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

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Valuing the Ocean
Extended Executive Summary

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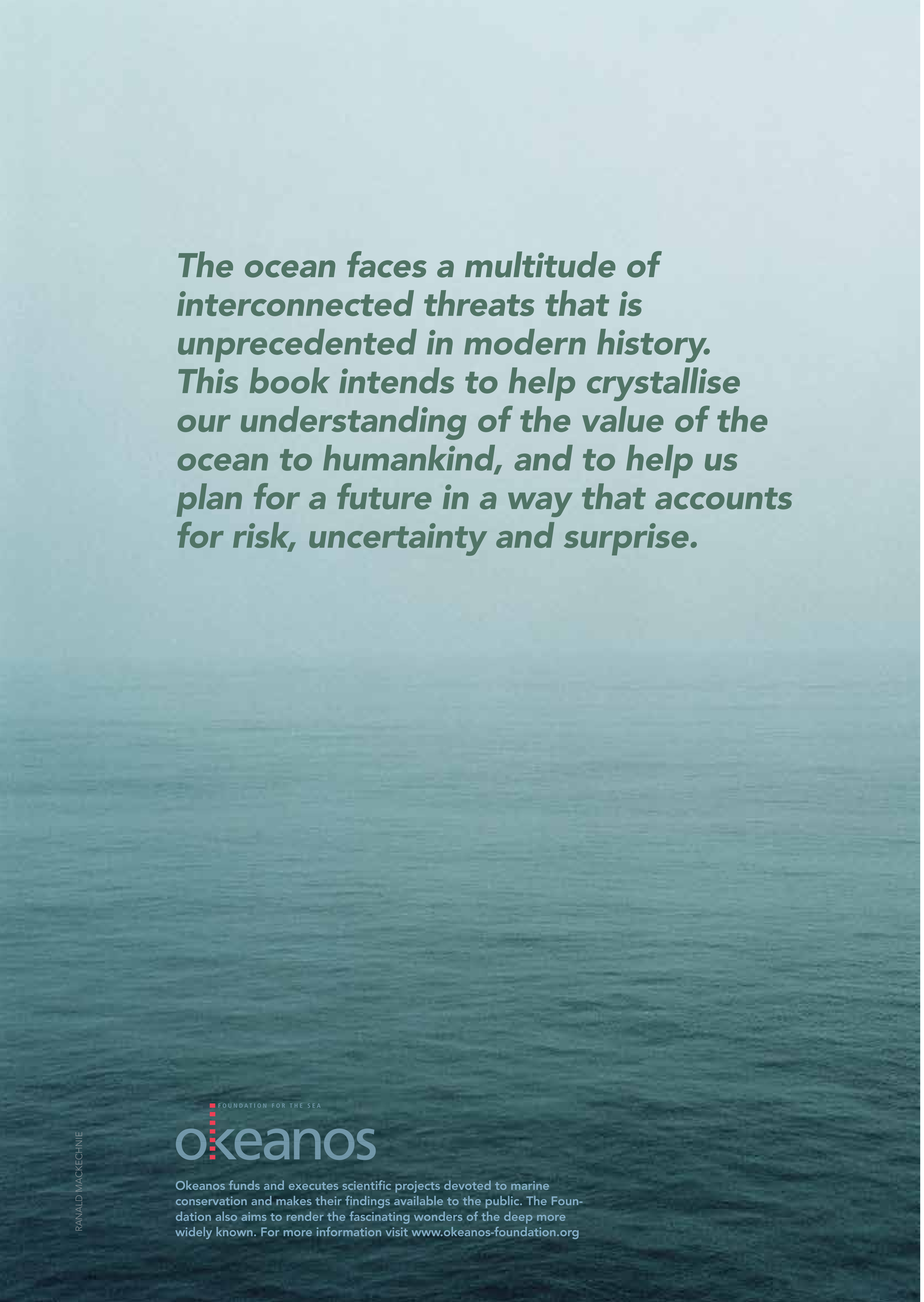

RANALD MACKECHNIE

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 the ocean to humankind, and to help us plan for a future in a way that accounts for risk, uncertainty and surprise.

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Valuing the Ocean

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

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 much of the heat added to the global system in the past 200 years. 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', 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 tourism, to storm protection, to carbon absorption – can and should be assigned monetary values and incorporated in broader global and national economic policies, so 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 human 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 and overexploitation.

Ocean services contribute in very tangible and substantial ways to local livelihoods, as well as national economies and foreign exchange receipts, government tax revenues and employment; a fact that is not sufficiently taken into account when considering the cost of protecting the marine ecosystems and biodiversity on which these contributions are based. 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 in 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 much greater appreciation of the value of the services it bestows.

Bridging gaps and building trust
The forthcoming collaborative book 'Valuing the Ocean' seeks to bridge these gaps between our current perception and understanding of the ocean, and the real economic – and other – losses we stand to incur if we continue to fail to address these multiple threats, i.e. the consequences of inaction. In so doing, the authors aim to help derive a new framework that enables more informed decision-making on marine issues.

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 damages due to global environmental change in the marine domain, i.e. the actual monetary value of not causing further detriment to the ocean.

By pricing the difference between low and high CO_2 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 them. In the final chapters, a discussion of different ways to plan for a future 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.

This book seeks to improve on methodologies for holistic, cross-scale analysis of the function of the coupled human-environmental system. We also want to improve on our ability to perform global-scale economic valuation of ecosystem goods and services. Effective decision-making requires a level of trust between actors – in this case between the research community and stakeholders in the policy and private sectors. We want to enable greater consistency in decision support and decision-making across sectors and scales – to help see to it that local and regional decisions move us in positive directions on the global scale.

Values, threats and knowledge
'Valuing the Ocean' aims to expand the research frontier in marine sciences, including by forging links between the natural sciences, ecology and the lesser-known field of ocean economics. Decisions in the marine domain will need to be made despite having a number of significant 'known' and 'unknown' unknowns. It is intended that this book will help to identify some of these potential surprises, assess their risks, and put bounds on their significance and impact.

Some things that cannot be assigned meaningful market prices are nonetheless critical to the functioning of the Earth System. Nutrient cycling, oxygen production and genetic resources are examples of properties of the ocean 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.

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 remains 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. The final chapter delivers high level recommendations focusing on what is still needed to stimulate the development of policies that will really move us towards the sustainable use of marine resources and services.

A central conclusion is that we critically need to go beyond the current approach of addressing (or ignoring) one threat at a time. We must create management strategies that are aimed at optimising the sustainable benefits we can obtain from marine resources across scales from local to global, and in the face of several interacting and escalating threats. In order to avoid further damage to the ocean, we must develop a holistic view of the full impact and cost of our actions, and create a framework for ocean management in the Anthropocene – the current epoch in which human beings are the dominant drivers of global environmental change.

What is the ocean worth to you?
The very chemical, thermodynamic and biological foundations of the ocean are being impacted by human activity, putting at risk marine ecosystems and services on which humankind so essentially depends. Stakeholders need to be made aware of what we all 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 ocean is really worth to them and to the future of our planet.

R.DIRSCHERL/FLPA

Ocean Acidification

The atmosphere and the ocean exchanges gases across the sea surface to such an extent that over the last 200 years the oceans have absorbed 25-30 percent – or around 500 G tonnes of the globally accumulated human emissions of CO_2. Without ocean uptake, atmospheric CO_2 would have already reached around 450 ppm, 60 ppm higher than it is today. However, while this process partially buffers climate change, the resulting perturbations to the ocean's carbonate system – known as ocean acidification – has potentially serious consequences for the organisms that inhabit it.

Ocean acidification is already happening, and is a direct consequence of increased CO_2 emissions to the atmosphere. This is not speculation; it is highly certain based on known chemical equilibria. Mean surface ocean acidity has increased by 30 percent since the industrial revolution and, if we continue to emit CO_2 at the same rate, the acidity could increase by 150-200 percent by 2100. This rate of change is around ten times faster than any other event experienced by the ocean for the last 65 million years. If CO_2 emissions are not curbed substantially it will take tens of thousands of years for ocean pH to return to close to what it is today.

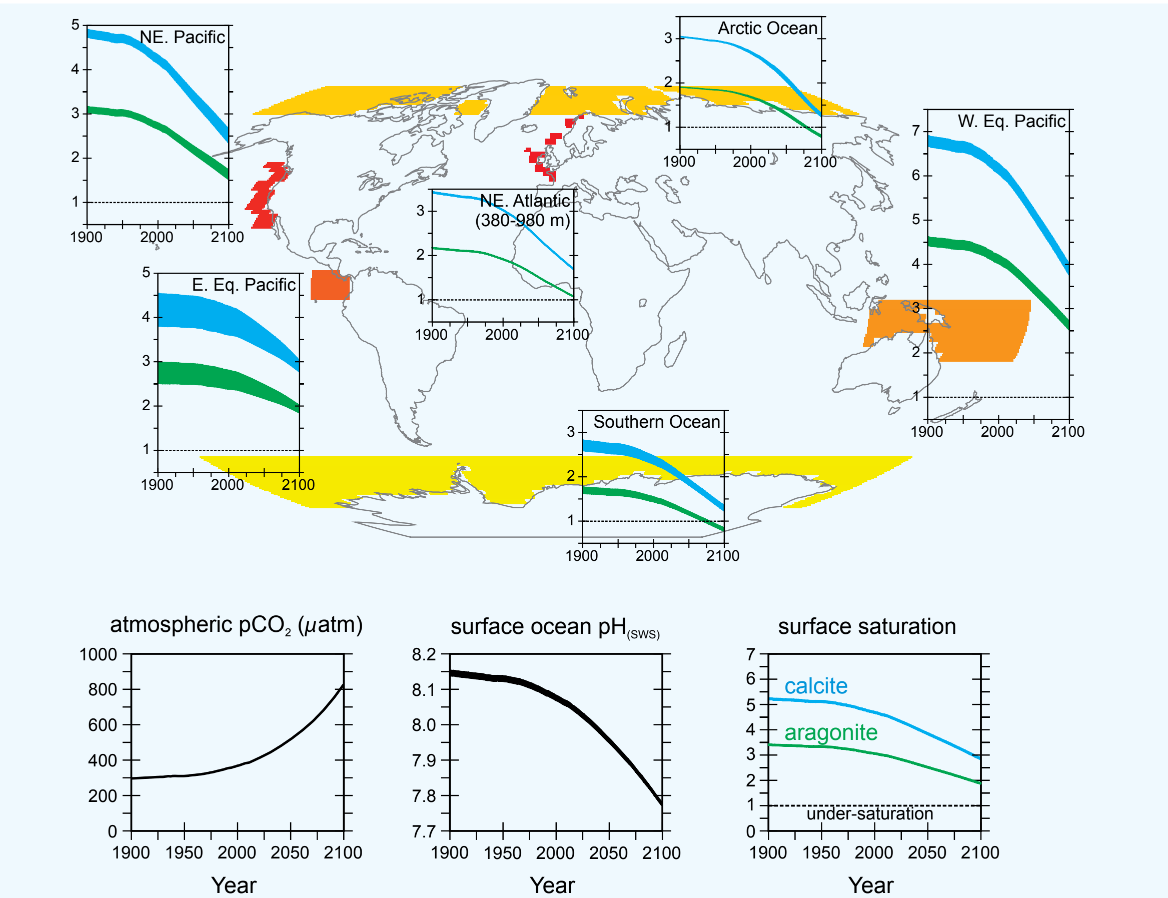
On exchange with the atmosphere, dissolved CO_2 reacts with seawater to form carbonic acid. In this process, ocean pH falls and acidity increases. A combination of chemical reactions – explained in detail in this chapter – results in a decrease in calcium carbonate minerals in the ocean. This is hugely significant for ocean ecosystems as calcium carbonate in the form of calcite, aragonite and magnesium-calcite are the building materials for the shells and skeletons of many marine organisms.

The saturation horizon, below which calcium carbonate becomes soluble, is projected to move upwards towards the ocean surface as a direct product of these changes to ocean chemistry, which will leave more organisms exposed to corrosive conditions.

Regions that naturally experience lower pH than the global average may be particularly vulnerable to future ocean acidification. Some coastal shelf seas and estuary zones near river mouths are also vulnerable because of inputs of freshwater, which changes the carbonate chemistry.

In some vulnerable regions this is already happening at a startling rate. The pH in the Arctic Ocean is declining even faster than the global average, and the aragonite saturation horizon is rising at a rate of 4 metres per year. This means that an additional 800 square kilometres of sea floor are being exposed every year to seawater chemical conditions that are corrosive to unprotected shells.

Figure 1 Projected regional changes in ocean chemistry likely to be experienced by particularly vulnerable ecosystems compared to global-scale surface ocean changes if CO_2 emissions continue at the same rate. The transient simulation of climate and carbonate chemistry was performed with the UVic Earth System Climate Model using observed historical boundary conditions to 2006 and the SRES A2 scenario to 2100. Reprinted from *Marine Pollution Bulletin*, Vol. 60, Turley, C., Eby, M., Ridgwell, A.J., Schmidt, D.N., Findlay, H.S., Brownlee, C., Riebesell, U., Gattuso, J.-P., Fabry, V.J. & Feely R.A., The societal challenge of ocean acidification, p. 787-792, Copyright (2010), with permission from Elsevier.



Future scenarios

Even the ocean, in all its vastness, has its limits. Today, the atmosphere, land and surface layer of the ocean together hold less than 4,000 billion tonnes of carbon. Fossil fuel reserves are estimated at 5,000 billion tonnes of carbon. Comparing these two figures clearly shows that the capacity of surface reservoirs to absorb carbon will be overwhelmed if fossil fuel burning continues unabated.

While reaching equilibrium between the atmosphere and the mixed upper layer of the ocean takes under a year, exchange between this upper layer and the massive deep ocean reservoir takes around 1,000 years. In addition, ocean warming will also affect the solubility of CO_2 and increase stratification which may further slow ocean mixing.

Ocean acidification is therefore 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 global environmental change.

In Figure 1, the blue shaded bands indicate the annual range in ocean saturation state with respect to aragonite, while the green shaded bands indicate the range for calcite saturation. The thickness of the lines indicates the seasonal range, with the threshold of undersaturated environmental conditions marked as a horizontal dashed line. The corresponding regions from which the annual ranges are calculated are shown in colour on the map. These projections are based on the IPCC SRES A2 scenario, which is one of medium to high emissions with CO_2 emissions reaching approximately 3 GtC/year, and mean global temperatures increasing by 3.4°C by 2100. Under such conditions, by the end of this century the Arctic and Southern Oceans will be undersaturated in these carbonate ions and therefore corrosive to unprotected shells and skeletons.

Actual future global ocean acidification will depend entirely on the CO_2 mitigation pathways that humanity follows, ranging from a global mean pH decline of 0.16 under a low emissions scenario, to a decline of 0.35 under a high emissions scenario. This must be added to the 0.1 pH decline which has already occurred. Since it is based on basic chemical equilibria, this is one area where the outcomes under different scenarios can be predicted with great certainty. Effective emissions reduction measures would make a direct and very significant difference to ocean chemistry and prevent serious impact from acidification.

Impacts on ocean organisms

A growing body of scientific research is supporting concerns that these unprecedented rapid changes to ocean chemistry will impact marine organisms, ecosystems and food webs and through them the resources, services and provisions they supply humankind. While there are some marine animals and plants that appear to be unaffected, an increasing number of organisms are displaying sensitivity to ocean acidification, either in their physiology, behaviour or developmental stages. As outlined in detail in this chapter, some species have malformed and eroded shells, while others are displaying more risky behaviour, or suffering from compromised fertilization success rates when exposed to waters with higher CO_2.

Reduced calcification has already been observed in corals in the Great Barrier Reef and in some kinds of plankton, although this cannot be unequivocally linked to ocean acidification. The stresses created by ocean acidification could also affect some species' ability to cope with other climate change related impacts such as rising temperatures and decreasing levels of dissolved oxygen.

Impacts on humanity

If CO_2 emissions continue at the same rate, current evidence points towards substantial changes this century at the species, population and ecosystem level everywhere from the cold polar and sub polar waters to the tropics, the deep ocean and the most productive coastal and upwelling areas. Some of the organisms affected by ocean acidification are ecosystem builders and land protectors such as corals, whilst others are key links in food webs such as pteropods, or are directly providing a substantial protein and income source for millions of people, such as shellfish.

The impacts on particular communities and economies is hard to predict, but research is pointing to some significant concerns and in some regions, such as the northwest coast of North America, acidification is already affecting important commercial shellfish. One major worry in the future is that impacts on zooplankton communities could alter food webs that include salmon and whales in polar and sub-polar regions. Food security and the livelihoods of millions in the future could be at risk if the food sources of key fish species are impacted.

The solution

Increased acidification is a growing and urgent threat to the ocean. At the global level, the only way to reduce future ocean acidification is by the rapid and substantial reduction of CO_2 emissions to the atmosphere. At regional and national levels, bolstering ecosystem resilience by reducing other stressors such as pollution and overfishing may help maintain biodiversity and conserve a diverse set of habitats.

Ocean Warming

As the surface temperature of the Earth increases due to global environmental change, a significant portion of the associated additional energy is being transferred to the ocean causing a substantial warming trend. The resulting rising mean surface ocean temperatures have serious implications for marine ecosystems and resources, as well as for people around the globe.

In addition to sea level rise, which is treated separately in Chapter 5, there are two primary impacts of ocean warming: physical consequences related to changes in extreme weather events; and biological consequences, including range shifts in fish populations and coral bleaching. Some of these impacts, such as damage to or even the destruction of coral reefs, will be felt in the oceans themselves. Others, such as changes in hurricane intensity, will also be felt far away from the ocean domain.

Physical consequences of ocean warming

• Extreme weather: Precipitation and flooding
As the ocean and the atmosphere warm, the amount of water vapour in the atmosphere at a given relative humidity increases. This increase is not linear, but exponential; the amount of water at a given relative humidity increases very rapidly.

These changes in the amount of water vapour are expected to lead to concomitant changes in the hydrological cycle, including an increase in the intensity of precipitation. Climate extremes such as extreme precipitation or droughts are not driven exclusively, or sometimes even dominantly, by ocean temperature increases, but are examples of the kinds of changes in global climate that are due at least in part to ocean warming, and that will be felt in areas well removed from the ocean basins.

Recent studies based on both observations and model simulations of trends in extreme precipitation in the Northern Hemisphere during the period between 1951 and 1999, revealed sufficiently robust spatial patterns of changes to detect a clear signal of anthropogenic influence on the extreme values. Observations showed an increase in extreme precipitation over much of North and Central America, as well as over central and Eastern Europe. The findings also indicated areas of both increased and decreased extreme precipitation over much of East and South Asia, with decreases (associated with warming and drying) over the Iberian Peninsula in Europe.

Overall, the observations showed a 65 percent increase in one-day extreme precipitation throughout the period, and a 61 percent increase in five-day extreme precipitation. These kinds of extreme events can have huge impacts on society, for example causing flood damage, crop losses during droughts, and damage to built infrastructure. It is becoming increasingly clear that human-induced changes in extreme precipitation will have major societal and economic consequences.

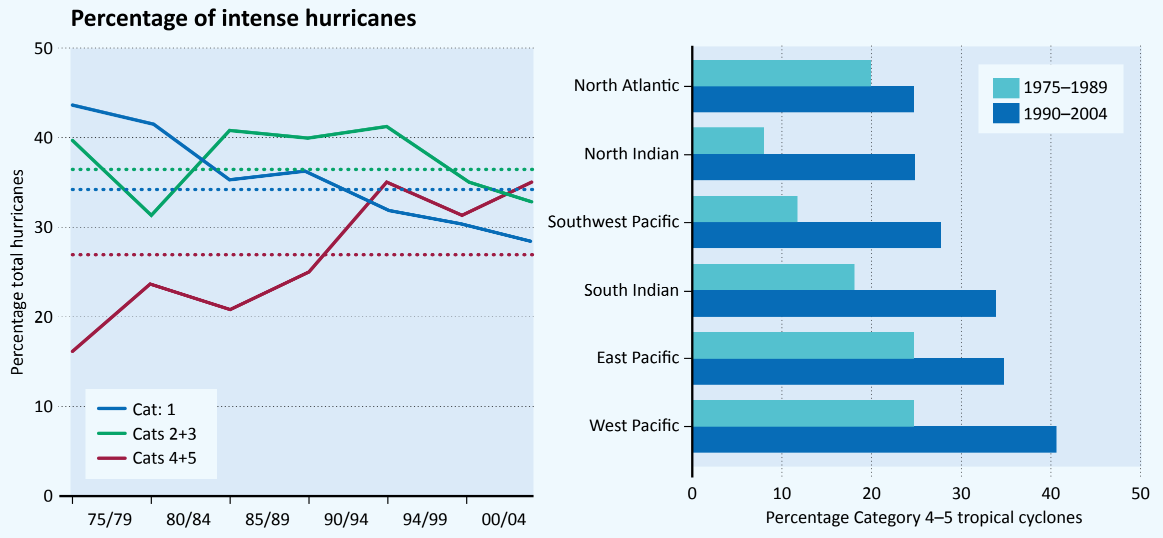


Figure 2. Panel A: Percentage of tropical cyclones in different Saffir-Simpson hurricane categories (1-weakest, 5-strongest). Reprinted from *Science*, Vol. 309, Sept. 16, 2005, P. J. Webster, G. J. Holland, J. A. Curry, H.-R. Chang, Changes in tropical cyclone number, intensity and duration in a warming environment, Copyright (2005), with permission from The American Association for the Advancement of Science (AAAS).

Panel B: Increase in percentage of the strongest storms across ocean basics.

• Tropical cyclones: increasing intensity
The life cycles of tropical cyclones are intimately linked to ocean warming as seawater surface temperature above $26^{\circ}C$ is one of the prerequisites for their occurrence, along with high humidity, low wind shear, and strong convection and cloud formation.

It is very difficult to extract a clear signal for changes in the number and properties of tropical cyclones from the very large inter-annual and decadal-scale variability that exists in their life cycles. To date, there is no robust observational evidence that changes in tropical cyclone frequency have exceeded natural variability. Satellite data from the period 1970-2004 reveals a good deal of variability in the number of storms during this period, with no clear trend.

In contrast to the number of tropical cyclones, an increase in the their intensity has been observed in recent studies, and linked to anthropologically-driven ocean warming. As shown in Figure 1, one major study found that the percentage of the strongest storms (category 4 and 5) increased globally from less than 20 percent in 1970–1974 to about 35 percent in 2000–2004, and increases were apparent across all major ocean basins.

Given the variability of tropical cyclones, the number of factors that influence their formation and life cycle, and the limited length of consistent global observations (especially from satellites), it is not surprising that there is ongoing debate about detecting and attributing trends in their intensity and frequency. However, there is accumulating evidence that, globally, the intensity of tropical cyclones has increased in recent decades, coincident with an increase in sea surface temperature.

Impacts and projections

Alongside this increase in intensity, there are also projections that, for a variety of reasons, the overall frequency of tropical cyclones will decrease by the end of the century. Although figures vary, a recent literature review with a global perspective bracketed projections of the decrease in frequency of tropical cyclones by 6-34 percent, with an increase in intensity of 2-11 percent by 2100.

Why is it so important to pay attention to the most intense tropical cyclones if the total number is expected to decline? Because the stronger storms cause exponentially more damage to people and property. Mean damage ratios increase rapidly once storms reach the category 4 and 5 level. More intense tropical cyclones will cause increased severe damage to settlements, agriculture and infrastructure.

Economic damage is a function not only of hurricane strength, but also of demographic changes such as increases in population and housing in coastal areas. On one hand, intense tropical cyclones regularly make landfall in many areas of Central Americas, East and South Asia, the Pacific, and even some parts of southern Africa, where less affluent people – including those living in heavily populated areas – are highly exposed to their impacts. On the other hand, there are also growing concentrations of more affluent people – and their property – in vulnerable coastal areas, for example in the United States where hurricanes already account for more economic losses than any other natural disasters.

Economic losses due to tropical cyclones will be greater in wealthy coastal settlements; human impacts will be more devastating in the poorer communities, as they often lack the capacity to adequately prepare for or respond to such events. Both categories of loss are projected to increase alongside the intensity of tropical cyclones, potentially by a great deal.

Biological consequences of ocean warming

Ocean warming is impacting the lifecycles of some species and disrupting food webs underlying globally significant fisheries. It is also affecting species distribution, with the range shifts of some valuable fish stocks moving toward higher latitudes (poleward) and into deeper waters. These unprecedented shifts in the distribution of fish will adversely impact many coastal nations and further threaten food security, especially in developing nations, as is discussed in greater detail in Chapter 11, which presents the case of the Pacific Ocean.

Increased temperatures are also predicted to cause the bleaching and potentially even the death of highly valuable and productive coral reefs, which are among the planet'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 at-risk 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 future impacts of ocean warming, and in the absence of strong global action to combat its root cause, rising CO_2 emissions.

Hypoxia

The importance of oxygen to the worth of our ocean

Over the last 50 years, trends of rapidly decreasing oxygen concentrations have emerged in both coastal and open ocean systems. The expansion of these low oxygen areas poses an unprecedented threat to life in the sea. No other environmental variable of such ecological importance to coastal ecosystems has changed so drastically in such a short period of time. Without sufficient levels of oxygen, many ecosystem services would be severely reduced. This includes all fisheries.

Many of these trends are linked to human activities associated with an ever-expanding global population and resource use. Low dissolved oxygen environments (known as hypoxic or 'dead' zones) now occur in over 500 coastal systems and vary in frequency, seasonality and persistence. They are overwhelmingly caused by organic and nutrient over-enrichment – or eutrophication – related to sewage/industrial discharges and runoff from agricultural lands. The creation of more dead zones represents a potentially enormous ecological and economic threat to ocean ecosystem services. Alongside this anthropogenic phenomenon, naturally occurring hypoxic habitats (oxygen minimum zones or OMZs) are also expanding for reasons related to global environmental change.

The overall forecast under business-as-usual is for all forms of hypoxia to worsen, with increased frequency, intensity and duration. The future status of hypoxia and its consequences for the environment, society and economies will depend on a combination of global environmental change (primarily from warming, and altered wind, current and precipitation patterns) and land-use change (primarily due to human population growth, agriculture and nutrient loadings).

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

NASA C/O JEFF SCHMALTZ MODIS LAND RAPID RESPONSE

Causes of hypoxia

Coastal hypoxia is closely related to agricultural practices on the continents. It is estimated that, largely as a result of fertilizer use since the 'Green Revolution' in the second half of the twentieth century, the flux of nitrogen has already doubled over natural values while the flux of phosphorus has tripled. By 2050, as we strive to feed and provide for a global population predicted to rise to nine billion people, coastal marine systems are expected to experience a further two- to three-fold increase in nitrogen and phosphorus loading compared to today's levels.

When more nutrients are added to the sea, more organic matter is produced, creating greater oxygen demand when it is decomposed. The relatively low solubility of oxygen in seawater combines with two other principal factors to lead to the development of hypoxia (low oxygen) and at times anoxia (no oxygen). These factors are water column stratification that isolates the bottom water from exchange with oxygen-rich surface water, and the decomposition of organic matter in the isolated bottom water by microbes that reduces oxygen levels. Both factors must be at work for hypoxia to develop and persist.

Global patterns

Since the 1960s, there has been about a ten-fold increase in reported eutrophic driven hypoxic areas, taking the number above 500. However, this figure presents an incomplete picture as it is based primarily on the well-studied North American and European regions; once the Asian and Indo-Pacific regions start to report, the number of dead zones is likely to double to over 1,000.

Many of these hypoxic zones are not permanent, but seasonal. For example, for about three months every year Chesapeake Bay experiences seasonal hypoxia that covers an area of 3,500 km^2. In the northern Gulf of Mexico, severe seasonal hypoxia lasts for six months a year and covers about 20,000 km^2. By contrast, the Baltic Sea suffers from perennial hypoxia that extends to 70,000 km^2.

Deoxygenation and global environmental change

Natural OMZs are permanent, stable, low-oxygen oceanic features that occur at depths from 100 to 1200 metres. They are most widespread in the eastern Pacific, off the western coast of Africa, and in the northern Indian Ocean. OMZs often occur beneath upwelling regions, and upwelling-induced productivity is a primary contributor to persistent hypoxia.

OMZs currently cover about 30 million km^2 of open ocean globally, but this figure is expected to rise. Global environmental change will expand OMZs and make coastal systems more susceptible to the development of hypoxia through direct effects on water column stratification, solubility of oxygen and mineralisation rates. This is likely to occur primarily as a result of ocean warming and the subsequent decrease in oxygen solubility. Warmer surface waters will in turn extend and enhance water column stratification, and increase organism metabolism, both key factors in the development of low oxygen.

As pointed out in the chapter on multiple stressors, the influence of multiple global environmental change drivers on ocean oxygen levels needs to be considered in order to understand what changes to expect in the future, but research in this area is still in its infancy. Acidification is one of the most significant changes taking place in the ocean due to rising greenhouse gas emissions, but while its effects on biogeochemical cycles are becoming better understood, its effects on oxygen and nutrient supplies are not. Such global environmental drivers are expected to magnify the local and regional effects of an expanding human population.

Environmental consequences

Hypoxic or dead zones place huge stress on aquatic ecosystems and can cause fish kills, disrupt food webs and even have impacts on human health through shellfish poisoning. The increase in harmful algal blooms and hypoxia are two of the most prominent impacts associated with eutrophication. However, even small changes in dissolved oxygen levels can have major consequences as has been shown for high performance open ocean fishes.

While it is known that when a dead zone forms fish, crabs, shrimp and other marine life swim to areas of higher oxygen concentration, there is little specific information on population level effects of hypoxia and anoxia. A combination of other stressors – including global environmental change, pollution and habitat destruction – also produce similar responses, which further complicates the identification of population level responses specific to hypoxia.

Hypoxia causes 'habitat compression' as zones avoided by marine species are functionally lost from the system. If it is important for fish to reach critical nursery or feeding areas at certain times in their life cycle then hypoxia may impact on population dynamics if it causes these movements to be disrupted.The cost of delayed migration in terms of population mortality and production is not known. Quantifying the effects of hypoxia on fish populations is critical for the effective management of coastal ecosystems and for the design of effective remediation strategies. More research is urgently needed to fill these knowledge gaps.

Economic consequences

Economic effects directly attributable to hypoxia are subtle and difficult to quantify even when mass mortality events occur. However, it is known that species can experience a range of problems that negatively affect economic interests. These are tied to the direct impacts on fish stocks such as reduced growth, movement to avoid low oxygen zones and predation pressure. Direct effects on fishers include increased time on fishing grounds, cost of searching for stocks and market forces that control dockside prices.

Several large systems have suffered serious economic consequences from severe seasonal hypoxia. Among the most notable cases are the Kattegat, which experienced a localised loss of catch and recruitment failures of Norway lobsters in the late 1980s, and the northwest continental shelf of the Black Sea, which suffered a regional loss of bottom fishery species, also in the 1980s.

Hypoxia creates hostile environmental conditions incompatible with many commercial fisheries, and the associated habitat compression can also make them more vulnerable to over-exploitation. For example, further expansion of the Atlantic OMZ coupled with continued overfishing could further threaten the sustainability of valuable fisheries and marine ecosystems. Consequences of hypoxia have also been linked to shifts in ecosystem services away from high value fisheries to smaller lower value fisheries at local and regional levels.

Restoration and the future

The bad news is that the overall forecast is for all forms of hypoxia to worsen in the future. The good news is that the consequences of eutrophication-induced hypoxia can and have been reversed with long-term and persistent efforts to manage and reduce nutrient loads, leading to the restoration of ecosystem services. A good example is the transboundary effort in the Danube river basin that has prevented large scale hypoxia from returning to the north-western continental shelf of the Black Sea. However, reversing the expansion of OMZs in the global oceans will far more difficult, ultimately requiring a global strategy to reduce greenhouse gas emissions.

Both human and climate-dominated processes have to be considered in predicting and understanding the complexities of oxygen dynamics. In order to achieve this, long-term monitoring programmes are needed to measure dissolved oxygen at proper spatial and temporal scales.

Three of the five major mass extinction events in the Earth's history involved widespread deep-water anoxia. There is an urgent need to identify and reduce the drivers of both eutrophication related hypoxia and the expansion of natural OMZs. The management of these drivers will often require transboundary or even global action, but local circumstances can ultimately determine how soon hypoxia reaches critical thresholds.

Sea Level Rise

Global mean sea level has risen by approximately 25cm since 1850, and the pace is accelerating: sea level rose by approximately 6cm in the nineteenth century and by 19cm in the twentieth century. The rate was about 1.8mm per year over the last five decades, doubling to 3.1mm per year in the 1990s, and 2.5mm per year in the period between 2003 and 2007.

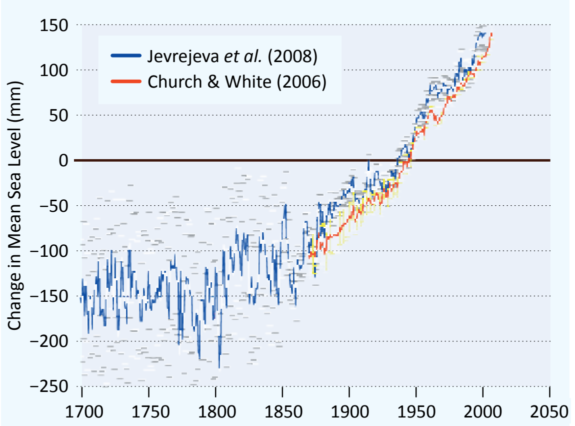
Research into sea level rise has made very substantial progress in the last few years. The understanding of more recent trends has benefitted greatly from the advent of data from satellite instruments in the 1990s, providing measurements that are independent of the traditional tide gauge readings. Like the tide gauge data shown in Figure 3, satellite observations show a clear upward trend in sea levels.

Sources and causes

Changes in mean sea level at any given location are a caused by a combination of different processes. The most significant are the thermal expansion of the ocean due to warming temperatures, and the addition of water to the ocean from the continents through melting or transport of ice from glaciers and ice caps.

Given the huge volume of water in the ocean, even the smallest degree of thermal expansion caused by warming water can result in substantial changes in sea level. As the surface temperature of the Earth increases, some of the energy associated with the warming is transferred into the ocean. Recent, more advanced methods of calculating this transfer have revealed a substantial warming trend of 0.64 W m^2 between 1993 and 2008.

Figure 3 Changes in mean sea level derived from tide gauge data. Grey bars indicate uncertainties in the Jevrejeva *et al.* analysis; yellow bars for the Church & White analysis. Jevrejeva, S., J. C. Moore, A. Grinsted, and P. L. Woodworth (2008) 'Recent global sea-level acceleration started over 200 years ago?', *Geophys. Res. Lett., 35(8)*, L08715. Church, J. A., and N. J. White (2006), 'A 20th century acceleration in global sea-level rise,' *Geophys. Res. Lett., 33(1)*, L01602.



A composite summary of recent reports and sources estimates that thermal expansion was responsible for 1.6mm of the 3.1mm per year of sea level rise experienced in the decade from 1993 and 2003. While different studies all show that the ocean has been expanding due to heating over the 1950-2000 period, the differences between various model calculations indicate more work still needs to be done to improve the descriptions of heat transport to and especially within the ocean.

Freshwater is stored on the continents in the form of small glaciers and ice caps, as well as in the very large ice sheets covering most of Greenland and Antarctica. We tend to take these ice sheets for granted, but they were not always present. The Greenland ice sheet formed 'only' a few million years ago when atmospheric CO_2 concentrations decreased during the Late Pliocene era. Ice sheets have played a critical role in the Earth's climate during the entire period of human evolution.

If all this ice were to melt, small glaciers and ice caps would cause sea level to rise by 0.6 metres, the Greenland ice sheet would raise sea levels by about 7 metres, and the ice in Antarctica would cause a 56 metre rise.

How rapidly the major ice sheets will respond to increases in global mean surface temperature – their 'response times' – remains uncertain. Measurements of the gain or loss of ice mass in Greenland and Antarctica since the 1990s suggest dynamic processes other than simple melting are causing the acceleration of the transport of water mass from the continents to the ocean. For example, meltwater can percolate down to the base of glaciers and act as a lubricant, causing the glaciers to flow more rapidly. Ice shelves act like a cork, holding back the glaciers that feed into them. If they thin or break up (like the Larsen B ice shelf did in 2002), the glaciers flowing into them can flow faster, transferring ice into the ocean more rapidly.

Both Greenland and Antarctica have some areas that have gained mass and others that have lost. Greenland tends to increase in mass at the high-elevation centre of the ice sheet and lose it at the edges, while Antarctica has gained mass in the eastern regions while losing it in the west. Gains in mass are caused by increases in precipitation, losses are caused by melting or the physical flow of ice from the land into the ocean.
In Greenland, ice mass loss increased by a factor of seven in the decade between the mid-1990s and the mid-2000s. In Antarctica, ice loss nearly doubled in the same decade, almost entirely due to changes in west Antarctica and the Peninsula, with little change in east Antarctica. If these trends continue into the future, the response times of the major ice sheets could be much more rapid than is currently estimated.

Melting ice has been the dominant source of sea level rise for about the last decade, and continental glaciers contributed to this by more than 20mm since 1960.

Future projections

Although our understanding of these complex, dynamic processes is growing, obtaining a precise estimate for sea level rise at the end of the century remains beyond our abilities. Projections for 2100 among various experts and studies vary between a minimum of 0.2 metres and a maximum of about 2 metres.

Perhaps the greatest known source of uncertainty is the extent to and rate at which melting glaciers, ice caps and ice sheets will contribute to rising sea levels in the future. More comprehensive observations of ice melt and flow are needed, along with improvements in how these processes are described in climate models.

Three recent studies all concluded that sea level rise of more than 2 metres by 2100 was not tenable. A 2-metre rise by 2100 is considered physically possible, but would require all of the variables influencing the melting and transport of ice into the ocean to be at their maximum values. Many experts consider that a more plausible estimate would be about 0.8 metres.

Impacts and costs

Sea level rise will impact all coastal areas, but it will do so to differing extents. It 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 of coastal land, saltwater intrusion, erosion and habitat destruction. National security could be even threatened in certain cases if areas vital to the functioning of vulnerable states – for example capital cities – are made uninhabitable by rising seas.

The highest risk areas are coastal zones with dense populations, low elevations, high rates of land subsidence and limited adaptive capacity. Figure 4 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 metre of mean high water – of whom more than 70 percent are in Asia – and 268 and 397 million live within 5 and 10 metres, respectively. People living in at-risk areas essentially have two choices of how to respond to increasing sea level: fight or flee. Fighting involves strengthening or building coastal defenses – seawalls, dikes and other built infrastructure. Fleeing involves relocating people to higher ground. In the case of the populations of threatened SIDS, fleeing necessitates the migration to other countries, a devastating prospect.

On a global scale, a 2010 study estimated that the total costs of coastal protection, relocation of people, and loss of land to sea level rise ranges from about US$ 200 billion for an increase of sea level of 0.5 metres to five times that – US$ 1 trillion – for a 1-metre rise, to about US$ 2 trillion for an increase of 2 metres. This demonstrates that substantial costs in terms of both population displacement and land loss would be averted by taking the earliest possible protection measures.

It is therefore clear that considerable disruption, damage and cost can be avoided through adaptation action taken now, complemented by a strong global strategy to combat the global environmental change that is at the root of most sea level rise, in particular by reducing greenhouse gas emissions.

Figure 4 Regions vulnerable to flooding caused by sea level rise. Originally Figure 3 in Nicholls, R. J. and A. Cazenave (2010), Sea Level Rise and its Impact on Coastal Zones, *Science*, 328(5985), 1517–1520.

Pollution

Pollution

Marine pollution comes in many different forms, including toxic chemicals, nutrient and sediment input due to human activities (e.g. agriculture, deforestation, sewage discharge and aquaculture), radioactivity, oil spills, solid waste, noise and debris such as discarded fishing nets and plastics. The three main sources of marine pollution are: direct discharge as effluents and solid waste from land or human activities at sea, runoff mainly via rivers and atmospheric fallout. Furthermore, the spread of invasive species throughout the ocean is increasingly referred to as biological pollution.

Marine pollution alters the physical, chemical and biological characteristics of the ocean and coastal zones, threatening biodiversity and affecting 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 more than half of all investigated coastal oceans, large lakes and riverine systems around the world, making it very much a global issue.

STEVE SPRING/MARINE PHOTOBANK

This chapter discusses the main risks associated with marine pollution – including in the context of global environmental change and the prevalence of other marine stressors – and identifies some of the knowledge gaps which make a complete assessment impossible.

Effects on the marine environment and ecosystem services

For a long time, it was widely believed that the 'solution to pollution is dilution', making the disposal of toxic waste into the vast ocean seem logical. Today it is recognised that the chemical pollution of the ocean can adversely affect both human and ecosystem health, and that bioaccumulation can lead to some pollutants becoming more rather than less concentrated when they accumulate in marine ecosystems and are passed along food chains (biomagnification) to higher predators and, eventually, to people.

A main concern over chemical pollution is the potential for toxic effects on wildlife and, especially, humans through the consumption of contaminated seafood. These effects can be hard to quantify as, while 80,000 -100,000 chemicals are registered for commercial use, toxicity data exists for a just few thousand of these, and there is virtually no understanding of their combined 'cocktail' effects. Since wildlife is frequently exposed to many different substances it can also be difficult to link observed effects to a single substance.

In certain cases, however, the evidence is strong enough to warrant precautionary action. For example, the EU has introduced regulations that determine the highest concentrations of dioxins and dioxin-like PCBs permitted in foodstuffs and animal feeds. Baltic herring and salmon often contain levels above these limits and as a result cannot be sold in most of the EU. This demonstrates how chemical pollution can cause losses to the fishing industry, and to those whose livelihoods are linked to it.

Tourism can also be impacted if chemical pollution reduces the desirability of a region for activities such as diving, recreational fishing or whale watching. Since pollutants can be transported by moving air masses and ocean currents, even the most remote, non-industrialised areas – such as the Arctic – are becoming affected.

Sound also travels very efficiently in the ocean, and natural marine sounds are increasingly being overwhelmed by anthropogenic noise. In some areas, noise pollution has doubled every decade for the last 60 years, with underwater explosions, seismic exploration by the oil and gas industries, shipping and the operation of naval sonar being the main sources.

Although it is known that most marine animals rely on sound more than vision for communication, avoiding predators and orientation, the effects of underwater noise on particular fish and mammals is relatively poorly studied. Impacts can range from fatalities to hampering the growth and reproduction of affected animals, and it is an issue that requires greater attention and research.

Oil spills can have serious impacts on the marine ecosystem, with the affects on seabirds being the most well known. They can also cause major economic problems in terms of huge clean-up costs to restore beaches and harbours, loss of revenue from closed fisheries and the affects on local tourism. Depending on conditions, the oil in the water eventually degrades or evaporates naturally. This process is highly dependent on the ambient temperature, with higher temperatures being more conducive to eliminating the oil; an important aspect to consider when assessing the risks of oil exploration and transport in the Arctic.

As well as oil and chemicals, a wide range of solid substances are both deliberately and unintentionally introduced into the ocean. As shown in Figure 5, some

of the most commonly reported items of marine debris are plastics, wood, metals, glass, rubber, clothing and paper. The quantity of plastic debris has increased in recent decades, and is now present in marine habitats from the poles to the equator and from the sea surface and intertidal zone to the deep sea. This trend is set to continue unless we dramatically change our production and disposal habits. Lost and discarded fishing nets are a particular problem since they can continue to capture fish and damage habitats for long periods, a process known as 'ghost fishing'. An issue of recent concern is the accumulation of small pieces of plastic, known as microplastics, which can result from the fragmentation of larger items. Microplastics are widespread and increasing in abundance and it is unlikely that they can effectively be removed from the environment.

Cleaning up our act

As a consequence of improved legislation, raised awareness and better port reception facilities, the indiscriminate dumping of waste into the sea is declining in many regions. Regulations regarding chemical use and emissions today exist at national, regional as well as global levels, whether in the form of complete bans, restricted use or requirements for more effective treatment of effluents. One of the most important global treaties is the Stockholm Convention on Persistent Organic Pollutants, which entered into force in 2004, outlawing nine of the 'dirty dozen' chemicals, and limiting the use of the three others. A new set of chemicals (including brominated flame retardants) was added to the Convention in 2009.

If implemented, such bans and restrictions of chemical pollutants can have considerable effect on concentrations in the environment. In the Baltic Sea, for example, the concentration of DDT in 2000 was approximately four percent of 1970s levels. However, other, less studied chemicals have been introduced and are currently used without restrictions.

As a result of the coordinated efforts by the tanker industry and governments, largely collaborating under the auspices of International Maritime Organisation, the total volume of oil entering the ocean from tankers and tanker accidents has decreased greatly during the last decades. In the 1970s on average of 25 major spills occurred every year, with a total loss of between 200 and 700 thousand tonnes. Gradually these figures have dropped to on average three to four major spills with a total loss of between 20 and 60 thousand tonnes per year.

Similar international action is now needed to reverse the rise in plastic debris, and to address the growing threats of contaminated seafood and noise pollution.

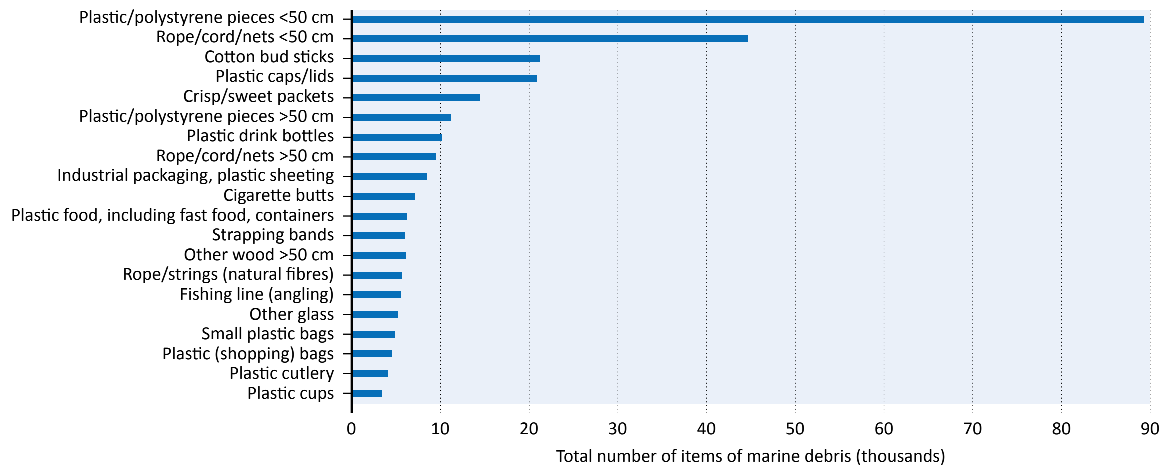
Global environmental change

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 the pollutant and region.

However, it is understood that, since some of the most important properties of chemicals are temperature dependent, levels of pollutants can be influenced by ocean warming and variability. Higher temperature will increase the volatility of organic chemicals and thus make them more mobile. 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 and hypoxia.

Currently available scientific data, the level of coordination of data and existing monitoring systems, do not allow for a rigorous and comprehensive quantification of the risks of pollution on marine ecosystems at a global scale, or for reliable projections of the magnitude of future marine pollution under different global environmental change scenarios. More research is urgently needed to enhance our understanding of not only the impacts of individual pollutants, but also how marine pollution is linked to other global and regional trends and threats.

Figure 5 The most common marine litter items, i.e. found in the highest numbers on the reference beaches. Reprinted with permission from 'OSPAR Pilot Project on Monitoring Marine Beach Litter: Monitoring of marine litter in the OSPAR region 2007', p. 32, 2007.



Overuse of Marine Resources

Overuse of Marine Resources

Fish are important to people
Fishing is an ancient method of gathering food that has gone on for many millennia, however, the vital importance of fish as a component of humanity's diet today is often not fully appreciated. 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 small island developing states (SIDS) and poorer coastal areas this figure can reach 90 percent.

At least 90 percent of fishers and fish farmers are small-scale, with the majority located in Asia (85.5 percent), followed by Africa (9.3 percent). In developing countries alone, more than 200 million people are dependent on small-scale fishing for at least part of their income.

Today, FAO estimates that about 79.5 million tonnes of marine fish are landed from capture fisheries annually, a decline from about 86.3 million tonnes at its peak in 1996. A further 11 – 26 million tonnes a year are caught as illegal or unreported catches. The value of marine fish at first landing has been estimated at about US$ 84.1 billion per annum, with an additional US$ 10 – 23.5 billion lost to unreported and illegal fishing every year. But these figures do not reflect the overall economic value of marine capture fisheries. Fishing is an activity that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depends on manufactured goods such as boats and nets, and the fish themselves are processed, transported and sold on up through a chain of supply. Overall, the total economic impact of fishing is estimated at US$ 225 – 240 billion per year, about three times the size of the value at first landing.

Fisheries are extremely important, especially as the global population is projected to rise to more than nine billion by 2050, with almost all this growth occurring in developing states. Today, exports of fish are of great value to developing countries, and in many cases are worth more than agricultural commodities such as rice and sugar, reaching a value of US$ 27.2 billion in 2008. Low-income, food-deficit countries are playing an increasing role in the fish exporting industry.

Considering the potential for declines in wheat and rice production, future population growth and the corresponding requirement for more protein, it is predicted that an additional 75 million tonnes of fish and invertebrates will need to be obtained from aquatic systems by 2050. Aquaculture is playing an increasing role in meeting demand for fish – growing from less than one million tonnes in the 1950s to 52.5 million tonnes today – and may soon exceed capture fisheries in providing fish for human consumption. However, given the increase in global requirements, and given that there are issues regarding the sustainability of several important forms of aquaculture (e.g. the farming of carnivorous fish and habitat destruction of mangrove forests through shrimp culture), healthy wild fish stocks will remain vital.

State of the world's fisheries
The world's marine capture fisheries are in a severely troubled state. While evidence of human communities affecting fish stocks stretches back hundreds, even thousands, of years, it is since the development of steam trawlers in the 1880s that we have begun to fish further offshore for longer periods and deploy larger gear in deeper waters.

FAO estimates that 85 percent of fish stocks are fully exploited, overexploited, 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 continues largely unabated. All these factors combine to threaten the long-term sustainability of the world's most important fisheries.

The loss of marine biodiversity will be further exacerbated by the impacts of global environmental change. As marine fishes and invertebrates require certain conditions to say alive, changes in temperature and ocean chemistry directly affect the physiology, growth and reproduction of these organisms. Ocean acidification and the expansion of oxygen minimum zones will likely have negative impacts on fisheries. Global environmental change is, therefore, expected to affect the primary productivity of the ocean and fish distribution in it, further complicating the problems caused by the overuse of fish stocks. The economic impact of these environmental changes is estimated in Chapter 9 of this book, whereas this chapter focuses specifically on the economic effects of overfishing.

The global cost of overusing marine fish stocks
To estimate the potential cost of overusing marine fish stocks, this chapter examines the other side of the same coin by calculating the potential net gain that could be achieved by rebuilding overused fish stocks. This requires a complicated series of calculations, based on: estimates of catch loss resulting from overfishing (defined as the difference between current landings and maximum sustainable yields, or MSYs, for each species) and its impact on fish prices; the current value of harmful subsidies to global fisheries; an assumed period of time required for rebuilding stocks (taken to be 10 years); and potential resource rents (what remains after fishing costs and subsidies are deducted from revenue, a key economic performance indicator). Full details of these calculations, and the assumptions and estimates they are based upon, are given in this chapter and the results are summarised in Table 1.

According to recent studies and calculations by the authors of this chapter and other experts, global marine fisheries landings could increase to an average of 89 million tonnes a year if rebuilt, with a corresponding mean landed value of US$ 101 billion per year. This means that compared to current catches and landed values, the world could currently be losing up to 20 million tonnes and US$ 30 billion a year.

By reducing fishing effort to the capacity needed to land MSYs, eliminating harmful subsidies, and putting in place effective management after rebuilding, resource rent from rebuilt global fisheries would be US$ 54 (US$ 39–77) billion per year. The gain in resource rent from the current situation to a rebuilt global fishery would be US$ 66 (US$ 51–89) billion a year.

Therefore the real cost to society of rebuilding fisheries – once the elimination of an estimated US$ 19 billion per year of harmful and ambiguous subsidies is taken into account – is negative, implying that society as a whole will make money. The estimated total amount that governments may need to invest in order to rebuild world fisheries is between US$ 130 and US$ 292 billion in present value. When discounted over the next 50 years using a three percent real discount rate, the US$ 66 billion a year resource rent gain from rebuilding global fisheries generates a present value of between US$ 660 and US$ 1,430 billion; that is between three and seven times the mean cost of fisheries rebuilding.

These results strongly suggest that there is a substantial net economic benefit to be derived from rebuilding global fisheries, with net gains large enough to compensate for any uncertainties in the assumptions and estimates. The current overused state of world fisheries is extremely costly, and we need to find the political will to rebuild overfished stocks.

TABLE 1: KEY ECONOMIC FIGURES OF GLOBAL FISHERIES. NPV: NET PRESENT VALUE

Key indicators, annual data (unit)	Current	Rebuilt fisheries		
		Lower bound	Mean	Upper bound
Catch (t)	80.2	82.7	88.7	99.4
Catch value (US$ billions)	87.7	92.6	100.5	116.3
Subsidies (US$ billions)	27.2	10.0	10.0	10.0
Rent net of subsidies* (US$ billions)	-12.5	39.0	54.0	77.0
Rent increase over current values (US$ billions)	-	51.2	66.4	89.4
NPV of resource rent increases (US$ billions)	-	665.2	972.0	1,428.1
Transition costs** (US$ billions)	-	129.9	202.9	292.2
NPV net of transition costs (US$ billions)	-	535.3	769.1	1,135.9

* The (resource) rent is the return to 'owners' of fish stocks, which is the surplus from gross revenue after total cost of fishing is deducted and subsidies taken into account.
** Transition costs include the costs to society of reducing current fishing effort to levels consistent with maximum sustainable yield and the payments governments may decide to employ to adjust capital and labour to uses outside the fisheries sector. Such payments may include vessel buyback programs and alternative employment training initiatives for fishers (Table adapted from Sumaila *et al.*, *in press*).

The Impacts of Multiple Stressors

A complex web of challenges

The Impacts of Multiple Stressors

No marine system remains unaffected by human impacts. The intensity and spatial distribution of these anthropogenic threats is currently expanding to levels unprecedented in human history. Since many of the stressors outlined in the earlier chapters of this book co-occur in time and space, marine organisms and ecosystems are increasingly subjected to the simultaneous impacts of multiple stressors. It is estimated that over 40 percent of the marine environment is already impacted by a combination of stressors.

There are complex feedback loops at play in the ocean. The effects that the different stressors, and particularly their combination, will have on ocean organisms and ecosystems, and on the important services they provide to humanity, are currently poorly understood. Improving this situation, and defining management solutions, has been identified as among the most pressing and complicated challenges in marine ecology today.

At the moment, information is rarely synthesised to convey where multiple threats are occurring, or whether their combined affects are antagonistic (less than the sum of their parts) or synergistic (greater than the sum of their parts) as opposed to simply additive. The vast majority of management strategies therefore proceed on a single issue-specific basis, with little consideration for the relationships and feedbacks between multiple stressors.

Global versus local stressors
Stressors of marine systems can be divided into two categories: those that act globally but with varying intensity, such as increased temperature, ocean deoxygenation (the global trend of decreasing oxygen as a result of ocean warming and increasing stratification) and ocean acidification; and those that act at a local to regional level but occur globally, such as overfishing, pollution and coastal hypoxia (low dissolved oxygen environments due to increased nutrient levels).

The emission of CO_2 into the atmosphere is the primary driver for all the global scale stressors and needs to be addressed through global climate policy. At local to regional scales, the drivers are varied, but are all related to the expanding human population and resource use. Regional/local stressors can be addressed through policies and actions at these scales. The potential for interaction between global and local stressors, however, calls for coordination across all scales, something which is lacking in current ocean management.

Hotspots and vulnerabilities
While the chemical and physical changes associated with ocean warming, acidification and deoxygenation occur globally, the imprint of these global stressors will have a strong regional and local nature. The coalescence of the different global stressors in certain regions is already creating a number of 'hotspots' (Figure 6), among which the Eastern Boundary Upwelling Regions stand out, but the high-latitude north Pacific, the Arctic, and the Southern Ocean also deserve attention.

In addition to these regional 'hotspots', certain marine ecosystems are also showing signs of particular vulnerability to multiple stressors. Foremost among these are coral reefs, which are among the most diverse ecosystems on Earth and estimated to contain approximately one third of all described marine species. The mass bleaching of coral reefs has been shown to occur more frequently, largely in response to ocean warming, but this condition may have been amplified by a combination of stressors acting simultaneously and often synergistically.

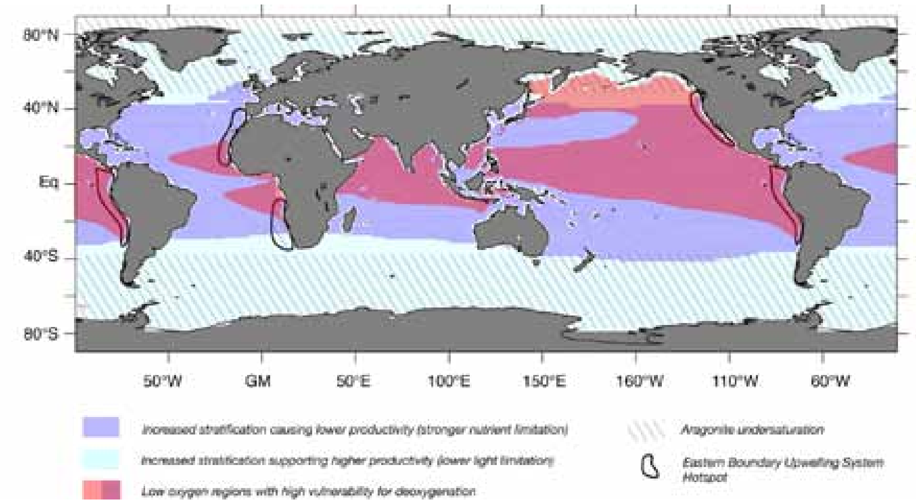

Figure 6 Global map showing regions of particular vulnerability to the three main global stressors – ocean warming (which increases vertical stratification), acidification (indicated by aragonite undersaturation), and deoxygenation. From Gruber, N. (2011), Warming up, turning sour, losing breath: Ocean biogeochemistry under global change, *Phil. Trans. R. Soc. A*, 369, 1980-1996, doi:10.1098/rsta.2011.0003.

Recent studies indicate that future predictions of bleaching must also take into account the additional effects of ocean acidification, and point out that any potential adaptation of corals to thermal stress may be offset by further decreases in the pH of the ocean. In addition, a number of local/regional scale stressors, such as pollution, overfishing and fragmentation of reefs by destructive fishing and coral mining could affect coral reefs, particularly since they are found primarily in coastal areas where local anthropogenic impacts often occur. The potential for these local/regional scale stressors to interact with global scale stressors such as increased temperature and ocean acidification is high. In many cases, these local stressors undermine the resilience of coral reef ecosystems to other stresses, diminishing their capacity to provide services such as storm surge protection, which itself is increasingly vital in the face of global environmental change.

The combination of global and local/regional stressors can also threaten particular species, including some economically and nutritionally important ones. One example described in the chapter comes from the eastern tropical Pacific, where the combination of decreasing pH, increasing temperature and deoxygenation have the potential to significantly impact the jumbo squid, one of the top predators in the region and an important component of the diet of birds, fish and mammals.

Multiple global stressors at the ecosystems level can also impact fish catches. Recent scenario modelling studies on the impact of decreased pH and oxygen content on the important fisheries of the north east Atlantic have projected catch potential reductions of 20 to 30 percent by 2050 under business-as-usual carbon emissions. This would have serious economic consequences for fishing communities.

Local actions, global impact
One example of the potential for the interaction between global and local stressors is the combined impact of increased temperatures and exposure to commonly used herbicides on coral species. Studies have shown that increased nitrate concentrations can amplify temperature stress in corals; therefore, controlling nutrient concentrations – for example by reducing nutrient run-off at the local level – can raise the upper thermal bleaching limits of corals, making them more resilient to ocean warming.

This example highlights one of the central conclusions of this chapter: that the management of local stressors has the potential to buffer – at least temporally – the impact of global stressors. By aggregating these local actions up to a global scale, through coordinated networks of initiatives, such interventions can help increase ecosystem resilience and buy valuable time to deal with the global stressors.

Implications for marine policy and governance
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 relevant scales.

Research into where multiple stressors are occurring and how they are affecting the functioning and resilience of marine ecosystems should be prioritised. Although many details remain unclear, a number of fundamental insights are firmly established, particularly with regard to the global stressors. We know that a substantial fraction of the CO_2 released to the atmosphere by human activities has been absorbed by the ocean and has led to acidification. Most of the excess energy flux stemming from increased greenhouse concentrations in the atmosphere is taken up by the ocean, which causes warming that will lead to increased stratification which then tends to enhance oxygen depletion in the open ocean. Acidification and oxygen depletion can synergistically interact to enhance negative impacts on marine ecosystems. Though the interactions between these global stressors are complex, they are all driven by the same process, i.e. increasing levels of CO_2 in the atmosphere, thus requiring a single policy response: the reduction of our CO_2 emissions.

At the local and regional level, many of the key issues associated with local and regional stressors are also well understood. It is known how such local stressors need to be addressed individually. What is sorely lacking is the combined perspective that looks simultaneously at the impact of multiple stressors.

There is an urgent need for the global community to address multiple stressors affecting marine systems by making policy decisions aimed at optimising outcomes for these complex systems, and approaching ocean governance from strategic perspectives that utilise multi-management schemes and networks. Creating such a cross-scale governance system for marine resources that actually works is an urgent and complex challenge, but one that is far from impossible to achieve.

Local governments should act to reduce local stressors wherever possible. 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.

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 twenty 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

Some things are too valuable to be assigned meaningful prices; some questions are too big for meaningful answers. Life as we know it would cease without the ocean: it – and the wondrous variety of life it supports – is literally 'priceless'.

Rather than asking what the ocean itself is worth, this chapter seeks to at least partially answer the question: 'what is the value of avoiding further damage to the ocean?' Or, framing the question another way: 'what is the cost of the environmental damage that could be done to the ocean if we do not take action?'

The scope of this question is still too broad for a simple, definitive answer. Valuing all the multiple threats to the ocean as they interact with the economic consequences of climate change and other global environmental problems is a daunting challenge.

The analysis offered here is restricted to five categories of damages that can be priced, and that can realistically be affected by policy decisions taken today and in the coming decades. Past damage, and unavoidable future damage that is already in the pipeline, is excluded, as are all fundamentally priceless values. For example, the value of the whale-watching tourism industry can be estimated, but the value of whales themselves cannot. The value of the storm damage protection provided by coastal wetlands can be estimated, but the value of wetlands themselves and the biodiversity they contain cannot.

Awareness of the difference between what we can and cannot change, and what we can and cannot price, is essential to understanding the global costs of inaction.

Pricing the distance between our hopes and fears
The avoidable portion of future climate damage is in effect the distance between our hopes and our fears. Our hopes are represented by a 'low emissions, low climate impacts' future, our fears by a 'high emissions, high climate impacts' future, based in this analysis on the recently developed IPCC Representative Concentration Pathways RCP2.6 and RCP6 scenarios.

Comparisons to unattainable twentieth-century norms or to an imaginary world with no climate change are effectively pointless. It is the difference between the low- and high-climate-impact costs – the avoidable damages – that really counts.

The first scenario, RCP2.6, is a rapid-emission-reduction pathway, whereby temperatures are estimated to reach 2.2°C above pre-industrial levels by 2100. The second, RCP6, is a business-as-usual pathway that sees temperatures rising 4.0°C by 2100. To simplify comparisons, the same projections for global population, GDP and carbon price are used for both scenarios.

Impacts are estimated for five specific categories of ocean services, which have measurable damages that can meaningfully priced: fisheries, sea level rise, storm protection, tourism and the ocean carbon sink. This chapter builds on the analysis of the six specific threats provided in previous chapters, and on the most significant and up-to-date climate economics and science literature from a variety of sources, in order to develop monetary valuations of major impacts on ocean ecosystems and services.

The cost of inaction: Five easy pieces
By 2050, the value of these important global environmental change 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 US$ 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 US$ 1,367 billion; that is more than a trillion dollars per year by 2100, equivalent to 0.25 percent of global GDP. It is this trillion-plus dollars a year difference that policy-makers should take particular note of, and which should be included in the complex web of global environmental change accounting.

TABLE 2: 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%*

Uncertainties, variabilities, unquantifiabilities: The floor is open
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 impacts of the total disappearance that is possible – even probable – for certain coastal or island communities.

Compared to the global economy, these figures are certainly significant, but they are not so shockingly high that political commitment and public action will necessarily be mobilised to mitigate and adapt to global environmental change. Indeed, the measure of the problem, and the need for immediate action, cannot be based solely on hard dollar estimates; respect for the priceless value of the ocean, and precautionary responses to the risks of tipping points and catastrophic losses add crucial, qualitatively different dimensions to the story.

The figures developed in this chapter are not as staggering as some previous estimates – such as the controversial calculation by Robert Costanza and co-authors in 1997, which valued global (primarily ocean) ecosystems at US$ 33 trillion, a figure greater than global GDP at the time – but our aim was to avoid problematical valuations and provide a basis for continued discussion of the components of the problem that have meaningful prices.

Much is still unknown and uncertain, and this figure represents just a fraction of the ocean services that we know are at risk from avoidable climate damage. Uncertainty and variability are themselves a challenge, creating a need for adaptation but making it difficult – and very expensive – to achieve.

Sadly, it is the poorest countries that are most vulnerable to the impacts of global environmental change on the ocean. Severe economic problems already being felt include the losses suffered by African and east Asian countries, due to the poleward movement of capture fisheries, the cost of preparing for sea level rise in countries such as Vietnam and Bangladesh, and the downturns predicted for the tourism industry in the Caribbean and Pacific island nations.

In addition to the predictable, measurable risks of gradual change, as discussed in this chapter, a complete economic analysis must also consider the uncertain but potentially catastrophic consequences that could ensue as the world reaches tipping points for global environmental change. This important topic is the subject of Chapter 10 of this study, which focuses on 'Planning for Surprise'.

The values presented in this chapter are certainly not set in stone, but are subject to change along with the continuous flow of research and discovery. The intention is 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.


DAVID BURDICK/MARINE PHOTOBANK

Tipping Points, Uncertainty and Precaution

Planning for surprise

Tipping Points, Uncertainty and Precaution

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 chapter is therefore dedicated specifically to the issue of planning for an unpredictable future.

If pushed far enough, natural systems can reach thresholds or tipping points beyond which the behaviour of the system suddenly changes. Scientists have identified a number of potential tipping points at which a small change in conditions could lead to a large, lasting change in the global climate or major ecosystems. Many of these involve the ocean, including the loss of major ice sheets, widespread coral bleaching, weakening or collapse of the African and South Asian monsoons and the disruption of the Atlantic thermohaline circulation or the El Niño-Southern Oscillation.

Sea level rise presents a particular, and highly uncertain, threat. While we have good evidence of at least two stable states for the planet – one with major ice sheets and one without – we do not know exactly what combination of conditions could cause the system to flip from one state to the other, or how long such a transition might take. However, as CO_2 concentrations rise, with the resulting temperature rise, the complete loss of the Greenland ice sheet (causing an eventual 7 metres of sea level rise) becomes less and less unlikely.

Making decisions in the dark

Predicting impacts and tipping points is difficult, in part because individual threats interact in complex, nonlinear fashions, as seen in Chapter 8 on Multiple Stressors. We are dealing with potential tipping points far outside our collective experience. No one has ever destroyed all the coral reefs before, or melted a block of ice the size of Greenland; no one can be sure exactly if, how or when these disasters will occur. Humanity is walking an uncertain distance from the edge of a cliff, in a fog that obscures our vision.

This chapter analyses in some detail the multiple meanings of uncertainty and the challenge of making decisions in circumstances involving both known and unknown probabilities. This involves the immense practical challenge of first specifying the range of possibilities to be considered – ranging from 'risks', to 'uncertainties', to 'imaginable surprises'.

With so much at stake, how can we be expected to make decisions in the dark, in the absence of knowledge of the probabilities of reaching these dangerous tipping points? The threats to the oceans identified in this book include both predictable, gradual changes for which monetary values can be estimated, such as those identified in Chapter 9, and abrupt, low-probability changes associated with rapid, catastrophic losses. Unfortunately, economic and policy debate often narrows its focus to the former category, particularly when relying on cost-benefit analysis.

Due to the lack of numerical estimates, cost-benefit analysis, in effect, often assigns a probability of zero to the most ominous, uncertain, but still possible, threats that we face – threats which global environmental change is making ever more imaginable. This is a major shortcoming, and directly at odds with the preventative, precautionary approach to which both common sense and scientific evidence are pointing. In fact, rigorous analysis has shown that when we are truly uncertain about future outcomes, good policy decisions depend solely on the most extreme possibilities, i.e. the best and worst cases – not on averages or best guesses.

Under conditions of serious uncertainty, there is frequent disagreement about the credible best- and worst-case outcomes. Exploration of possible environmental futures is therefore often addressed through scenarios that trace multiple possible paths of evolution. The IPCC scenarios for greenhouse gas emissions are a well-known example related to global environmental change, yet they are limited by design, stopping short of covering the outcomes of greatest concern.

Peering into the future: Can we insure ourselves against surprise?

In other areas of life, naturally risk-averse individuals and institutions adopt much more sophisticated approaches to uncertainty than the simple cost-benefit outlook. We routinely buy insurance to cover rare calamities such as residential fires or the death of young parents, even though these unlikely events have extremely low probabilities. 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.

Planning for worst-case scenarios is at the heart of military and security policies. Military planning is all about worst cases; on an average day, no one needs an army. This kind of precautionary framework underlies the US military analysis of climate change risks discussed in this chapter.

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 and uncertain events. Using methods derived from insurance models could be helpful. 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. But the insurance model does not apply literally to such global threats. There is no interplanetary insurance company that will compensate us for the destruction of the only planet we have.

The only valid solution is the development of public policies at the national and international levels that will 'self-insure' humanity against tipping points and catastrophic losses, by controlling global environmental 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, and should encourage decision-makers to take strong action to address threats.

Tolerable windows and planetary boundaries

Proposed policy responses to uncertainty about tipping points, discontinuities and irreversible losses have included the 'safe minimum standards' and 'tolerable windows' frameworks. These policies identify and protect the minimum level of environmental resources necessary to ensure the survival of a species or ecosystem service, overriding cost-benefit analyses of rival resource uses. The tolerable windows approach recasts the climate policy debate, specifying standards or 'guardrails' for the tolerable evolution of global environmental change, such as a maximum increase in global average temperature.

In relation to such approaches, it is also useful to be aware of the links between threats to the marine environment and the recently identified set of 'planetary boundaries'. As the Earth and its ecosystems and resources are finite, existing patterns of economic growth and resource use will eventually 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 and phosphorus (fertiliser) run-off into the ocean, which causes hypoxia.

These boundaries are non-negotiable in the sense that they are hard-wired into how the Earth System works. It does not matter to the ocean who or what is responsible for increasing atmospheric CO_2 concentrations; regardless of the driver the result is the same – an acidifying ocean. It is tough to negotiate with a chemical equilibrium.

The fact that all the approaches considered have their strengths and shortcomings is key to the take-home message of this chapter: that we need to formulate new strategic plans that work across scales and for several variables simultaneously, and which address worst-case risks and account for the element of surprise.

The problem of decision-making based on uncertainty, or planning for surprises, is inescapable in addressing major environmental policy problems such as protecting the world's ocean. The scientific findings described in earlier chapters provide a warning of what could happen if we do not take decisive action. What is needed now is the collective will to respond to that warning.

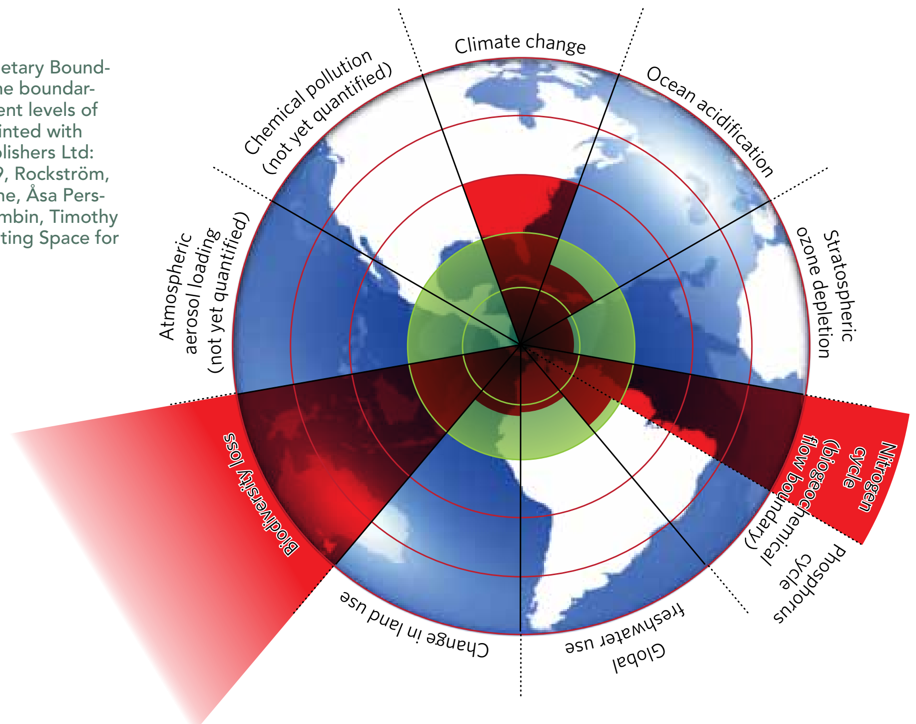

Figure 7 Illustration of the Planetary Boundaries; green circles represent the boundaries, red wedges represent current levels of exploitation of resources. Reprinted with permission from Macmillan Publishers Ltd: *Nature*, Vol. 461 (7263), © 2009, Rockström, Johan, Will Steffen, Kevin Noone, Åsa Persson, F. Stuart Chapin, Eric F. Lambin, Timothy M. Lenton, *et al.*, A Safe Operating Space for Humanity, p. 472–475.

The Pacific Ocean

The Pacific Ocean represents almost half of the world's total ocean area. It contains every major variety of marine habitat, and borders the coastline of 50 countries or territories. This vast ocean plays a vital role in the regulation of the global climate and biochemical cycles, generates 60 percent of world fishing revenues, and provides vast economic services in the realms of tourism, fishing, recreation, natural gas, atmospheric and climate regulation and transportation. It is also a central component in the nutrition, income and cultural identity of millions of people from Alaska to Tuvalu.

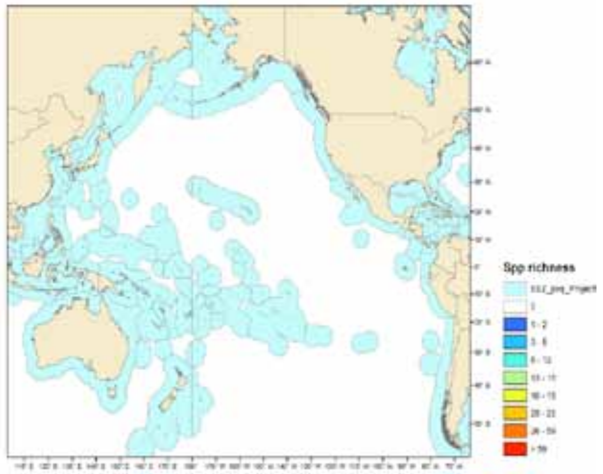

Figure 8 The boundaries of the Exclusive Economic Zones of the 50 countries and territories in the Pacific region (in blue).

The huge variety of habitat types, ranging from shallow coasts to the abyssal regions that reach thousands of metres in depth, and including coral reefs, seagrass, mangroves and estuaries, host an immeasurable diversity of organisms. The coral triangle in the Indo-Pacific region is considered to be one of the epicentres of global marine biodiversity, and the Pacific Ocean is believed to have the highest species richness of exploited fish and invertebrates.

Alongside this bounty brews an equally diverse concoction of threats, including all of those presented earlier in this book, making the Pacific basin an ideal laboratory to examine the impacts of and potential responses to the complex web of multi-stressors. This case study examines these threats in a regional context to demonstrate that the overlapping pressures faced by the Pacific Ocean present a very strong and urgent case for developing integrated regional policies to address the multiple stressors that are impacting all the world's oceans.

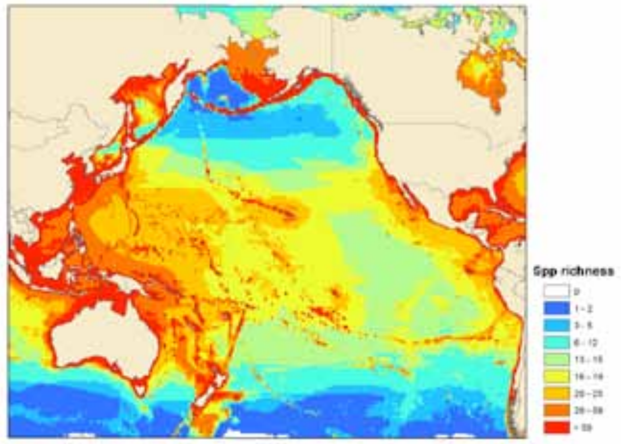

Figure 9 Predicted species richness of exploited marine fish and invertebrates (Cheung *et al.* 2009).

Over-exploitation of marine resources

More than half of reported global fisheries landings are caught in the Pacific Ocean, providing gross revenues amounting to approximately US$ 50 billion every year. But, today, fisheries resources in the Pacific Ocean are generally fully or over exploited. Decades of rapidly expanding fishing 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.

As shown in Figure 10 below, the total catch increased from around 10 million tonnes in the 1950s to peak at around 50 million tonnes in the early 1990s, before dropping slightly to around 45 million tonnes in the 2000s. However, some regions are already experiencing far more dramatic losses. For example, in the northern South China Sea, vulnerable fish species such as skates and rays have declined by over 90 percent during the last 40 years. Analysis of fisheries in many small island developing states (SIDS) in Oceania and Asia points to an estimated loss of production of 55-70 percent, with devastating consequences for local economies.

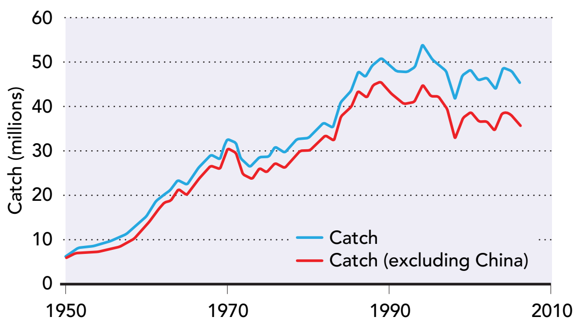

Figure 10 Estimated fisheries catch in the Pacific Ocean (data source: Sea Around Us Project).

There are many challenges to overcome if the sustainable management of fisheries resources in the Pacific is to be achieved, including: the lack of well-defined and enforced access rights; 'bad' subsidies, which intensify overcapitalisation; Illegal, Unreported and Unregulated (IUU) fishing, which distorts markets and makes accurate stock assessments impossible; and, perhaps most fundamentally, the inherent tendency to focus on short-term benefits at the expense of long-term conservation.

Global environmental change

Many regions of the Pacific have already experienced considerable sea-surface warming. In the Northwest Pacific, average annual sea-surface temperatures have increased by approximately 0.7°C since the 1960s, and further rises of up to 1.5°C above 2000 levels are predicted in some regions by 2050. Even more ominous are the associated risks of more intense tropical storms and shifting monsoon patterns, and the threat of sea level rise, which could alter the entire coastline of the basin and wipe some islands and low-lying areas entirely off the map.

Many cases of species range shifts are already being reported. In the Bering Sea continental shelf region, a recent study found that the centres of distribution of 40 taxa of fish and invertebrates had shifted northward by an average of 34 kilometres between 1982 and 2006, causing the invasion of subarctic fauna into the region. Another recent study concluded that the core ranges of pelagic fish, such as tuna, off the coast of Australia are expected to shift southward by up to 40 kilometres per decade between now and 2100. Poleward shifts in distributions are projected to lead to high rates of species invasion in high latitude regions such as the North Pacific, while high rates of local extinction are predicted for the tropical Pacific.

The changes in species distribution and primary production (i.e. shifts in phytoplankton ranges) are expected to alter potential fisheries catch in the Pacific. Recent studies project that tropical Pacific will suffer from a large reduction in potential catch by 2050 relative to the 2000s under the SRES A1B climate change scenario (which entails a temperature increase of 1.7–4.4°C by 2100). Moreover, modelling projections for marine fishes and invertebrates suggest that ocean acidification, together with warming and deoxygenation, may lead to up to 30 percent additional loss of catch potential.

The large areas of coral reefs in the Pacific region are particularly vulnerable to ocean warming and acidification, with consequences for the rich biodiversity they contain and growing tourism industry they support. A major study of several sites, using projected future sea-surface temperatures, concluded that monthly temperature thresholds in regions including French Polynesia and the Great Barrier Reef will be exceeded more frequently, potentially leading to biennial coral bleaching within 20 to 40 years.

The full impacts of the synergistic effects of these multiple factors are not yet fully understood. This further highlights the urgent need to address and prepare for the threat of multiple climate and environmental stressors on coastal communities, and on the marine fisheries so vital to their lives and livelihoods.

Recommended actions for the sustainable management of the Pacific Ocean

Solutions to these challenges 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. It is vital that the region moves towards ecosystem-based management where multiple threats are addressed within integrated strategies.

The most fundamental need, as exemplified by the current and projected impacts on the Pacific and the millions of people who live along its shores, is to take urgent action to mitigate climate change. However, 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 by the creation of carefully sited marine protected areas (MPAs).

It is equally urgent to accelerate action to adapt communities to the already inevitable consequences of global environmental change, including more intense tropical storms and sea level rise. The Pacific region includes many highly vulnerable SIDS and coastal communities which require international support to enhance their capacity to prepare for and cope with these mounting risks.

The governments of the Pacific basin should take urgent coordinated action, including through protective infrastructure to guard against sea level rise and extreme weather, as well as the development of alternative skills and livelihoods to diversify local economies and reduce their total dependence on fishing and tourism.

Within these integrated management strategies, governments in the region also need to take a proactive stance against overfishing, especially considering the additional stresses of global environmental change, including by:

- Re-establishing the natural protection once afforded to fish that has been lost as a result of technological progress by establishing more MPAs, including areas in the high seas. These would not only enable key stocks to recover, but can also act as a control for the large scale monitoring of changes in the ocean where the effects of climate change can be separated from the impacts of fishing and other human impacts.

- Eliminating distorting subsidies through a coordinated international approach.

- Introducing more effective ownership structures at different levels – from the local to the national, and transnational, in the case of straddling stocks and high sea fisheries – to combat over-exploitation and IUU fishing. Measures must actively address the motivations behind pirate fishing, not least the fact that at present there is a lot of money to be made and too little chance of being apprehended.

- Taking the interests of future generations into account by introducing effective intergenerational discounting systems. In this way, we count the value of fish to be eaten by future generations as their own and not those of the current generation.

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. 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 to address multiple stressors, can be clearly envisaged. These recommendations aim to help ensure the sustainability of Pacific Ocean marine ecosystems, resources and services for the benefit of current and future generations.


REINHARD DIRSCHERL / FLPA

Paths to Sustainable Ocean Resources

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

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Key Conclusions

- Viewing the ocean and its resources as invaluable does little to provide clarity on the merits of protecting marine ecosystem services in the face of multiple threats, or on whether the costs of action outweigh the costs of inaction. The services provided by the ocean are immensely valuable but are inadequately integrated into national, regional and global economic analyses and plans. As such, the ocean is the victim of a massive market failure and dilution of political will.

- Multiple stressors are combining in many marine areas to exacerbate the impacts of individual threats and seriously degrade critical ocean services. While this trend is becoming more common, very few management strategies are addressing multiple stressors in a coherent way. This undermines the resilience of ecosystems to withstand additional pressures 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 alarming, scientifically verifiable, highly significant to humankind and set to become far worse if we do not take coordinated action.

- Processes such as ocean acidification and warming are increasing the probability of high risk, high impact events such as intense tropical storms and mass destruction of coral reefs. In light of this, traditional cost-benefit approaches to risk assessment and planning are no longer sufficient.

- Substantial 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 a widespread upgrade of protection measures, but at a substantial cost that rises steeply along with the predicted sea level. 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.

- Developing countries are at greatest risk from 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, Southeast Asia, West Africa and the Caribbean stand to lose livelihoods and food security as fish stocks migrate in search of cooler water. For some SIDS sea level rise is a question of their very existence.

- Positive change is possible. Concerted management efforts can effectively reverse or remediate certain ocean damages. Some hypoxic zones have recovered, and the occurrence of some of the most toxic pollutants has been greatly reduced. It is possible to rebuild overexploited fish stocks in about ten years, and reap great economic benefits. Other threats, such as ocean acidification, could take thousands of years to reverse if they continue unabated at current rates.

- Local, national and regional actions can increase the ability of specific, important ecosystems to withstand multiple threats and help prepare and protect vulnerable populations. Local governments, in particular, are crucial connectors and coalition-builders, and are often best placed to address problems directly and buy valuable time as we grapple with global threats.

- In light of the current absence of concerted efforts to address climate change at the global scale, it is more essential than ever that management decisions are enacted at the regional, national and local levels to build ecosystem resilience and provide for more effective governance to help sustain marine resources and services.

- 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.

Paths to Sustainable Ocean Resources

Key Recommendations

Strengthening ocean governance

- A United Nations High Commissioner for the Ocean, reporting directly to the Secretary-General, should be appointed to coordinate research, prioritise action and speak up for the ocean at the highest levels.

- Weaknesses in current international ocean governance regimes – in particular governance gaps in areas beyond national jurisdiction – must be addressed with greater urgency, including through the adoption of shared principles, prior environmental impact assessments (EIAs), the establishment of marine protected areas (MPAs) and the development of a time-bound process for agreeing on equitable benefit sharing. In this regard, an implementing agreement under the UN Convention on the Law of the Sea could be enacted to extend the governance and protection of marine biodiversity to the high seas.

- Cross-sectoral, cross-scale, network approaches to ocean governance, focused on strengthening the entire management framework at a regional or ecosystem level, should be actively pursued.

- A global financing strategy for the ocean and coasts should be developed to support inter-agency, regional and multilateral coordination and boost capacity building, particularly in vulnerable developing states and SIDS. The creation of a UN Secretary-General Ocean Budget report could help address financing needs and identify sources.

- The implementation of ocean use agreements in the exclusive economic zones (EEZs) of developing countries should be accelerated, to promote the use of marine resources for local benefit, social equity, conservation and public transparency.

- Regional and local issues and actions should be embedded in the larger picture. Local managers must be able to use the information generated globally to ensure that local decisions are consistent with international strategies, and can be built upon and scaled up to help achieve resilience and mitigate global impacts.

Valuing and protecting ocean services

- Ocean services should be fully included in the valuation of ecosystem functions, even considering those services that cannot, at this time, be appropriately measured (e.g. nutrient cycling) and more effectively integrated in economic assessments and policies. Innovative instruments and incentives should be developed to allow services – such as the storm protection provided by mangroves and coral reefs – to be captured and appreciated by markets.

- Decision-makers should be made explicitly aware of the huge economic gains that can be obtained – and costs averted – from well managed ocean environments, for example as a result of responsible fisheries policies or the effective use and recycling of nutrients.

- The valuation of 'blue carbon' ecosystems and activities (which conserve the huge CO_2 reserves stored in marine ecosystems such as mangroves) should be pursued under the United Nations Framework Convention on Climate Change (UNFCCC) and fully incorporated into other carbon financing mechanisms. States should initially work to develop a network of 'blue carbon' demonstration projects.

- 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 also actively prepare for a sea level rise of 1–2 metres by the end of this century.

- 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, and which can account for low probability but high impact extreme events and local disasters. States and regions should also develop long-term policies and resilient management strategies to deal with several threats acting together. Such policies themselves function as insurance against the risk of catastrophic and irreversible global environmental change.

Addressing multiple stressors

- We cannot afford to manage actions for one place, one issue, one sector, one point in time, but must embrace multidimensional management schemes that address overlapping, multiple stressors and allow for the optimisation of more than one goal at a time.

- Local governments should act to reduce stressors wherever possible, including by promoting the need for inter-sectoral coordination, especially across land-based and water-based ministries that do not typically work together. National level efforts should strive to support well-informed decisions and effective actions at the local level that appreciate the complexity of multiple stressors.

- Decision-makers must adopt a precautionary approach in the context of multiple stressors. The strategic use of MPAs and EIAs can help to achieve this.

Closing knowledge gaps

- Research into where multiple stressors are occurring and how they are impacting on marine ecosystem resilience and processes must be prioritised.

- It is critically important to better understand how stressors interact. For example, more research is urgently needed to gain knowledge of how the co-occurrence of ocean acidification, ocean warming and hypoxia affects marine resources. There is also great uncertainty regarding how shifting climate zones, increased temperatures and altered precipitation patterns will influence the behaviour of pollutants.

- Steps should be taken to bridge the gaps between economists, ecologists and natural scientists in order to better understand the potential damages and costs related to multiple stressors and global environmental change, and develop tools to more effectively assess risks and outcomes. This will help build the capability of management strategies to adapt to 'surprises'.

- To feed into the work of the IPCC, marine research related to global environmental change should be promoted throughout SIDS and vulnerable developing countries, with a focus on ocean-related technology and knowledge transfer.

- It is important to emphasise again, however, that while more research is critical to enabling the more effective management of ocean resources in light of multiple impacts, provisions exist today that can and must be enacted immediately to caution against the dangerous changes marine ecosystems stand to undergo. A lack of perfect understanding must not delay the implementation of proven techniques for improving ecosystem resilience and the effectiveness of governance arrangements.

Tackling global environmental change

- It must be recognised that, since we are inevitably locked in to a certain degree of global environmental change in the coming decades, we must redouble efforts to give the ocean, and the communities that depend upon it, the best possible chance of withstanding the impacts. At regional and national levels, actions should focus on ensuring ecosystem resilience by maintaining and increasing biodiversity and by conserving a diverse set of habitats. This is critical to maximising the ability of marine ecosystems to resist and recover from additional, and in the short-term, unavoidable stress.

- All possible actions should be taken to enhance the resilience of the most valuable and vulnerable marine ecosystems, such as coral reefs, by removing avoidable sources of anthropogenic stress, such as overfishing, destructive fishing practices, invasive species and pollution. At the same time, states must also afford protection to those ecosystems and resources most naturally resistant to global threats like ocean acidification and warming in order to provide havens for biodiversity. Carefully sited MPAs can be instrumental in achieving both these goals.

- The international community must unequivocally recognise that the impacts of global environmental change on the most exposed and vulnerable coastal communities in developing states and SIDS will be disproportionately great, and are likely to completely overwhelm local resources. With urgency, the capacity of these areas to predict and prepare for rising sea levels and other impacts must be formalised and strengthened. Innovative, international financial instruments and funding mechanisms must be mobilised without delay to support these needs.

- Carbon emissions must be drastically and rapidly 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 in order to avert unprecedented negative impacts on the ocean.

In today's world of increasingly complex challenges – and limited funds to address them – it is essential that states, regions and the international community prioritise and concert efforts towards addressing the most pressing issues that cannot wait: the threat to the ocean is one of these issues.

To forge a path to sustainability, we must close ocean governance gaps, revolutionise risk assessment and take steps to capture and incorporate the value of marine ecosystem services into our markets and policies. We can provide for the sustainable marine resources and services so critical to our lives, but to do so we must commit ourselves and our capacities, shift our thinking and act with urgency.

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Tipping Points, Uncertainty and Precaution		
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The Pacific Ocean		
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Paths to Sustainable Ocean Resources		
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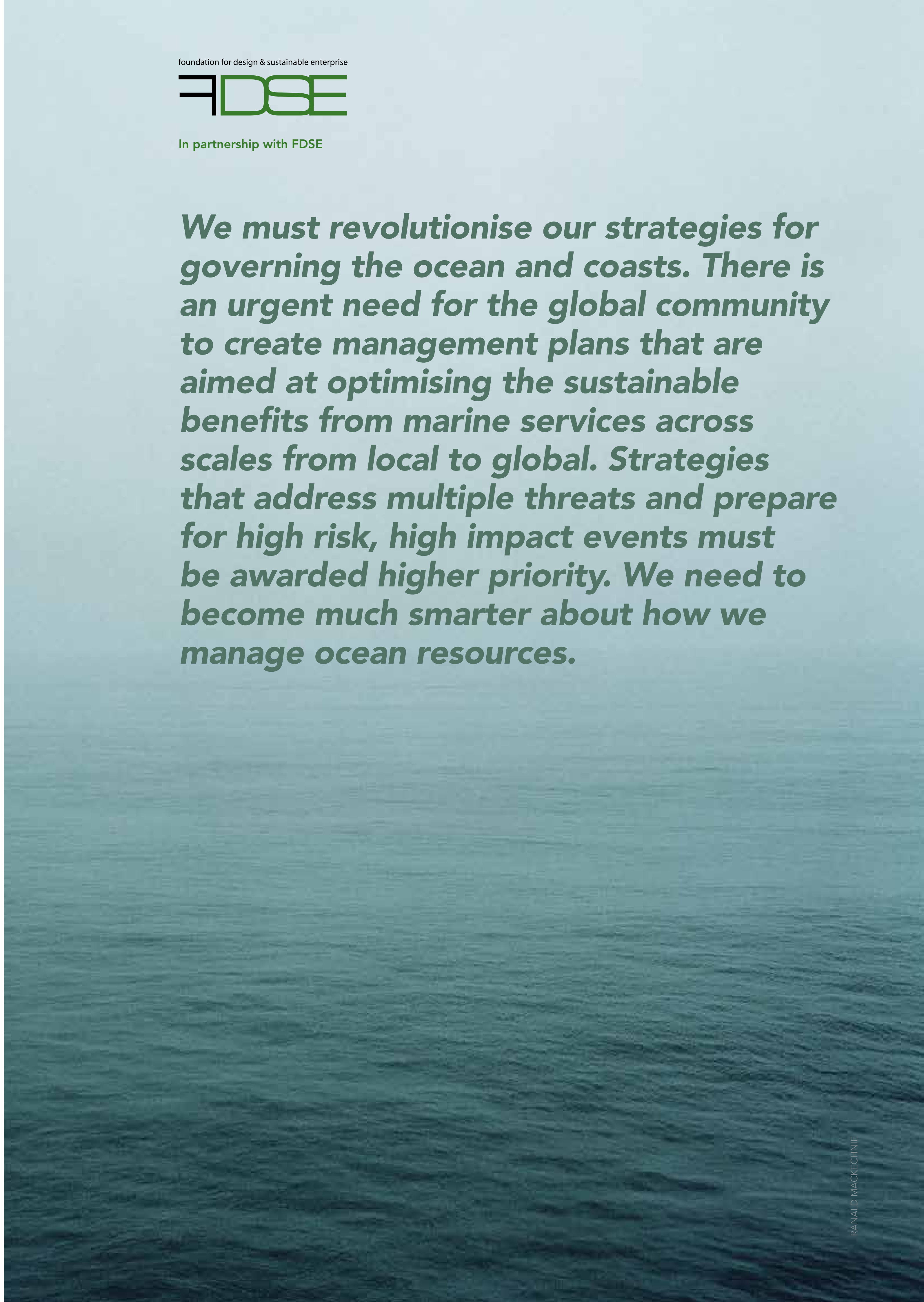

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We must revolutionise our strategies for governing the ocean and coasts. There is an urgent need for the global community to create management plans that are aimed at optimising the sustainable benefits from marine services across scales from local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

RANALD MACKECHNIE

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

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