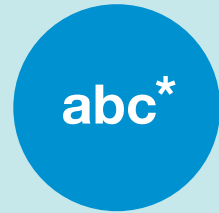
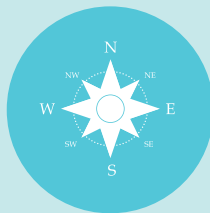
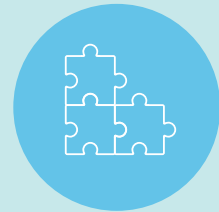
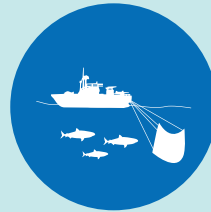
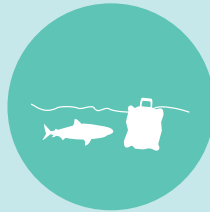
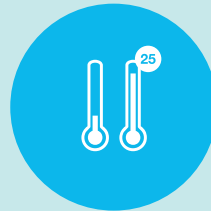
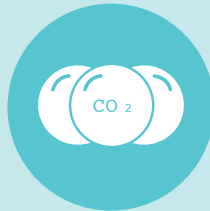

Preview of results from a book on
valuing the oceans and the economic
consequences of action or inaction

Edited by:
Kevin Noone
Rashid Sumaila
Robert J Díaz

Valuing the Ocean

Draft Executive Summary



The ocean faces a multitude of interconnected threats that is unprecedented in modern history. This book intends to help crystallise our understanding of the value of ocean services to humankind, allowing them to be accounted for as we plan for a future fraught with risk and uncertainty.

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Valuing the Ocean

Draft Executive Summary



Introduction

The ocean is the cornerstone of our life-support system. It covers over 70 percent of our planet and generates the oxygen in every second breath we take; it has cushioned the blow of climate change by absorbing 25–30 percent of all anthropogenic carbon emissions and 80 percent of the heat added to the global system; it regulates our weather and provides food for billions of people. The ocean is priceless.

The ocean has always been thought of as the epitome of unconquerable, inexhaustible vastness and variety, but this 'plenty more fish in the sea' image may be its worst enemy. The immense scale of the ocean, and its remoteness from most of our daily lives, has contributed to its chronic neglect. For rather than being 'too big to fail', even the ocean is not immune to the destructive capacity of anthropogenic climate change and, more broadly, global environmental change. Its capacities are being stretched and some of the vital services it provides to humankind are seriously degraded. Unlike the ocean itself, many of these services – from food security, to storm protection, to carbon absorption – can and should be assigned monetary values and incorporated in broader global and national economic policies, so that they become visible when we plan for the future.

As financial and institutional resources are stretched in the face of economic recession and a multitude of pressing global challenges, the ocean is not rising fast enough up political agendas, despite mounting research pointing to the multiple threats being faced and growing evidence of the causes behind them. Rather than benefiting from economies of scale, the ocean is the victim of a global market failure, as we continue to largely ignore the true worth of its ecosystems, services and functions, and externalise the true costs of pollution. A radical shift in the way we view and value the ocean is needed.

Some threats to the ocean, such as overfishing and coral bleaching, are widely researched and increasingly well known to the public. Other less visible threats, such as acidification and hypoxia (deoxygenation) of the ocean, are only just beginning to be understood and remain beyond the awareness of most people. Even less well grasped are the ways in which the many complex changes occurring in the ocean overlap and interact, and the extent of their impact on different communities and economies. It is clear that we require new ways of understanding the ocean and the threats it faces, and a greater appreciation of the value of the services it bestows.

This forthcoming collaborative book seeks to bridge these gaps. The opening chapters provide thorough

overviews of the current status of the six most important marine challenges, namely ocean acidification, ocean warming, hypoxia, sea level rise, pollution and the overuse of marine resources. There is a substantial literature on each of these issues, but thus far they have largely been researched and reported separately. In this book, concise reviews of the state of the science in these areas will now be found all in one place. The book then breaks new ground by fitting the pieces together in a chapter examining the significance of multiple stressors and their policy implications, and by making a first attempt to actually put a price on the avoidable portion of future global environmental change in the marine domain, i.e. the monetary value of not causing further damage to the ocean.

By pricing the difference between low- and high-emission scenarios, characterised as the distance between our hopes and our fears, the book intends to crystallise our understanding of the value of ocean services to humankind and allow policy-makers to more effectively account for these services when assessing the economic implications of global environmental change and what to do about it. In the final chapters, a discussion of different ways to plan for a future fraught with risk and uncertainty is presented, followed by a case study of the Pacific Ocean, which shows how the global analyses presented can be applied in a regional context.

Some things that cannot be assigned meaningful prices are nonetheless critical to the functioning of the Earth System. Nutrient cycling, oxygen production and genetic resources are examples of properties of the oceans that are vital to maintaining our life-support system, but which cannot be measured in monetary terms. These kinds of Earth System Values are also highlighted in the book through the use of an 'expert survey' approach to complement the more traditional scenario-based planning. In these ways, the authors intend to expand the research frontier in marine sciences and improve on methodologies for holistic, cross-scale analysis. Decisions in the marine domain will need to be made despite having a number of significant 'known' and 'unknown' unknowns. It is hoped that this book will help to identify some of these potential surprises and put bounds on their significance and impact.

This book is a link in a chain rather than an end in itself. The conclusions and monetary figures it presents are not definitive – too much is yet unknown and uncertain for that – but are intended to contribute towards a new approach to ocean governance, one that is fully integrated and prioritised within the broader picture of social, environmental and economic policy. We critically need to go beyond the current approach of addressing (or ignoring!) one problem at a time. We must create management strategies that are aimed at optimising the sustain-

Six Threats to the Ocean

able benefits we can obtain from marine resources across scales from local to global, and in the face of several interacting and escalating threats.

The very chemical, thermodynamic and biological foundations of the ocean are being jeopardised by human activity, putting at risk marine ecosystems and services on which humankind so essentially depends. We need to be made aware of what we stand to lose if we continue to neglect the ocean and fail to adequately address global environmental change. This book hopes to guide policy-makers, accelerate the implementation of new management tools and systems, and – most importantly – encourage people to ask themselves what the oceans are really worth to them and to the future of our planet.



Ocean Acidification

The atmosphere and the ocean exchange gases across the sea surface to such an extent that over the last 200 years the oceans have absorbed 25–30 percent of the global accumulated emissions of CO₂. While this process partially buffers climate change, the resulting perturbations to the ocean's carbonate system – known as ocean acidification – have wor-

rying consequences for the chemistry of the ocean, for the organisms that inhabit it, and for humanity. Ocean acidification is a direct consequence of increased CO₂ emissions. Mean surface ocean acidity has increased by 30 percent since the industrial revolution and if we continue to emit CO₂ at the same rate, the acidity could increase by 150–200 percent by 2100. This rate of change is around 10 times faster than that caused by any other event experienced by the ocean in the last 65 million years.

This is highly certain as it is based on known chemistry. In some regions, such as the northwest coast of North America, acidification is already impacting on important commercial shellfish. In the Arctic Sea an additional 800 square kilometres of sea floor are being exposed every year to seawater chemical conditions that are corrosive to unprotected shells.

Ocean acidification is also predicted to slow down the absorbing capacity of the ocean's great carbon sink, meaning that as we move into the future more carbon will remain in the atmosphere and add to climate change. We simply cannot afford these rapid changes to ocean chemistry and their direct consequences on future human security. If global emissions of CO₂ are not rapidly curbed it will take tens of thousands of years for oceanic pH to return to current levels.



Six Threats to the Ocean

Continued



Ocean Warming

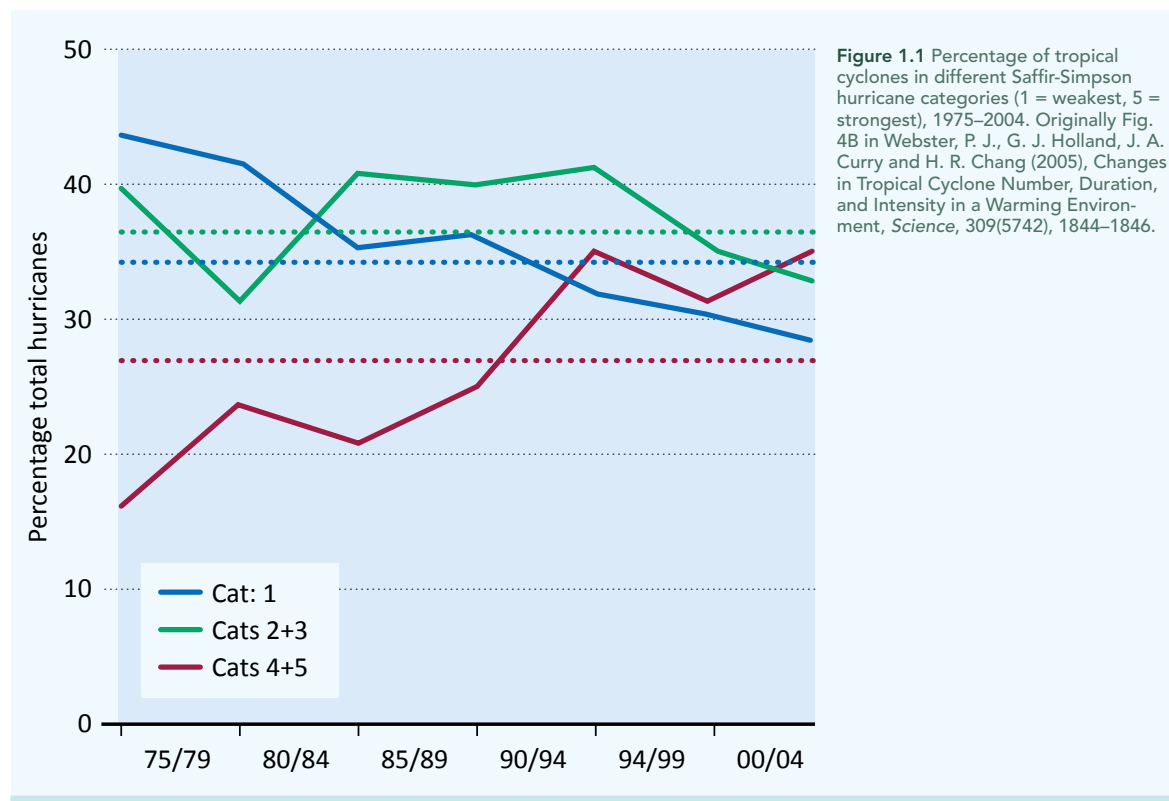
The ocean has absorbed 80 percent of the heat added to the climate system over the past 200 years, resulting in rising mean surface ocean temperatures and serious implications for marine ecosystems and resources, as well as for coastal populations around the globe. In addition to sea level rise, there are two primary impacts of ocean warming: physical aspects related to changes in extreme weather events; and biological consequences, including range shifts in fish populations and coral bleaching.

One consequence of global warming is expected to be an increase in more extreme weather events. Observations and models point to a greater intensity of precipitation in some areas, causing excessive flooding and erosion, and drought in other areas. Further, the lifecycles of tropical cyclones are intimately linked to sea-surface temperatures and an increase in the intensity of tropical cyclones has already been observed. As shown in Figure 1.1, the percentage of the strongest storms (category 4 and 5) increased from less than 20 percent in 1970–1974 to about 35 percent in 2000–2004. Storms in these categories cause by far the most damage.

More intense tropical cyclones stand to severely damage settlements and infrastructure in densely populated coastal areas, and may particularly impact some of the world's most vulnerable coastal communities as they lack the capacity to adequately prepare for or respond to such events. Unless action is taken to address the growing concentrations of people and property in coastal areas where tropical cyclones make landfall, damage will increase – and by a great deal.

Ocean warming is also impacting species distribution and foodwebs underlying globally significant fisheries, with the range shifts of species moving toward higher latitudes (poleward) and into deeper waters. Shifts in the distribution of fish will adversely impact many coastal nations and further threaten food security, especially in developing nations. Increased temperatures are also predicted to cause the bleaching and death of highly valuable and productive coral reefs, which are among the ocean's most biologically diverse ecosystems. Not only do coral reefs serve as nurseries for many fish species vital to commercial fishing industries, they also act as a buffer against storms, protecting many island and coastal states.

The value of these services is enormous. Maintaining the resilience of marine ecosystems and ensuring the proper management of fisheries is ever more critical in light of the anticipated impacts of ocean warming.



Six Threats to the Ocean

Continued



Hypoxia

Over the last 50 years alarming trends of declining oxygen concentrations have been observed in both coastal and open ocean systems. Hypoxia (or deoxygenation) is one of the most acute consequences of eutrophication, the over-enrichment of waters with nutrients and organic matter, in particular anthropogenic nitrogen from fertiliser run-off, sewage and industrial waste. There are now over 500 known hypoxic 'dead zones' in the global ocean, where limited supplies of dissolved oxygen prohibit the growth and reproduction of organisms, and the number is increasing fastest in the developing world. This phenomenon is already endangering important ecosystems that provide communities with food. In addition, the volume of naturally occurring low-oxygen areas, or oxygen-minimum zones, is also expanding due to global environmental change and rising sea temperatures.

No other environmental threat of such critical importance to marine ecosystems has accelerated so drastically in such a short timeframe. Excess reactive nitrogen in the environment is considered one of the three out of nine 'planetary boundaries' that have already been exceeded. Future scenarios for hypoxia in the global oceans will largely depend on a combination of factors related to global environmental

change and land-use, including a growing human population, especially along the coasts; agricultural practices; and nutrient loadings. Under a business as-usual-scenario, the amount of reactive nitrogen entering the ocean is projected to grow by 50 percent by 2050, leading to the increased frequency, intensity and duration of coastal hypoxia.

Integrated action is urgently required to prevent and remediate hypoxia. Its global extent and threat to human health and marine ecosystem services are just beginning to be appreciated, and much remains unknown regarding its social and economic consequences. Virtually all of the information we do have is from North America and Europe. We know very little about conditions in the most populated parts of the planet or oceanic islands. The good news is that it is possible to recover oxygen levels even in the deadest of dead zones. To do so will require dramatic increases in fertiliser-use efficiency, and therefore institutional capacities for managing nutrient levels need to be strengthened at the local, national, regional and global levels. New public-private partnerships are also needed across key sectors to stimulate innovation in nutrient reduction and reuse technology. Addressing the expansion of oxygen-minimum zones is an even greater challenge as these areas are directly related to warming trends. The only effective solution is to mitigate global environmental change by curbing carbon emissions.



Phytoplankton blooms in the Black Sea, after floods on the Danube River swept over broad stretches of farmland June 20, 2006.

NASA IMAGE C/O JEFF SCHWALTZ/MODIS LAND RAPID RESPONSE TEAM AT NASA GSFC

Six Threats to the Ocean Continued



Sea Level Rise

Global mean sea level has already risen by about 25cm since the 1800s, and the pace is accelerating. Levels rose by approximately 1.8mm per year over the last five decades, doubled to 3.1mm per year in the 1990s, and were 2.5mm per year in the period 2003–2007. Sea level rise is caused by melting glaciers and ice caps, loss of ice from major ice sheets in Greenland and Antarctica, thermal expansion of the ocean, and changes in terrestrial storage. Melting ice has been the dominant source of sea level rise for about the last decade. How rapidly the major ice sheets will respond to further increases in temperature is dependent on dynamic processes and feedback loops and remains uncertain; this will be the major determining factor in future sea level rise. In Greenland, ice loss already increased by a factor of seven in the decade between the mid-1990s and the mid-2000s. In parts of Antarctica, ice loss nearly doubled in the same period.

Although our understanding of these processes is growing, obtaining a precise estimate for sea level at the end of the century remains beyond our abilities. The projections for sea level rise by 2100 vary between a minimum of 0.2 metres and a maximum of about 2 metres. What is known is that while sea level rise will impact all coastal areas, it will do so to differing extents. Sea level is an existential threat for some small island developing states (SIDS), which will

disappear entirely with even modest increases. Other, more widespread, impacts include submergence and flooding of coastal land, saltwater intrusion, increased erosion, and habitat destruction. The highest risk areas are coastal zones with dense populations, low elevations, high rates of land subsidence, and limited adaptive capacity. Figure 1.2 shows the locations of these vulnerable regions, which include the entire coast of Africa and South and Southeast Asia, as well as Pacific, Indian Ocean and Caribbean islands.

Approximately 145 million people live within 1 meter of mean high water, more than 70% of whom are in Asia, and 268 and 397 million live within 5 and 10 meters, respectively. National security could be threatened in certain cases if low-lying areas that are key to the functioning of vulnerable states are decimated by rising seas. People living in at-risk coastal areas have essentially two choices about how to respond to increasing sea level: fight or flee. Fighting involves improving or building coastal defenses – seawalls, dikes and other built infrastructure. Fleeing involves relocating people from low-lying areas to higher ground.

The international community must recognize that considerable damages and costs can be avoided through adaptation measures taken now. The people who stand to be most affected by climate change are among the least responsible for greenhouse gas emissions: innovative strategies, financial instruments and funding mechanisms must be mobilized to address their urgent needs.

Figure 1.2 Regions vulnerable to flooding caused by sea level rise. Originally Fig. 3 in Nicholls, R. J. and A. Cazenave (2010), *Sea Level Rise and its Impact on Coastal Zones*, *Science*, 328(5985), 1517–1520.



Six Threats to the Ocean Continued



Pollution

Marine pollution comes in many different forms, including toxic chemicals, solid waste, nutrient and sediment input due to human activities (e.g. agriculture, deforestation, sewage discharge, aquaculture), radioactivity, oil spills, and debris such as discarded fishing nets and plastics. Furthermore, the spread of invasive species throughout the ocean is increasingly referred to as 'biological pollution'. The combined 'cocktail effects' of different chemicals and synergies between different types of pollutants are virtually unknown. Marine pollution changes the physical, chemical and biological characteristics of the ocean and coastal zones, which threatens biodiversity and affects the quality, productivity and resilience of marine ecosystems. Although the direct impacts of pollution are often localised, the United Nations Environment Programme (UNEP) has found that pollution is a major concern in coastal oceans, large lakes and riverine systems in over half of all investigated regions, making it very much a global threat. Coordinated international efforts have already succeeded in reducing oil spills; similar action is needed now to reverse the rise in plastic debris found throughout the ocean, and to address the growing threat of contaminated seafood.



The effects of global environmental change on the distribution of pollution and contamination are largely unknown. More research is needed to determine how shifting climate zones, increased temperatures and altered precipitation patterns will influence the pathways and effects of pollutants at global and regional scales, where impacts may be amplified or decline depending on pollutant and region. However, it is known that since some of the most important properties of chemicals are temperature dependent, environmental levels of pollutants can be influenced by climate change and variability. Pollutants can also have a negative impact on the ability of organisms to cope with a changing climate, for example by undermining their immune and reproduction systems, and can weaken the resilience of marine ecosystems to other stressors such as acidification.



Overuse of Marine Resources

Fishing is an ancient method of gathering food that has gone on for many millennia. Today, exports of fish are particularly important for developing countries and in many cases are higher in value than agricultural commodities such as rice and sugar. The vital importance of fish as a component of diet is often not recognised. According to the Food and Agriculture Organization of the United Nations (FAO), fish provide 20 percent of the intake of animal protein for 1.5 billion people and 15 percent for about 3 billion people. In SIDS and poorer coastal areas this figure can reach 90 percent. Globally, the total economic value of fishing is estimated at USD 225–235 billion per annum. The majority of fishers and fish farmers are located in Asia (85.5 percent), followed by Africa (9.3 percent), while in developing countries alone more than 200 million people are dependent on small-scale fishing. Fisheries are hugely important, both economically and in terms of food security, especially as the global population is projected to rise to more than 9 billion by 2050, with almost all this growth occurring in developing states.

The world's marine capture fisheries are in a severely troubled state. The FAO estimates that 85 percent of fish stocks are fully exploited, over-exploited, depleted or recovering from depletion. Harmful subsidies continue to contribute to the overcapacity of the global fishing fleet, inconsistencies in regional fisheries management organisations (RFMOs) lead to poor regulation, and illegal and unreported fishing – estimated to drain USD 50 billion from the sector every year – remains largely unabated; all threaten the long-term sustainability of these key resources.

The loss of marine biodiversity will be further exacerbated by global environmental change (GEC) impacts. Ocean warming is already leading to shifts in the range, depth and distribution of some key species and is expected to further disrupt migration patterns, leading to uncertainty in the ability of coastal communities to rely on these fisheries to support their livelihoods. Another potentially important link between global environmental and fisheries are the effects on phytoplankton, the foundation of ocean foodwebs, which are negatively impacted by warming, acidification and hypoxia. While numerous uncertainties regarding impacts on fisheries remain, GEC-related variability is an ongoing challenge for those whose livelihoods depend on fishing, creating a need for adaptation but making it difficult to achieve. The greatest vulnerability to climate-related fishing losses is concentrated in tropical least-developed countries, many of them in Africa and Southeast Asia.

The Impacts of Multiple Stressors

A complex web of challenges



The Impacts of Multiple Stressors

The ocean faces a multitude of interconnected threats that is unprecedented in modern human history. All regions of the ocean stand to be impacted by multiple stressors in the near future, while over 40 percent of marine ecosystems are already simultaneously facing several of the six major pressures outlined in this book. Despite this fact, most management strategies proceed on an issue-specific basis with little consideration for the interactions between different threats or the impacts of multiple stressors occurring at the same time. Information is rarely synthesised to convey a clear picture of where multiple threats are manifesting globally, regionally or locally, or whether their effects are antagonistic or synergistic.

The need to understand the complex interactions and potentially cumulative effects of multiple stressors is one of the most pressing issues in marine ecology today. The stressors can be divided into two categories: those that act globally but with varying intensity such as increased temperature, decreased oxygen and ocean acidification; and those that act at a local to regional level but which occur globally, such as overfishing, pollution, increased nutrients and hypoxia. The co-existence of more than one threat can create impacts that are greater than the sum of the parts; this is known as a 'synergistic response'. The risk of such responses has been shown to double where three or more stressors intersect. The potential for synergies is one of the largest uncertainties surrounding the prediction of the impacts of anthropogenic stressors.

To present one important example, the occurrence of mass bleaching of coral reefs has been shown to occur more frequently in response to a combination of stressors acting simultaneously – and often synergistically. The impacts of globally acting stressors, such as increasing temperature and acidification, interacting with local stressors, such as pollution, have been shown to have significant consequences for coral reefs in a number of regions across the world. In these cases, pollution undermines the resilience of coral reef ecosystems to other stresses, which diminishes their capacity to provide services such as storm surge protection, which is itself increasingly vital in the face of global environmental change.

There are complex feedback loops at play in the oceans. More research is urgently required, for example, to improve our comprehension of how ocean acidification, ocean warming and hypoxia interact and affect marine resources. However, a path of inaction cannot be permitted while we acquire better knowledge and understanding. For some feedback loops we have enough information to act

now. We already know that increased CO₂ in the atmosphere results in acidification; ocean warming leads to increased stratification; increased stratification enhances both acidification and hypoxia; hypoxia in turn enhances the effects of acidification; and that there may also be an increase in hypoxia as a result of acidification. This is complicated before we even start to consider the consequences for marine organisms, but it is becoming alarmingly apparent that the ocean is being subjected to a vicious cycle of severe threats as a direct result of human emissions – especially of carbon.

Though these challenges are daunting, there is an incredibly important implication of the observed links between globally and locally acting stressors: the control of local- to regional-scale threats has the potential to mitigate the impacts of global stressors, which is a prime indication that coordinated local interventions can aggregate upwards to have a global significance.



DAVID BURDICK/MARINE PHOTOBANK

The cumulative effect of these overlapping threats is a key reason why their impacts are being observed at a faster rate than previously predicted. It is therefore paramount that they be addressed together and across all scales. We need to learn to make policy decisions that aim to optimise these complex systems, approaching ocean governance from strategic perspectives that utilise multi-management schemes. While much remains unknown and unpredictable we should adopt a precautionary approach in the context of these unprecedented multiple stressors. The words of Agenda 21 may be 20 years old but they ring truer today than ever: ocean management strategies must be "integrated in content, and precautionary and anticipatory in ambit".

Valuing the Ocean Environment

Economic perspectives



Valuing the Ocean Environment

Uniting an analysis of the ways multiple threats interact in the ocean with a global economic analysis of the comparative consequences of action or inaction on global environmental change, and in particular climate change, is a major and ongoing challenge. While there is no universally accepted definition of the 'blue economy', the goal of strengthening it is widely considered to require that we integrate and make sustainable all sectors and functions that rely on marine resources and ecosystems, allowing them to continue to provide their vital and irreplaceable services.

Some things are too valuable to be assigned meaningful prices. Rather than asking the impossible question of what the ocean itself is worth, what this chapter seeks to at least partially calculate is 'what is the value of preventing further damage to the ocean?'. Or, 'what is the cost of the environmental damage that could be done to the ocean if we do not take action?'.

The analysis is restricted to five categories of damages that can be meaningfully priced and that can realistically be affected by policy decisions taken today and in the coming decades. The difference in climate impacts is measured between two scenarios: a scenario of only limited, slow-moving abatement, where emissions continue to grow for many decades; and a rapid abatement scenario, where emissions are reduced quickly and effectively, starting at once and approaching zero within this century.

The best estimates, based on the most reliable and up-to-date analyses available, of the 'price' of the five categories of damages discussed here are presented in Figure 1.3. By 2050, the value of these important climate impacts is estimated to be more than four times higher under a high emissions, high

impact scenario. By 2100, the cost of damage if we follow the high emission pathway rises to USD 1,980 billion, equivalent to 0.37 percent of global GDP. The difference between the two scenarios, or the amount that can be saved by lowering emissions, is well over a trillion dollars per year by 2100, equivalent to 0.25 percent of GDP. It is this difference – the avoidable damages – that policy-makers should take particular note of, and that should be included in the complex web of climate change accounting.

This is not a scaremongering forecast. Some people may even argue that the value of protecting these services is not particularly large in the great scheme of things. However, while considering these figures it is important to remember that they are only the 'sum of some things'. They do not take into account the worth beyond measure of the actual species which live in the ocean; or some of the critical processes and features of the ocean such as nutrient cycling, ecosystem functioning and genetic resources to which meaningful prices cannot be assigned; or the irreplaceable losses to cultural heritage and the dignity and identity of communities that are anticipated to be caused by global environmental change. The study also does not take into account the total disappearance that is possible – even probable – for certain coastal or island communities, and does not fully consider the catastrophe that will result if global environmental change tipping points are reached.

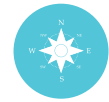
The figures are also not set in stone, but are subject to change along with the continuous flow of research and discovery. This chapter simply hopes to jumpstart a reasoned debate aimed at guiding policy-makers through the monetary value of the services provided by the ocean and what we stand to lose if we do not protect these services, and to encourage the integration of ocean services in economic plans. Decisions in the coming years will determine whether this trillion-dollar-a-year figure becomes part of the savings made by rapidly reducing carbon emissions, or yet another cost of inaction.

Figure 1.3 Valuation of selected climate impacts on the ocean (in billions of 2010 US dollars).

	Low climate impacts		High climate impacts		Difference	
	2050	2100	2050	2100	2050	2100
Fisheries	67.5	262.1	88.4	343.3	20.9	81.2
Sea level rise	10.3	34.0	111.6	367.2	101.3	333.2
Storms	0.6	14.5	7.0	171.9	6.4	157.4
Tourism	27.3	301.6	58.3	639.4	31.1	337.7
Ocean carbon sink	0.0	0.0	162.8	457.8	162.8	457.8
Total	105.7	612.2	428.1	1,979.6	322.5	1,367.4
Percent of GDP	0.06%	0.11%	0.25%	0.37%	0.18%	0.25%

Planning for Surprise

How to deal with the reality of uncertainty



Planning for Surprise

Preparing for the future involves assessing the opportunities and risks that tomorrow may bring us, and devising plans and strategies to deal with them. In the context of multiple marine threats and uncertainties this is a daunting task, and one for which we are currently not very well equipped. This book therefore includes a chapter dedicated specifically to planning for an unpredictable future.

The threats to the oceans identified in this book include both predictable, gradual changes, such as those for which monetary values can be estimated, and abrupt, low-probability changes associated with tipping points and potentially catastrophic losses. Unfortunately, economic and policy debate often narrows its focus to the former category, adopting the available numerical estimates for calculations of costs and benefits. This in effect assigns a probability of zero to the most ominous, but uncertain, threats that we face.

In other areas of life, individuals and institutions adopt much more sophisticated approaches to uncertainty. We routinely buy insurance to cover rare calamities such as residential fires, car accidents, or the death of young parents, even though these unlikely events have very low probabilities, often just tenths of a percent per year. Faced with less predictable threats of extreme events, businesses often explore alternative scenarios – as in the example discussed in this chapter, which is borrowed from a major energy corporation. It uses contrasting stories of future development, intentionally reflecting a wide range of possibilities, to create scenarios aimed at guiding business strategies.

Planning for worst-case scenarios is central to military and security policies. Costly, or at least time-consuming, precautions against unlikely, catastrophic risks are familiar to anyone who travels by plane; if predictable, average, or most likely outcomes were all that mattered, there would be no need for airport screening of passengers or luggage. Military planning is all about worst cases; on an average day, no one needs an army. The same precautionary framework also underlies a US military analysis of climate change risks, discussed in this chapter. That analysis examines a worst-case, though still possible, scenario based on the most extreme potential outcomes of different climate projections. It is not based on any theoretical or numerical model, but uses interviews with climate experts to extrapolate plausible climate change implications for national security.

A central implication of the economic analysis in this book is the need for better risk models, recognising that traditional cost-benefit analysis is inadequate in the face of extreme events. Using methods derived from insurance models could be more appropriate. This is applicable on two levels: the creative use of insurance mechanisms to cope with extreme events and ensuing local disasters; and the development of long-term policies that function as insurance against catastrophic and irreversible global risks. Insurance against extreme events is needed because the impacts of these events on the most exposed and vulnerable coastal communities, such as SIDS, will be greater than the global averages suggest, and may overwhelm local resources. Insurance tools can also help to create awareness of the risks associated with multiple stressors, providing a range of tools, including risk assessment and hazard mapping, to facilitate adaptation efforts and help invest resources most wisely.

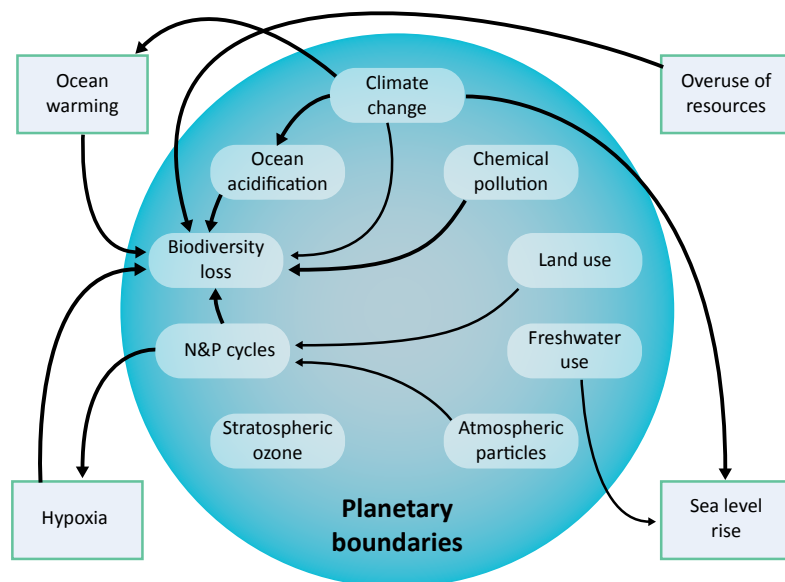


Figure 1.4 Links between threats to the global oceans (in boxes outside the circle) and the nine planetary boundaries identified in Rockström, J., et al. (2009), A safe operating space for humanity, *Nature*, 461(24 September), 472-475. Note that one of these boundaries – ocean acidification – is identical to one of the six ocean threats. 'N&P' refers to nitrogen and phosphorus.

Planning for Surprise

How to deal with the reality of uncertainty

Beyond the existing threats of extreme events and local losses lies a greater unknown: the ultimate risk of reaching tipping points at which global environmental change results – perhaps quite rapidly – in catastrophic and irreversible damages to the global environment. The insurance framework does not apply literally to such global threats; there is no interplanetary insurance company that will cover our destruction of the only planet we have. The only valid solution is the development of global policies that will 'self-insure' humanity against tipping points and catastrophic losses, by controlling climate change and environmental degradation at a level that makes disasters less, rather than more, likely in the future. These ultimate goals must be included as we consider the value of protecting the ocean environment.

In this regard, it is also useful to be aware of the links between threats to the marine environment and the recently identified nine 'planetary boundaries'. The earth and its ecosystems and resources are finite; therefore, existing, resource-intensive patterns of economic growth will, sooner or later, reach thresholds at which dangerous changes are threatened. According to a major recent study, those boundaries are being reached sooner rather than later: we have already passed into the danger zone on climate change, biodiversity loss, and overuse of nitrogen, and we are fast approaching the boundaries in other areas, including ocean acidification, phosphorus (fertiliser) run-off into the oceans, and other critical areas.

The examination of related processes, as shown in Figure 1.4, could be a useful aid in strategic planning. The figure illustrates the nexus between four of the ocean threats discussed in the book (shown in boxes) with the nine planetary boundaries. The arrows show causal links; for instance, increased CO₂ in the atmosphere (Climate change in the figure) increases both ocean acidification and warming, both of which impact marine biodiversity. Agricultural land

use influences the cycles of nitrogen and phosphorus, which impact hypoxia in the oceans. Taking this kind of holistic view helps to predict how action – or inaction – in one field impacts on another, for better or worse, and could help policy-makers to maximise the effectiveness of interventions.

The use of expert surveys is also increasingly being applied to environmental risk assessment. Figure 1.5 is a preliminary values-threats matrix showing the anticipated difference between the low and high emissions scenarios used in this book. The question put to marine experts for each threat/value combination (for instance, ocean acidification and ecosystem function) is: comparing the two Intergovernmental Panel on Climate Change (IPCC) emissions scenarios used in the economic analysis, how will the effects of ocean acidification influence ecosystem function? An arrow pointing straight down indicates that the experts surveyed thought the threat would become much worse; a 45 degree angle downwards indicates that the situation would become worse; a horizontal arrow indicates no significant change. The size of the arrows indicates the degree of consensus between experts: long arrows indicate a high degree of consensus; short arrows show little consensus. This kind of matrix can aid decision-makers with strategic planning in several ways. We can quickly identify areas in which there is strong consensus in the expert community that threats will become worse, and where coordinated, multinational efforts to address the problems are necessary. We can also quickly identify areas in which consensus is lacking, and where we need more research to support decision-making.

The fact that all the approaches considered have their shortcomings is key to the take-home message of this section: that we need to develop innovative management tools which help formulate strategic plans that work across scales and for several variables simultaneously, and which account for the element of surprise.

Threat/value category	Ocean acidification	Hypoxia/Anoxia	Sea level rise	Pollution	Overuse of resources	Warming
Earth system function value						
Carbon sink	↘	?	→	→	↘	↘
Biodiversity and generic resources	↓	↘	↘	↘	↓	↘
Oxygen production	↘	↘	→	→	→	↘
Ecosystem function	↓	↓	→	↘	↓	↘
Hydrological cycle	→	→	→	→	→	↘
DMS-cloud feedback; GHGs	↘	→	→	→	→	→
Nutrient cycling	↘	↓	→	→	→	↘

Figure 1.5. A values-threats matrix indicating the anticipated difference between low and high emissions scenarios for different threat/value combinations.

The Pacific Ocean

A case for coordinated action



The Pacific Ocean

The Pacific Ocean ecosystem contains half of the world's ocean area and generates 60 percent of its fishing revenues. It also provides vast economic services in the realms of tourism, recreation, natural gas, atmospheric and climate regulation, and transportation; is the foundation of the cultural heritage of millions of coastal and island people who live along the shores of this great ocean; and is home to an immeasurable wealth of biodiversity.

Alongside this bounty brews an equally diverse concoction of threats, including all of those presented in this book, making the Pacific basin the perfect laboratory to examine the impacts of and potential responses to the complex web of multi-stressors at a regional level. Decades of overfishing and the subsequent alarming decline of key fisheries, especially in the western and southwest Pacific, are major problems, long driven by subsidies and set to be further exacerbated by the effects of global environmental change. Many regions of the Pacific have already experienced considerable sea-surface warming, and projected changes in species distributions are expected to lead to a large decrease in maximum potential catch in the tropical Pacific by the 2050s. In addition, the large areas of coral reefs in the Pacific region are vulnerable to ocean warming and acidification, with consequences for the rich biodiversity they contain and growing tourism industry they support. This does not begin to consider the looming threat of sea level rise, which could alter the entire coast of the basin and wipe some islands off the map.

Solutions to these issues must be holistic, multi-

sectoral and cross-scale, putting into effect the concept of optimising a complex system presented in the multiple stressors chapter of this book. The governments of the Pacific region need to take a proactive stance against overfishing, especially considering the additional stresses of global environmental change; agree to eliminate distorting subsidies; and institute joint management of shared and high seas fish stocks. Coordinated action must be taken to mitigate and prepare for the effects of climate change on coastal and island communities, including through protective infrastructure to guard against sea level rise and increased severe weather, as well as the development of alternative skills and livelihoods to diversify local economies and ease their total dependence on fishing and tourism.

In the face of so many uncertainties, protection from unmanageable surprises (and valuable time) can be bought by bolstering the resilience of important ecosystems such as mangroves and coral reefs, as well as through the creation of carefully sited marine protected areas. With so much to protect, and so much to lose, the influential tourism and fishing industries should become strong advocates for the reduction of carbon emissions in other sectors of national economies (as well as their own), and lobby their governments to take a strong stance in international negotiations. The Pacific provides humanity with hundreds of billions of dollars of vital services every year, as well as playing a priceless role in the lives and traditions of its coastal and island inhabitants, and is home to an astonishing variety of species. In this one, albeit vast, basin the value of preventing the further deterioration of the ocean, and the immense costs and devastating losses that will ensue if effective and coordinated action is not taken across all scales to address multiple stressors, can be clearly envisaged.



REINHARD DIRSCHERL / FLPA

Key Conclusions and Recommendations

The key conclusions and recommendations presented here are an excerpt from a larger set to be found in the forthcoming book. Here, we concentrate on the more overarching conclusions and organise our recommendations into three categories: strengthening ocean governance; valuing and protecting ocean services; and addressing multiple stressors.



Conclusions

- The services provided by the ocean are immensely valuable but inadequately integrated in national, regional and global economic analyses and plans. The ocean is the victim of a massive market failure and dilution of political will, with devastating consequences for its ecosystems and the billions of people dependent on them. For example, the ocean stores an enormous portion of the planet's CO₂. However, if marine ecosystems are further degraded, their carbon uptake could be reduced or potentially even reversed. The value of this 'blue carbon' is not being awarded sufficient attention, and remains wholly unvalued by many governments and sectors.
- Multiple stressors are in some regions combining to create a perfect storm of impacts that threatens to seriously degrade critical ocean services. Unfortunately, this trend is becoming more and more common, yet very few management strategies are addressing multiple stressors in a coherent way. This undermines the resilience of marine ecosystems to withstand additional stress and places many coastal and island communities at heightened risk.
- Global environmental change impacts on the ocean are occurring faster and more significantly than predicted in the 2007 IPCC report. Fundamental changes being observed in the ocean are extremely alarming, scientifically verifiable, highly significant to humankind, and set to become far worse if we do not take coordinated action.
- Climate change and its related threats are increasing the probability of high risk, high impact events such as major floods and intense tropical storms. In light of this, traditional cost-benefit approaches to risk assessment and planning are no longer appropriate as they do not capture the full effects of these events.
- Huge savings can be made if we act now to reduce carbon emissions. For example, many of the impacts of sea level rise are potentially avoidable with widespread upgrade of protection measures, but at substantial cost. Increases in adaptation costs are estimated at USD 25 billion per year for a 0.5 metre rise, but escalate to USD 270 billion per year by 2100 for a 2 metre rise. The benefits of early action stretch far beyond financial calculations to also include preserving the dignity of vulnerable island communities and the national security of heavily impacted states that could be imperiled by a last minute scramble for survival.
- Developing countries are at greatest risk from the global environmental change impacts on the ocean: states most at risk from sea level rise include some of the world's poorest and most heavily populated; fishing communities in, for example, Asia, West Africa and the Caribbean stand to lose livelihoods and food security as fish species migrate poleward in search of cooler water; for some SIDS climate change is a question of their very existence.
- It is possible to reverse or remediate certain ocean damages through concerted management efforts. Some hypoxic zones have recovered, and the occurrence of certain pollutants has been reduced. Other changes, such as ocean acidification, could take thousands of years to reverse if they continue unabated at current rates.
- Much can and must be done now. We cannot afford to wait for perfect information and perfect political circumstances; they may never materialise. The absence of total understanding and global agreement must not delay the implementation of proven techniques to enhance ocean ecosystem resilience and the effectiveness of governance strategies.
- Local and national actions can increase the ability of specific, and important, ecosystems to withstand multiple threats and help prepare and protect vulnerable populations. Local governments are crucial connectors and coalition-builders, and are often best placed to address problems directly.

Key Recommendations for Sustainable Ocean Resources



Key Recommendations

Strengthening ocean governance:

- A United Nations High Commissioner for Oceans should be appointed to coordinate research, prioritise action and speak up for the ocean at the highest levels.
- Gaps in the current international ocean governance regimes must be addressed with greater urgency; in particular governance gaps in areas beyond national jurisdiction, including the adoption of shared principles, prior environmental assessment, establishment of Marine Protected Areas (MPAs), and a time-bound process for discussing equitable benefit sharing. Previously agreed-to resolutions for governance in areas beyond national jurisdiction should be fully implemented.
- Cross-sectoral, cross-scale, network approaches to ocean governance, focused on strengthening the entire management framework at a regional or ecosystem level, should be pursued. Inter-agency, regional and multilateral coordination and capacity would be greatly enhanced by the development of a global financing strategy for oceans and coasts.

Valuing and protecting ocean services

- Ocean services should be included in the valuation of ecosystem functions and integrated in economic assessments and policy, as they are critical components of the 'blue economy'. The valuation of 'blue carbon' activities and ecosystems should be pursued under the United Nations Framework Convention on Climate Change (UNFCCC) and fully incorporated into other carbon financing mechanisms.
- Management strategies for high risk, high impact events must be given higher priority; a one-in-twenty probability event today could become a one-in-five probability event by 2050 or 2100. Coastal zone protection, planning and smart growth are crucial, as are investments in improved forecasting, early warning systems and coordinated disaster relief strategies. States should actively prepare for a sea level rise of 1–2 metres by the end of this century. The cost benefits of taking action to adapt and protect ourselves now will increase significantly with time.

- Radically different risk assessment models should be developed which view the threats to the ocean – and, by extension, impacted communities – through the lens of insurance rather than cost-benefit analysis. We need to develop insurance mechanisms to cope with extreme events and local disasters, and develop long-term policies and resilient management strategies to cope with several threats acting together, which themselves function as insurance against the risk of catastrophic and irreversible global environmental change.

Addressing multiple stressors

- Research into where multiple stressors are occurring and how they are impacting on marine ecosystem resilience and processes should be prioritised. There is an urgent need for the global community to address these overlapping threats by embracing multi-dimensional management schemes and developing strategic planning approaches that allow for the optimisation across scales of more than one goal at a time.
- Local governments should act to reduce stressors wherever possible, including through promoting the need for inter-sectoral coordination, especially across land-based and water-based ministries that do not typically work together. At the national level, efforts should strive to support well-informed decisions and effective action at the local level that appreciate the complexity of multiple stressors, and that aggregate up to the regional and global level. This will move us collectively forward and buy valuable time in the fight against global environmental change.

- Innovative international financial instruments and mechanisms should be developed to strengthen the ability of vulnerable communities to predict, understand and prepare for the risks posed by multiple stressors, including rising sea levels and other climate-related threats. Capacity-building at local, regional and national levels must be given more urgent attention to enable communities and states to address the pressing and escalating issue of multiple stressors on the marine environment.

- Carbon emissions must be drastically and urgently reduced. Actions such as all those proposed above can help make a bad situation better, and prepare for a bad situation to become worse, but humankind must set itself on a low emissions, low climate impact pathway without delay or we are headed for catastrophe.

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We must revolutionise our strategies for governing the oceans and coasts. There is an urgent need for the global community to create management plans that are aimed at optimising the sustainable benefits from marine services across scales from local to global. Strategies that address multiple threats and prepare for high risk, high impact events must be awarded higher priority.

Preview of results from a book on
threats to the global oceans and
the economic consequences of
action or inaction

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