security for coastal communities worldwide, particularly marginalised and Indigenous populations (Golden et al. 2021b; FAO et al. 2022; Tigchelaar et al. 2022).

Current challenges to the health of the ocean threaten food security and increase the risk of malnutrition. These challenges include climate change, pollution, loss of marine biodiversity, improper ocean governance, ineffective fisheries management, poverty and the inequitable distribution of seafood (Winther et al. 2020; Nash et al. 2022; FAO et al. 2022; Maycock et al. 2023).

It is essential that we recognise the magnitude and severity of these threats and develop just and equitable solutions that safeguard human health and wellbeing through protecting and preserving the nutritional resources of the sea.

The ocean, food security and human health

The ocean is essential to global food security and thus to human health. Fish and other seafood currently provide vital nutrients for 40 percent of the world's population, and overall global per capita consumption of seafood is on the rise (FAO et al. 2022; Maycock et al. 2023). Rising incomes, urbanisation, increasing recognition of the health benefits of seafood consumption, population growth and improvements in post-harvest technologies are projected to increase global demand for seafood by another 15 percent in the next decade (FAO et al. 2022; Maycock et al. 2023). This growing demand creates enormous opportunities for the development of sustainable new foods from the ocean and underscores the importance of sustainable and effective management of existing fish stocks.

Fish and other foods from the ocean are key sources of protein and thus critical to the prevention of protein-calorie malnutrition. Malnutrition is increasing globally, after declining for many decades. An estimated 828 million people now suffer from hunger, and more than 3.1 billion people cannot afford a healthy diet (FAO et al. 2023).

Fish and other foods from the ocean are key sources of micronutrients such as iron; zinc; vitamins A, B12 and D; as well as long-chain omega-3 fatty acids. They are thus critical to the prevention of micronutrient deficiency (Hicks et al. 2019; Mellin et al. 2022). Micronutrients benefit growth and neurodevelopment in infancy and childhood (Byrd et al. 2022), and they contribute to the prevention of cancer and cardiovascular disease in people of all ages (FAO and WHO 2011) (Figure 4). Although less obvious than protein-

calorie malnutrition, micronutrient deficiencies compromise immune systems, hinder child growth and development, increase the risk of infectious and non-communicable diseases, and reduce human potential worldwide (Stevens et al. 2022).

Fish and other foods from the ocean can provide nutrition in emergency situations and in places where diets are predominantly plant-based and lacking in key micronutrients (Beal et al. 2017; Robinson et al. 2022). Dietary intake of seafood as a source of nourishment is especially valuable given that increased concentrations of atmospheric carbon dioxide appear to reduce levels of protein, zinc and iron in staple food crops (Myers et al. 2014). Seafood products are key ingredients in emergency supplementary and ready-to-use therapeutic food (RUTF) programmes (Borg et al. 2018; Borg et al. 2019), as well as in school feeding programmes (Ahern et al. 2021), where they play a critical role in preventing micronutrient deficiency and its health consequences (Stevens et al. 2022).

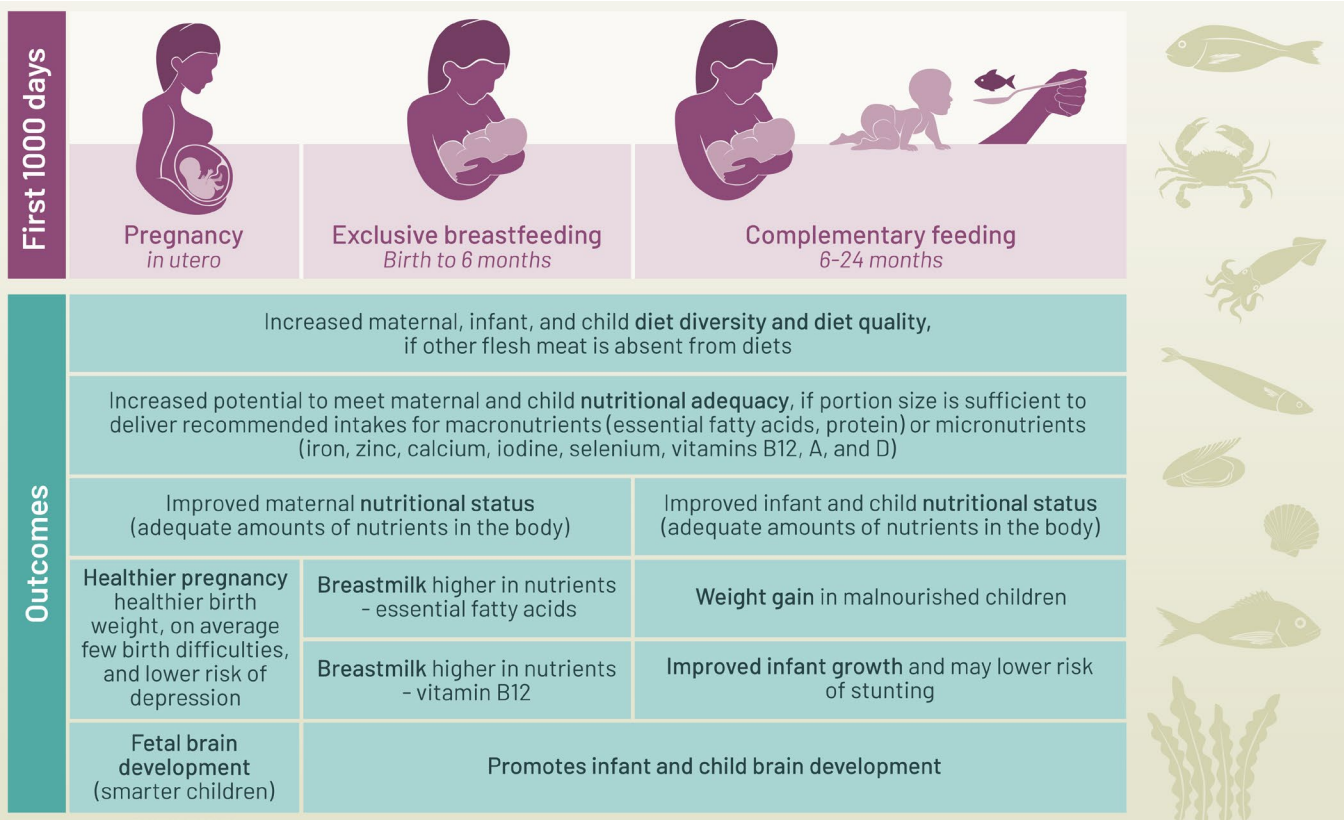
Efforts to scale up the use of local aquatic foods in feeding programmes can address immediate nutritional needs, offer long-lasting coping strategies and generate local income (SDGs 1–3). These programmes are most effective when the food is procured locally and people are taught about the benefits of using it and shown how to prepare it (see Case study 3) (Jomaa et al. 2011).

Key risks to ocean food security

Climate change

Climate change is one of the most significant and pervasive pressures on both ocean environments and coastal communities, and the impacts of climate change are expected to become more severe in coming decades (Hughes et al. 2018). Climate change has already altered fish species distributions and productivity, and further declines are expected globally in wild and aquaculture production and in

FIGURE 4. **Nutrition and health outcomes from eating fish and other aquatic foods in the first 1,000 days of life**



Source: Adapted with permission from Byrd et al. 2022.

CASE STUDY 3. **Inclusion of small fish powder in the meals of children in Anganwadis and primary schools in Assam, India**

In September 2023 the Assam state government initiated a feeding programme, Matsya Paripushti (Complete Nourishment through Fish), that includes the addition of small fish powder to the midday meals of 4,000 children aged 3–6 years attending rural healthcare centres and children aged 6–10 years in lower primary schools in Kamrup district. The goal is to improve the nutrition and health of children by improving dietary diversity and increasing the intake of micronutrients, essential fatty acids and protein.

Small fish powder is added to a mixed dish of dhal (lentils), vegetables and rice or dhal and vegetables, served with boiled rice, three days per week, so that each child gets seven to eight grams of small fish powder per meal. The intention is to increase this amount with time. Small fish species are caught by local fishermen or members of farmer interest groups (FIGs) and solar-dried.

The dried small fish are ground into a powder, packed and delivered to the institutions twice per month. Protocols for handling and food safety have been developed and are being followed. Workers, schoolteachers, members of FIGs and parents and caregivers receive nutrition messaging. Following the normal procedure in Assam, the weight of all children under five years of age and body mass index in older children are being monitored and will be used to compare children consuming small fish powder with those who are not.

This programme is linked to the Assam Agribusiness and Rural Transformation Project, which promotes the production of mola and other small fish species in polyculture with carp species in homestead ponds, and is funded by the World Bank, to the Assam state government, and with technical support from WorldFish. It builds on successful trials carried out in the state of Odisha from 2017 to 2021.

the availability of seafood-associated macro- and micronutrients (Hoegh-Guldberg and Bruno 2010; Lam et al. 2020; Maulu et al. 2021).

Climate change's impacts on ocean health are expected to escalate in coming decades, even as international efforts to reduce greenhouse gas emissions move forward. These worsening impacts will further jeopardise the contributions that aquatic food production systems can make to nutrition (Cheung et al. 2023). For example, under a climate scenario in which maximal warming is held below 2.0°C, 10 percent declines in key micronutrients from fisheries are expected. By contrast, under a 'business-as-usual' scenario in which there is global warming of 4–5°C by 2100, a 30 percent decline in fisheries production is estimated (Cheung et al. 2023). Meeting the targets of the Paris Climate Agreement is critical to limiting marine-based nutritional losses, and yet the world is not currently on track to meet these targets (IPCC 2023).

The negative impacts of climate change on nutrition are not distributed equally. Many areas of the world are ill-equipped to adapt to the losses of nutrients from fisheries. This is particularly true in the tropics, already the region most vulnerable to climate change (Allison et al. 2009; Golden et al. 2016; Lam et al. 2020). For example, under a high-emission scenario in which a 30 percent decline in nutrients from fisheries is expected globally, temperate regions will experience only minimal losses, while losses in the tropics will approach 60 percent (Cheung et al. 2023). In addition, temperature increases are expected to harm fishers' ability to work and draw quality fish and other aquatic foods into supply chains (Fiorella et al. 2021).

Pollution

Ocean pollutants come from a variety of sources, with more than 80 percent arising on land. The threat they present to food security is still of uncertain magnitude but appears to be great and growing. Coastal communities dependent on seafood for their nutrition and livelihoods are at heightened risk of pollution exposure and adverse health effects.

Marine pollutants, including heavy metal contaminants (e.g. mercury), microplastics and antibiotics that are known to cause mortality in fish (Wear et al. 2024) and habitat degradation (Bryars and Neverauskas 2004) make their way into foods produced for human consumption and directly threaten human health (Landrigan et al. 2020; Thiele et al. 2021). Plastic pollution is a great and growing problem (Landrigan et al. 2023). Plastic pollution from fishing activities such as lost and abandoned fishing gear, which directly enters the ocean, is a particular problem for marine life and ocean habitats.

Treated and untreated wastewater from sewage, agricultural runoff and industrial discharge is released into coastal waters, resulting in microbial pollution and harmful algal blooms along the world's coastlines.

The impacts of pollution on marine life are further magnified through the overuse and destruction of coastal ecosystems, particularly mangroves and seagrass beds that provide 'sanitation services' for microbial pollution and protect the ocean food supply through their natural bioremediation of waste (Armitage 2022). Coastal pollution causes a range of disease that results in over $200 billion a year in healthcare costs and lost productivity (Wenger et al. 2023).

Overfishing and wasteful fishing practices

Overfishing depletes fish breeding populations and can result in the crashing of fish stocks. Over-exploitation of wild marine organisms has been exacerbated by fishing practices such as dredging and bottom trawling, which destroy some seabed habitats (Clark et al. 2016; Collie et al. 2017; Pitcher et al. 2022), and illegal, unreported and unregulated (IUU) fishing (Widjaja et al. 2021). Overfishing has contributed to dramatic declines in fish populations globally (Myers and Worm 2003) and already to some local species extinctions (Roberts 2007).

With the spread of distant-water fishing, the commercial fishing industry can threaten stocks of vulnerable seafood in insecure economies in the Global South, many of which have limited capacity to manage their own marine resources (Shen and Huang 2020). Investments in such sectors as infrastructure (Laurance 2018), globalised trade (Lenzen et al. 2012) and distant-water fishing (Sumaila et al. 2019) follow complex international routes and drive rapid ecosystem decline in areas far removed from the sources of finance.

By 2019, annual fishing subsidy payments by governments totalled $35.4 billion globally (Sumaila et al. 2019). Researchers estimate that two-thirds of this total flows into already wealthy industrial fleets, exacerbating overfishing (Sumaila et al. 2019). Historically, fishery subsidies from developed and large developing countries have helped the commercial fishing industry to deplete fish stocks with impunity (WTO 2022). The recent World Trade Organization agreement on fisheries subsidies (WTO 2022) may help to combat this and is explored in greater detail below.

Illegal, unregulated and unreported fishing

Much fishing activity remains unregulated, and many fish landings remain unreported, particularly across the tropics, where fisheries are often small-scale and informal, and where coastal communities are most highly dependent on fisheries for their livelihoods and food security (Song et al. 2020; FAO 2022). Adding to this complexity is a rise in illegal fishing by national and distant-water industrial fleets.

Illegal fishing can take the form of fishing without a license, dumping of low-grade fish or harvesting of fish from closed areas. Illegal fishing is estimated to cost low- and middle-income nations between $2 billion and $15 billion annually (Liddick 2014). Illegal fishing is often associated with other criminal activities, including smuggling, human rights abuses and slavery at sea (Kittinger et al. 2017; Belhabib and Le Billon 2022).

Illegal fishing is often categorised together with unregulated and unreported fishing (IUU). However, the term and approaches used to combat IUU may inadvertently criminalise small-scale fishing, exacerbating inequalities between countries and sectors, and undermining successful customary governance arrangements, including marine tenure arrangements developed, in some cases, over hundreds of years (Song et al. 2020).

Globalisation

The ability to exploit fisheries around the world is a facet of globalisation that affects nutrition and food security. Seafood resources cross multiple regional and regulatory bodies and are traded globally. In

ILLEGAL, UNREPORTED AND UNREGULATED (IUU) FISHING

A broad term that includes the use of bonded labour, destructive fishing practices and deceptive practices to reap profits at the expense of local fisheries, coastal states and the marine environment. IUU fishing threatens the sustainability of global fisheries in national coastal waters and on the high seas. (Widjaja et al. 2021)

fact, seafood is currently the most heavily traded food commodity in the world (Gephart et al. 2023). Although 3 billion people, mostly in low- and middle-income coastal economies, rely on the ocean for food and income, global seafood production and revenue are controlled by a small number of companies that influence global governance (Österblom et al. 2015), highlighting the inherent inequities in the globalised seafood system.

These corporations are structured to respond primarily to global drivers, an approach that can contrast sharply with the needs of the countries where they operate and that can lead to human rights abuses in supply chains (Yea and Stringer 2021). This makes globalised commerce a major driver of inequity and of wide-scale declines in biodiversity (Carmenta et al. 2023).

Sector-specific bodies such as the Global Tuna Alliance and cross-sector collaborations between the global seafood industry and academic experts, such as SeaBOS (n.d.), offer positive models for sustainable transformation within the seafood sector.

Lack of transparency

Lack of transparency across supply chains (e.g. lack of information on the geographic origin and species of seafood products) further compounds inequity by driving overfishing and illegal fishing, and undermining global commitments to halt biodiversity decline. It presents a major obstacle to supporting food security (dos Reis et al. 2020). Both fishery governance and the finance that shapes access to fish need to be viewed as global issues and managed accordingly.

Opportunities for improving food security and human and ocean health

Strengthening marine tenure

For many people in many places, health and wellbeing depend on the security of their rights to the ocean.

Traditional and contemporary 'marine tenure' regimes, which societies (and in some cases, the law) use to define and regulate people's relationship and rights associated with the ocean, coasts, shores, other aquatic spaces and associated resources, can provide a mechanism to protect health and wellbeing and buffer populations against food insecurity. These regimes can enhance food security and reduce illegal fishing. Intact and respected tenure regimes allow groups to determine who is allowed to use which resources, in what way, for how long and under what conditions. Bundled together with rights are responsibilities for and relationships around the ocean and coasts: secure tenure provides communities with the incentive and agency to responsibly govern and manage areas and resources (USAID 2017).

Marine tenure regimes are frequently informal and/or overlooked and disregarded by top-down institutional change (even those who aspire to conserve the ocean or respond to climate change). These processes of the erosion of tenure undermine the opportunity for local governance and threaten human health and wellbeing as well as local food security (Cohen and Foale 2013; Lau et al. 2019).

Aquaculture

As wild fishery production stabilised in the 1990s, in a time of growing global demand for seafood, aquaculture production began to expand, a trend that continues to the present (FAO 2022). Global aquaculture production tripled from 34 million tonnes (Mt) in 1997 to 112 Mt in 2017 (Naylor et al. 2021).

Preliminary data indicate that aquaculture accounted for 56 percent of global seafood production in 2020; both farming of marine species (aka mariculture) and aquaculture of freshwater species have contributed to this growth (FAO 2022). However,

mariculture production is currently only a fraction of aquaculture production (about 30 percent by weight) (Costello et al. 2020; Naylor et al. 2021; FAO 2022).

Aquaculture, including mariculture, can be an important source of income in many areas, including low- and middle-income countries, contributing to the health and wellbeing, and boosting the economy, of coastal communities. Fish aquaculture is becoming an ever-more sophisticated industry, as well as an important global source of protein-rich food.

Aquaculture value chains are, however, marred by social and economic inequalities. Care must therefore be taken that aquaculture is undertaken sustainably and ethically, and considers impacts on broader ecosystems as well on human health and wellbeing (Bottema et al. 2021). Poor management practices, exploitative labour practices and poorly planned aquaculture intensification and expansion can negatively impact ecosystems (de Graaf and Xuan 1998). Equitable expansion of mariculture may benefit from association with global certification schemes that promote transparency compliance with labour rights, human rights and gender equity (Human Rights at Sea 2023). Lessons can be learned from past mistakes, as well as from Indigenous and traditional coastal communities.

Aquaculture operations must also be cognisant of climate-related risks, such as increasing temperatures and unpredictable weather (Oyinlola et al. 2018; Galappaththi et al. 2020; IPCC 2023). Climate and economic constraints suggest that mariculture growth, in particular, is unlikely to continue at the same rate in the future as it has in the past two decades (Oyinlola et al. 2018; Belton et al. 2020; Cheung et al. 2023).

Promoting consumption of molluscs and seaweed

Seaweed and molluscs have multiple advantages as food sources. They are some of the most sustainable and nutritious aquatic foods, they are commonly accessible to women and are amenable to both wild harvesting and low-input cultivation (Lau and Scales 2016; Gephart and Golden 2022). As noted in Section 1, these species contain high levels of key micronutrients commonly lacking in diets around the world (Golden et al. 2021b; Zamborain-Mason et al. 2023).

In their wild form, both seaweed and molluscs can be harvested with a small environmental footprint because they tend to be found close to shore, and therefore do not require fuel, feed or land (Gephart et al. 2021), in contrast to fed aquaculture like shrimp (Kauffman et al. 2017). Small-scale cultivation of these species has the additional benefit of being traditionally accessible to women, creating a direct link between these strategies and improved food and nutritional security (Lau and Scales 2016). They can also be part of important local ecosystem restoration activities, including MPAs and OECMs, and thus positive for both ocean and human health (Bayraktarov et al. 2016; Northrop et al. 2020).

Aquaculture of local species (e.g. molluscs and seaweed) is a strategy for avoiding over-harvesting in marine fisheries, while providing food from the ocean. Governmental support for mariculture, such as by facilitating new cultivation sites (Lake and Utting 2007), could be linked with educational campaigns that extol the nutritional and climate benefits of seaweed and molluscs and offer new recipes for dishes from these products. The goal is to help consumers understand that these are sustainable choices.

A further caveat is that currently seaweed and mollusc production do not necessarily provide good jobs. Despite the importance of seaweed and mollusc production as a source of food security, nutrition and livelihoods, the small-scale sector is consistently undervalued and overlooked in planning and development policies. Governmental intervention to support labour rights in mariculture operations will be essential.

Encouraging sustainable seafood consumption

Shifting meat-centric diets towards less resource-intensive foods that emphasise sustainable and nutritious seafood (e.g. cultivated molluscs), vegetables, fruits and legumes can help meet global climate goals and contribute to a sustainable food future (Hilborn et al. 2018; Searchinger et al. 2019; Crona et al. 2023; Hoegh-Guldberg et al. 2023). This increasing global demand for seafood must address sustainability, equity, resource allocation and the importance of food sovereignty for coastal communities, particularly in the Global South.

Reducing seafood loss and waste

One-third of ocean food is lost or wasted through value chains (FAO 2022). Waste reduction through full use of the marine catch, including bycatch, can increase fisheries' sustainability and food security (Ajayi et al. 2023; UN 2023b). Supporting safe and clean conditions for fish processors and traders (particularly small-scale supply chain actors, who may experience poor conditions) can help reduce waste, increase food quantity and quality, and raise incomes (Nwazuo et al. 2016).

Global governance and multilateral institutions

The world's multilateral organisations, including the World Health Organization (WHO), the UN Food and Agriculture Organization (FAO) and the World Trade Organization (WTO), recognise that accelerating climate change, worsening pollution and wide-scale biodiversity loss pose major challenges to human health and wellbeing, societal sustainability and ocean health. These changes threaten both planetary health and economic development, and they have stymied global efforts to make any progress towards the Sustainable Development Goal of achieving zero hunger (SDG 2) (UN 2023b). Multilateral transboundary organisations and agreements are therefore taking steps to reform management of marine resources globally, including working with local communities and incorporating OECMs that provide effective protection (Gurney et al. 2021).

Reducing fishing subsidies

A very important reform was achieved when member states of the World Trade Organization agreed in 2022 to prohibit some fishing subsidies (Briley 2023). The WTO (2022) acknowledged that the $20 billion in annual fishery subsidies by national governments encourages and supports overfishing, particularly by more economically developed countries, and results in resource depletion, especially in less economically developed countries, with impacts on food security and hence health (Sumaila et al. 2019). This was only the second agreement on fishery subsidies ever reached by the WTO, requiring more than 20 years of negotiation, and thus highlighting the great difficulty in reaching consensus in multilateral forums (Johnson et al. 2023; Okonjo-Iweala 2023).

Regulating trade and assuring equitable finance to enhance food security

Recent successes have been achieved in brokering other international agreements in fisheries, such as the Agreement on Port State Measures and the High Seas Treaty (FAO n.d.; Stokstad 2023). There has also been movement towards reforming global financial and trading systems to provide more equitable access to marine resources (Villars Framework 2023). With these agreements successfully in place and effectively enforced, sustainability and equity can be advanced, and countries, especially those in the Global South, can meet both their developmental and climate targets (Persaud 2023; Villars Framework 2023) (see Case study 4).

Examples of reform of multilateral banks and international financial institutions include initiatives such as the New Global Financial Pact and the Bridgetown Initiative's proposal of a large-scale stimulus package to invest in the Sustainable Development Goals, an effort which could bring more equitable access to affordable capital (UN 2023c). If properly implemented, these initiatives could unleash previously inaccessible investment and technologies into areas that are key to supporting food security and creating resilient economies in low- and middle-income countries.

Multilateral rules, including those put forth by the WTO, can promote equitable and fair outcomes in food security by

- redirecting finance towards investment in technologies that support sustainable production practices and efforts designed to meet global climate targets (Villars Framework 2023; Cheung et al. 2023);
- slowing the removal of highly nutritious aquatic foods from nations with high prevalence of malnutrition and micronutrient deficiencies so that there is sufficient high-quality seafood to prevent malnutrition in low- and middle-income countries (Nash et al. 2022); and
- ensuring that trade works for low-income nations, through debt relief and through aligning trade with domestic food security policy (Villars Framework 2023) (see Case study 4).

CASE STUDY 4. **Remaking trade rules for a sustainable ocean economy**

The Remaking Global Trade for a Sustainable Future project seeks to re-gear the trade system to be more sustainable, inclusive and just (Villars Framework 2023). The project has identified tangible ways through which a reformed trade system can promote a more resilient and sustainable ocean economy that will enable all nations to support their development and finance needs.

NEW TRADE RULES TO REDUCE FISHERY SUBSIDIES

The new World Trade Organization (WTO) Fisheries Subsidies Agreement, negotiated at the 12th Ministerial Conference, focuses on eliminating only some (i.e. IUU) fishery subsidies, while overlooking the most harmful subsidies relating to overfishing. A new approach to subsidies regulation proposed at the WTO, the Villars Framework, which is consistent with but additional to the Fisheries Subsidies Agreement, would prohibit 'harmful' subsidies that do not promote sustainable outcomes while encouraging 'helpful' subsidies that promote sustainability. Such a new analytical framework combines the traditional WTO focus on the degree of trade distortion with a new focus on sustainability (Figure CS-4.1).

Under the Villars Framework, funds from harmful subsidies would be repurposed and allocated to a Global Trade Sustainability Fund. This fund would assist low- and middle-income countries in complying with obligations imposed by the new Fisheries Agreement, support domestic food security and cover other costs of transition (Villars Framework 2023).

FIGURE CS-4.1. **Sustainable and trade-distorting subsidies matrix**

	More positive sustainability impact	More negative sustainability impact
Less trade distortion	Allowed	Rebuttable presumption of inconsistency with WTO law
More trade distortion	Rebuttable presumption of consistency with WTO law	Prohibited—obligation to end immediately/countervailable

Source: Cima and Esty n.d.

If these multilateral transboundary agreements are effectively enforced, sustainability and equity can be advanced. Countries, especially those in the Global South, will be able to develop sustainably, feed their populations and achieve climate targets (Persaud 2023; Villars Framework 2023).

International conventions on human rights

A human rights–based approach to the sustainable management of marine resources such as fisheries and aquaculture could do much to protect people's access to sufficient and healthy food. Several core human rights treaties (including a treaty on the right to food: Article 11 of the International Covenant on Economic, Social and Cultural Rights) and numerous treaties on the rights of workers (the same covenant's Article 6) have been ratified by most countries but are routinely violated.

Upholding these rights in ocean spaces would eliminate the most egregious disparities by income, race, education and gender that affect access to food security and nutrition (HLPE 2023). Three strategies for upholding the rights enshrined in these treaties would require international organisations, governments and the private sector to

- understand and bolster marine tenure, discussed above (Cohen et al. forthcoming);
- recognise, protect and provide support for ocean defenders and Indigenous communities (Bennett et al. 2022); and
- legislate do-no-harm principles to guide international investments by transnational corporations involved in aquatic food production.

International, multi-stakeholder protocols to monitor corporations

By passing additional laws that build on successful human rights–based certification schemes, such as the Global Seafood Alliance Responsible Fishing Vessel Standard (Global Seafood Alliance 2022; Human Rights at Sea 2023), and applying these principles to actors invested in marine food production, governments could make it incumbent on transnational companies and others to provide evidence that they are not promoting labour abuse and undermining local food security in their fishing practices.

Such an approach could be modelled on the Kimberley Process (Howard 2015), an international certification programme designed to increase transparency and oversight in the diamond supply chain and eliminate trade in conflict diamonds. Such measures would have the additional benefit of contributing to the long-term conservation and sustainable use of marine resources and marine ecosystems.

Another example is the FAO (n.d.) Agreement on Port State Measures. This international treaty, which went into force in 2016, seeks to prevent, deter and eliminate IUU fishing. It is operationalised at the country level through national regulations that prevent foreign flag vessels engaged in IUU fishing from using ports and landing their catches. Through this mechanism, the Agreement on Port State Measures blocks foreign fishery products derived from IUU fishing from reaching national and international markets.

Improving fishery management

With nutrient composition data now widely available, examples of successful approaches to fisheries management (e.g. Cohen and Foale 2013; Hilborn et al. 2020; McClanahan 2021) can be identified and adapted to support a sustainable increase in the production of fish. For example, intensively managed fisheries across temperate latitudes that have already proved effective at rebuilding stocks and regulating sustainable fishing (Hilborn et al. 2020) could be adapted in other locales to maximise specific nutrients. Nutrient yield curves could be used to estimate the point (maximum nutrient yield) at which fishing for a specific nutrient is maximised, based on the relative contribution of nutritious species to total catch and their vulnerability to fishing (Robinson et al. 2022).

Elsewhere, species could be identified that are both resilient to the impacts of climate change and overfishing and rich in target nutrients such that they can help close population-level nutrient gaps (Mellin et al. 2022; Robinson et al. 2022). For example, small pelagic fish (e.g. *Sardina pilchardus, Sardinella aurita, Sardinella madarensis*) are both rich in nutrients lacking in some diets and have life-history characteristics enabling them to sustain higher levels of exploitation than other marine species (Golden et al. 2021a; Golden et al. 2021b; Robinson et al. 2022).

Nutrition-sensitive approaches to sustainable fishery management could help maximise the contribution of wild-caught fish to global food and nutrition security (SDGs 2, 3 and 14), particularly in countries where alternate sources of animal proteins are not accessible, if attention is given to identifying marginalised groups and supporting equity (Case study 5) (Grantham et al. 2022; Tilley et al. 2021; Allegretti and Hicks 2023).

Actions and opportunities

The ocean can produce enough food to feed all of humanity and contribute to ending food insecurity, but multiple challenges impede realisation of this potential. These challenges can be addressed through the following actions and opportunities.

Recognise and protect access to the health and wellbeing benefits the ocean provides to all of society. Sustainable use and management of marine food resources will require governance policies that are based on equity, protection of environmental health, human health and wellbeing for all people, and respect for traditional marine tenure regimes**.** This includes increasing the level of operationalised commitment to existing health, ocean and human rights instruments, particularly as new ocean opportunities are explored and pursued.

Support marine tenure for local communities and Indigenous Peoples. Marine tenure regimes of coastal communities and Indigenous Peoples

CASE STUDY 5. Nutrition-sensitive fisheries: An inclusive, nutrition-sensitive approach to fisheries management in Timor-Leste

Timor-Leste is a small island developing state (SIDS; also known as a 'large ocean state') in the Asia-Pacific region. Acute food insecurity, chronic malnutrition and low dietary diversity are widespread, and half of children under age five are chronically malnourished (Grantham et al. 2022). Fishing is the primary occupation in many coastal communities, and women are as involved in fishing as men (Tilley et al. 2021) (Figure CS-5.1). Yet per capita seafood consumption in Timor-Leste is far below that in other island nations, highlighting the potential for seafood to close significant dietary gaps.

PRINCIPLES FOR NUTRITION-SENSITIVE FISHERIES

A nutrition-sensitive approach to fisheries management should embed fisheries policy in the broader food and social security system; recognise multiple forms of knowledge, identities and vulnerabilities; and be oriented towards local needs (Allegretti and Hicks 2023).

Since 2013, WorldFish has been working in Timor-Leste to pilot a nutrition-sensitive approach to fisheries, under 11 core principles. These include the creation of nutrition and equity indicators and objectives and the co-design and coordination of policy and management systems across other sectors (health, environment, water, sanitation, education).

In conjunction with support for traditional fisheries management, this programme has now identified barriers to increased fish consumption among vulnerable groups. In response, it has developed new products that extend shelf life, extended supply chains inland to reach vulnerable populations and shared tips on preparing fish for children with 50 percent of households in Timor-Leste.

FIGURE CS-5.1. **Husband and wife team prepare their nets for a fishing trip, Adara village, Timor-Leste**

Photo credit: ©Dave Mills, 2016.

ensure that cultural, livelihood and stewardship benefits continue, and can provide a mechanism to buffer populations against marine food insecurity. They need to be understood, bolstered and, when necessary, codified into law.

Uphold human rights. Human rights–based strategies can decrease the most egregious disparities in food security and nutrition related to income, race, education and gender. They include supporting marine tenure; protecting labour rights at sea, in mariculture and in seafood processing (Selig et al. 2022); recognising, protecting and supporting the heroic women and men who defend them, often unrecognised, unsung 'ocean defenders'; and legislating principles of do-no-harm to guide international investments and transnational corporations involved in aquatic food production practices.

Reform global finance and trade. Build on recent multilateral successes (e.g. the new UN High Seas Treaty and the WTO agreement) to phase out harmful fisheries subsidies. These efforts should redirect finance to support investment in technologies that support sustainable production practices and efforts to meet global climate targets; slow the removal of nutritious aquatic foods from nations with a high prevalence of deficiencies; and ensure that trade works for low-income nations, through debt relief and aligning trade with domestic food security policy. These efforts could target other subsidies that lead to overfishing and overcapacity but remain in place.

Support seaweed and mollusc cultivation and harvest. Seaweed and molluscs, some of the most sustainable and nutritious sources of aquatic foods, are commonly accessible to women and amenable to both wild harvesting and low-input cultivation. Moreover, they require extremely low energy inputs. Supporting the development of these sectors could reduce pressure on wild fisheries while supporting food security, enhancing gender equality, reducing malnutrition and poverty, and boosting local economies in low- and middle-income countries. A further benefit of seaweed and mollusc cultivation is their contribution to climate mitigation through carbon capture (Hoegh-Guldberg et al. 2023).

Efficient and effective support of mariculture requires area-based approaches (e.g. OECMs) that consider entire coastal ecosystems and use collaborative approaches to shared risk management with local communities. Equitable expansion of mariculture will require governance reforms that support small-scale fishers and farmers and uphold labour rights. It will also require the application of a global certification scheme that increases transparency and assures compliance with respect to human rights and gender equity.

Promote the health benefits of seafood consumption with attention to distribution, equity and sustainability issues, particularly for coastal populations in LMICs**.** Such campaigns could be modelled on the experience of countries like Indonesia that have policies in place to encourage sustainable seafood consumption.

Develop nutrition-sensitive fishery management approaches. With nutrient composition data for fish species now widely available, successful approaches to fishery management could be identified or adapted to support a sustainable increase in the production of fish rich in target nutrients to help close nutrient gaps and maximise the contributions of wild-caught fish to global food and nutrition security.

Embed local aquatic food procurement in early and emergency interventions. Efforts to scale up the use of local aquatic foods in direct, early and emergency, food security and nutrition intervention programmes can address immediate food security needs while creating lasting coping strategies to combat both malnutrition and micronutrient deficiency. These programmes are most effective when they are based on local procurement strategies and coupled with healthy preparation, eating education, awareness and skills-training programmes. Such efforts have the potential to increase domestic consumption of seafood in low-income countries and can also generate local income.

3. Ocean opportunities for enhancing physical health, mental health and societal wellbeing

A growing body of evidence demonstrates that spending time in, on and by the ocean supports human physical health and mental wellbeing, and that interacting with a healthy ocean can contribute to 'the fundamental right of every human being . . . to enjoy . . . the highest attainable standard of health' (WHO n.d.).

Resolutions from the UN Human Rights Council in 2021 (A/HRC/RES/48/13) and the UN General Assembly in 2022 (A/RES/76/300) recognise that a clean, healthy and sustainable environment is a human right.

However, there are clearly many threats to ocean health and to the health of the people and communities who interact with the ocean. These threats need to be managed to maintain the ocean's current benefits for human health and wellbeing and hopefully to increase them in the future.

The health benefits of a healthy ocean

The ocean benefits human health by being a place where individuals can relax and be physically active, play, be creative, spend quality time with friends and family, and satisfy the deeply held human need to feel connected to the wider natural world around us (Britton et al. 2020; White et al. 2020). A healthy ocean can offer us the opportunity to not only survive but thrive.

The Global Burden of Disease study (IHME n.d.) points out that the disease burdens in many countries are shifting from communicable, nutritional and neonatal issues to non-communicable diseases (NCDs) (e.g. cardiovascular diseases, diabetes and depression). It is in the prevention of NCDs that living near the ocean may offer important but often unrecognised human health benefits.

Coastal residents are more likely than inland dwellers to meet the recommended levels of physical activity (Pasanen et al. 2019) that reduce the risk of many NCDs. After correcting for income and other factors, longitudinal studies show that moving to the coast is associated with sustained improvements in mental health (White et al. 2023). Several multi-country studies show that because of these and other factors (e.g. generally lower levels of air pollution), people living nearer the coast report better overall health (Elliott et al. 2023; Geiger et al. 2023).

The benefits of residence near the coast appear to be particularly strong among poorer communities with high levels of environmental and socioeconomic disadvantage (Garrett et al. 2019), as well as during times of stress such as in financial downturns and the COVID-19 pandemic (Pouso et al. 2021). The disproportionate benefits of coastal residence are seen globally and are by no means restricted to the Global North (Maharja et al. 2023b) (see Case study 6).

In particular, research is beginning to show that communities living in and around MPAs and other areas designated as 'protected' experience diverse

human health and wellbeing benefits, including decreased overall national mortality and improved child health as well as positive ecosystem impacts (Madarcos et al. 2021; Haque et al. 2023; Nowakowski et al. 2023). The research to date is also clear that collaborative and effective management of these areas with the ongoing involvement of local communities is essential to creating and sustaining these ocean and human health benefits (Ban et al. 2019; Gollan and Barclay 2020; Rasheed 2020).

For inland residents, the ocean is a key tourism destination (European Commission n.d.). Economists assume that the health and wellbeing benefits people derive from recreational visits and coastal holidays reflect the amount of time and money they invest in them (Börger et al. 2021). Thus, the $5 trillion spent annually on coastal and marine tourism (5 percent of global GDP) reflects the value visitors place on these benefits.

Many health professionals have a limited awareness of (or time to review) the mounting evidence that contact with the ocean can improve mental and physical health. Greater efforts to engage, motivate and secure buy-in from this influential group are needed (Depledge et al. 2019) (see Case study 7).

CASE STUDY 6. Thriving during the COVID-19 pandemic (Indonesia): The ocean as a source of solace in times of stress

Artisanal fishing is the predominant work in small island communities in Indonesia, and these communities rely on local coastal and marine ecosystems for their livelihoods (Maharja et al. 2023a). Emerging evidence indicates, however, that these ecosystems are important not only as a source of sustenance but also as a source of health and wellbeing.

For instance, despite their relative isolation, these communities were not immune to the stress and anxiety caused by the COVID-19 pandemic. Lockdown measures imposed during the pandemic resulted in economic loss, increased household conflict and diminished access to healthcare (Richter et al. 2021). However, engagement in ocean-based recreational activities by these communities during this challenging time, especially collective immersive interactions such as swimming and snorkelling, were shown to protect or 'buffer' people against adverse mental health outcomes (Maharja et al. 2023b) (Figure CS-6.1).

Put simply, the benefits of engaging in marine recreational activities for mental and social wellbeing are not restricted to affluent post-industrial societies in the Global North (Britton et al. 2020).

FIGURE CS-6.1. **Ocean recreation as a buffer against the adverse mental health outcomes of COVID-19 lockdown restrictions**

Photo credit: Sainal.

CASE STUDY 7. The National Health Service and Healthcare Ocean: Positive action for ocean health

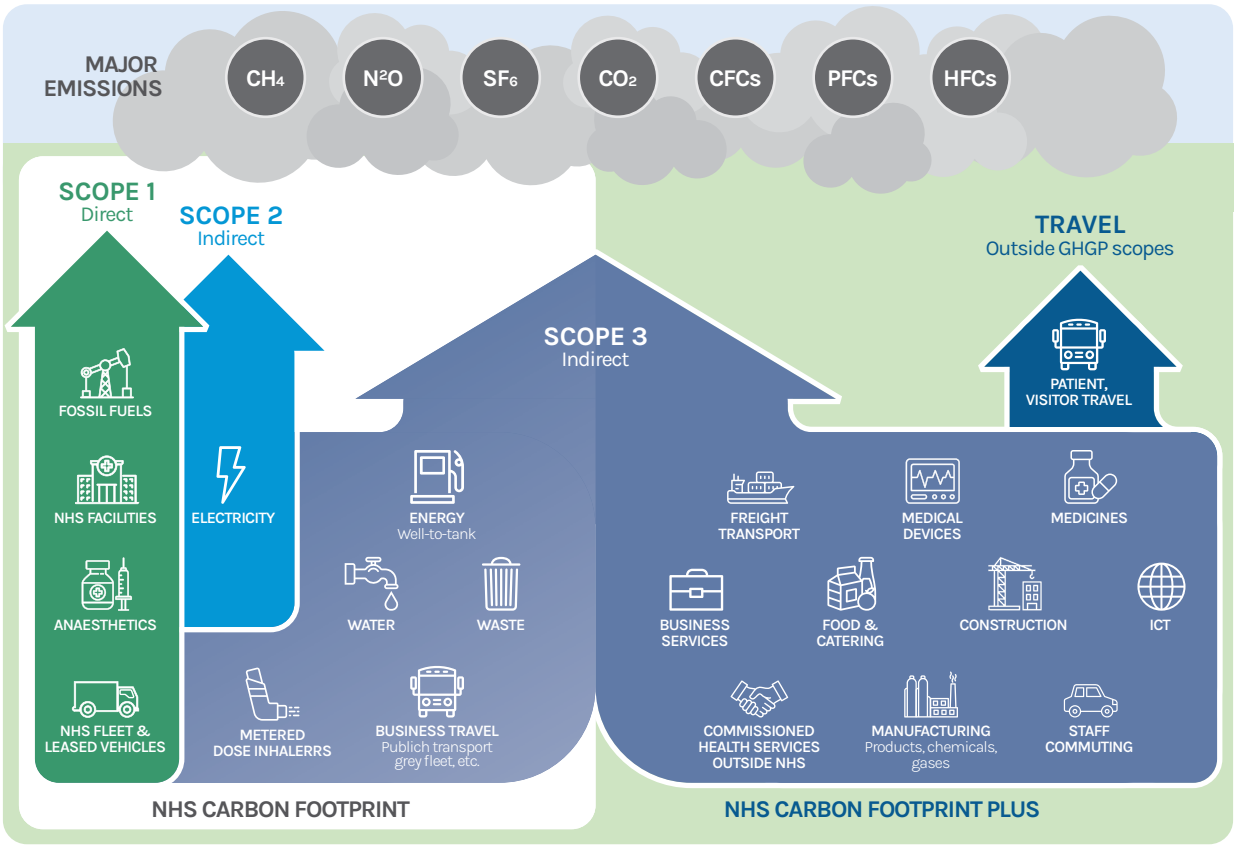
Healthcare locally and globally has significant unintentional negative impacts on ocean health. These include greenhouse gas emissions, pharmaceutical and plastic pollution, shipping and destructive land use.

Healthcare systems, both conventional and traditional, are also unique in their opportunity to support health and wellbeing within communities through place-based approaches that reduce inequalities in coastal and blue spaces. The benefits of connecting patients with nature (including the ocean) to improve physical and psychological health outcomes are becoming well established. Uniquely, the health sector can play a key role in advocating with local people and local authorities for improved blue space infrastructure and quality and for clean coastal waters that encourage physical activity and restore mental health. The health sector is also uniquely well qualified to identify those who could benefit the most from blue place activities, for example through 'social prescribing' programmes ('blue prescriptions') designed to enhance the health and wellbeing of community members.

The UK National Health Service (NHS) serves an island of over 67 million people, spending £32 billion a year with 80,000 global suppliers. It was the first global healthcare system to declare a climate emergency, aiming to be net zero by 2045 (including all supply chains). Within the first year of the Greener NHS Programme, the NHS reduced its emissions equivalent to powering 1.1 million homes annually. To date, the ambition of delivering a net zero NHS has focused predominantly on carbon (Figure CS-7.1).

Recognising that human health and wellbeing are inextricably linked to the health of both the ocean and waterways, a group of UK healthcare providers have started Healthcare Ocean (n.d.). The goal is to raise awareness of the interconnections between human and ocean health. They work with international shipping companies and NHS suppliers, as well as community and healthcare 'blue prescription' providers, towards sustainable, equitable and biodiverse approaches.

FIGURE CS-7.1. **Scope 1, 2 and 3 emissions mapping for the UK National Health Service**



Note: CFCs = chlorofluorocarbons; CH_4 = methane; CO_2 = carbon dioxide; GHGP = Greenhouse Gas Protocol; HFCs = hydrofluorocarbons; N_2O = nitrous oxide; PFCs = perfluorochemicals; SF_6 = sulphur hexafluoride.

Source: NHS n.d.

Health risks of ocean degradation

Although potentially beneficial for human health and wellbeing, the ocean can also be a frightening and dangerous place for both visitors and residents of coastal communities, because of its vast size and specific threats (e.g. tsunamis, extreme weather), as well as the multiple and increasing stressors on ocean health. This is particularly true for Indigenous and traditional coastal communities at the 'cliff face' of the interactions between our rapidly changing climate and the ocean, as well as from pollution and socioeconomic inequalities.

Climate change and biodiversity loss

Climate change and biodiversity loss are already undermining the benefits of the ocean to human mental, physical and social wellbeing (Whitmee et al. 2015). Flooding, land erosion, rising sea levels and more frequent and violent storms pose a growing threat to the physical and mental health of coastal communities. A World Bank report on the West African countries of Benin, Côte d'Ivoire, Senegal and Togo estimates that pollution and flooding cause over 13,000 deaths a year; and that the total cost of coastal-related environmental degradation in 2017 was $3.8 billion, 5.3 percent of these countries' GDP (Croitoru et al. 2019).

Hotter ocean temperatures resulting from global warming endanger delicate ecosystems such as coral reefs (Chaijaroen 2022). They also encourage invasive species, microbial pollution and harmful algal blooms (HABs) (Gobler 2020). For example, HABs jeopardise ocean and human health by contaminating seafood and exposing people to the natural toxins when they swim or even breathe inland air because these toxins can be aerosolised (Berdalet et al. 2016). In addition, HABs reduce recreational benefits and cause the loss of 'cultural-ecosystem services' by killing off iconic and locally culturally important species (Beaumont et al. 2008).

Pollution

Pollution is another great challenge confronting the ocean (Fleming et al. 2019), jeopardising both human health and ecosystems that up to 3 billion people depend on for their food and livelihoods, particularly coastal communities in the Global South. Land-derived pollutants include heavy metals, macro- and microplastics, pesticides, persistent organic pollutants, inadequately treated sewage, pharmaceuticals, antibiotics and excessive nutrients (e.g. nitrogen and phosphorus). These enter freshwater and marine systems (including contaminating food chains), mostly from urban, agricultural and industrial runoff and discharge.

Pollution's impacts occur far from the freshwater and marine ecosystems where pollutants are discharged, and many of these health impacts are poorly understood and underestimated. Furthermore, marginalised coastal communities already vulnerable to the impacts of climate change and socioeconomic inequality are disproportionately more likely to be exposed to pollutants from the ocean and other sources (Landrigan et al. 2020).

Known human health consequences of pollution exposure include skin and gastrointestinal infections, increased risk of some cancers, infertility and birth defects, neuro-behavioural toxicity, endocrine disruption and antimicrobial resistance (Landrigan et al. 2020). Accumulations on beaches of plastic waste (Beaumont et al. 2019) and microbial pollution can deter people from visiting the sea at all (Börger et al. 2021).

Socioeconomic challenges

Relatively poorer coastal communities may benefit most from interactions with the ocean (Garrett et al. 2019), and people living nearer the coast report better overall health (Elliott et al. 2023; Geiger et al. 2023). Nevertheless, a recent report by the United Kingdom's chief medical officer (CMO) summarised the many challenges of coastal living, even in a relatively high-income country such as the United Kingdom. The report pointed out that compared to inland communities, coastal residents tend to have lower life expectancy and higher rates of many major diseases. In the United Kingdom, this is currently caused by, among other factors, older adults moving to the coast for retirement, difficulties in attracting medical and social care staff to peripheral communities, limited transport and only seasonal employment options (UK Chief Medical Officer 2021).

Coastal 'gentrification' (when more wealthy people move into seaside communities, often forcing out local populations) is another challenge to health and wellbeing. In many prime locations internationally, tourism and gentrification are pushing up property prices and rendering residential and other access to the ocean unaffordable (Freeman and Cheyne 2008). Yet in other contexts threatened by sea-level rises (e.g. the U.S. city of Miami) (Li and Grant 2022), higher-income households may be leaving coastal areas for higher ground, leaving poorer households vulnerable to potential harms from ongoing and future climate change.

Development and spatial planning

The UK CMO report highlights the medium- to long-term risks to the health and wellbeing of coastal communities resulting from economic growth that is neither environmentally nor socially sustainable. Over-development of fishing or tourism industries beyond local 'carrying capacities' may provide short-term economic returns but leads to significant future ocean and human health problems (Leka et al. 2022; Sun et al. 2022).

At the same time, protection measures for coastal ecosystems must ensure that the trade-offs, which can lead to inequitable benefit sharing (cf. Praptiwi et al. 2021), can be mitigated. Thus, the involvement of local coastal communities in the governance of marine areas through community participatory approaches with policymakers and scientists is required to ensure the sustainable future of both people and the ocean (Estradivari et al. 2022).

Planning policies that allow or even support richer citizens to move to, or have second homes by, the coast create further problems. They can make it increasingly difficult for local residents to afford homes in traditional coastal locations (much less access ocean benefits), leading to yearly boom-and-bust cycles of low-paid seasonal employment opportunities, in which many properties are empty for much of the year (Dykes and Walmsley 2015; Depledge et al. 2017).

The need to protect 'high-value' properties from coastal erosion can also lead to the construction of inappropriate coastal defences that simply shift the problem to other more vulnerable areas along the coast; or restrict public access, effectively privatising access to the coast, making it exclusively the playground of the wealthy and actively excluding local residents (Cooper and McKenna 2008; Reed 2009).

Current limitations and knowledge gaps

To date, much of the data on benefits are derived from research in the Global North, and much of this research has been short-term. There is a particular dearth of research looking at both the risks and benefits of the ocean for human physical, mental and social wellbeing in the Global South (but see Case study 6) (Rasheed 2020; Short et al. 2021).

One way to address this knowledge gap is to commission in-depth cohort studies which follow the health and wellbeing of specific ocean communities (particularly in the Global South and populations living in and around MPAs), as well as ocean health, over several years to understand how changes in local ocean conditions affect changes in community health over time. Such studies can yield valuable data, but they are expensive and can require many years to yield actionable findings.

Causal mechanisms

As with any environmental exposure, identifying causal pathways linking the ocean with human health is difficult against a background of multiple exposures, interacting mechanisms (including inter-generational impacts) and varying time from exposure to health impacts that range in time-scale from minutes to decades (Fleming et al. 2019). Mechanisms and effects must be clearly defined, plausible and testable. Clear definition requires measurement of various elements, including dose composition (i.e. the type of ocean contact), frequency (how often), duration (how long), intensity (how immersed), consistency (same dose over time) and passivity (whether participation is required).

Geographical evidence–action mismatches

Even when reasonably high-quality data exist, the geographical scales of ocean and health data may be incompatible with policy-action needs. For instance, the European Union has relatively joined-up multi-country data and policies with respect to ocean

health, but human health data and policies primarily shape interventions at the member-state (country) or subnational level (H2020 SOPHIE Consortium 2020).

Similar mismatches may existin countries where geographical units related to ocean management do not match geographical units related to health services. Marine protected areas, for instance, may reflect a relatively coherent ocean ecosystem but also include very different human communities from different countries, with very different access to healthcare services and consequently data on health outcomes.

Solutions to these problems will require more collaborative thinking among environmental scientists, health scientists, geographers, demographers, local communities and policymakers to ensure that right-scale ocean and human health data are available for the right kind of health actions and vice versa (Rasheed 2020). Co-created research with local communities (especially in the Global South) is particularly essential.

Generalisability: Scaling up and scaling out

Many studies showing health benefits of ocean interactions are small-scale, build heavily on local knowledge, experience and opportunities, and often rely on highly motivated individuals who persist in the face of numerous challenges (Britton et al. 2020). Although they often provide useful information, it is frequently unclear how relevant these place-based results of one intervention are for other places and peoples (especially in the Global North versus the Global South) and how appropriate or feasible it is to scale up these interventions to larger populations and in different locations (see Case study 8).

Actions and opportunities

Assessing the feasibility and impact of high-level goals (e.g. to increase the amount of the ocean that is protected, or reduce depression rates within a country) is very difficult. It is often more realistic to assess the feasibility, timing and impact of specific attempts to operationalise these goals, either among specific populations and locations, or the generalisation of current good practices to other populations and locations (scaling up and scaling out).

Deliver on the Global Biodiversity Framework targets, among them to designate 30 percent of the ocean as MPAs by 2030, including working with local communities and OECMs (Gurney et al. 2021). This is critically important work for human health and wellbeing as well as for ecosystems, but timelines and mechanisms are yet to be decided. In particular, co-created longitudinal research and other activities with coastal communities living in and around MPAs and other protected areas are essential to examine

CASE STUDY 8. **Blue health and wellbeing 'prescriptions': The Bay (Morecombe, United Kingdom)**

Morecombe Bay is a large stretch of coastline in northwest England. Working closely with local Wildlife Trusts and the Eden Project, the Lancashire and South Cumbria National Health Service (NHS) Foundation Trust has established 'The Bay', an ocean-based wellbeing programme along the whole of the bay's coastline.

Focusing on 'blue social prescribing', healthcare providers refer patients to programmes supported by and supporting different local coastal communities. The Bay programme offers a range of interventions, including treatment-focused specialist support for people with chronic mental health issues, through to more prevention-focused activities encouraging greater coastal use for people at risk of poor health.

Building on relationships established with referral partners, the Bay's blue social prescribing programme is on target to support nearly 500 individuals most seriously impacted by social exclusion and isolation over the first two years of delivery.

The Bay programme's broader 'whole population approach' brings together over 4,000 people every year with activities including litter picks, rockpool rambles for children and families, citizen science projects such as sea watches and monitoring reefs, and policy-focused actions including lobbying decision-makers. The health of the coastal marine environment is growing stronger as a result of the local communities' becoming healthier and better connected (Figure CS-8.1).

Early social return on investment analyses suggests that every £1 invested in Bay activities brings £2.16 of benefit in terms of reduced costs of treating mental health-related conditions. This doubling of return is a conservative estimate: it does not consider the wider economic benefits of reducing unemployment, increasing visitors to the coastline and environmental cost savings from the positive work achieved (Wildlife Trusts 2023).

FIGURE CS-8.1. **Outcomes of blue prescribing sessions**

	CONNECT with the people around you	**BE ACTIVE** discover an activity you enjoy	**TAKE NOTICE** be aware of the world around you	**KEEP LEARNING** try something new or rediscover an old interest	**GIVE** do something good for the community
Specialised sessions	**88%** met new people	**95%** have become more active	**95%** noticed something new	**98%** learned something new	**86%** had given something back
Targeted events	**90%** met new people	**100%** were out and active at the event	**9.5 out of 10** engagement with nature	**99%** learned something new	**95%** inspired to take action for nature

Source: NAGHP n.d.

and address the risks and benefits to both ocean and human health (Rasheed 2020; Madarcos et al. 2021; Haque et al. 2023; Nowakowski et al. 2023).

Use of nature-based solutions (NBS). Societal and local interventions tend to focus on making changes to the environment through urban planning or environmental management initiatives. When these involve supporting restoration or improvement of ecosystems, they are often referred to as 'nature-based solutions' (NBS). Individual-level nature-based actions tend to focus on supporting specific individuals with specific health-related conditions or behaviours (e.g. depression, anxiety, physical inactivity) and are often referred to as 'nature-based therapies' (NBTs). Many NBS are already in place to reduce stormwater coastal flooding and can be leveraged to create NBTs, such as local community engagement in mangrove-planting schemes in the Philippines, which can provide both individual and community benefits.

Reduce microbial, chemical, plastic, pharmaceutical, nutrient and other pollution at the source. An example is the European Chemicals Agency proposal to restrict production of perfluoroalkyl and polyfluoroalkyl substances to 'essential uses' only. Minimally identifying the sources and preventing ocean pollution from the land and the air is essential. This is also very relevant to the health sector (including the pharmaceutical industry), with its extensive chemical and carbon footprint internationally (Belkhir and Elmeligi 2019; Steenmeijer et al. 2022).

Promote ocean sustainable healthcare systems and practices. Conventional healthcare systems need to embed ocean health criteria in their climate strategies and to harness their influence with healthcare suppliers through procurement frameworks that address both climate and ocean criteria (such as pollution mitigation of plastic and pharmaceutical wastes) to protect ocean and human health (see Case study 7 and Case study 11). The health sector in the Global North can also learn from sustainable healthcare strategies in the Global South as well as from traditional and Indigenous medicine practices (Harris 2023).

Adopt a 'human-health-in-all-policies' approach for both local marine and terrestrial plans. As an example, the Motion for the Ocean programme is a model to help local authorities play their part in realising a clean, healthy and productive ocean and all its direct benefits for the economy, human health and societal wellbeing (LGA Coastal SIG n.d.). Ideally this 'health-and-environment-in-all-policies' approach would be adopted globally at all policy levels.

Ensure local community co-creation in all localised planning implicating the marine environment. An example is an interdisciplinary urban 'blue acupuncture' initiative to improve access to a local beach in a deprived community that was co-designed with local residents, schoolchildren, community actors and local government (Bell et al. 2020).

Upscale existing, and develop new, blue care prescription programmes. Upscale blue prescribing programmes that encourage participatory management with both individuals and local communities, prioritise underserved groups and contribute to ocean or coastal recovery (as shown in Case study 6 and Case study 8). A further benefit of these programmes is that they provide opportunities to support the health and wellbeing of marginalised groups (including people of colour), allowing them to re-engage with beaches and other high-quality blue spaces from which they have been excluded because of historical racial and other segregation or complete lack of access.

Upscale ocean literacy programmes, focusing on links between ocean and human health. Healthcare personnel interact with many people but are largely unaware of relationships between ocean and human health. Educated in ocean and human health, they could be important leaders and partners. To address the disparity of knowledge among healthcare personnel, ocean health could be integrated into professional development opportunities such as required continuing education training certification or Grand Rounds (Healthcare Ocean n.d.).

Youth are also an important target group for ocean literacy as part of their development as ocean citizens. As an example, the Australian state of New South Wales has developed educational materials for Year 10 Personal Development, Health and Physical Education (PDHPE) students titled 'Moving Ocean'. This programme empowers individuals to support ocean health and is an excellent example of aligning personal health and ocean health curricula.

4. Ocean opportunities for growing the economy and improving health by addressing inequity

The ocean is a source of enormous wealth. The ocean economy is estimated to generate $1.5 trillion to $2.5 trillion annually, provide jobs for more than 30 million people (OECD 2016) and support the livelihoods of millions more informally employed in artisanal and small-scale fisheries. Properly managed, the great resources of the ocean have the potential to benefit all sectors of society in all countries through increased employment opportunities, enhanced economic revenues and strengthened infrastructure, while reducing environmental risks, ecological scarcities and social injustices (UN 2014).

By contrast, unsustainable ocean-based industries that focus on short-term profit-making and accumulation of great wealth for the few challenge that democratic vision. Often claiming the banner of the 'Blue Economy', these industries—which include unsustainable fisheries, seabed mining and oil drilling—degrade the ocean environment, release vast quantities of greenhouse gases, produce pollution and deplete marine resources (Bennett 2018; Cisneros-Montemayor et al. 2021). They threaten human health, increase societal inequalities, degrade the ocean environment, and create long-term financial liabilities for governments (Ocean Panel 2020).

To be sustainable and healthy, the ocean economy must embrace equity, address economic and social inequalities and place protection of ocean and human health at its core (Cisneros-Montemayor et al. 2021). It must encourage development without causing ecosystem destruction (Ocean Panel 2020; Cisneros-Montemayor et al. 2021). Achievement of these goals will require that national governments and international organizations establish new governance structures and apply economic metrics for the ocean economy that look beyond short-term gain and explicitly value human and natural capital.

These goals can be achieved by incorporating measures of natural and human capital as well as formal assessments of impacts on human health and wellbeing in addition to metrics of short-term gain, such as GDP, into assessments of the benefits of ocean development (Fenichel et al. 2020). Bringing the frameworks of the precautionary principle and environmental justice into such evaluations has the potential to transform traditional approaches to often siloed environmental, equity and health policies. And because LMICs are disproportionately impacted by climate change and ocean pollution (including ocean plastic pollution), increasing the scope and impact of ocean policies to mitigate climate change and prevent ocean pollution has the potential to improve the environment and human health and deliver a more equitable ocean environment.

This section examines the complex interlinkages between ocean and human health and the ocean economy. It analyses the opportunities and actions available to deliver a socially inclusive, sustainable ocean economy that generates wealth for all and sustains a healthy ocean that benefits human health today and for future generations. Two case studies, one from the Global North and one from the Global South, are used to demonstrate that policies grounded in pro-environmental behavioural change and social innovation can ensure the equitable distribution of both the social and economic benefits of a healthy ocean.

Key risks and opportunities for human health

Globally, coastal communities in countries at every level of income are experiencing the most severe negative economic, environmental and health impacts of unrestrained human-induced changes to marine and coastal ecosystems, such as uncontrolled coastal development and coastal pollution (Ehsan et al. 2022). Many of these communities report high levels of poor health and wellbeing (Depledge et al. 2017; UK Chief Medical Officer 2021).

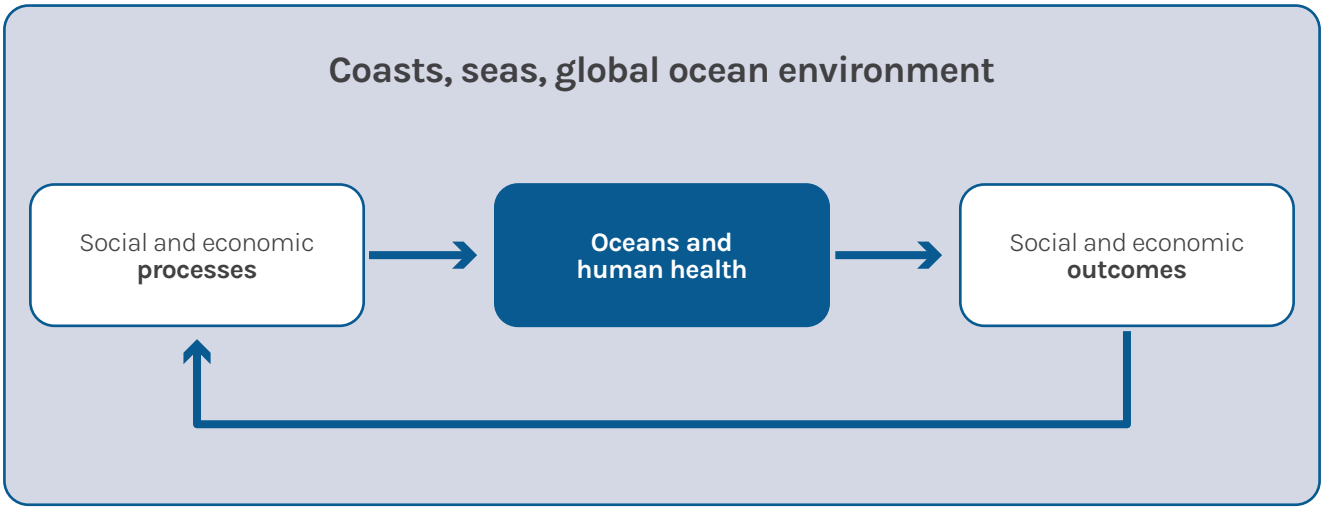
These impacts are most obvious in LMICs, where people rely directly on intact ecosystems for their daily sustenance and livelihood (Ehsan et al. 2022). But they are seen also in high-income countries, where economic pressures, environmental degradation and climate-driven change have resulted in economic precarity in low-income coastal communities (Acheson and Acheson 2020).

Economic inequality is both a key determinant and an outcome of negative changes to ocean ecosystems and of their knock-on effects on human health and wellbeing (Bambra 2011; Berthe and Elie 2015) (Figure 5). Inequality is typically the consequence of long-standing inadequate and/or negligent institutional practices, such as exclusionary ownership of land or fishing rights, race-based discrimination, gender-based exclusion and economic and taxation policies that favour the few at the expense of the many.

The health and wellbeing of coastal communities can be enhanced, inequity reduced, and fisheries and other marine resources restored through policies and programmes that take an inclusive approach to improving human and ocean health. Such policies have been shown to have positive impacts on ocean ecosystems, livelihoods (both ones related and not related to the ocean), as well as other employment and financial opportunities in coastal communities. Such policies also improve access to key services, including health services (Gollan and Barclay 2020; Rasheed 2020; Das 2023).

One promising area for improving the health and wellbeing of coastal communities is through 'social innovation', a process whereby relevant actors and institutions join in self-organising, community-driven networks to develop new and improved ways of collaborative action. The core objective of social innovation is to deliver bottom-up individual and community behavioural change across multiple actors (Merz et al. 2023).

FIGURE 5. **The reinforcing role of social and economic processes in creating inclusive ocean and human health**



Source: Authors.

A positive example of such intervention is seen in the case of small-scale fisheries in LMICs, where a focus on an equitable ocean and human health has been linked to increased ocean health, improved nutritional outcomes and food security, stabilisation of local economies and better physical and mental wellbeing outcomes across all age groups (Béné et al. 2010). An example of a 'bottom up' approach by small-scale fishers in the Global South to preserve an ocean fishery, reduce economic insecurity and improve human health and wellbeing is seen in Case study 9, while Case study 10 presents an example of cooperative, community-led action in a high-income country to protect an endangered fishery and marine habitat.

However, a continuing challenge to such 'bottom up' approaches is that they often do not result in changes to the prevailing systems and power structures that impede equitable development. Political and economic power, regulation, enforcement, resources and ongoing commitment are all issues to be considered in efforts to bring community-led approaches to regional and national scales.

Such interventions have the potential to particularly benefit communities living in and around MPAs and other protected areas in the Global South. Burgeoning research in these communities demonstrates diverse human health and wellbeing benefits, including decreased overall mortality and improved child health, as well as positive ecosystem impacts (Rasheed 2020; Madarcos et al. 2021; Haque et

CASE STUDY 9. Bangladeshi fishers' collective action to create inclusive growth for ocean and human health

The hilsa shad (*Tenualosa ilisha* (Hamilton 1822)) constitutes Bangladesh's single-most important fishery, contributing about 12 percent of total production and about 1 percent of the country's GDP; and employing an estimated 50,000 people, predominantly artisanal fishers (Islam et al. 2018).

A structural problem in the hilsa industry is that access to fishing equipment and to lucrative urban markets is largely in the control of middlemen. These fish brokers secure their hold on the industry by extending investment capital to fishers at high interest rates, thus locking fishers into poverty, jeopardising their economic security and threatening their health and wellbeing.

The hilsa fishers' precarious existence is further endangered by increasing numbers of climate change–driven tropical depressions and cyclones in the Bay of Bengal. These events jeopardise fishers' incomes as well as their lives. Each year, dozens of fishers are killed or go missing at sea, and fishers report insufficient life-saving equipment. These problems were exacerbated in 2019, when an existing 65-day fishing ban for industrial fishing was extended to small-scale fishing boats without any discussion with the artisanal fishers (Islam et al. 2021).

FISHERS' ACTION

Fishers in several villages along the southern coast of Bangladesh have begun to form rural self-developing societies and cooperatives that extend financial support and equipment to their members. These groups have the potential to protect community interests, enhance communal and individual health and wellbeing, and promote ocean stewardship.

Fishing cooperative members typically contribute to a common fund, which entitles them to a variety of material and non-material benefits, including access to low-interest loans and fishing gear. Membership in cooperatives also enhances fishers' political position and strengthens their bargaining power when negotiating with fish brokers and government agencies.

RESULTS

Within rural fishing communities that have formed cooperatives, reports show that increased social cohesion and collective action is emerging as a basis for future adaptation strategies, and that positive social support within the group benefits mental health. Further benefits of these cooperatives are particularly relevant to physical health; for example, awarding collateral-free loans supports food and nutritional security during seasonal fishery closures, and medical treatment during illness. Building alternative skills and self-help infrastructure development in rural communities could also support better market access, enhance fishery income and generate support for poverty-alleviation programmes (Islam et al. 2021). The challenge remains of how to support such initiatives in the face of powerful and competing interests that are able to deliver, and profit from, economies of scale.

al. 2023; Nowakowski et al. 2023). To unlock the opportunities that a socially inclusive, sustainable ocean development agenda can deliver, bold policies and actions are needed in ocean protection, fishery management and international trade regulations (Nash et al. 2022).

Limitations to current knowledge requiring additional research

Ocean economy initiatives have often failed to advance socially inclusive ocean and human health because of lack of concern for factors beyond economic development, and the lack of the tools and knowledge needed to ensure equity and justice from ocean-based activities. To confront these problems and to inform policy and develop interventions, more information is needed in the following areas:

- The complex and reinforcing interconnections between ocean health, human health, and economic and social processes.
- Relationships between ocean and human health and social equity and justice outcomes in both LMICs and high-income countries.
- The scale at which policies can most effectively drive a more inclusive ocean and human health agenda.
- The capacity of ocean sectors, including and beyond small-scale fisheries, to advance an inclusive ocean and human health agenda at a community level.

Measuring progress in all the above areas will require the development, deployment and field-testing of new, holistic economic indicators of the ocean economy that move beyond a sole focus on productivity, such as GDP, and account for the natural, social and human capital provided by a healthy ocean (Fenichel et al. 2020).

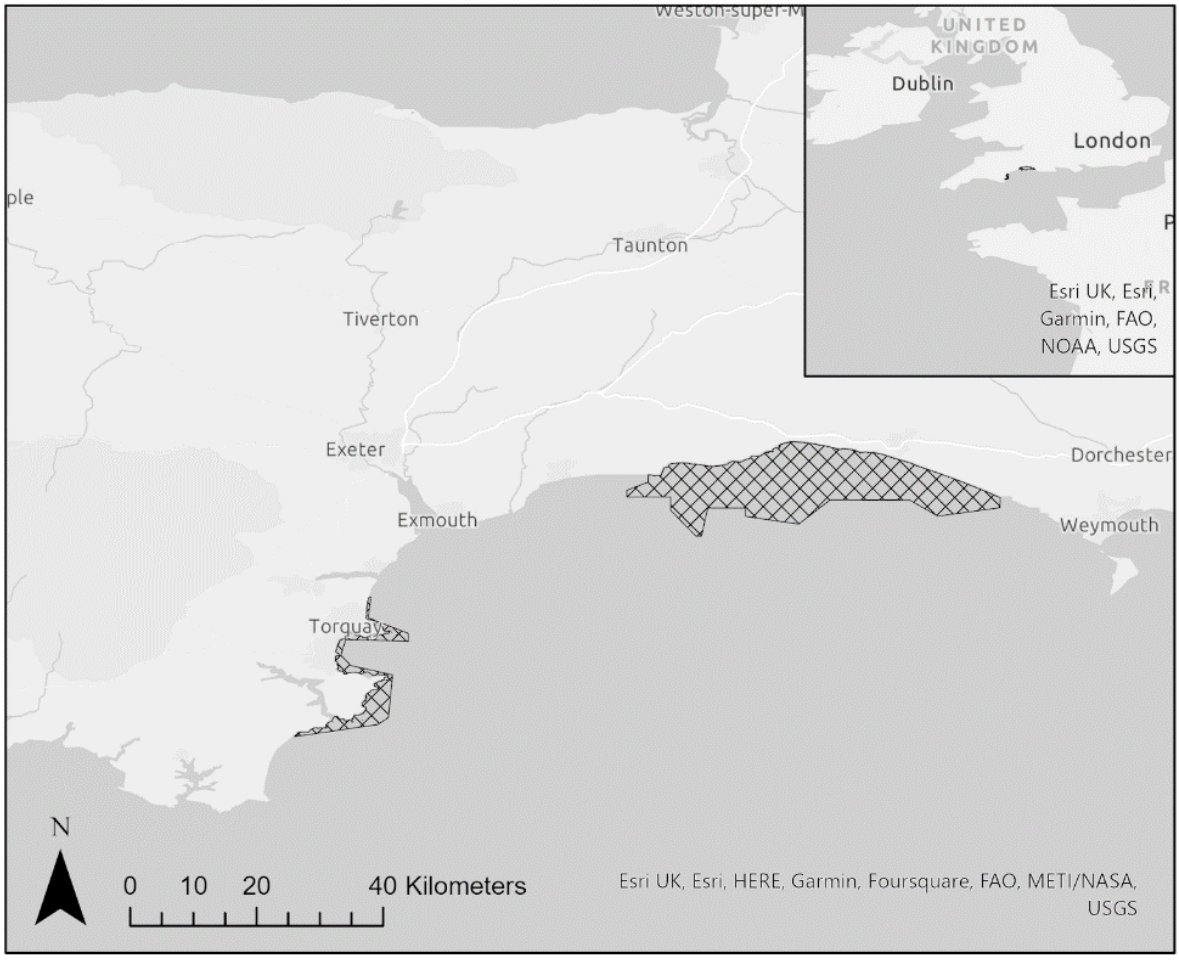
Behaviour change across all sectors of society is required to meet the UN Sustainable Development Goals and mitigate the impact of climate change on the ocean and human health in an inclusive manner (Merz et al. 2023). The recent multilateral successes in sustainable and collaborative fishery management discussed in detail in Section 2 offer models. These include the new UN High Seas Treaty and the WTO (2022) agreement to phase out selected fishery subsidies and favour equity (Stokstad 2023).

CASE STUDY 10. **Lyme Bay Fisheries and Conservation Reserve**

Lyme Bay Fisheries and Conservation Reserve, located in southwest England, is one of the largest marine protected areas in England, with 206 square kilometres of seabed protected from dredging and trawling (Rees et al. 2010) (Figure CS-10.1). It is a marine biodiversity hotspot supporting unusual species such as the pink sea fan (*Eunicella verrucosa* (Pallas 1766)) and ross coral (*Pentapora fascialis* (Pallas 1766)). It is also important socially and economically (Singer and Jones 2021).

Although the scallop and demersal trawl fishers lost access to valuable fishing grounds, static gear and diving fishers have been able to continue their activities without conflict, and a closed conservation area has led to recovered seabed and coral gardens (Rees et al. 2010). Scallop populations have recovered and the number of new entrants to the scallop diving industry has increased, as has whelk fishing effort (Singer and Jones 2021), all contributing to increased human wellbeing.

FIGURE CS-10.1. **Location of Lyme Bay (east) and Torbay (west) Special Area of Conservation (hatched polygons)**



Source: Authors.

The governance approach to the reserve has been a combination of voluntary bottom-up and statutory top-down measures. Voluntary agreements were made, and broke down, several times prior to the statutory closure (Rees et al. 2010).

Key positive actions that emerged from this effort have included collaborative learning through a joint working group of scientists, regulators, nongovernmental organisations and the private sector; peer enforcement due to dialogue between regulators and fishers to promote recognition of regulations and restrictions; and efforts to increase social capital, building trust through the working group and increased transparency from regulators (Singer and Jones 2021).

Actions and opportunities

We identify the following priorities to deliver an inclusive ocean and human health developmental agenda.

Create governance policies to ensure sustainable use of and equitable access to ocean resources. Sustainable and equitable use of 100 percent of marine resources (Ocean Panel 2020), attainment of the UN Sustainable Development Goals and mitigation of climate change will require governance policies at the local, national and international levels that are designed explicitly to protect ocean health, advance economic and social equity, and safeguard human health and wellbeing. Sustainable Ocean Plans are an example of an effective approach to achieve this (Ocean Panel 2021).

Develop and deploy indicators to measure progress in both ocean and human health. Assessment of the efficacy of new governance structures will require the development, deployment and refinement of new economic indicators. These indicators will need to move beyond a sole focus on measuring productivity, such as gross domestic product, because productivity metrics fail to capture the natural capital provided by a healthy ocean, while also hiding how the ocean's benefits are derived and to whom they accrue (Fenichel et al. 2020). The development and use of new, more holistic indicators that account for both natural and human capital and for the equitable and sustainable distribution of wealth from the ocean offer a key opportunity to highlight the need for, and the returns from, an inclusive ocean economy agenda centred on ocean and human health (Kumar et al. 2019).

Reform global finance and trade. Strict regulation of industries that destroy marine resources; removal of government subsidies for industries that destroy marine resources such as distant-water fishing, seabed mining and fossil fuel extraction, and incentivisation of industries that advance sustainability are actions that will protect human health and wellbeing and advance social justice. Such actions could build on recent multilateral successes, such as the new UN High Seas Treaty and the WTO agreement on fisheries to ensure that trade works for low-income nations.

Advance behavioural change policies to foster pro-environmental behaviour for ocean and human health. Behavioural change across all sectors of society, supported by international treaties and enforced through national and local regulations, is of great importance.

For example, in the health sector, pharmaceuticals are crucial for improving healthcare but often end up in the ocean, resulting in growing threats to ocean and human health such as antimicrobial resistance; particularly in LMICs where labour is cheap, environmental laws less stringent, and many pharmaceuticals are made. An example of an early-stage intervention to combat the impact of pharmaceuticals in the ocean is Scotland's first blue-

green prescribing programme to protect the ocean from pharmaceutical pollution by using nature-based health interventions or 'blue prescriptions' (see Case study 8 for an example) for people with mental health conditions in addition to prescribing less environmentally harmful medications (Janković 2023). Recognising the global extent of this problem, WHO (2015) has developed a Global Action Plan on Antimicrobial Resistance.

Another example in the health sector is the ongoing work between the UK NHS with its suppliers and shippers towards a more sustainable approach to international shipping, discussed in Case study 11.

Catalyse actions to create cross-sectoral linkages and partnerships, encourage co-creation and bridge organisational divides. Confronting current environmental and societal challenges in ocean and human health requires new institutional structures that facilitate multi-actor, cross-sectoral collaborations that emerge directly from the environmental, economic and health needs of communities. Actions arising from social innovation–based processes offer an important pathway to address issues of equity while simultaneously improving human and ocean health at the community level.

An example of a good practice is outlined in Case study 9, which highlights the capacity for communities in southern coastal Bangladesh to develop locally sustaining, inclusive actions for ocean and human health that also can further encourage multi-sector collaborations across local, regional and national scales.

CASE STUDY 11. Decarbonising healthcare's maritime logistics

The National Health Service (NHS) in England serves a population of 56 million people and is supported by 80,000 global suppliers. It has committed to reaching net zero carbon emissions for all the emissions it controls, including in its supply chain, by 2045. Transportation of healthcare goods from manufacturer to use is part of the product's lifecycle; and 80 percent of NHS goods arrive via maritime routes.

THE MARITIME CHALLENGE

The global healthcare system depends on fast, reliable, smooth and affordable maritime shipping to deliver more than 80 percent of the goods needed to maintain human health and wellbeing. However, the emissions from maritime shipping activities for the healthcare and other sectors pose a threat to planetary health and hence human health. The healthcare system's workload is fuelled by the planetary harm it causes.

Although container shipping is the most economical and sustainable global mass transportation, there are still environmental impacts, with direct and indirect human health implications. These impacts include emissions (1 billion tonnes of CO_2 per year) at sea and in ports, transfer of invasive species, underwater radiated noise, damage to marine protected areas, wastewater and other marine pollution, and marine mammal collisions. NHS England's global supply chain emissions represent 62 percent of its overall greenhouse gas footprint. Decarbonisation of the maritime shipping sector is essential to achieve the NHS net zero goals.

Shipping is included in NHS England's (n.d.) Evergreen Sustainable Supplier Assessment, which sets a clear standard for sustainable maritime logistics. Suppliers can become signatories of the Aspen Institute's Cargo Owners for Zero Emission Vessels ambition statement (coZEV n.d.), a collective aim from cargo owners to only use zero emission shipping services by 2040, and subsequently become members of the Zero Emission Maritime Buyers Alliance (ZEMBA). ZEMBA is a buyers' group within the maritime sector that aims to accelerate commercial deployment of zero emission shipping, enable economies of scale and help cargo owners to maximise emissions reduction beyond what any one freight buyer could accomplish alone.

Many of NHS England's suppliers deliver goods to industries beyond healthcare. Therefore, these changes for the healthcare sector can be amplified across multiple sectors, accelerating positive change, and be taken up by the national health services in all countries globally.

5. Immediate actions for a healthy, sustainable ocean and a healthy human future

The previous sections of this Blue Paper have shown that the health and wellbeing of humanity, as well as the state of the global economy, are linked inextricably to the health of the ocean. We find that a healthy ocean benefits human health and wellbeing in many ways:

- The ocean sustains all life on Earth by providing 50 percent of the oxygen produced on Earth each year and 80 percent of all the oxygen ever created (Grégoire et al. 2023).
- The ocean is critical to the fight against climate change (Hoegh-Guldberg et al. 2023; Villasante et al. 2023). It absorbs 25 percent of all CO_2 emissions and more than 90 percent of excess atmospheric heat, slowing global warming (Hoegh-Guldberg et al. 2023).
- The ocean is a source of new medicines and biotechnologies, from essential pain medicines, to cancer drugs, to plastic alternatives (Antunes et al. 2023; Bouley et al. 2023).
- For more than 3 billion people, nearly 40 percent of the world's population, the ocean is an essential source of food and livelihood (Golden et al. 2021b; FAO 2022; Tigchelaar et al. 2022).
- The ocean economy is estimated to generate $1.5 trillion to $2.5 trillion annually and to provide formal employment for more than 30 million people (OECD 2016), with millions more informally employed in artisanal and small-scale fisheries.
- Interactions with the ocean and with other blue spaces enhance the physical health and mental wellbeing of humans from infancy to old age (White et al. 2020).

The ocean's great benefits for humanity are threatened by climate change, worsening pollution and loss of biodiversity. All these threats are driven by the relentless quest for short-term economic gain (primarily by the Global North and by multinational corporations) without concern for the consequences for biodiversity, equity, health, human dignity or sustainability (Whitmee et al. 2015; Abbasi et al. 2023).

We must act now to address this global ocean and human health emergency. Building cross-national, cross-sectoral partnerships, engaging and involving marginalised communities, and sustaining a global structure of laws, treaties, organisations and regulations that protect the environment and prioritise human health and wellbeing will be essential.

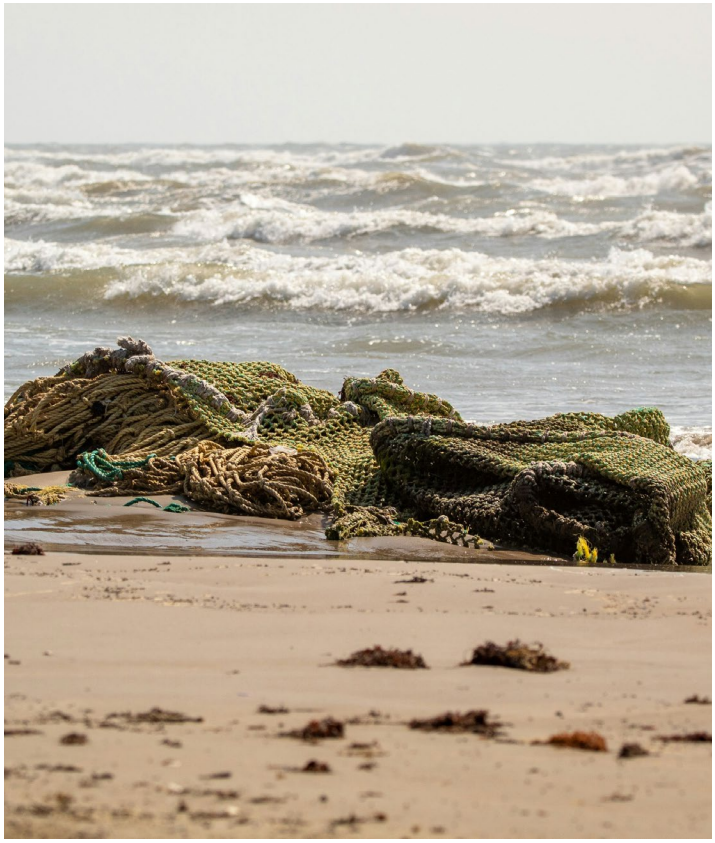
Past successes in environmental remediation and health protection, such as the global removal of lead from petrol, the Montreal Protocol ban restricting aerosol products containing chlorofluorocarbons and hydrochlorofluorocarbons, improvements in ambient air quality in a growing number of nations, and the Paris Climate Agreement, show that positive change is possible and attainable. And because LMICs are disproportionately impacted, increasing the scope and impact of ocean policies to mitigate climate change and prevent ocean pollution has the potential to improve the environment and human health and deliver a more equitable ocean environment.

Reducing pressures on the ocean

The evidence presented in previous sections of this Blue Paper documents that the health of the ocean is increasingly under threat. These threats are largely of human origin and have been worsening rapidly over the past 50 years. Moreover, evidence is mounting that environmental damage to the coasts, seas and ocean inevitably harms human health and wellbeing. It damages the global economy. And it exacerbates poverty and social injustice. Humans cannot thrive when the ocean is sick (Fleming et al. 2023).

The negative consequences for human health and wellbeing of damaging the ocean are many. Coastal flooding and violent storms destroy coastal communities and result in disease, injury and death. The collapse of fisheries results in malnutrition, starvation, migration and even war. Mercury pollution results in brain injury in infants exposed before birth via maternal consumption of contaminated fish. Plastic pollution, including in the form of lost or discarded fishing gear, entangles whales and turtles, kills seabirds, results in microplastic pollution of food chains and accumulates on beaches and in mangroves. Evidence is building that chronic exposure to microplastics impairs health and increases risk for noncommunicable diseases (Landrigan et al. 2023).

All these negative impacts fall with disproportionate severity on poor, minority, Indigenous and marginalised communities and on countries in the Global South (Landrigan et al. 2023). They are exacerbated by climate change, uncontrolled economic growth, perverse economic incentives and inequality in land and ocean resource ownership (Whitmee et al. 2015; Ma et al. 2021; Callahan and Mankin 2022).



There are multiple gaps in our knowledge of the ocean and in the current understanding of the harms to human health and wellbeing that result from damages to the ocean. Even less is known about the interactions among these harms to the ocean and their possible synergistic impacts on human health.

But we do know with a high degree of certainty that great damage has already been done to the ocean, that human activity is the main cause of this damage and that in the absence of urgent intervention, this damage will only grow worse. We know, in short, that our current use of the ocean is not sustainable.

Recognising and mapping the many harms done to the ocean is, however, only one part of the story of humanity's interaction with the ocean.

On the positive side, this Blue Paper emphasises that the ocean offers myriad, still largely undiscovered benefits for human health and wellbeing, as well as enormous opportunities for sustainably and equitably strengthening the global economy. Properly and equitably accessed, these benefits could address many of the challenges that surround us today and could sustain humanity in the centuries to come.

The key to realising these benefits will be to harness our intelligence and creativity, curb our appetite for short-term gain, rebalance our relationship with nature and with each other, and take individual and collective evidence-based action to protect and restore the health of the ocean for the good of all humanity (Kelly et al. 2023).

The achievement of these goals will require building cross-sectoral and cross-national partnerships based on mutual respect and creating and honouring a global network of laws, treaties, regulations and organisations that truly involve marginalised communities and whose goal is to promote health, wellbeing, equity and social justice for the good of all humanity and the ocean.

Synthesis of actions and opportunities

The actions highlighted in Sections 1–4, if begun immediately and fully implemented, will ensure that humanity enjoys sustainable and equitable ocean-based opportunities now and for many generations to come. These benefits will advance medicine and biotechnology; food security; and physical,

mental and social wellbeing. They can help resolve the injustices caused by economic, social and other inequalities.

The health sector can lead the way as industry leaders across diverse sectors and suppliers, placing nature and ocean at the centre of all strategies through understanding and monitoring its own environmental footprint, helping recovery from decades of mistreatment, re-examining equitable connections to our coasts and ensuring that initiatives benefit both humans and all our natural environments.

In addition, we support the call of the 18 heads of state who comprise the High Level Panel for a Sustainable Ocean Economy (Ocean Panel 2020):

> *We have a collective opportunity and responsibility to protect and restore the health of our ocean, and build a sustainable ocean economy that can provide food, empower coastal communities, power our cities, transport our people and goods, and provide innovative solutions to global challenges.*

The ocean and human health actions presented below can begin immediately and build on those outlined in the Transformations Agenda under the five pillars of health, equity, knowledge, wealth and finance (Ocean Panel 2020) (see Table 1 and Figure 6).

ACTIONS OF OVERARCHING IMPORTANCE

Three key actions of overarching importance must begin immediately and will enhance and sustain the specific actions recommended in the preceding sections of this Blue Paper:

- **Protect, restore and manage biodiversity**: The great potential for marine medicines and biotechnology and marine food sources depends on collaboratively and effectively protecting and managing marine biodiversity. **To this end, the world's nations need to ratify and implement—with genuine commitment to effective management for biodiversity protection, equity and human wellbeing goals—the Convention on Biological Diversity (CBD) Global Biodiversity Framework, the WTO Fisheries Subsidies Agreement and the Agreement under the UN Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ),** in collaboration with local resource users. These are global actions of overarching importance that can and will protect and restore the ocean, improve human health and wellbeing, and reduce stressors on ocean ecosystems. The resourced, equitable and intentional implementation of MPAs and OECMs is a no-regret solution with clear co-benefits for both ocean and human health.
- **Combat climate change and eliminate pollution**: The health of coastal populations depends on slowing climate change to prevent extreme weather events and limit sea level rise, and limiting to the greatest degree possible all pollution from reaching the ocean to conserve healthy marine food sources, with particular focus on reducing emissions from fossil fuels to net zero by 2050 and eliminating plastic pollution. **Uphold the commitments of countries to the Paris Agreement, the COP 28 outcomes and the UN Global Plastics Treaty, currently in negotiation.** To protect human health and wellbeing, the UN Global Plastics Treaty must impose strict safety requirements on the more than 10,000 synthetic chemicals added to plastics, a mandatory cap on global plastic production and mechanisms to curb the manufacture of single-use plastics. The EU Zero Pollution vision is a cross-cutting objective contributing to the UN 2030 Agenda for Sustainable Development and complementing its 2050 climate-neutrality goal. It steers the European Union towards the 2050 vision of a 'Healthy Planet for All' by setting key 2030 targets to speed up pollution reduction. Its main objective is to include pollution prevention in all relevant EU policies. Other countries should follow suit.
- **Improve measurement and support equity**: Integrate linked ocean health and human health indicators as well as metrics of natural and human capital for ongoing monitoring, prevention and evaluation programmes and make these data widely available. **Incorporate the evidence and linked indicators of both ocean and human health into all policies and decision-making around ocean-human interactions.** We need to simultaneously deploy indicators of both human and ocean health to establish baselines and to track changes in both ocean and human health as actions and interventions (including those outlined below) are rolled out with an overall vision of always improving sustainability and equity. Through continued measurement, effectiveness can be assessed, unintended consequences detected, policies improved and course corrections made towards long-term prevention and equity. To be useful, these monitoring data and appropriate expertise must be shared widely and made available and accessible.

The following symbols are used to cross-reference to the thematic topic, as explored in the sections of this Blue Paper.

 Medicine and biotechnology

 Building and sustaining food security

 Enhancing physical health, mental health and societal wellbeing

 Growing the economy and improving health by addressing inequity

Ocean and human health actions

 **Governments must take action to effectively conserve and manage biodiversity, encourage increased investment support for sustainable and ethical marine biotechnology start-ups with benefit sharing, and support responsible transdisciplinary research.** This must be co-designed and implemented with the participation of local communities and other potentially impacted stakeholders.

 **All industries including (and especially) healthcare must minimise their ocean footprint, helping restore what has been lost and including good ocean stewardship in sustainability strategies**. Polluters should pay, instead of profiting from the destruction of ocean and other ecosystems. Systematic incentive structures are needed for industries to invest in long-term sustainable practices. The goal must be to create the inclusive, accessible, clean, productive and resilient ocean called for in the UN Ocean Decade (UN 2021), an ocean that equitably and sustainably benefits the health and wellbeing of all global citizens now and in future generations.

 **Collaboration between the healthcare and supplier industries (and other sectors) with improved education and communication** can lead to changes in procurement frameworks, minimising ocean impacts from product manufacture, use, disposal and marine logistics (see Case study 11). As an example, seaweed-derived home-compostable bioplastics can be utilised for community healthcare products, reducing the need for fossil fuel–derived single-use plastics.

 **Researchers and public health organisations must scan the horizon for emerging climate-associated disease threats** such as antimicrobial-resistant water- and vector-borne diseases in the ocean which not only produce disease in individuals and communities but collectively strain healthcare systems, making it more difficult for them to reduce their climate and pollution footprint.

Ocean equity actions

 **Ensure genuine engagement of coastal communities, small-scale fishers and Indigenous Peoples in local marine planning, recognising traditional territories and/or incorporating OECMs.** The resilience of coastal communities is part of the resilience assessment of any coastal area.

 **Uphold the marine tenure of local communities and Indigenous Peoples** to help support stewardship of the ocean and the security of food, livelihoods and a way of life. This needs to be made explicit when new governance structures are introduced.

 **Create new institutional structures to facilitate multi-actor, cross-sectoral collaborations.** Responsible business practices that engage and co-create with coastal communities, creating inclusive governance in planning and decision-making processes, are essential. However, we need to go further to bridge the organisational and community divides and address the challenges of the full socioeconomic and ecological system, and enable human and ocean health.

Ocean knowledge actions

 **Enhance ocean skills and knowledge by investing in DNA libraries** containing the genetic blueprints of marine life in the ocean. The rich genetic biodiversity of marine species is threatened by habitat destruction, over-exploitation, land-based development and pollution, climate change, de-oxygenation and ocean acidification. We can better appreciate, manage and sustainably utilise the species in the ocean if this resource is

jointly owned by governments to support ethical investment and public-private partnerships to develop ocean-sourced medicines, and a variety of new products using the DNA blueprints.

Develop and share technologies and management approaches to produce sustainable, nutrition-sensitive marine food. The ocean provides valuable food and nutrition security to many people. Seafood is generally a good source of dietary micronutrients (e.g. omega-3) that can be increased sustainably and equitably. However, we must address growing inequalities in seafood distribution and consumption.

Share scientific data and expertise through collaborations and partnerships between global institutions and coastal communities to sustainably and equitably manage marine food production already impacted by a combination of climate change, overfishing, pollution and globalisation. For example, small-scale fishers (including women) should be supported who have knowledge useful for the sustainable management of extractive marine food such as seaweeds and molluscs.

Foster pro-ocean policies that will ensure pro-environmental behaviour through knowledge-sharing, ocean literacy and citizenship, increasing sustainable and high-quality blue space access, and appealing to personal and societal values. This is particularly important for the healthcare sector: significantly undervalued, the ocean provides many benefits to human health and wellbeing.

Ocean wealth actions

Identify management processes and ocean products that should be developed as socially relevant, economically sustainable and environmentally friendly so that the ocean can continue to produce sustainably for future generations. The ocean holds enormous, still undiscovered, potential for new medicines, new materials and new products.

End overfishing, reduce seafood loss and waste and stop illegal seafood harvesting, including by ratifying and implementing the Agreement on Port State Measures. Seafood plays an essential role in the diet of the world's populations, providing proteins and micronutrients. But these resources must not be diverted (as they currently are through mostly legal means) to the benefit of the richest countries.

Support sustainable mollusc and seaweed cultivation and harvest. The development of food technologies with a low carbon footprint should be encouraged. In addition to its potential as food, seaweed has many other potential sustainable uses, such as animal feed, fertilisers, bio-plastics and bio-fuels.

Upscale existing, and develop new, blue care prescription programmes. The cost to society of chronic diseases (cardiovascular, mental health, etc.) has been demonstrated, as has the contribution to health and wellbeing of access to marine and other blue space areas (a process known as the 'Blue Health Effect'). Make the ocean sustainably and equitably accessible for targeted intervention programmes to reduce health-related and other costs.

Ocean finance actions

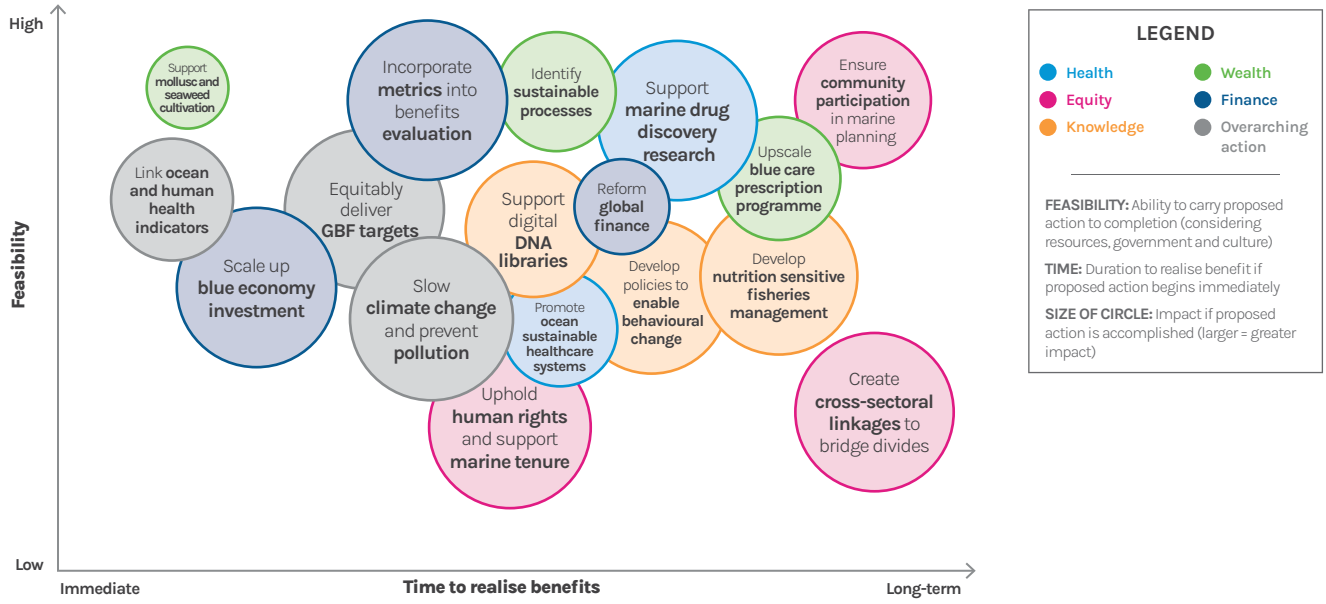
Deliver blue health economy investment pathways that align with Sustainable Ocean Plans for 100 percent of the ocean. These would facilitate access to effective healthcare, blue foods and clean water for all coastal and island communities, and increase opportunities to engage in marine research and product development around the globe. Knowledge and management of marine ecosystems is underfunded, and the opportunities for returns are often not fully appreciated, yet the world economy depends on a healthy blue planet.

Reform global finance and trade to provide more equitable access to marine resources. Build on recent multilateral successes (e.g. the new UN High Seas Treaty and the WTO agreement) to phase out selected fisheries subsidies. To this end, redirect finance to support investment in technologies that support sustainable production practices and efforts to meet global climate targets; slow the removal of nutritious aquatic foods from nations with a high prevalence of nutrient deficiencies; and ensure that trade works for low-income nations, through debt relief and aligning trade with domestic food security policy. These efforts could target other subsidies that lead to overfishing and overcapacity but remain in place.

Link the health and ocean finance institutional efforts with a focus on ocean-positive actions and blue infrastructure investments that use nature-based solutions to deliver equitable returns to human and ocean health. By integrating ocean wellbeing solutions systemically into public health and social care, we can reduce costs and improve outcomes.

This requires key reforms of the global trade and finance system, integrating inclusive and ethical accounting for both nature and human wellbeing. Public-private partnerships and insurance solutions can serve to deliver further support and introduce price signals. Using these formats will help to re-allocate risk and encourage private sector engagement alongside public funders.

FIGURE 6. **Opportunities for action to support both ocean health and human health and wellbeing in a changing planetary environment**



Notes: GBF = Global Biodiversity Framework. Circles are plotted by feasibility (y-axis—ability to carry proposed action to completion considering resources, government and culture) and time to realise benefits (x-axis—the duration required to realise benefits of proposed action). The relative size of the circle reflects the magnitude of impact of the action (in terms of overall benefit to ocean and human health globally). All actions need to be initiated immediately. This figure is included primarily as a visual aid for readers. It is based on the authors' interpretation of best available evidence, not a quantitative analysis of all available information.

Source: Authors.

TABLE 1. **Summary of key recommended actions to promote human and ocean health**

OPPORTUNITY/ACTION IDENTIFIED	TRANSFORMATIONS AGENDA PILLAR (OCEAN PANEL 2020)	THEME	ACTORS	FEASIBILITY LOW TO HIGH (1–5)	TIMING TO REALISE BENEFIT SHORT-TERM TO LONG-TERM (1–5)	MAGNITUDE OF IMPACT LOW TO HIGH (1–5)
Equitably deliver the Global Biodiversity Framework targets, with genuine commitment to equity and human wellbeing goals and integrating other effective area-based conservation measures	Overarching actions	Overarching actions	Government	4	2	5
Slow climate change and prevent pollution from reaching the ocean, particularly by reducing greenhouse gas emissions from fossil fuels to net zero by 2050 and eliminating plastic pollution			Government and private sector	2	3	5
Link ocean and human health indicators for ongoing monitoring, prevention and evaluation with shared data			Government	4	1	4
Support equitable and sustainable marine medicine discovery research	Health	Medicine and biotechnology	Government and private sector	4	4	5
Promote ocean-sustainable healthcare systems		Enhancing physical health, mental health and societal wellbeing	Government and healthcare sector	3	3	3
Uphold human rights and support marine tenure for local communities and Indigenous Peoples	Equity	Building and sustaining food security	Government	3	3	5
Ensure community co-creation and involvement in marine planning		Building and sustaining food security	Government	5	4	4
Create cross-sectoral linkages to bridge divides and encourage co-creation		Growing the economy and improving health by addressing inequity	Government and private sector	2	5	5
Create and support digital DNA libraries containing the genetic blueprints for most marine life	Knowledge	Medicine and biotechnology	Government and private sector	4	3	4
Promote sustainable, nutrition-sensitive aquaculture and fisheries management		Building and sustaining food security	Government and private sector	4	4	5
Develop policies to enable behavioural change to foster pro-environmental behaviour		Enhancing physical health, mental health and societal wellbeing	Government	3	3	5

TABLE 1. **Summary of key recommended actions to promote human and ocean health (cont.)**

OPPORTUNITY/ACTION IDENTIFIED	TRANSFORMATIONS AGENDA PILLAR (OCEAN PANEL 2020)	THEME	ACTORS	FEASIBILITY LOW TO HIGH (1–5)	TIMING TO REALISE BENEFIT SHORT-TERM TO LONG-TERM (1–5)	MAGNITUDE OF IMPACT LOW TO HIGH (1–5)
Identify processes and products to be developed as socially relevant, economically sustainable and environmentally friendly	Wealth	Medicine and biotechnology	Government and private sector	5	4	4
Support sustainable seafood cultivation and harvest		Building and sustaining food security	Government and private sector	5	1	3
Upscale blue care prescription programmes		Enhancing physical health, mental health and societal wellbeing	Government and healthcare sector	4	4	3
Scale up investment in a sustainable and equitable ocean economy	Finance	Growing the economy and improving health by addressing inequity	Government, private sector and philanthropy	4	2	5
Incorporate metrics of natural capital and human capital into all benefits evaluations		Growing the economy and improving health by addressing inequity	Government	5	3	5
Reform global finance and trade to provide more equitable access to marine resources		Growing the economy and improving health by addressing inequity	Government	3	3	4

Note: Actions are categorised by both the themes of this Blue Paper, and by the themes of the Transformations Agenda (Ocean Panel 2020). The broad delivering party for each action is also indicated. All actions need to be initiated immediately. Scorings in this table are semi-quantitative and based on the authors' interpretation of best available evidence, not a fully quantitative analysis of all available information.

Conclusion

We must act now to address the growing challenges of the climate and health crisis. It is essential to begin to implement these Blue Paper actions immediately in order to prevent more damage, realise the benefits of these actions, and protect both ocean and human health into the future.

Most of these actions are already represented in current and ongoing global policy efforts relevant to protecting and sustaining both ocean and human health. Therefore, it is important to uphold and implement the many existing relevant policy actions (e.g. 30x30 with integration of OECMs; the International Covenant on Economic, Social and Cultural Rights; responsible business and innovation) mentioned throughout this Blue Paper.

In addition to the ongoing work of the Ocean Panel, new policy actions towards ocean and human health are also emerging. For example, in the recent Vigo Declaration (2023), members of the European marine science community have pledged to work together to ensure ocean sustainability; the Villars Framework (2023) redirects finance towards investment in technologies that support sustainable fisheries production practices and efforts designed to meet global climate targets (Cheung et al. 2023); and ongoing international efforts by the United Nations and many others seek to support and produce a legally binding global plastics treaty (UNEP 2021). The resolutions from the UN Human Rights Council in 2021 (A/HRC/RES/48/13) and the UN General

Assembly in 2022 (A/RES/76/300) recognise that a clean, healthy and sustainable environment is a human right, giving legal value to the environment; these resolutions also help protect individuals and communities from environmental risks to their health and livelihoods (UNGA 2021). The historic examples of the Montreal Protocol, the Stockholm Convention and the Minamata Convention show us that positive change is attainable, and that humanity can come together to thrive and to preserve planetary health.

Going forward, coastal communities, the healthcare sector, government, academia, business and finance need to join and support these global cooperative efforts for ocean and human health (U.S. Ocean Policy Committee 2023). In the face of uncertainty about strategies for managing ocean resources, governments and international organisations should be guided towards a vision of universal ocean citizenship and planetary stewardship (Kelly et al. 2023) and apply the precautionary principle to prevent future harm (Spalding 2016). Only then can we provide truly transdisciplinary, science-based policy advice and action in all levels of governance, with sustainability, equity and inclusion at the core of all their actions, to ensure that the best decisions are made for both the ocean and people, with no one left behind.

Appendix A. Key definitions and glossary

WORD/CONCEPT	DEFINITION	SOURCE
Blue justice	An effort to empower coastal communities responding to blue injustices through centring their knowledge, strength and agency. 'Ultimately, concerted efforts are needed by all to support and empower coastal communities to reject blue injustices and to achieve their diverse aspirations for blue justice.'	Blythe et al. 2023
Environmental change	A result of both natural and human processes. In the current geological era, the Anthropocene, most environmental change is the consequence of human action and results from the transformation and transportation by humans of large quantities of energy and materials.	EEA 1995
Environmental (ocean) health inequity	A disproportionate burden of harmful environmental exposure and environmentally related health injury among poor, minority, marginalised and Indigenous communities.	Gochfeld and Burger 2011
Equity	The fair allocation of resources and opportunities to all groups in a society. The absence of systematic disparities in health (or in the major social determinants of health) between social groups who have different levels of underlying social advantage or disadvantage.	Braveman and Gruskin 2003
Food security	The availability, accessibility, sustainability and stability of food supplies, the ability of people's bodies to make use of the food they eat, and people's agency to access enough of the right types of culturally relevant foods.	HLPE 2020; Clapp et al. 2022
Green chemistry	The design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances during industrial chemical processes.	Anastas and Warner 2000
Health	A state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity.	WHO 1946
Healthcare sector	All organisations, people and actions whose primary intent is to promote, restore or maintain health. This includes hospitals, healthcare systems, public health, pharmaceuticals, social care and Indigenous health.	WHO 2007
Healthcare systems	Defined broadly, systems that 'encompass the full continuum between public health (population-based services) and medical care (delivered to individual patients)'.	Woolf and Aron 2013
Health equity	The absence of unfair, avoidable or remediable differences in health status among population groups defined socially, economically, demographically or geographically.	WHO 2020
Illegal, unreported and unregulated (IUU) fishing	A broad term that includes the use of bonded labour, destructive fishing practices and deception to reap profits at the expense of local fisheries, coastal states and the marine environment. IUU threatens the sustainability of global fisheries in national coastal waters and on the high seas.	Widjaja et al. 2021
Low- and middle-income countries (LMICs)	A classification of countries based on their gross national income per capita. The categories range from $1,045 or less for low-income countries to $4,096–$12,695 for upper-middle-income countries.	Lencucha and Neupane 2022
Marine protected area (MPA)	Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, and historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment.	Resolution 17.38 of the IUCN General Assembly, 1988, reaffirmed in Resolution 19.46, 1994

WORD/CONCEPT	DEFINITION	SOURCE
Marine tenure	Establishes a set of rights and responsibilities as to who is allowed to use which resources, in what way, for how long and under what conditions, as well as who is entitled to transfer rights to others and how.	USAID 2017
Nature-based solutions (NBS)	Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human wellbeing, ecosystem services, resilience and biodiversity benefits.	UNEP 2022
Ocean coasts, seas, global ocean)	'Ocean' versus 'oceans': In the ocean literacy community, the terms 'ocean' and 'global ocean' both in the singular) are increasingly used to express the concept that the world's 'oceans' are, in fact, one ocean, which contains unique ecosystems within specific regional ocean areas, and for which all humans have a shared responsibility.	Fleming et al. (2023
Ocean 'health'	The state of the ocean when it is resilient, productive and diverse.	Franke et al. 2020
Other effective area-based conservation measures (OECMs)	A geographically defined area other than a protected area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity with associated ecosystem functions and services and, where applicable, cultural, spiritual, socioeconomic and other locally relevant values.	CBD 2018
Public-private partnerships (PPPs)	Long-term agreements between government and a private partner whereby the private partner delivers and funds public services using a capital asset, sharing the associated risks. PPPs may deliver public services both with regards to infrastructure assets (such as bridges and roads) and social assets (such as hospitals, utilities and prisons).	OECD 2012
Small island developing states (SIDS), also known as a 'large ocean states'	A distinct group of 39 States and 18 Associate Members of UN regional commissions that face unique social, economic and environmental vulnerabilities.	UN 2023a
Social innovations	The design and implementation of new solutions that imply conceptual, process, product or organisational change, which ultimately aim to improve the welfare and wellbeing of individuals and communities.	OECD n.d.
Social prescribing	The holistic approach of healthcare workers connecting patients to a range of non-clinical services in the community to improve health and wellbeing. Social prescribing seeks to address the underlying causes of patients' health and wellbeing concerns, as opposed to simply treating symptoms.	WHO 2022
Wellbeing	A positive state experienced by individuals and societies. Wellbeing encompasses both physical health and mental health and is determined by social, racial economic, environmental and historical conditions.	WHO 2021
Frameworks		
Ecological public health	Material, biological, social and cultural aspects of public health considered in a way that accepts the complexity and non-linearity of the dynamics of natural systems.	Lang and Rayner 2012
Ecosystem services	Benefits that people obtain from ecosystems, which include provisioning services that products such as food, fuel, water, medicines and fibre; regulating services such as climate regulation and disease control; and cultural services that provide nonmaterial benefits such as spiritual or aesthetic benefits.	Watson et al. 2005

WORD/CONCEPT	DEFINITION	SOURCE
Frameworks (cont)		
Global health	The pursuit of health equity at a global level by addressing transnational health issues, determinants and interventions and formal structures beyond the control of national institutions.	Smith et al. 2006
One health	A collaborative, multi-sectoral and transdisciplinary approach—working at the local, regional, national and global levels—with the goal of achieving optimal health outcomes while recognising the interconnection among people, animals, plants and their shared environment.	CDC 2023
Pillars of sustainability	The three equally dependent dimensions—economic, social and environmental—of sustainable development.	UNGA 2015
Planetary boundaries	A framework that defines a safe operating space for humanity based on the intrinsic biophysical processes that regulate the stability of the Earth system.	Steffen et al. 2015
Planetary health	The health of human civilisation and the state of the natural systems on which it depends. OR The understanding that human health and human civilisation depend on flourishing natural systems and the wise stewardship of those natural systems.	Whitmee et al. 2015
Public health	The science and art of preventing disease, prolonging life and promoting health through the organised efforts and informed choices of society, organisations, public and private communities, and individuals.	CDC 2021
Sustainable ocean economy	The sustainable use of ocean resources for economic growth, improved livelihoods and jobs while preserving the health of ocean ecosystems.	World Bank and UNDESA 2017

Appendix B. Summary of key recommended actions by section

Actions to promote human and ocean health. All actions need to be initiated immediately. Note, scorings in this table are only semi-quantitative and based on the authors' expert opinion, employing best available evidence. They do not represent a fully quantitative analysis of all available information.

SECTION	OPPORTUNITY/ACTION	DETAILS	FEASIBILITY 1–5 (LOW TO HIGH)	TIME TO REALISE BENEFITS 1–5 (SHORT-TERM TO LONG-TERM)	MAGNITUDE OF IMPACT 1–5 (LOW TO HIGH)
1	Create and support digital DNA libraries containing the genetic blueprints for most marine life	Monumental efforts, including the Earth BioGenome Project (n.d.), the International Barcode of Life Consortium (n.d.) and the Darwin Tree of Life Project (n.d.), need stable international funding by consortia of nation-states. It is conceivable that the DNA blueprints saved in these projects could be used to 'resurrect' species that go extinct.	4	4	5
1	Improve funding for equitable and sustainable marine medicine discovery research that connects biodiverse but financially-poor countries with wealthy ones	Much marine life remains unstudied for its potential to yield valuable resources, especially in regions where scientific infrastructure is not well developed. International research partnerships that connect biodiversity-rich regions with those having high scientific capacity—while also promoting scientific training, building capacity, following good stewardship practices and abiding by international standards recognising the inherent rights of countries to their genetic resources—should receive broad financial support. Such investments have the potential to advance scientific development in low- and middle-income countries (LMICs) while also advancing attainment of the UN Sustainable Development Goals.	4	4	5
1	Prioritise development of marine-based processes and products that are socially relevant, economically sustainable and environmentally friendly	Assessment of the published literature by expert bodies can identify promising processes and products. Impacts of such products must be considered in a balanced way, taking into full account policies, needs and negative results.	5	4	5
2	Uphold human rights and support marine tenure	Strategies that can help uphold human rights—and eliminate the most egregious disparities related to income, race, education and gender affecting food security and nutrition—include understanding and bolstering marine tenure (Cohen et al. forthcoming); recognising, protecting and supporting ocean defenders; and legislating principles of do-no-harm to guide international investments and transnational corporations involved in aquatic food production practices (Wallis 2005; Human Rights at Sea 2023).	2	2	4

SECTION	OPPORTUNITY/ACTION	DETAILS	FEASIBILITY 1–5 (LOW TO HIGH)	TIME TO REALISE BENEFITS 1–5 (SHORT-TERM TO LONG-TERM)	MAGNITUDE OF IMPACT 1–5 (LOW TO HIGH)
2	Reform global finance and trade to provide more equitable access to marine resources	Reforming the global financial and trade system, such that sustainability and equity are at the core, could build on recent multilateral successes. These include the new UN High Seas Treaty and the World Trade Organization's success in phasing out some fishery subsidies; although other subsidies that lead to overfishing and overcapacity remain in place (Sumaila et al. 2019; Stokstad 2023). Building on these successes, multilateral cooperation in trade should now look to redirect finance to support investment in technologies that support sustainable production practices and efforts to meet global climate targets (Cheung et al. 2023); slow the removal of nutritious aquatic foods from nations with a high prevalence of deficiencies (Nash et al. 2022); and ensure that trade works for low-income nations, through debt relief and aligning trade with domestic food security policy (Villars Framework 2023).	3	3	4
2	Develop sustainable nutrition-sensitive aquaculture and fisheries management approaches	With nutrient composition data for fish species now widely available (Hilborn et al. 2020), successful approaches to fishery management can be identified or adapted to support a sustainable increase in the production of fish rich in target nutrients to help close population-level nutrient gaps (Robinson et al. 2022). Such an approach can help maximise the contributions of wild-caught fish to global food and nutrition security.	3–4	1–3	2
3	Promote ocean-sustainable healthcare systems and practices	Conventional healthcare systems need to embed ocean criteria in their climate strategies and harness their influence with healthcare suppliers through procurement frameworks that address both climate and ocean criteria (such as pollution mitigation) to protect ocean and human health (see Case study 7).	2	3	3
3	Ensure local community co-creation in all localised planning implicating the marine environment	Interdisciplinary urban 'blue acupuncture' initiatives to improve access to a local beach in a deprived community should be co-designed with local residents, schoolchildren, community actors and local government (Mishra et al. 2023).	5	4	2

SECTION	OPPORTUNITY/ACTION	DETAILS	FEASIBILITY 1–5 (LOW TO HIGH)	TIME TO REALISE BENEFITS 1–5 (SHORT-TERM TO LONG-TERM)	MAGNITUDE OF IMPACT 1–5 (LOW TO HIGH)
3	Upscale existing, and develop new, blue care prescription programmes	Upscale blue prescribing programmes that encourage participatory management with local communities, prioritise underserved groups and contribute to ocean or coastal recovery (as seen in Case study 6 and Case study 8). A further benefit of these programmes is that they provide opportunities to support the health and wellbeing of marginalised groups (including people of colour), allowing them to re-engage with beaches and other high-quality blue spaces from which they have been excluded because of historical racial and other segregation or complete lack of access.	4	4	3
4	Develop and deploy indicators to measure progress in both ocean and human health	The use of economic indicators, such as gross domestic product, has failed to capture the natural capital provided by a healthy ocean, while also hiding how these benefits are derived and to whom these benefits accrue (Fenichel et al. 2020). The development and use of holistic indicators that account for the distribution of wealth from ocean activity, while prioritising both ocean and human health, offer a key opportunity to highlight the need for, and the returns from, an inclusive ocean and human health–centred ocean economy agenda (Kumar et al. 2019).	4	3	4
4	Advance behavioural change policies to foster pro-environmental behaviour for ocean and human health	In the healthcare sector, pharmaceuticals are crucial for improving healthcare but often end up in the ocean; particularly in LMICs where labour is cheap, environmental laws less stringent and where many pharmaceuticals are made. An example of an early-stage intervention to combat the impact of pharmaceuticals in the ocean is Scotland's first blue-green prescribing programme to protect the ocean from pharmaceutical pollution by using nature-based health interventions (Janković 2023).	3	3	4
4	Catalyse actions to create cross-sectoral linkages, encourage co-creation and bridge organisational divides	An example of a good practice is outlined in Case study 9, which highlights the capacity for communities in southern coastal Bangladesh to develop locally sustaining, inclusive actions with ocean and human health that also have the potential to further encourage multi-sector collaborations across local, regional and national scales (Islam et al. 2021; Islam 2022).	2	4	4

References

Abbasi, K., P. Ali, V. Barbour, T. Benfield, K. Bibbins-Domingo, S. Hancocks, R. Horton et al. 2023. "Time to Treat the Climate and Nature Crisis as One Indivisible Global Health Emergency." *BMJ* 383: 2355. https://doi.org/10.1136/bmj.p2355.

Acheson, J., and A. Acheson. 2020. "What Does the Future Hold for Maine's Lobster Industry?" *Maine Policy Review* 29: 83–90. https://digitalcommons.library.umaine.edu/mpr/vol29/iss2/11.

Ahern, M.B., S.H. Thilsted, M. Kjellevold, R. Overå, J. Toppe, M. Doura, E. Kalaluka et al. 2021. "Locally-Procured Fish Is Essential in School Feeding Programmes in Sub-Saharan Africa." *Foods* 10 (9). https://doi.org/10.3390/foods10092080.

Ajayi, O., M. Bottema, A. Frankfort, G. Parkes, V. Erasmus, D. Russell, M. Siggs et al. 2023. *Maximizing Seafood By-product Utilization: Heads and Viscera Left at Sea. A Case Study on Namibian Hake.* World Economic Forum. https://www3.weforum.org/docs/WEF_Maximizing_Seafood_By_Product_Utilization_2023.pdf.

Allegretti, A., and C.C. Hicks. 2023. "'Getting the Right Nutrients to Those Who Need Them Most': Towards Nutrition-Sensitive Governance of Fisheries in the Global South." *Reviews in Fish Biology and Fisheries* 33 (3): 561–71. https://doi.org/10.1007/s11160-022-09743-6.

Allison, E.H., A.L. Perry, M.-C. Badjeck, W.N. Adger, K. Brown, D. Conway, A.S. Halls et al. 2009. "Vulnerability of National Economies to the Impacts of Climate Change on Fisheries." *Fish and Fisheries* 10 (2): 173–96. https://doi.org/10.1111/j.1467-2979.2008.00310.x.

Anastas, P.T., and J.C. Warner. 2000. *Green Chemistry: Theory and Practice.* New York: Oxford University Press.

Antunes, E.M., D.R. Beukes, E.J.E. Caro-Diaz, N.E. Narchi, L.T. Tan and W.H. Gerwick. 2023. "Medicines from the Sea." In *Oceans and Human Health, Opportunities and Impacts*, edited by L. Fleming, L.B. Alcantara-Creencia, W.H. Gerwick, H.C. Goh, M.O. Gribble, B. Maycock and H. Solo-Gabriele. Amsterdam: Elsevier.

Armitage, R. 2022. "Sewage in UK Waters: A Raw Deal for Wild Swimmers." *British Journal of General Practice* 72: 486–87. https://doi.org/10.3399/bjgp22X720833.

Bambra, C. 2011. "Health Inequalities and Welfare State Regimes: Theoretical Insights on a Public Health 'Puzzle.'" *Journal of Epidemiology and Community Health* 65 (9): 740–45. https://jech.bmj.com/content/jech/65/9/740.full.pdf.

Ban, N.C., G.G. Gurney, N.A. Marshall, C.K. Whitney, M. Mills, S. Gelcich, N.J. Bennett et al. 2019. "Well-Being Outcomes of Marine Protected Areas." *Nature Sustainability* 2 (6): 524–32. https://doi.org/10.1038/s41893-019-0306-2.

Bates, A.E., R.S.C. Cooke, M.I. Duncan, G.J. Edgar, J.F. Bruno, L. Benedetti-Cecchi, I.M. Côté et al. 2019. "Climate Resilience in Marine Protected Areas and the 'Protection Paradox.'" *Biological Conservation* 236: 305–14. https://doi.org/10.1016/j.biocon.2019.05.005.

Bayraktarov, E., M.I. Saunders, S. Abdullah, M. Mills, J. Beher, H.P. Possingham, P.J. Mumby and C.E. Lovelock. 2016. "The Cost and Feasibility of Marine Coastal Restoration." *Ecological Applications* 26 (4): 1055–74. https://doi.org/10.1890/15-1077.

Beal, T., E. Massiot, J.E. Arsenault, M.R. Smith, and R.J. Hijmans. 2017. "Global Trends in Dietary Micronutrient Supplies and Estimated Prevalence of Inadequate Intakes." *PLOS ONE* 12 (4): e0175554. https://doi.org/10.1371/journal.pone.0175554.

Beaumont, N.J., M.C. Austen, S.C. Mangi and M. Townsend. 2008. "Economic Valuation for the Conservation of Marine Biodiversity." *Marine Pollution Bulletin* 56 (3): 386–96. https://doi.org/10.1016/j.marpolbul.2007.11.013.

Beaumont, N.J., M. Aanesen, M.C. Austen, T. Börger, J.R. Clark, M. Cole, T. Hooper et al. 2019. "Global Ecological, Social and Economic Impacts of Marine Plastic." *Marine Pollution Bulletin* 142: 189–95. https://doi.org/10.1016/j.marpolbul.2019.03.022.

Belhabib, D., and P. Le Billon. 2022. "Fish Crimes in the Global Oceans." *Science Advances* 8 (12): eabj1927. https://doi.org/10.1126/sciadv.abj1927.

Belkhir, L., and A. Elmeligi. 2019. "Carbon Footprint of the Global Pharmaceutical Industry and Relative Impact of Its Major Players." *Journal of Cleaner Production* 214: 185–94. https://doi.org/10.1016/j.jclepro.2018.11.204.

Bell, S., H.S. Mishra, L.R. Elliott, R. Shellock, P. Vassiljev, M. Porter, Z. Sydenham and M.P. White. 2020. "Urban Blue Acupuncture: A Protocol for Evaluating a Complex Landscape Design Intervention to Improve Health and Wellbeing in a Coastal Community." *Sustainability* 12 (10). https://doi.org/10.3390/su12104084.

Belton, B., D.C. Little, W. Zhang, P. Edwards, M. Skladany and S.H. Thilsted. 2020. "Farming Fish in the Sea Will Not Nourish the World." *Nature Communications* 11 (1): 5804. https://doi.org/10.1038/s41467-020-19679-9.

Béné, C., B. Hersoug and E.H. Allison. 2010. "Not by Rent Alone: Analysing the Pro-poor Functions of Small-Scale Fisheries in Developing Countries." *Development Policy Review* 28 (3): 325–58. https://doi.org/10.1111/j.1467-7679.2010.00486.x.

Bennett, N.J. 2018. "Navigating a Just and Inclusive Path towards Sustainable Oceans." *Marine Policy* 97: 139–46. https://doi.org/10.1016/j.marpol.2018.06.001.

Bennett, N.J., T.S. Whitty, E. Finkbeiner, J. Pittman, H. Bassett, S. Gelcich and E.H. Allison. 2018. "Environmental Stewardship: A Conceptual Review and Analytical Framework." *Environmental Management* 61 (4): 597–614. https://doi.org/10.1007/s00267-017-0993-2.

Bennett, N.J., P. Le Billon, D. Belhabib and P. Satizábal. 2022. "Local Marine Stewardship and Ocean Defenders." *npj Ocean Sustainability* 1 (1): 3. https://doi.org/10.1038/s44183-022-00002-6.

Berdalet, E., L.E. Fleming, R. Gowen, K. Davidson, P. Hess, L.C. Backer, S.K. Moore et al. 2016. "Marine Harmful Algal Blooms, Human Health and Wellbeing: Challenges and Opportunities in the 21st Century." *Journal of the Marine Biological Association of the United Kingdom* 96 (1): 61–91. https://doi.org/10.1017/S0025315415001733.

Berkes, F., J. Colding and C. Folke. 2000. "Rediscovery of Traditional Ecological Knowledge as Adaptive Management." *Ecological Applications* 10 (5): 1251–62. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.

Berthe, A., and L. Elie. 2015. "Mechanisms Explaining the Impact of Economic Inequality on Environmental Deterioration." *Ecological Economics* 116: 191–200. https://doi.org/10.1016/j.ecolecon.2015.04.026.

Blasiak, R., J.-B. Jouffray, C.C.C. Wabnitz, E. Sundström and H. Österblom. 2018. "Corporate Control and Global Governance of Marine Genetic Resources." *Science Advances* 4 (6). http://advances.sciencemag.org/content/advances/4/6/eaar5237.full.pdf.

Blasiak, R., R. Wynberg, K. Grorud-Colvert, S. Thambisetty, N.M. Bandara, A.V.M. Canário, J. da Silva et al. 2020. The Ocean Genome: Conservation and the Fair, Equitable and Sustainable Use of Marine Genetic Resources. Washington, DC: World Resources Institute. https://oceanpanel.org/publication/the-ocean-genome-conservation-and-the-fair-equitable-and-sustainable-use-of-marine-genetic-resources/.

Blythe, J.L., D.A. Gill, J. Claudet, N.J. Bennett, G.G. Gurney, J.A. Baggio, N.C. Ban et al. 2023. "Blue Justice: A Review of Emerging Scholarship and Resistance Movements." *Cambridge Prisms: Coastal Futures* 1: e15. https://doi.org/10.1017/cft.2023.4.

Borg, B., S. Mihrshahi, M. Griffin, D. Sok, C. Chhoun, A. Laillou, J. Berger and F.T. Wieringa. 2018. "Randomised Controlled Trial to Test the Effectiveness of a Locally-Produced Ready-to-Use Supplementary Food (RUSF) in Preventing Growth Faltering and Improving Micronutrient Status for Children under Two Years in Cambodia: A Study Protocol." *Nutrition Journal* 17 (1): 39. https://doi.org/10.1186/s12937-018-0346-x.

Borg, B., S. Mihrshahi, A. Laillou, S. Sigh, D. Sok, R. Peters, C. Chamnan et al. 2019. "Development and Testing of Locally-Produced Ready-to-Use Therapeutic and Supplementary Foods (RUTFs and RUSFs) in Cambodia: Lessons Learned." *BMC Public Health* 19 (1): 1200. https://doi.org/10.1186/s12889-019-7445-2.

Börger, T., D. Campbell, M.P. White, L.R. Elliott, L.E. Fleming, J.K. Garrett, C. Hattam et al. 2021. "The Value of Blue-Space Recreation and Perceived Water Quality across Europe: A Contingent Behaviour Study." *Science of the Total Environment* 771: 145597. https://doi.org/10.1016/j.scitotenv.2021.145597.

Bottema, M.J.M., S.R. Bush and P. Oosterveer. 2021. "Assuring Aquaculture Sustainability beyond the Farm." *Marine Policy* 132: 104658. https://doi.org/10.1016/j.marpol.2021.104658.

Bouley, T.A., C. Machalaba, J. Keast, W.H. Gerwick and L.E. Fleming. 2023. "Marine Biotechnology: A One Health Approach to Linking Life on Land to Life Underwater." Chap. 6 of *Oceans and Human Health*, 2nd ed., edited by L.E. Fleming, L.B. Alcantara-Creencia, W.H. Gerwick, H.C. Goh, M.O. Gribble, B. Maycock and H. Solo-Gabriele, 149–80. San Diego, CA: Academic.

Braveman, P., and S. Gruskin. 2003. "Defining Equity in Health." *Journal of Epidemiology and Community Health* 57 (4): 254. https://doi.org/10.1136/jech.57.4.254.

Briley, J. 2023. "A Global Deal to End Harmful Fisheries Subsidies." *Pew Trust Magazine*, 1 February. https://www.pewtrusts.org/en/trust/archive/winter-2023/a-global-deal-to-end-harmful-fisheries-subsidies.

Britton, E., G. Kindermann, C. Domegan and C. Carlin. 2020. "Blue Care: A Systematic Review of Blue Space Interventions for Health and Wellbeing." *Health Promotion International* 35 (1): 50–69. https://doi.org/10.1093/heapro/day103.

Bruno, J.F., A.E. Bates, C. Cacciapaglia, E.P. Pike, S.C. Amstrup, R. van Hooidonk, S.A. Henson and R.B. Aronson. 2018. "Climate Change Threatens the World's Marine Protected Areas." *Nature Climate Change* 8 (6): 499–503. https://doi.org/10.1038/s41558-018-0149-2.

Bryars, S., and V. Neverauskas. 2004. "Natural Recolonisation of Seagrasses at a Disused Sewage Sludge Outfall." *Aquatic Botany* 80 (4): 283-289. https://doi.org/10.1016/j.aquabot.2004.09.001.

Byrd, K.A., J. Shieh, S. Mork, L. Pincus, L. O'Meara, M. Atkins and S.H. Thilsted. 2022. "Fish and Fish-Based Products for Nutrition and Health in the First 1000 Days: A Systematic Review of the Evidence from Low- and Middle-Income Countries." *Advances in Nutrition* 13 (6): 2458–87. https://doi.org/10.1093/advances/nmac102.

Callahan, C.W., and J.S. Mankin. 2022. "National Attribution of Historical Climate Damages." *Climatic Change* 172 (3): 40. https://doi.org/10.1007/s10584-022-03387-y.

Carmenta, R., J. Barlow, M.G. Bastos Lima, E. Berenguer, S. Choiruzzad, N. Estrada-Carmona, F. França et al. 2023. "Connected Conservation: Rethinking cConservation for a Telecoupled World." *Biological Conservation* 282: 110047. https://doi.org/10.1016/j.biocon.2023.110047.

Carroll, A.R., B.R. Copp, R.A. Davis, R.A. Keyzers and M.R. Prinsep. 2023. "Marine Natural Products." *Natural Product Reports* 40 (2): 275–325. https://doi.org/10.1039/D2NP00083K.

CBD (Convention on Biological Diversity). 2018. "Protected Areas and Other Effective Area-Based Conservation Measures." 2–7 July. https://www.cbd.int/doc/c/9b1f/759a/dfcee171bd46b06cc91f6a0d/sbstta-22-l-02-en.pdf.

CDC (Centers for Disease Control). 2021. "Introduction to Public Health." https://www.cdc.gov/training/publichealth101/public-health.html.

CDC. 2023. "One Health." https://www.cdc.gov/onehealth/index.html.

Cerone, M., and T.K. Smith. 2021. "A Brief Journey into the History of and Future Sources and Uses of Fatty Acids." *Frontiers in Nutrition* 8. https://www.frontiersin.org/articles/10.3389/fnut.2021.570401.

Chaijaroen, P. 2022. "Tradeoffs between Fertility and Child Development Attributes: Evidence from Coral Bleaching in Indonesia." *Environment and Development Economics* 27 (4): 295–315. https://doi.org/10.1017/S1355770X21000279.

Chau, R., J.A. Kalaitzis and B.A. Neilan. 2011. "On the Origins and Biosynthesis of Tetrodotoxin." *Aquatic Toxicology* 104 (1): 61–72. https://doi.org/10.1016/j.aquatox.2011.04.001.

CHEMnetBASE. n.d. "Dictionary of Natural Products." Accessed 23 October 2023. https://dnp.chemnetbase.com/chemical/ChemicalSearch.xhtml?dswid=-5745.

Cheung, W.W.L., E. Maire, M.A. Oyinlola, J.P.W. Robinson, N.A.J. Graham, V.W.Y. Lam, M.A. MacNeil and C.C. Hicks. 2023. "Climate Change Exacerbates Nutrient Disparities from Seafood." *Nature Climate Change* 13: 1242–49. https://doi.org/10.1038/s41558-023-01822-1.

Chilakala, R., C. Thannaree, E.J. Shin, T. Thenepalli and J.W. Ahn. 2019. "Sustainable Solutions for Oyster Shell Waste Recycling in Thailand and the Philippines." *Recycling* 4 (3). https://doi.org/10.3390/recycling4030035.

Cima, E., and D.C. Esty. n.d. "Making International Trade Work for Sustainable Development: Toward a New World Trade Organisation Framework for Subsidies." Unpublished manuscript.

Cisneros-Montemayor, A.M., M. Moreno-Báez, G. Reygondeau, W.W.L. Cheung, K.M. Crosman, P.C. González-Espinosa, V.W.Y. Lam et al. 2021. "Enabling Conditions for an Equitable and Sustainable Blue Economy." *Nature* 591 (7850): 396–401. https://doi.org/10.1038/s41586-021-03327-3.

Clapp, J., W.G. Moseley, B. Burlingame and P. Termine. 2022. "Viewpoint: The Case for a Six-Dimensional Food Security Framework." *Food Policy* 106: 102164. https://doi.org/10.1016/j.foodpol.2021.102164.

Clark, M.R., F. Althaus, T.A. Schlacher, A. Williams, D.A. Bowden and A.A. Rowden. 2016. "The Impacts of Deep-Sea Fisheries on Benthic Communities: A Review." *ICES Journal of Marine Science* 73: i51–i69. https://doi.org/10.1093/icesjms/fsv123.

Cohen, P.J., and S.J. Foale. 2013. "Sustaining Small-Scale Fisheries with Periodically Harvested Marine Reserves." *Marine Policy* 37: 278–87. https://doi.org/10.1016/j.marpol.2012.05.010.

Cohen, P.J., B. Tholan, K. Dean-Fitz, S. Pradhan, V. Solis Rivera, H. Govan, S. O'Conner, and V. Molyneaux. forthcoming. *Marine & Coastal Tenure.* Report. James Cook University.

Collie, J., J.G. Hiddink, T. van Kooten, A.D. Rijnsdorp, M.J. Kaiser, S. Jennings, and R. Hilborn. 2017. "Indirect Effects of Bottom Fishing on the Productivity of Marine Fish." *Fish and Fisheries* 18 (4): 619–37. https://doi.org/10.1111/faf.12193.

Cooper, J.A.G., and J. McKenna. 2008. "Social Justice in Coastal Erosion Management: The Temporal and Spatial Dimensions." *Geoforum* 39 (1): 294–306. https://doi.org/10.1016/j.geoforum.2007.06.007.

Costello, C., L. Cao, S. Gelcich, M.Á. Cisneros-Mata, C.M. Free, H.E. Froehlich, C.D. Golden et al. 2020. "The Future of Food from the Sea." *Nature* 588 (7836): 95–100. https://doi.org/10.1038/s41586-020-2616-y.

coZEV (Cargo Owners for Zero Emission Vehicles). n.d. "Together We Can Decarbonize Ocean Shipping." Accessed 29 January 2024. https://www.cozev.org/.

Croitoru, L., J. J. Miranda and M. Sarraf. 2019. *The Cost of Coastal Zone Degradation in West Africa: Benin, Côte d'Ivoire, Senegal and Togo.* Washington, DC: World Bank. https://documents1.worldbank.org/curated/en/822421552504665834/pdf/The-Cost-of-Coastal-Zone-Degradation-in-West-Africa-Benin-Cote-dIvoire-Senegal-and-Togo.pdf.

Crona, B.I., E. Wassénius, M. Jonell, J.Z. Koehn, R. Short, M. Tigchelaar, T.M. Daw et al. 2023. "Four Ways Blue Foods Can Help Achieve Food System Ambitions across Nations." *Nature* 616 (7955): 104–12. https://doi.org/10.1038/s41586-023-05737-x.

Darwin Tree of Life. n.d. "Darwin Tree of Life." Accessed 23 October 2023. https://www.darwintreeoflife.org/.

Das, J. 2023. "Blue Economy, Blue Growth, Social Equity and Small-Scale Fisheries: A Global and National Level Review." *Studies in Social Science Research* 4. https://doi.org/10.22158/sssr.v4n1p38.

de Graaf, G.J., and T.T. Xuan. 1998. "Extensive Shrimp Farming, Mangrove Clearance and Marine Fisheries in the Southern Provinces of Vietnam." *Mangroves and Salt Marshes* 2 (3): 159–66. https://doi.org/10.1023/A:1009975210487. https://doi.org/10.1023/A:1009975210487.

Depledge, M.H., R. Lovell, B.W. Wheeler, K.M. Morrissey, M. White and L.E. Fleming. 2017. *Future of the Sea: Health and Wellbeing of Coastal Communities.* London: Government Office of Statistics.

Depledge, M.H., M.P. White, B. Maycock and L.E. Fleming. 2019. "Time and Tide: Our Future Health and Wellbeing Depends on the Oceans." *BMJ* 366: l4671. https://doi.org/10.1136/bmj.l4671.

dos Reis, T.N.P., P. Meyfroidt, E.K.H.J. zu Ermgassen, C. West, T. Gardner, S. Bager, S. Croft et al. 2020. "Understanding the Stickiness of Commodity Supply Chains Is Key to Improving Their Sustainability." *One Earth* 3 (1): 100–115. https://doi.org/10.1016/j.oneear.2020.06.012.

Dykes, S., and A. Walmsley. 2015. "The Reluctant Tourist? An Exploration of Second Home Owners' Perceptions of Their Impacts on North Cornwall, UK." *European Journal of Tourism, Hospitality and Recreation* 6: 95–116.

Earth BioGenome Project. n.d. "Earth BioGenome Project: Sequencing Life for the Future of Life." Accessed 23 October 2023. https://www.earthbiogenome.org/.

EEA (European Enviroment Assembly). 1995. *Europe's Environment: The Dobris Assessment.* Luxembourg: EEA.

Ehsan, S., R. Ara Begum and K. Nizam Abdul Maulud. 2022. "Household External Vulnerability Due to Climate Change in Selangor Coast of Malaysia." *Climate Risk Management* 35: 100408. https://doi.org/10.1016/j.crm.2022.100408.

Elliott, L.R., T. Pasanen, M.P. White, B.W. Wheeler, J. Grellier, M. Cirach, G.N. Bratman et al. 2023. "Nature Contact and General Health: Testing Multiple Serial Mediation Pathways with Data from Adults In 18 Countries." *Environment International* 178: 108077. https://doi.org/10.1016/j.envint.2023.108077.

Estradivari, M.F. Agung, D.S. Adhuri, S.C.A. Ferse, I. Sualia, D.A. Andradi-Brown, S.J. Campbell et al. 2022. "Marine Conservation beyond MPAs: Towards the Recognition of Other Effective Area-Based Conservation Measures (OECMs) in Indonesia." *Marine Policy* 137: 104939. https://doi.org/10.1016/j.marpol.2021.104939.

European Commission. n.d. "Coastal Tourism." Accessed 1 November 2023. https://blue-economy-observatory.ec.europa.eu/eu-blue-economy-sectors/coastal-tourism_en.

Fact.MR. 2023. "Marine-Derived Pharmaceuticals Market to Be Worth US$ 9,083.1 Million by 2033." 7 August. https://finance.yahoo.com/news/marine-derived-pharmaceuticals-market-worth-160000476.html?guccounter=1.

FAO (Food and Agriculture Organization of the United Nations). 2022. *The State of the World Fisheries and Aquaculture 2022.* Rome: FAO.

FAO. n.d. "Agreement on Port State Measures (PSMA)." Accessed 22 November 2023. https://www.fao.org/port-state-measures/background/en/.

FAO and WHO (World Health Organization). 2011. *Report of the Joint FAO/WHO Expert Consultation on the Risks and Benefits of Fish Consumption.* Rome: FAO; Geneva: WHO. https://www.fao.org/3/ba0136e/ba0136e00.htm#:~:text=The%20Expert%20Consultation%20concluded%20the,cultural%20traditions%20of%20many%20peoples.

FAO, Duke University and WorldFish. 2022. *Illuminating Hidden Harvests: The Contributions of Small-Scale Fisheries to Sustainable Development.* Rome: FAO.

FAO, IFAD (International Fund for Agricultural Development), UNICEF (UN Children's Fund), WFP (World Food Programme) and WHO. 2023. *The State of Food Security and Nutrition in the World 2023: Urbanization, Agrifood Systems Transformation and Healthy Diets across the Rural-Urban Continuum.* Rome: FAO.

Fenichel, E.P., B. Milligan, I. Porras, E.T. Addicott, R. Árnasson, M. Bordt, S. Djavidnia et al. 2020. *National Accounting for the Ocean and Ocean Economy.* Washington, DC: World Resources Institute. https://oceanpanel.org/publication/national-accounting-for-the-ocean-and-ocean-economy/.

Filbee-Dexter, K., A. Pessarrodona, C.M. Duarte, D. Krause-Jensen, K. Hancke, D. Smale and T. Wernberg. 2023. "Seaweed Forests Are Carbon Sinks That May Help Mitigate CO_2 Emissions: A Comment on Gallagher et al. (2022)." *ICES Journal of Marine Science* 80 (6): 1814–19. https://doi.org/10.1093/icesjms/fsad107.

Fiorella, K.J., E.R. Bageant, N.B. Schwartz, S.H. Thilsted and C.B. Barrett. 2021. "Fishers' Response to Temperature Change Reveals the Importance of Integrating Human Behavior in Climate Change Analysis." *Science Advances* 7 (18): eabc7425. https://doi.org/10.1126/sciadv.abc7425.

Fleming, L.E., B. Maycock, M.P. White and M.H. Depledge. 2019. "Fostering Human Health through Ocean Sustainability in the 21st Century." *People and Nature* 1 (3): 276–83. https://doi.org/10.1002/pan3.10038.

Fleming, L.E., M. Depledge, T. Bouley, E. Britton, S. Dupont, C. Eatock, R. Garside et al. 2021. "The Ocean Decade: Opportunities for Oceans and Human Health Programs to Contribute to Public Health." *American Journal of Public Health* 111 (5): 808–11. https://doi.org/10.2105/AJPH.2021.306229.

Fleming, L., L.B. Alcantara-Creencia, W.H. Gerwick, H.C. Goh, M.O. Gribble, B. Maycock and H. Solo-Gabriele. 2023. *Oceans and Human Health: Opportunities and Impacts.* 2nd ed. Amsterdam: Elsevier.

Franke, A., T. Blenckner, C.M. Duarte, K. Ott, L.E. Fleming, A. Antia, T.B.H. Reusch et al. 2020. "Operationalizing Ocean Health: Toward Integrated Research on Ocean Health and Recovery to Achieve Ocean Sustainability." *One Earth* 2 (6): 557–65. https://doi.org/10.1016/j.oneear.2020.05.013.

Freeman, C., and C. Cheyne. 2008. "Coasts for Sale: Gentrification in New Zealand." *Planning Theory & Practice* 9 (1): 33–56. https://doi.org/10.1080/14649350701843846.

Friedlingstein, P., M.W. Jones, M. O'Sullivan, R.M. Andrew, J. Hauck, G.P. Peters, W. Peters et al. 2019. "Global Carbon Budget 2019." *Earth System Science Data* 11 (4): 1783–38. https://doi.org/10.5194/essd-11-1783-2019.

Galappaththi, E.K., S.T. Ichien, A.A. Hyman, C.J. Aubrac and J.D. Ford. 2020. "Climate Change Adaptation in Aquaculture." *Reviews in Aquaculture* 12 (4): 2160–76. https://doi.org/10.1111/raq.12427.

Garrett, J.K., T.J. Clitherow, M.P. White, B.W. Wheeler and L.E. Fleming. 2019. "Coastal Proximity and Mental Health among Urban Adults in England: The Moderating Effect of Household Income." *Health Place* 59: 102200. https://doi.org/10.1016/j.healthplace.2019.102200.

Geiger, S.J., M.P. White, S.M.C. Davison, L. Zhang, O. McMeel, P. Kellett and L.E. Fleming. 2023. "Coastal Proximity and Visits Are Associated with Better Health but May Not Buffer Health Inequalities." *Communications Earth & Environment* 4 (1): 166. https://doi.org/10.1038/s43247-023-00818-1.

Gephart, J.A., and C.D. Golden. 2022. "Environmental and Nutritional Double Bottom Lines in Aquaculture." *One Earth* 5 (4): 324–28. https://doi.org/10.1016/j.oneear.2022.03.018.

Gephart, J.A., P.J.G. Henriksson, R.W.R. Parker, A. Shepon, K.D. Gorospe, K. Bergman, G. Eshel et al. 2021. "Environmental Performance of Blue Foods." *Nature* 597 (7876): 360–65. https://doi.org/10.1038/s41586-021-03889-2.

Gephart, J., J.A. Gephart, R.A. Bejarano, K. Gorospe, A. Godwin, C.D. Golden, R.L. Naylor et al. 2023. "Globalization of Wild Capture and Farmed Aquatic Foods." Authorea Preprints.

Gheysari, H., F. Mohandes, M. Mazaheri, B. Dolatyar, M. Askari and A. Simchi. 2019. "Extraction of Hydroxyapatite Nanostructures from Marine Wastes for the Fabrication of Biopolymer-Based Porous Scaffolds." *Marine Drugs* 18 (1). https://doi.org/10.3390/md18010026.

Global Seafood Alliance. 2022. *Responsible Fishing Vessel Standard.* https://bspcertification.org/Downloadables/pdf/BSP%20-%20RFVS%20Standard%20-%20Issue%202.0%20-%2022.-June-2022.pdf.

Gobler, C.J. 2020. "Climate Change and Harmful Algal Blooms: Insights and Perspective." *Harmful Algae* 91: 101731. https://doi.org/10.1016/j.hal.2019.101731.

Gochfeld, M., and J. Burger. 2011. "Disproportionate Exposures in Environmental Justice and Other Populations: The Importance of Outliers." *American Journal of Public Health* 101 (Suppl. 1): S53–63. https://doi.org/10.2105/ajph.2011.300121.

Golden, C.D., E.H. Allison, W.W.L. Cheung, M.M. Dey, B.S. Halpern, D.J. McCauley, M. Smith et al. 2016. "Nutrition: Fall in Fish Catch Threatens Human Health." *Nature* 534 (7607): 317–20. https://doi.org/10.1038/534317a.

Golden, C.D., J.A. Gephart, J.G. Eurich, D.J. McCauley, M.K. Sharp, N.L. Andrew and K.L. Seto. 2021a. "Social-Ecological Traps Link Food Systems to Nutritional Outcomes." *Global Food Security* 30: 100561. https://doi.org/10.1016/j.gfs.2021.100561.

Golden, C.D., J.Z. Koehn, A. Shepon, S. Passarelli, C.M. Free, D.F. Viana, H. Matthey et al. 2021b. "Aquatic Foods to Nourish Nations." *Nature* 598 (7880): 315–20. https://doi.org/10.1038/s41586-021-03917-1.

Gollan, N., and K. Barclay. 2020. "'It's Not Just about Fish': Assessing the Social Impacts of Marine Protected Areas on the Wellbeing of Coastal Communities in New South Wales." *PLOS ONE* 15 (12): e0244605. https://doi.org/10.1371/journal.pone.0244605.

González-Cano, R., M.C. Ruiz-Cantero, M. Santos-Caballero, C. Gómez-Navas, M.Á Tejada and F.R. Nieto. 2021. "Tetrodotoxin, a Potential Drug for Neuropathic and Cancer Pain Relief?" *Toxins* 13 (7). https://doi.org/10.3390/toxins13070483.

Grantham, R., J. Lau, D.J. Mills and G.S. Cumming. 2022. "Social and Temporal Dynamics Mediate the Distribution of Ecosystem Service Benefits from a Small-Scale Fishery." *Ecosystems and People* 18 (1): 15–30. https://doi.org/10.1080/26395916.2021.2003866.

Grégoire, M., A. Oschlies, D. Canfield, C. Castro, I. Ciglenečki, P. Croot, K. Salin et al. 2023. *Ocean Oxygen: The Role of the Ocean in the Oxygen We Breathe and the Threat of Deoxygenation.* Ostend, Belgium: European Marine Board.

Gurney, G.G., E.S. Darling, G.N. Ahmadia, V.N. Agostini, N.C. Ban, J. Blythe, J. Claudet et al. 2021. "Biodiversity Needs Every Tool in the Box: Use OECMs." In *Nature*, 26 July, 646–49.

Hanschen, E.R., and S.R. Starkenburg. 2020. "The State of Algal Genome Quality and Diversity." *Algal Research* 50: 101968. https://doi.org/10.1016/j.algal.2020.101968.

Haque, S.S., B.J. Bennet, T.D. Brewer, K. Morrissey, L.E. Fleming and M.O. Gribble. 2023. "Marine Protected Area Expansion and Country-Level Age-Standardized Adult Mortality." *Ecohealth* 20: 236–48. https://doi.org/10.1007/s10393-023-01658-3.

Harris, M. 2023. *Decolonizing Healthcare Innovation: Low-Cost Solutions from Low-Income Countries.* New York: Routledge.

Healthcare Ocean. n.d. “Healthcare Ocean.” Accessed 23 October 2023. https://www.healthcareocean.org/.

Herdman, W.A. 1880. *Preliminary report on the Tunicata of the Challenger expedition*, part 2. *Proceedings of the Royal Society of Edinburgh* 10 (2): 714–26.

Hicks, C.C., P.J. Cohen, N.A.J. Graham, K.L. Nash, E.H. Allison, C. D’Lima, D.J. Mills et al. 2019. “Harnessing Global Fisheries to Tackle Micronutrient Deficiencies.” *Nature* 574 (7776): 95–98. https://doi.org/10.1038/s41586-019-1592-6.

Hilborn, R., J. Banobi, S.J. Hall, T. Pucylowski and T.E. Walsworth. 2018. “The Environmental Cost of Animal Source Foods.” *Frontiers in Ecology and the Environment* 16 (6): 329–35. https://doi.org/10.1002/fee.1822.

Hilborn, R., R.O. Amoroso, C.M. Anderson, J.K. Baum, T.A. Branch, C. Costello, C.L. de Moor et al. 2020. “Effective Fisheries Management Instrumental in Improving Fish Stock Status.” *Proceedings of the National Academy of Sciences* 117 (4): 2218–24. https://doi.org/10.1073/pnas.1909726116.

HLPE (High-Level Panel of Experts). 2020. *Food Security and Nutrition: Building a Global Narrative towards 2030*. Rome: HLPE.

HLPE. 2023. *Reducing Inequalities for Food Security and Nutrition*. Rome: HLPE.

Hoegh-Guldberg, O., and J.F. Bruno. 2010. “The Impact of Climate Change on the World’s Marine Ecosystems.” *Science* 328 (5985): 1523–28. https://doi.org/10.1126/science.1189930.

Hoegh-Guldberg, O., E. Northrop, O.S. Ashford, T. Chopin, J. Cross, C. Duarte, S. Gaines et al. 2023. *The Ocean as a Solution to Climate Change: Updated Opportunities for Action*. London: High Level Panel for a Sustainable Ocean Economy. https://oceanpanel.org/publications/.

Hosseini, S.F., L. Ramezanzade and D.J. McClements. 2021. “Recent Advances in Nanoencapsulation of Hydrophobic Marine Bioactives: Bioavailability, Safety, and Sensory Attributes of Nano-Fortified Functional Foods.” *Trends in Food Science & Technology* 109: 322–39. https://doi.org/10.1016/j.tifs.2021.01.045.

Hotaling, S., J.L. Kelley and P.B. Frandsen. 2021. “Toward a Genome Sequence for Every Animal: Where Are We Now?” *Proceedings of the National Academy of Sciences* 118 (52): e2109019118. https://doi.org/10.1073/pnas.2109019118.

Howard, A. 2015. “Blood Diamonds: The Successes and Failures of the Kimberley Process Certification Scheme in Angola, Sierra Leone and Zimbabwe.” *Washington University Global St Louis Review of Law* 137. https://openscholarship.wustl.edu/law_globalstudies/vol15/iss1/8.

H2020 SOPHIE Consortium. 2020. *A Strategic Research Agenda for Oceans and Human Health in Europe*. Ostend, Belgium: SOPHIE Project.

Hughes, T.P., K.D. Anderson, S.R. Connolly, S.F. Heron, J.T. Kerry, J.M. Lough, A.H. Baird et al. 2018. “Spatial and Temporal Patterns of Mass Bleaching of Corals in the Anthropocene.” *Science* 359 (6371): 80–83. https://doi.org/10.1126/science.aan8048.

Human Rights at Sea. 2023. *Does It Do What It Says on the Tin? Fisheries and Aquaculture Certification, Standards and Ratings Ecosystem: An Independent Review*. https://www.humanrightsatsea.org/sites/default/files/media-files/2023-03/HR_HRAS_Fisheries%20Human%20Rights%20Standards_8%20MARCH%2023_v1.1.pdf.

IHME (Institute for Health Metrics and Evaluation). n.d. “Global Burden of Disease (GBD).” Accessed 23 October 2023. https://www.healthdata.org/research-analysis/gbd.

International Barcode of Life. n.d. “International Barcode of Life.” Accessed 23 October 2023. https://ibol.org/.

IPCC (Intergovernmental Panel on Climate Change). 2023. *Synthesis Report of the IPCC Sixth Assessment Report (AR6)*. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf.

Islam, M.M. 2022. *Country Report, Bangladesh Section: Social Innovations for Transforming the Governance of Small-Scale Fisheries in the Indian Ocean Region*. Brooklyn, NY: Social Science Research Council.

Islam, M.M., R. Aktar, M. Nahiduzzaman, B.K. Barman and M.A. Wahab. 2018. “Social Considerations of Large River Sanctuaries: A Case Study from the Hilsa Shad Fishery in Bangladesh.” *Sustainability* 10 (4). https://doi.org/10.3390/su10041254.

Islam, M.M., A. Begum, S.M.A. Rahman and H. Ullah. 2021. “Seasonal Fishery Closure in the Northern Bay of Bengal Causes Immediate but Contrasting Ecological and Socioeconomic Impacts.” *Frontiers in Marine Science* 8. https://www.frontiersin.org/articles/10.3389/fmars.2021.704056.

Janković, S. 2023. “RPS Scotland Collaborates on Final Version of ‘Blue-Green’ Prescribing Strategy.” *Pharmaceutical Journal*, 5 September. https://pharmaceutical-journal.com/article/news/rps-scotland-collaborates-on-final-version-of-blue-green-prescribing-strategy.

Johnson, E., A.M. Thow and N. Nisbett. 2023. “Opportunities to Strengthen Trade Policy for Food and Nutrition Security: An Analysis of Two Agricultural Trade Policy Decisions.” *Food Security* 15 (4): 1109–25. https://doi.org/10.1007/s12571-023-01377-1.

Jomaa, L.H., E. McDonnell and C. Probart. 2011. “School Feeding Programs in Developing Countries: Impacts on Children’s Health and Educational Outcomes.” *Nutrition Reviews* 69 (2): 83–98. https://doi.org/10.1111/j.1753-4887.2010.00369.x.

Karthikeyan, A., A. Joseph and B.G. Nair. 2022. "Promising Bioactive Compounds from the Marine Environment and Their Potential Effects on Various Diseases." *Journal of Genetic Engineering and Biotechnology* 20 (1): 14. https://doi.org/10.1186/s43141-021-00290-4.

Katona, S., D. Paulikas, S. Ali, M. Clarke, E. Ilves, T.E. Lovejoy, L.P. Madin and G.S. Stone. 2023. "Land and Deep-Sea Mining: The Challenges of Comparing Biodiversity Impacts." *Biodiversity and Conservation* 32 (4): 1125–64. https://doi.org/10.1007/s10531-023-02558-2.

Kauffman, B.J., V.B. Arifanti, H. Hernández-Trejo, J.G.M. Carmen, J. Norfolk, M. Cifuentes, D. Hadriyanto and D. Murdiyarso. 2017. "The Jumbo Carbon Footprint of a Shrimp: Carbon Losses from Mangrove Deforestation." *Frontiers in Ecology and the Environment* 15 (4): 183–88. https://doi.org/10.1002/fee.1482.

Kelly, M.R., J.-M. Kasinak, E. McKinley, C. McLaughlin, J.M.P. Vaudrey and J.H. Mattei. 2023. "Conceptualizing the Construct of Ocean Identity." *npj Ocean Sustainability* 2 (1): 17. https://doi.org/10.1038/s44183-023-00025-7.

Kittinger, J.N., L.C.L. Teh, E.H. Allison, N.J. Bennett, L.B. Crowder, E.M. Finkbeiner, C. Hicks et al. 2017. "Committing to Socially Responsible Seafood." *Science* 356 (6341): 912–13. https://doi.org/10.1126/science.aam9969.

Kubiszewski, I., R. Costanza, C. Franco, P. Lawn, J. Talberth, T. Jackson and C. Aylmer. 2013. "Beyond GDP: Measuring and Achieving Global Genuine Progress." *Ecological Economics* 93: 57–68. https://doi.org/10.1016/j.ecolecon.2013.04.019.

Kumar, P., et al. 2019. *Mainstreaming Natural Capital and Ecosystem Services into Development Policy.* Edited by P. Kumar. New York: Routledge.

Lake, N., and S. Utting. 2007. *English Shellfish Industry Development Strategy: Securing the Industry's Future.* London: Seafish. https://shellfish.org.uk/files/Literature/Projects-Reports/0712-SIDS-strategy.pdf.

Lam, V.W.Y., E.H. Allison, J.D. Bell, J. Blythe, W.W.L. Cheung, T.L. Frölicher, M.A. Gasalla and U.R. Sumaila. 2020. "Climate Change, Tropical Fisheries and Prospects for Sustainable Development." *Nature Reviews Earth & Environment* 1 (9): 440–54. https://doi.org/10.1038/s43017-020-0071-9.

Landrigan, P.J., J.J. Stegeman, L.E. Fleming, D. Allemand, D.M. Anderson, L.C. Backer, F. Brucker-Davis et al. 2020. "Human Health and Ocean Pollution." *Annals of Global Health* 86 (1). https://doi.org/10.5334/aogh.2831.

Landrigan, P.J., H. Raps, M. Cropper, C. Bald, M. Brunner, E.M. Canonizado, D. Charles et al. 2023. "The Minderoo-Monaco Commission on Plastics and Human Health." *Annals of Global Health* 89 (1): 23. https://doi.org/10.5334/aogh.4056.

Lang, T., and G. Rayner. 2012. "Ecological Public Health: The 21st Century's Big Idea?" *BMJ* 345: e5466. https://doi.org/10.1136/bmj.e5466.

Lau, J.D., and I.R. Scales. 2016. "Identity, Subjectivity and Natural Resource Use: How Ethnicity, Gender and Class Intersect to Influence Mangrove Oyster Harvesting in the Gambia." *Geoforum* 69: 136–46. https://doi.org/10.1016/j.geoforum.2016.01.002.

Lau, J.D., C.C. Hicks, G.G. Gurney and J.E. Cinner. 2019. "What atters to Whom and Why? Understanding the Importance of Coastal Ecosystem Services in Developing Coastal Communities." *Ecosystem Services* 35: 219–230. https://doi.org/10.1016/j.ecoser.2018.12.012.

Laurance, W.F. 2018. "Conservation and the Global Infrastructure Tsunami: Disclose, Debate, Delay!" *Trends in Ecology & Evolution* 33 (8): 568–71. https://doi.org/10.1016/j.tree.2018.05.007.

Leka, A., A. Lagarias, M. Panagiotopoulou and A. Stratigea. 2022. "Development of a Tourism Carrying Capacity Index (TCCI) for Sustainable Management of Coastal Areas in Mediterranean Islands: Case Study Naxos, Greece." *Ocean & Coastal Management* 216: 105978. https://doi.org/10.1016/j.ocecoaman.2021.105978.

Lencucha, R., and S. Neupane. 2022. "The Use, Misuse and Overuse of the 'Low-Income and Middle-Income Countries' Category." In *BMJ Global Health* 7 (6): e009067. doi:10.1136/bmjgh-2022-009067.

Lenzen, M., D. Moran, K. Kanemoto, B. Foran, L. Lobefaro and A. Geschke. 2012. "International Trade Drives Biodiversity Threats in Developing Nations." *Nature* 486 (7401): 109–12. https://doi.org/10.1038/nature11145.

LGA Coastal SIG. n.d. "Motion for the Ocean." Accessed 23 October 2023. https://lgacoastalsig.com/motion-for-the-ocean/.

Li, H., and R.J. Grant. 2022. "Climate Gentrification in Miami: A Real Climate Change–Minded Investment Practice?" *Cities* 131: 104025. https://doi.org/10.1016/j.cities.2022.104025.

Liddick, D. 2014. "The Dimensions of a Transnational Crime Problem: The Case of IUU Fishing." *Trends in Organized Crime* 17 (4): 290–312. https://doi.org/10.1007/s12117-014-9228-6.

Lightfoot, J. 1786. *A Catalogue of the Portland Museum, lately the property of the Dutchess Dowager of Portland, deceased; which will be sold by auction by Mr. Skinner & Co. London.*

Lindequist, U. 2016. "Marine-Derived Pharmaceuticals: Challenges and Opportunities." *Biomolecules & Therapeutics* (Seoul) 24 (6): 561–71. https://doi.org/10.4062/biomolther.2016.181.

Lomartire, S., J.C. Marques and A.M.M. Gonçalves. 2022. "An Overview of the Alternative Use of Seaweeds to Produce Safe and Sustainable Bio-packaging." *Applied Sciences* 12 (6). https://doi.org/10.3390/app12063123.

Luesch, H., R.E. Moore, V.J. Paul, S.L. Mooberry and T.H. Corbett. 2001. "Isolation of Dolastatin 10 from the Marine Cyanobacterium Symploca Species VP642 and Total Stereochemistry and Biological Evaluation of Its Analogue Symplostatin 1." *Journal of Natural Products* 64 (7): 907–10. https://doi.org/10.1021/np010049y.

Ma, N., V.J. Li, T.S. Cheong and D. Zhuang. 2021. "The Evolutionary Trend of Global Inequality: Analyzing the Impacts of Economic Structure." *Frontiers in Psychology* 12. https://www.frontiersin.org/articles/10.3389/fpsyg.2021.808976.

Madarcos, J.R.V., L. Alcantara-Creencia, B.R. Roberts, M.P. White, J. Nayoan, K. Morrissey and L.E. Fleming. 2021. "Understanding Local Perceptions of the Drivers/Pressures on the Coastal Marine Environment in Palawan, Philippines." *Frontiers in Marine Science* 8. https://www.frontiersin.org/articles/10.3389/fmars.2021.659699.

Maeda, Y., T. Yoshino, T. Matsunaga, M. Matsumoto and T. Tanaka. 2018. "Marine Microalgae for Production of Biofuels and Chemicals." *Current Opinion in Biotechnology* 50: 111–20. https://doi.org/10.1016/j.copbio.2017.11.018.

Maestro, M., M.L. Pérez-Cayeiro, J.A. Chica-Ruiz and H. Reyes. 2019. "Marine Protected Areas in the 21st Century: Current Situation and Trends." *Ocean & Coastal Management* 171: 28–36. https://doi.org/10.1016/j.ocecoaman.2019.01.008.

Maharja, C., R.A. Praptiwi, I. Richter, A. Crummy, D. Devine, L.J.A. Gajardo, N.T. Ha et al. 2023a. "The People of the Seas and the Seas of the People." Chap. 17 of *Oceans and Human Health*, 2nd ed., edited by L.E. Fleming, L.B. Alcantara-Creencia, W.H. Gerwick, Hong C.G., M.O. Gribble, B. Maycock and H. Solo-Gabriele, 499–30. San Diego, CA: Academic.

Maharja, C., R.A. Praptiwi, B.R. Roberts, K. Morrissey, M.P. White, N.M. Sari, F. Cholifatullah et al. 2023b. "Sea Swimming and Snorkeling in Tropical Coastal Blue Spaces and Mental Well-Being: Findings from Indonesian Island Communities during the COVID-19 Pandemic." *Journal of Outdoor Recreation and Tourism* 41: 100584. https://doi.org/10.1016/j.jort.2022.100584.

Maulu, S., O.J. Hasimuna, L.H. Haambiya, C. Monde, C.G. Musuka, T.H. Makorwa, B.P. Munganga et al. 2021. "Climate Change Effects on Aquaculture Production: Sustainability Implications, Mitigation, and Adaptations." *Frontiers in Sustainable Food Systems* 5. https://www.frontiersin.org/articles/10.3389/fsufs.2021.609097.

Maycock, B., A. Yee-Hui Then, N. Mohd Taufek, D.J. Mills and K. Blackford. 2023. "Food from the Ocean." In *Oceans and Human Health*, edited by L.E. Fleming, L.B. Alcantara-Creencia, W.H. Gerwick, Hong C.G., M.O. Gribble, B. Maycock and H. Solo-Gabriele, 71–101. San Diego, CA: Academic.

McCauley, D.J., M.L. Pinsky, S.R. Palumbi, J.A. Estes, F.H. Joyce and R.R. Warner. 2015. "Marine Defaunation: Animal Loss in the Global Ocean." *Science* 347 (6219). https://doi.org/10.1126/science.1255641.

McClanahan, T.R. 2021. "Marine Reserve More Sustainable than Gear Restriction in Maintaining Long-Term Coral Reef Fisheries Yields." *Marine Policy* 128: 104478. https://doi.org/10.1016/j.marpol.2021.104478.

Mellin, C., C.C. Hicks, D.A. Fordham, C.D. Golden, M. Kjellevold, M.A. MacNeil, E. Maire et al. 2022. "Safeguarding Nutrients from Coral Reefs under Climate Change." *Nature Ecology and Evolution* 6 (12): 1808–17. https://doi.org/10.1038/s41559-022-01878-w.

Merz, J.J., P. Barnard, W.E. Rees, D. Smith, M. Maroni, C.J. Rhodes, J.H. Dederer et al. 2023. "World Scientists' Warning: The Behavioural Crisis Driving Ecological Overshoot." *Science Progress* 106 (3): 00368504231201372. https://doi.org/10.1177/00368504231201372.

Milne Edwards, H. 1841. "Observations sur les Ascidies composées des côtes de la Manche." *Mémoires de l'Académie des Sciences de l'Institut de France* 18: 217–326.

Mishra, H.S., S. Bell, B. Roberts and M.P. White. 2023. "Theory-Based Design for Promoting Positive Behaviours in an Urban Blue Space: Pre-and-Post Observations of a Community Co-created Intervention in Plymouth, United Kingdom." *Landscape and Urban Planning* 233: 104708. https://doi.org/10.1016/j.landurbplan.2023.104708.

Montagne, C. 1840. "Plantae cellulares." In *Histoire naturelle des Îles Canaries*, edited by P. Barker-Webb and S. Berthelot. Vol. 3, part 2, sec. 4. Paris: Béthune.

Myers, R.A., and B. Worm. 2003. "Rapid Worldwide Depletion of Predatory Fish Communities." *Nature* 423 (6937): 280–83.

Myers, S.S., A. Zanobetti, I. Kloog, P. Huybers, A.D.B. Leakey, A.J. Bloom, E. Carlisle et al. 2014. "Increasing CO_2 Threatens Human Nutrition." *Nature* 510 (7503): 139–42. https://doi.org/10.1038/nature13179.

Nabti, E., B. Jha and A. Hartmann. 2017. "Impact of Seaweeds on Agricultural Crop Production as Biofertilizer." *International Journal of Environmental Science and Technology* 14 (5): 1119–34. https://doi.org/10.1007/s13762-016-1202-1.

NAGHP (North Ayrshire Green Health Partnership). n.d. "Benefits of Green Health." Accessed 26 January 2024.

Nash, K.L., C. Cvitanovic, E.A. Fulton, B.S. Halpern, E.J. Milner-Gulland, R.A. Watson and J.L. Blanchard. 2017. "Planetary Boundaries for a Blue Planet." *Nature Ecology & Evolution* 1 (11): 1625–34. https://doi.org/10.1038/s41559-017-0319-z.

Nash, K.L., M.A. MacNeil, J.L. Blanchard, P.J. Cohen, A.K. Farmery, N.A.J. Graham, A.L. Thorne-Lyman et al. 2022. "Trade and Foreign Fishing Mediate Global Marine Nutrient Supply." *Proceedings of the National Academy of Sciences* 119 (22): e2120817119. https://doi.org/10.1073/pnas.2120817119.

Navvabi, A., A. Homaei, B.I. Pletschke, N. Navvabi and S.K. Kim. 2022. "Marine Cellulases and Their Biotechnological Significance from Industrial Perspectives." *Current Pharmaceutical Design* 28 (41): 3325–36. https://doi.org/10.2174/1381612828666220406125132.

Naylor, R.L., R.W. Hardy, A.H. Buschmann, S.R. Bush, L. Cao, D.H. Klinger, D.C. Little et al. 2021. "A 20-Year Retrospective Review of Global Aquaculture." *Nature* 591 (7851): 551–63. https://doi.org/10.1038/s41586-021-03308-6.

NHS (UK National Health Service). n.d. "Delivering a Net Zero NHS." Accessed 29 January 2024. https://www.england.nhs.uk/greenernhs/a-net-zero-nhs/.

NHS England. n.d. "Evergreen Sustainable Supplier Assessment." Accessed 29 January 2024. https://www.england.nhs.uk/nhs-commercial/central-commercial-function-ccf/evergreen/.

Northrop, E., M. Konar, N. Frost and E. Hollaway. 2020. *A Sustainable and Equitable Blue Recovery to the COVID-19 Crisis*. High Level Panel for a Sustainable Ocean Economy. Washington, DC: World Resources Institute. https://oceanpanel.org/wp-content/uploads/2022/05/20_HLP_Report_COVID_Blue_Recovery.pdf.

Nowakowski, A.J., S.W.J. Canty, N.J. Bennett, C.E. Cox, A. Valdivia, J.L. Deichmann, T.S. Akre et al. 2023. "Co-benefits of Marine Protected Areas for Nature and People." *Nature Sustainability* 6 (10): 1210–18. https://doi.org/10.1038/s41893-023-01150-4.

Nwazuo, N.I., I.R. Keke, A.S. Egeruoh, S.O. Nwanjo and Q.C. Ugoeze. 2016. "Sanitation and Handling during Processing of Fish in Oguta Fishing Communities and Its Economic Implications." *International Journal of Scientific & Engineering Research* 7 (5): 621–31. https://www.ijser.org/researchpaper/Sanitation-and-Handling-during-Processing-of-Fish-in-Oguta-Fishing-Communities-and-Its-Economic-Implications.pdf.

Ocean Panel. 2020. *Transformations for a Sustainable Ocean Economy. A Vision for Protection, Production and Prosperity*. High Level Panel for a Sustainable Ocean Economy. https://oceanpanel.org/wp-content/uploads/2022/06/HLP_Transformations_2023_v5.pdf.

Ocean Panel. 2021. *100% Sustainable Ocean Management: An Introduction to Sustainable Ocean Plans*. Higher Level Panel for a Sustainable Ocean Economy. https://oceanpanel.org/wp-content/uploads/2022/06/21_REP_Ocean-SOP_v10.pdf.

OECD (Organisation for Economic Co-operation and Development). 2012. *Recommendation of the Council on Principles for Public Governance of Public-Private Partnerships*. Paris: OECD. https://www.oecd.org/governance/budgeting/PPP-Recommendation.pdf.

OECD. 2016. *The Ocean Economy in 2030*. Paris: OECD.

OECD. n.d. "Social Innovation." Accessed 1 November 2023. https://www.oecd.org/regional/leed/social-innovation.htm.

Okonjo-Iweala, N. 2023. "The WTO'S Contribution to the Challenges of Global Commons." *Journal of International Economic Law* 26 (1): 12–16. https://doi.org/10.1093/jiel/jgad005.

Orr, K.K. 2013. "Predicting the Ecosystem Effects of Harvesting Beach-Cast Kelp for Biofuel." PhD diss., University of Aberdeen.

Orr, K.K., T.A. Wilding, L. Horstmeyer, S. Weigl and J.J. Heymans. 2014. "Detached Macroalgae: Its Importance to Inshore Sandy Beach Fauna." *Estuarine, Coastal and Shelf Science* 150: 125–35. https://doi.org/10.1016/j.ecss.2013.12.011.

Österblom, H., J-B. Jouffray, C. Folke, B. Crona, M. Troell, A. Merrie and J. Rockström. 2015. "Transnational Corporations as 'Keystone Actors' in Marine Ecosystems." *PLOS ONE* 10 (5): e0127533. https://doi.org/10.1371/journal.pone.0127533.

Oyinlola, M.A., G. Reygondeau, C.C.C. Wabnitz, M. Troell and W.W.L. Cheung. 2018. "Global Estimation of Areas with Suitable Environmental Conditions for Mariculture Species." *PLOS ONE* 13 (1): e0191086. https://doi.org/10.1371/journal.pone.0191086.

Pallas, P.S. 1766. *Elenchus zoophytorum sistens generum adumbrationes generaliores et specierum cognitarum succintas descriptiones, cum selectis auctorum synonymis*. The Hague: Fransiscum Varrentrapp.

Pasanen, T.P., M.P. White, B.W. Wheeler, J.K. Garrett and L.R. Elliott. 2019. "Neighbourhood Blue Space, Health and Wellbeing: The Mediating Role of Different Types of Physical Activity." *Environment International* 131: 105016. https://doi.org/10.1016/j.envint.2019.105016.

Pascual Alonso, I., F. Almeida García, M.E. Valdés Tresanco, Y. Arrebola Sánchez, D. Ojeda del Sol, B. Sánchez Ramírez, I. Florent et al. 2023. "Marine Invertebrates: A Promissory Still Unexplored Source of Inhibitors of Biomedically Relevant Metallo Aminopeptidases Belonging to the M1 and M17 Families." *Marine Drugs* 21 (5). https://doi.org/10.3390/md21050279.

Patel, L. 2023. "Our Patients Need Us to Stand Up to Big Oil: The Industry Protects Profits over Public Health." *MedPage Today*, 13 December. https://www.medpagetoday.com/opinion/climate-checkup/107833?trw=no.

Persaud, A. 2023. "Breaking the Deadlock on Climate: The Bridgetown Initiative." *GREEN* 3 (1): 108–13. https://doi.org/10.3917/green.003.0108.

Pessarrodona, A., R.M. Franco-Santos, L.S. Wright, M.A. Vanderklift, J. Howard, E. Pidgeon, T. Wernberg and K. Filbee-Dexter. 2023. "Carbon Sequestration and Climate Change Mitigation Using Macroalgae: A State of Knowledge Review." *Biological Reviews*, 12 July. https://doi.org/10.1111/brv.12990.

Pettit, G.R., Y. Kamano, C.L. Herald, A.A. Tuinman, F.E. Boettner, H. Kizu, J.M. Schmidt et al. 1987. "The Isolation and Structure of a Remarkable Marine Animal Antineoplastic Constituent: Dolastatin 10." *Journal of the American Chemical Society* 109 (22): 6883–85. https://doi.org/10.1021/ja00256a070.

Pitcher, C.R., J.G. Hiddink, S. Jennings, J. Collie, A.M. Parma, R. Amoroso, T. Mazor et al. 2022. "Trawl Impacts on the Relative Status of Biotic Communities of Seabed Sedimentary Habitats in 24 Regions Worldwide." *Proceedings of the National Academy of Sciences* 119 (2): e2109449119. https://doi.org/10.1073/pnas.2109449119.

Pope Francis. 2015. "Laudato Si: Encyclical Letter on Care for Our Common Home." Vatican City: The Vatican.

Pouso, S., Á Borja, L.E. Fleming, E. Gómez-Baggethun, M.P. White and M.C. Uyarra. 2021. "Contact with Blue-Green Spaces during the COVID-19 Pandemic Lockdown Beneficial for Mental Health." *Science of the Total Environment* 756: 143984. https://doi.org/10.1016/j.scitotenv.2020.143984.

Praptiwi, R.A., C. Maharja, M. Fortnam, T. Chaigneau, L. Evans, L. Garniati and J. Sugardjito. 2021. "Tourism-Based Alternative Livelihoods for Small Island Communities Transitioning towards a Blue Economy." *Sustainability* 13 (12). https://doi.org/10.3390/su13126655.

Rasheed, A.R. 2020. "Marine Protected Areas and Human Well-Being: A Systematic Review and Recommendations." *Ecosystem Services* 41: 101048. https://doi.org/10.1016/j.ecoser.2019.101048.

Reed, M. 2009. "Seawalls and the Public Trust: Navigating the Tension between Private Property and Public Beach Use in the Face of Shoreline Erosion." *Fordham Environmental Law Review* 20 (1): 305–39.

Rees, S.E., M.J. Attrill, M.C. Austen, S. Mangi, J.P. Richards and L.D. Rodwell. 2010. "Is There a Win–Win Scenario for Marine Nature Conservation? A Case Study of Lyme Bay, England." *Ocean & Coastal Management* 53 (3): 135–45. https://doi.org/10.1016/j.ocecoaman.2010.01.011.

Richter, I., A. Avillanosa, V. Cheung, H.C. Goh, S. Johari, S. Kay, C. Maharja et al. 2021. "Looking through the COVID-19 Window of Opportunity: Future Scenarios Arising from the COVID-19 Pandemic across Five Case Study Sites." *Frontiers in Psychology* 12. https://www.frontiersin.org/articles/10.3389/fpsyg.2021.635686.

Rivera, J., N.A. Yaraghi, W. Huang, D. Gray and D. Kisailus. 2020. "Modulation of Impact Energy Dissipation in Biomimetic Helicoidal Composites." *Journal of Materials Research and Technology* 9 (6): 14619–29. https://doi.org/10.1016/j.jmrt.2020.10.051.

Roberts, C.M. 2007. *The Unnatural History of the Sea: The Past and Future of Humanity and Fishing.* London: Gaia.

Robinson, J.P.W., K.L. Nash, J.L. Blanchard, N.S. Jacobsen, E. Maire, N.A.J. Graham, M.A. MacNeil et al. 2022. "Managing Fisheries for Maximum Nutrient Yield." *Fish and Fisheries* 23 (4): 800–811. https://doi.org/10.1111/faf.12649.

Romanello, M., C. di Napoli, C. Green, H. Kennard, P. Lampard, D. Scamman, M. Walawender et al. 2023. "The 2023 Report of the Lancet Countdown on Health and Climate Change: The Imperative for a Health-Centred Response in a World Facing Irreversible Harms." *Lancet*, 16 December. https://doi.org/10.1016/S0140-6736(23)01859-7.

Roque, B.M., M. Venegas, R.D. Kinley, R. de Nys, T.L. Duarte, X. Yang and E. Kebreab. 2021. "Red Seaweed (*Asparagopsis taxiformis*) Supplementation Reduces Enteric Methane by over 80 Percent in Beef Steers." *PLOS ONE* 16 (3): e0247820. https://doi.org/10.1371/journal.pone.0247820.

Rotter, A., M. Barbier, F. Bertoni, A.M. Bones, M.L. Cancela, J. Carlsson, M.F. Carvalho et al. 2021. "The Essentials of Marine Biotechnology." *Frontiers in Marine Science* 8. https://www.frontiersin.org/articles/10.3389/fmars.2021.629629.

Safavi-Hemami, H., S.E. Brogan and B.M. Olivera. 2019. "Pain Therapeutics from Cone Snail Venoms: From Ziconotide to Novel Non-opioid Pathways." *Journal of Proteomics* 190: 12–20. https://doi.org/10.1016/j.jprot.2018.05.009.

Schneider, X.T., B.K. Stroil, C. Tourapi, C. Rebours, S.P. Gaudêncio, L. Novoveska and M.I. Vasquez. 2022. "Responsible Research and Innovation Framework, the Nagoya Protocol and Other European Blue Biotechnology Strategies and Regulations: Gaps Analysis and Recommendations for Increased Knowledge in the Marine Biotechnology Community." *Marine Drugs* 20 (5). https://doi.org/10.3390/md20050290.

SeaBOS. n.d. "Seafood Business for Ocean Stewardship." Accessed 24 November 2023. https://seabos.org/.

Searchinger, T., R. Waite, C. Hanson, J. Ranganathan, P. Dumas, E. Matthews and C. Klirs. 2019. *Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050.* Final report. Washington, DC: World Resources Institute.

Selig, E.R., S. Nakayama, C.C.C. Wabnitz, H. Österblom, J. Spijkers, N.A. Miller, J. Bebbington and J.L. Decker Sparks. 2022. "Revealing Global Risks of Labor Abuse and Illegal, Unreported, and Unregulated Fishing." *Nature Communications* 13 (1): 1612. https://doi.org/10.1038/s41467-022-28916-2.

Senay, E., I. Liu, G. Mickel, J. Bialowitz, T. Cort and D. Sherman Jodi. 2023. "Proposed SEC Climate Rules: Implications for the U.S. Health Care Sector." *NEJM Catalyst*, 3 November. https://catalyst.nejm.org/doi/full/10.1056/CAT.23.0293.

Shen, H., and S. Huang. 2020. "China's Policies and Practice on Combatting IUU in Distant Water Fisheries." *Aquaculture and Fisheries* 6 (1): 27–34. https://doi.org/10.1016/j.aaf.2020.03.002.

Short, R.E., D.T.C. Cox, Y. Ling Tan, A. Bethel, J.F. Eales and R. Garside. 2021. "Review of the Evidence for Oceans and Human Health Relationships in Europe: A Systematic Map." *Environment International* 146: 106275. https://doi.org/10.1016/j.envint.2020.106275.

Sigwart, J.D., R. Blasiak, M. Jaspars, J.-B. Jouffray and D. Tasdemir. 2021. "Unlocking the Potential of Marine Biodiscovery." *Natural Product Reports* 38 (7): 1235–42. https://doi.org/10.1039/d0np00067a.

Singer, R., and P.J.S. Jones. 2021. "Lyme Bay Marine Protected Area: A Governance Analysis." *Marine Policy* 127: 103201. https://doi.org/10.1016/j.marpol.2018.07.004.

Smith, B.J., Kwok C.T. and D. Nutbeam. 2006. "WHO Health Promotion Glossary: New Terms." *Health Promotion International* 21 (4): 340–45. https://doi.org/10.1093/heapro/dal033.

Song, A.M., J. Scholtens, K. Barclay, S.R. Bush, M. Fabinyi, D.S. Adhuri and M. Haughton. 2020. "Collateral Damage? Small-Scale Fisheries in the Global Fight against IUU Fishing." *Fish and Fisheries* 21 (4): 831–43. https://doi.org/10.1111/faf.12462.

Spalding, M.J. 2016. "The New Blue Economy: The Future of Sustainability." In "Oceans and National Income Accounts: An International Perspective," special issue of *Journal of Ocean and Coastal Economics* 2: article 8. https://doi.org/10.15351/2373-8456.1052.

Steenmeijer, M.A., J.F.D. Rodrigues, M.C. Zijp and S.L. Waaijers-van der Loop. 2022. "The Environmental Impact of the Dutch Health-Care Sector beyond Climate Change: An Input-Output Analysis." *Lancet Planetary Health* 6 (12): e949–57. https://doi.org/10.1016/S2542-5196(22)00244-3.

Steffen, W., K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, R. Biggs et al. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347 (6223): 1259855. https://doi.org/10.1126/science.1259855.

Stevens, G.A., T. Beal, M.N.N. Mbuya, H. Luo, L.M. Neufeld, O.Y. Addo, S. Adu-Afarwuah et al. 2022. "Micronutrient Deficiencies among Preschool-Aged Children and Women of Reproductive Age Worldwide: A Pooled Analysis of Individual-Level Data from Population-Representative Surveys." *Lancet Global Health* 10 (11): e1590–99. https://doi.org/10.1016/S2214-109X(22)00367-9.

Stokstad, E. 2023. "Nations Agree on Long-Sought High Seas Biodiversity Treaty." *Science* 379 (6636): 971. https://doi.org/10.1126/science.adh4964.

Sumaila, U.R., N. Ebrahim, A. Schuhbauer, D. Skerritt, Y. Li, H.S. Kim, T.G. Mallory et al. 2019. "Updated Estimates and Analysis of Global Fisheries Subsidies." *Marine Policy* 109: 103695. https://doi.org/10.1016/j.marpol.2019.103695.

Sun, J., J. Miao, H. Mu, J. Xu and N. Zhai. 2022. "Sustainable Development in Marine Economy: Assessing Carrying Capacity of Shandong Province in China." *Ocean & Coastal Management* 216: 105981. https://doi.org/10.1016/j.ocecoaman.2021.105981.

SymbioTex. n.d. "Welcome to SymbioTex." https://www.symbiotex.com/. Accessed 26 January 2024.

Thiele, C.J., M.D. Hudson, A.E. Russell, M. Saluveer and G. Sidaoui-Haddad. 2021. "Microplastics in Fish and Fishmeal: An Emerging Environmental Challenge?" *Scientific Reports* 11 (1): 2045. https://doi.org/10.1038/s41598-021-81499-8. https://doi.org/10.1038/s41598-021-81499-8.

Tigchelaar, M., J. Leape, F. Micheli, E.H. Allison, X. Basurto, A. Bennett, S.R. Bush et al. 2022. "The Vital Roles of Blue Foods in the Global Food System." *Global Food Security* 33: 100637. https://doi.org/10.1016/j.gfs.2022.100637.

Tilley, A., A. Burgos, A. Duarte, J. dos Reis Lopes, H. Eriksson and D. Mills. 2021. "Contribution of Women's Fisheries Substantial, but Overlooked, in Timor-Leste." *Ambio* 50 (1): 113–24. https://doi.org/10.1007/s13280-020-01335-7.

UK Chief Medical Officer. 2021. *Chief Medical Officer's Annual Report 2021: Health in Coastal Communities.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005216/cmo-annual_report-2021-health-in-coastal-communities-accessible.pdf.

UN (United Nations). 2014. "Blue Economy Concept Paper." https://sustainabledevelopment.un.org/content/documents/2978BEconcept.pdf.

UN. 2021. "2021–2030 United Nations Decade of Ocean Science for Sustainable Development." Accessed 24 April. https://oceandecade.org/vision-mission/.

UN. 2023a. "About Small Island Developing States." Accessed 15 December 2023. https://www.un.org/ohrlls/content/about-small-island-developing-states.

UN. 2023b. "The 17 Goals." https://sdgs.un.org/goals.

UN. 2023c. "With Clock Ticking for the SDGs, UN Chief and Barbados Prime Minister Call for Urgent Action to Transform Broken Global Financial System. Bridgetown Initiative 2.0 Highlights Six Key Action Areas to Build a More Equitable, Fit-for-Purpose Development Finance Architecture." Accessed 12 December 2023. https://www.un.org/sustainabledevelopment/blog/2023/04/press-release-with-clock-ticking-for-the-sdgs-un-chief-and-barbados-prime-minister-call-for-urgent-action-to-transform-broken-global-financial-system/.

UNEP (UN Environment Programme). 2021. "5/14: End Plastic Pollution: Towards an International Legally Binding Instrument." UN Environment Assembly of the UN Environment Programme, 5th sess. Resolution adopted by the UN Environment Assembly on 2 March 2022.

UNEP. 2022. "Resolution Adopted by the United Nations Environment Assembly on 2 March 2022." In *UNEP/EA.5/Res.5.* Nairobi: UNEP.

UNGA (UN General Assembly). 2015. "70/1: Transforming Our World: The 2030 Agenda for Sustainable Development." Resolution adopted by the General Assembly on 25 September 2015.

UNGA. 2021. "The Human Right to a Clean, Healthy and Sustainable Environment." Resolution. Geneva: UNGA.

USAID. 2017. *Marine Tenure and Small-Scale Fisheries: Learning from the Indonesia Experience.* https://pdf.usaid.gov/pdf_docs/PA00SSNT.pdf.

U.S. Ocean Policy Committee. 2023. *Ocean Justice Strategy.* Washington, DC: White House. https://www.whitehouse.gov/wp-content/uploads/2023/12/Ocean-Justice-Strategy.pdf?cb=1701982354.

Vigo Declaration. 2023. "Speaking with One Voice to Achieve the One Ocean We Want." EurOCEAN conference, Vigo, Spain, 10–11 October.

Vijayan, S.R., P. Santhiyagu, R. Ramasamy, P. Arivalagan, G. Kumar, K. Ethiraj and B.R. Ramaswamy. 2016. "Seaweeds: A Resource for Marine Bionanotechnology." *Enzyme and Microbial Technology* 95: 45–57. https://doi.org/10.1016/j.enzmictec.2016.06.009.

Villars Framework. 2023. *Villars Framework for a Sustainable Global Trading System*. Geneva: World Trade Organization. https://remakingtradeproject.org/villars-framework.

Villasante, S., K. Richter, J. Bailey, T. Blenckner, E. Farrell, R. Mongruel, K. Timmermann et al. 2023. *Building Coastal Resilience in Europe*. Ostend, Belgium: European Marine Board.

Voser, T.M., M.D. Campbell and A.R. Carroll. 2022. "How Different Are Marine Microbial Natural Products Compared to Their Terrestrial Counterparts?" *Natural Product Reports* 39 (1): 7–19. https://doi.org/10.1039/d1np00051a.

Wallis, A. 2005. "Data Mining: Lessons from the Kimberley Process for the United Nation's Development of Human Rights Norms for Transnational Corporations." *Northwestern Law Journal of Human Rights* 388. https://scholarlycommons.law.northwestern.edu/njihr/vol4/iss2/5.

Watson, R., A.H. Zakri and Millennium Ecosystem Assessment Board. 2005. *Ecosystems and Human Well-Being: Current State and Trends.* Washington, DC: Island.

Wear, S., S. Cunningham, I.C. Feller, E.A. Fiorenza, A. Frielaender, B.S. Halpern, C. Hirashiki et al. 2024. "Wastewater Pollution Impacts on Estuarine and Marine Environments." In *Treatise on Estuarine and Coastal Science*, 3–33. Amsterdam: Elsevier.

WEF (World Economic Forum). 2022. *SDG14 Financing Landscape Scan: Tracking Funds to Realize Sustainable Outcomes for the Ocean.* Geneva: WEF. https://www3.weforum.org/docs/WEF_Tracking_Investment_in_and_Progress_Toward_SDG14.pdf.

Wells, M.L., P. Potin, J.S. Craigie, J.A. Raven, S.S. Merchant, K.E. Helliwell, A.G. Smith et al. 2017. "Algae as Nutritional and Functional Food Sources: Revisiting Our Understanding." *Journal of Applied Phycology* 29 (2): 949–82. https://doi.org/10.1007/s10811-016-0974-5.

Wenger, A.S., E. Gómez Juárez, J. Thomas, T. Amaya, C. Corbin, J. Edmond, K. Falinski et al. 2023. *A Guide for Integrated Conservation and Sanitation Programs and Approaches*. New York: Wildlife Conservation Society.

White, M.P., L.R. Elliott, M. Gascon, B. Roberts and L.E. Fleming. 2020. "Blue Space, Health and Well-Being: A Narrative Overview and Synthesis of Potential Benefits." *Environmental Research* 191: 110169. https://doi.org/10.1016/j.envres.2020.110169.

White, K.M., R. Rosales, S. Yildiz, T. Kehrer, L. Miorin, E. Moreno, S. Jangra et al. 2021. "Plitidepsin Has Potent Preclinical Efficacy against SARS-CoV-2 by Targeting the Host Protein eEF1A." *Science* 371 (6532): 926–31. https://doi.org/10.1126/science.abf4058. https://doi.org/10.1126/science.abf4058.

White, M.P., T. Hartig, L. Martin, S. Pahl, A.E. van den Berg, N.M. Wells, C. Costongs et al. 2023. "Nature-Based Biopsychosocial Resilience: An Integrative Theoretical Framework for Research on Nature and Health." *Environment International* 181: 108234. https://doi.org/10.1016/j.envint.2023.108234.

Whitmee, S., A. Haines, C. Beyrer, F. Boltz, A.G. Capon, B.F. de Souza Dias, A. Ezeh et al. 2015. "Safeguarding Human Health in the Anthropocene Epoch: Report of the Rockefeller Foundation Commission on Planetary Health." *Lancet* 386 (10007): 1973–2028. https://doi.org/10.1016/S0140-6736(15)60901-1.

WHO (World Health Organization). 1946. *Summary Report on Proceedings and Final Acts of the International Health Conference.* Geneva: WHO.

WHO. 2007. *Everybody's Business: Strengthening Health Systems to Improve Health Outcomes. WHO's Framework for Action.* Geneva: WHO. https://iris.who.int/bitstream/handle/10665/43918/9789241596077_eng.pdf?sequence=1.

WHO. 2015. *Global Action Plan on Antimicrobial Resistance.* Geneva: WHO.

WHO. 2020. *WHO Guidance for Climate-Resilient and Environmentally Sustainable Health Care Facilities.* Geneva: WHO.

WHO. 2021. Health Promotion Glossary of Terms. https://www.who.int/publications/i/item/9789240038349.

WHO. 2022. *A Toolkit on How to Implement Social Prescribing.* Manila: WHO Regional Office for the Western Pacific. https://iris.who.int/bitstream/handle/10665/354456/9789290619765-eng.pdf?sequence=1.

WHO. n.d. "Constitution of the World Health Organisation." Accessed 23 October 2023. https://www.who.int/about/accountability/governance/constitution.

Widjaja, S., T. Long, H. Wirajuda, H. Van As, P.R. Bergh, A. Brett, D. Copeland et al. 2021. *Illegal, Unreported and Unregulated Fishing and Associated Drivers*. Washington, DC: World Resources Institute.

Wildlife Trusts. 2023. *A Natural Health Service: Improving Lives and Saving Money*. https://www.wildlifetrusts.org/sites/default/files/2023-07/23JUN_Health_Report_Summary_FINAL.pdf.

Wilson, K.L., D.P. Tittensor, B. Worm and H.K. Lotze. 2020. "Incorporating Climate Change Adaptation into Marine Protected Area Planning." *Global Change Biology* 26 (6): 3251–67. https://doi.org/10.1111/gcb.15094.

Winther, J.-G., M. Dai, T. Rist, A.H. Hoel, Y. Li, A. Trice, K. Morrissey et al. 2020. "Integrated Ocean Management for a Sustainable Ocean Economy." *Nature Ecology & Evolution* 4 (11): 1451–58. https://doi.org/10.1038/s41559-020-1259-6.

Woolf, S. H., and L. Aron. 2013. "The National Academies Collection: Reports Funded by National Institutes of Health." In *U.S. Health in International Perspective: Shorter Lives, Poorer Health*. Washington, DC: National Academies Press.

World Bank and UNDESA (UN Department of Economic and Social Affairs). 2017. *The Potential of the Blue Economy: Increasing Long-Term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries*. Washington, DC: World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/26843/115545. pdf?sequence=1&isAllowed=y.

WTO (World Trade Organization). 2022. Agreement on Fisheries Subsidies. https://www.wto.org/english/tratop_e/rulesneg_e/fish_e/fish_e.htm.

Xin, A., Y. Su, S. Feng, M. Yan, K. Yu, Z. Feng, K. Hoon Lee et al. 2021. "Growing Living Composites with Ordered Microstructures and Exceptional Mechanical Properties." *Advanced Materials* 33 (13): 2006946. https://doi.org/10.1002/adma.202006946.

Yea, S., and C. Stringer. 2021. "Caught in a vicious Cycle: Connecting Forced Labour and Environmental Exploitation through a Case Study of Asia-Pacific." *Marine Policy* 134: 104825. https://doi.org/10.1016/j.marpol.2021.104825.

Zamborain-Mason, J., D. Viana, K. Nicholas, E.D. Jackson, J.Z. Koehn, S. Passarelli, S.-H. Yoo et al. 2023. "A Decision Framework for Selecting Critically Important Nutrients from Aquatic Foods." *Current Environmental Health Reports* 10 (2): 172–83. https://doi.org/10.1007/s40572-023-00397-5.

Zhai, X., X.H. Zhang and M. Yu. 2023. "Microbial Colonization and Degradation of Marine Microplastics in the Plastisphere: A Review." *Frontiers in Microbiology* 14: 1127308. https://doi.org/10.3389/fmicb.2023.1127308.

Acknowledgements

The authors would like to thank an anonymous reviewer and the following experts for their valuable contributions and reviews, which have improved this Blue Paper: Bruce Maycock (Asia-Pacific Academic Consortium of Public Health), Timothy Bouley (BioFeyn), Michael Depledge (Eden Project), Matthew Carvalho (Georgetown University), Margaret Spring (Monterey Bay Aquarium), Nicola Bridge (Ocean Conservation Trust), Hong Ching (Universiti Malaya), Mariska Bottema (World Resources Institute), Nicola Frost (World Resources Institute), Micheline Khan (World Resources Institute), and Tom Pickerell (World Resources Institute).

We are most grateful for input from the Ocean Panel Expert Group Lead Expert Jacqueline Uku (Kenya Marine and Fisheries Research Institute), and from Stephanie Ockenden (World Resources Institute), who arbitrated this report.

We would like to sincerely thank Kathleen Schalch, who significantly improved the Blue Paper through a substantive edit, and Alex Martin, Romain Warnault and Shannon Collins for providing valuable editorial and design support.

Photo Credits

Pg. ii, Jean Carlo Emer; Pg. iv, Jason Pischke; Pg. 2, Drahomír Hugo Posteby-Mach; Pg. 8, Duangphorn Wiriya; Pg. 11, National Cancer Institute; Pg. 17, National Cancer Institute; Pg. 22, Paul Einerhand; Pg. 28, Paul Einerhand; Pg. 35, Joel Casilla; Pg. 41, orva studio; Pg. 43, Precious Madubuike; Pg. 46, Joshua J. Cotten; Pg. 49, yang wewe; Pg. 53, Oliver Ashford

About the authors

Lead Coordinating Authors

Lora E. Fleming: is an American physician and epidemiologist and Chair of Oceans, Epidemiology and Health at the European Centre for Environment and Human Health of the University of Exeter Medical School (Cornwall, United Kingdom).

Contact: l.e.fleming@exeter.ac.uk

Philip J. Landrigan: is an American paediatrician, public health physician and epidemiologist. He is a Professor at Boston College (Massachusetts, USA), Director of the Program for Global Public Health and the Common Good and the Global Observatory on Planetary Health, and a Consultant Scientist to the Centre Scientifique de Monaco.

Contact: phil.landrigan@bc.edu

Lead Authors

William Gerwick: is an American scientist studying marine natural products drug discovery at Scripps Institution of Oceanography and the Skaggs School of Pharmacy and Pharmaceutical Sciences, University of California San Diego.

Contact: wgerwick@health.ucsd.edu

Johanna J. Heymans: is Professor of Ecosystem Modelling at the University of the Highlands and Islands in Scotland, and Executive Director of the European Marine Board in Belgium. She studied in South Africa and is of Namibian descent.

Contact: sheymans@marineboard.eu

Christina C. Hicks: is a Kenyan British environmental social scientist and Professor at Lancaster University.

Contact: christina.hicks@lancaster.ac.uk

Karyn Morrissey: is an Irish economist focusing on the use of data-driven science to understand the role of the environment on human health in the Department of Technology, Management and Economics at the Technical University of Denmark.

Contact: kamorr@dtu.dk

Mathew P. White: is a British environmental psychologist at the University of Vienna (Austria).

Contact: mathew.white@univie.ac.at

Contributing Authors

Karen A. Alexander: is a British human geographer working on coastal community wellbeing, and an Assistant Professor in Marine Governance and Blue Economy at Heriot-Watt University (Orkney, United Kingdom).

Contact: karen.alexander@hw.ac.uk

Oliver S. Ashford: is a British marine biologist. He is a Program Associate within the Ocean Program at World Resources Institute, a member of the Ocean Panel Secretariat, and Associate Researcher at the University of Exeter (United Kingdom).

Contact: oliver.ashford@wri.org

Thomas Astell-Burt: is a British-Australian urbanist, social scientist and epidemiologist. He is Professor of Cities and Planetary Health at the School of Architecture, Design and Planning, University of Sydney (Australia), and an Australian Research Council Future Fellow in Nature-Based Solutions for Social Health.

Contact: thomas.astell-burt@sydney.edu.au

Roberto G.S. Berlinck: is a Brazilian chemist, Professor of Chemistry at the Universidade de São Paulo (Brazil) and Associate Editor of the American Chemical Society's Journal of Natural Products.

Contact: rgsberlinck@iqsc.usp

Philippa J. Cohen: is an environmental social scientist and environmental justice adviser, an Adjunct Professor at James Cook University and the lead of the Marine Tenure Initiative.

Contact: pip@pipcohen.com

Lota Alcantara-Creencia: is a Filipina fisheries technologist, marine biologist and coastal communities extensionist. She is a Professor at the College of Fisheries and Aquatic Sciences of Western Philippines University, Palawan.

Contact: lotacreencia@gmail.com

Contributing Authors (cont.)

Richard Hixson: is a British National Health Service (NHS) Consultant in Critical Care Medicine, a physician environmentalist, an Honorary Senior Clinical Lecturer (University of Exeter, United Kingdom), a Member of the UK Ocean Decade Committee and NHS England's Sustainable Procurement Forum, and Co-founder of Healthcare Ocean.

Contact: richardhixson@btinternet.com

Mohammad Mahmudul Islam: is a Bangladeshi marine social scientist. He is an Associate Professor and Chairman of the Department of Coastal and Marine Fisheries at Sylhet Agricultural University (Bangladesh).

Contact: mahmud2512@googlemail.com

Arihiro Iwasaki: is a Japanese marine natural product chemist. He is an Associate Professor in the Department of Applied Chemistry, Faculty of Science and Engineering, Chuo University (Tokyo, Japan).

Contact: aiwasaki686@g.chuo-u-ac.jp

Radisti A. Praptiwi: is an Indonesian environmental scientist. She is a lecturer in the Faculty of Health Sciences and Head of Sustainability Research Cluster at Esa Unggul University (Jakarta, Indonesia).

Contact: radisti_ayu@outlook.com

Hervé Raps: is a French physician with expertise in environmental health, health information technology and clinical trials. He is the Physician Delegate for Research at the Centre Scientifique de Monaco, conducting awareness-raising and capacity-building activities on environmental health issues.

Contact: hraps@centrescientifique.mc

Jan Yves Remy: is a Caribbean international trade law and dispute settlement expert, Director of the Shridath Ramphal Centre of the University of the West Indies, Co-lead of the Remaking Trade for a Sustainable Future Project, and the World Trade Organization Chair for Barbados (St. Lucia/Barbados).

Contact: janyves.remy@cavehill.uwi.edu

Georgina Sowman: is a British general practitioner and Co-founder of Healthcare Ocean. She is a Physical Activity Clinical Champion with Sport England at the Advanced Wellbeing Research Centre, Sheffield Hallam University (Sheffield, United Kingdom).

Contact: g_sowman@hotmail.com

Amy Swift: is a British Research Analyst within the Ocean Program at the World Resources Institute and a member of the Ocean Panel Secretariat.

Contact: amy.swift@wri.org

Eva Ternon: is a French Research Scientist at the Université Sorbonne's Laboratoire d'Océanographie de Villefranche (France).

Contact: eva.ternon@imev-mer.fr

Torsten Thiele: is a German economist and ocean finance expert affiliated with the Research Institute for Sustainability–Helmholtz Centre Potsdam (Germany). He is an Honorary Fellow at Plymouth Marine Laboratory (United Kingdom).

Contact: torsten@globaloceantrust.com

Shakuntala H. Thilsted: is a Danish aquatic food and nutrition expert, and Director of the Nutrition, Health and Food Security Impact Area Platform at CGIAR.

Contact: s.thilsted@cgiar.org

Ella M. Whitman: is an American early career researcher at the Global Observatory on Planetary Health at Boston College (Massachusetts, USA).

Contact: whitmane@bc.edu

HIGH LEVEL PANEL *for*
A SUSTAINABLE OCEAN ECONOMY

10 G Street NE
Suite 800
Washington, DC 20002, USA
+1 (202) 729-7600

oceanpanel.org