Ocean connections

An introduction to rising risks from a warming, changing ocean

D. Laffoley and J. M. Baxter

INTERNATIONAL UNION FOR CONSERVATION OF NATURE

Government Offices of Sweden
Ministry of the Environment and Energy

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Back cover: Brisbane, QLD, Australia - January 27: Queensland Fire Engine driving through a flooded street on 27 January 2013 in Brisbane (photo credit: © Silken Photography / Shutterstock)

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Table of Contents

Foreword

While we cannot afford to underestimate the severity of today's global challenges – climate change, ecosystem degradation, species extinction, to name a few – there is a growing cause for optimism. Change is happening, and it is happening at scale.

As we reflect on the scale of impact that humans are having on our ocean world, we perhaps lose touch with the enormity of the problems our actions are unleashing.

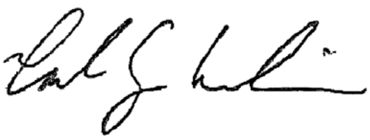
Experts are starting to speculate on whether a sixth category should be added to the familiar scale we use to measure the strength of hurricanes. The reason is disarmingly simple; it is down to the effects we have caused by significantly warming the ocean due to our activities. These changed ocean conditions are helping fuel the formation of stronger, more intense storms. We now understand only too well that what happens in the ocean, and what happens in the natural world, are intimately connected to our human world, as we live on an ocean planet. So we need to join up the equation and plan and act with the best information we can get.

This report helps provide such an overview, and has been facilitated and funded by XL Catlin – a global insurance and reinsurance company headquartered in Hamilton, Bermuda with more than 100 offices on six continents. It also builds on the results of an ocean risk workshop funded by the Swedish Ministry of the Environment and Energy.

By developing the new concept of *ocean risk*, the partnership between XL Catlin and IUCN is an excellent example of how companies are providing leadership and are investing to understand natural challenges, to provide tomorrow's solutions today. By working in partnership, we are stronger, and we can start to offer better solutions, and faster than we might have thought possible just a few years ago. By working in this way, we can also create a critically-needed common understanding and language between business, conservationists and scientists.

We know that time is fast running out to save ecosystems such as coral reefs, and yet all the elements associated with this report provide examples of the types of change we need to bring about in how we view and act on some of our biggest environmental concerns.

I believe these types of approaches will be critical elements moving forward to help safeguard nature, people and the array of benefits we derive from our precious natural world both now and in the future.



Carl Gustaf Lundin
Director, IUCN Global Marine and Polar Programme

Preface

The earth – our home – has been evolving since the beginning of time but we're now witnessing environmental changes occurring at extraordinary rates. Changes as well as challenges that, if left unchecked, will greatly impact present and future generations.

As a leading global insurance and reinsurance company, XL Catlin seeks to understand the implications of these changes and to work alongside others to find solutions that will reduce the resulting impacts.

That is why for the past three decades XL Catlin has supported ocean science research. We have committed significant funding to the Bermuda Institute of Ocean Sciences (BIOS), including as a founding partner and continuous sponsor of its Risk Prediction Initiative. We have also supported major expeditions to areas which represent key indicators of environmental change – sea ice loss in the Arctic, coral reef health in the tropics and deep ocean habitats.

Our interest in understanding the implications of the changing ocean, alongside our expertise in risk, led to the launch of our Ocean Risk Initiative in 2017. It was created to increase ocean literacy from the classroom to the corridors of power and to highlight the potential exposures from ocean-related risk. It is also intended to help find solutions that will build resilience to these changes at local, regional and global levels.

Under the umbrella of the Ocean Risk Initiative, we aim to reach 10 million children by 2020 with our Oceans Education program. The program provides school children across the world with learning materials and activities based on the research and findings of our scientific expeditions. Through the Ocean Risk Scholarships we annually fund PhD projects for early career scientists who focus on diverse areas of ocean science research.

In addition to this, we're proud to be the founding partner of the Ocean Risk Summit which brings together leaders from across the political, economic, scientific, environmental and risk management sectors to identify exposures to ocean-related hazards and explore the use of new approaches, tools and technologies to find solutions. And, of course, we will continue to work in partnership with others, like the IUCN, to generate and communicate the most advanced scientific thinking on the subject.

Supported by XL Catlin, the Total Foundation and 80 contributory scientists, the 2016 IUCN report on ocean warming brought awareness to the international community of the potential widespread implications of ocean warming. '*Ocean Connections: An introduction to rising risks from a warming, changing ocean*', alongside its sister report '*Ocean risk and the insurance industry*', helps to amplify the latest research to policy makers, the private sector and the public at large.

We hope this latest report helps to drive a deeper understanding of ocean risk and the important steps required to create a healthier ocean for the benefit of all.

Mike McGavick
CEO, XL Catlin

Acknowledgements

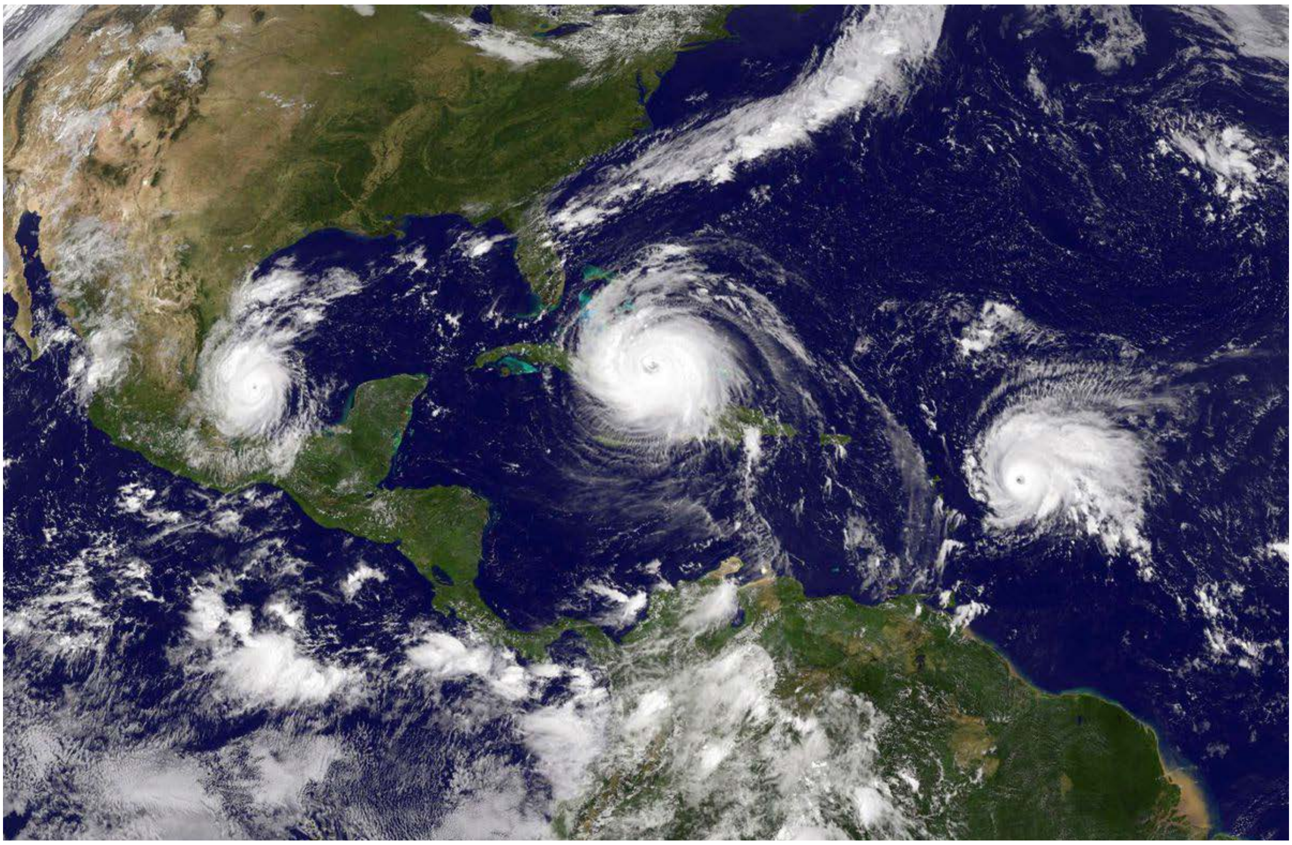
The authors would like to thank XL Catlin and especially Chip Cunliffe, Mike Maran and Tom Philp for their involvement and valuable input in developing the definition of ocean risk. The financial support of XL Catlin has also made the production of this report possible which is gratefully acknowledged.

This report draws in part from the 2016 IUCN Ocean Warming report[1] and we also wish to thank the 80 scientists who worked so readily to provide the solid foundation on which this ocean risk perspective is based. In particular, the case studies draw on material updated from this report and we would like to especially acknowledge Grant R. Bigg, Gustaaf M. Hallegraeff, Johann Bell, Camille Parmesan, and Scott F. Heron.

This report also draws on a workshop in November 2017 which focused on *Exploring ocean risk: Hazards, vulnerabilities, global priorities and regional resilience*. The authors would like to thank all the participants for their input to the workshop, to the Oxford Martin School in Oxford for hosting it, and to the Swedish Ministry of the Environment and Energy for its financial support to make the workshop possible.

Finally, the authors gratefully acknowledge the support of IUCN for making the production of this report possible and thank Carl Gustaf Lundin and James Oliver for their valuable input to the development of this document.

1. Background



NOAA's GOES satellite shows three storms in 2017 in the Atlantic: Hurricane Irma, Tropical Storm Jose, and Tropical Storm Katia, on September 8th. Photo by NASA/NOAA GOES Project

Ocean risk: the challenges a warming, changing ocean presents to humanity and life on earth

The ocean on which Earth depends for relatively predictable weather, temperature and provisioning of goods and services is now changing more rapidly than it has for millions of years. This is due to human interactions with the atmosphere and land, and increasing expansion of the footprint of human impacts across the ocean. It is increasingly evident that patterns and trends in ocean and atmospheric responses are falling outside documented historical norms.

As the effects of a warmer ocean take hold, significant impacts are being felt and the consequences are predicted to continue for decades, even if carbon dioxide (CO_2) emissions are immediately and significantly reduced. It is evident that even with the Paris Climate Change Agreement there is a gap (set against a 2017 baseline) between what would be achieved with global temperature rise if all action is taken and what is predicted to happen otherwise (Figure 1). There is a realization that consequences will become greater over time, and it is becoming arguable about how feasible a low-carbon trajectory really is, as it is apparent that to achieve this we will now need to extract CO_2 from the atmosphere.

These conclusions stimulated the desire to produce this short introductory report on ocean risk. The report explores the hazards and risks associated with ocean warming from a variety of angles, and by using innovative graphics looks at how these 'simple' temperature-related changes to the ocean can ripple out into many aspects of society.

This report explores:

- the definition of ocean risk and its relationship to hazards and vulnerability, and acts to bring together the language the insurance industry uses for risk, with the understanding that the science and conservation community have of the scale, nature and intensity of ocean change;

- five examples of how ocean warming has an impact on our way of life and, as a result, why we believe that ocean warming should be considered as a key risk by international bodies such as the United Nation's Intergovernmental Panel on Climate Change;

- how, even though ocean warming may be a single phenomenon, it is already being felt across a surprisingly wide spread of social, environmental and economic settings, and why this matters; and

- why far more immediate action is now needed with far greater ambition if society is to 'get ahead of the curve' of the consequences from ocean warming and other ocean changes in the coming years, due to long lag times between cause and effect.

This report is intended for a wide audience and aims to stimulate further discussion by exploring and exposing the issues that arise. Often, for example, people confuse risk with hazard and so clarifying these foundation issues becomes important at an early stage of planning for the future. It is purposely intended as a short report so key points are not lost in detail, and we hope as a result 'ocean risk' will become recognized as a discipline in its own right.

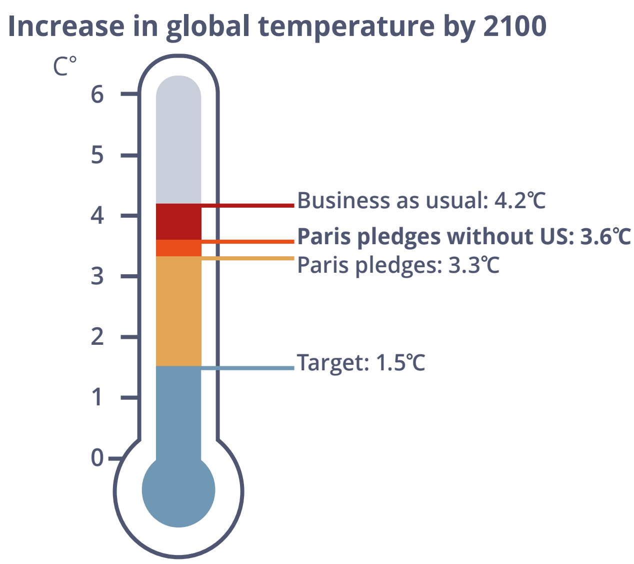


Figure 1. **Uncertainty range on US prediction is 2.1°C to 4.7°C**

This document is accompanied by a more technical sister report *Ocean risk and the insurance industry* prepared specifically for the insurance industry, which takes the approach defined in this report further by exploring impacts and opportunities and solutions. It considers how risks now arising from ocean warming have the potential to impact their business as well as open new markets and opportunities, and ensure people across a wider range of sectors are aware of the need to prepare for a more uncertain future due to influences we are now having on the climate system.

2. Introducing and exploring ocean hazards and risk

To introduce ocean risk, it is first necessary to explain what 'hazard' and 'risk' are. A common basis for understanding is critical, and adoption of a common terminology is key across the insurance, conservation and science worlds. The problem is that these two terms are often used synonymously, leading to confusion.

Understanding the actual definitions of hazard and risk and the relationship between them is key to understanding what ocean warming holds for society in the future, what risks can or could be manageable as a result, and on what timescales action must be taken. How much is actually 'manageable risk', as opposed to greater uncontrolled impacts on society, determines the degree of changes needed in lifestyles, livelihoods, and in political decision-taking and action.

Ocean hazard

A hazard is defined as any agent or stressor that can cause harm or damage to life, health, property or the environment. Hazards can be real, dormant, or potential with only a theoretical probability of resultant harm. An incident that is caused by exposure to a hazard is called an event. Identification of the hazards is the first step in performing a risk assessment.

> ***Hazard*** **noun**
> 1. a danger, threat or menace.

The consequences of ocean warming, combined with other stressors such as ocean acidification and deoxygenation, need to be traced through the hazards they are now creating and how much translates into risks to people and the environment.

A recent study explored such issues and identified four major interrelated dimensions to hazards that are leading towards the formation of significant ocean risk (Figure 2).

The two dimensions identified that are most directly associated with the changing ocean are:

- harmful changes in ocean physics and chemistry; and
- inappropriate human uses and ocean interactions.

The other two dimensions have more indirect associations and focus on:

- ineffective ocean policy, governance and leadership; and
- interactions between the ocean and other Earth systems.

The factors that contribute towards each of these dimensions driving the formation of significant ocean hazard are set out in Table 1.

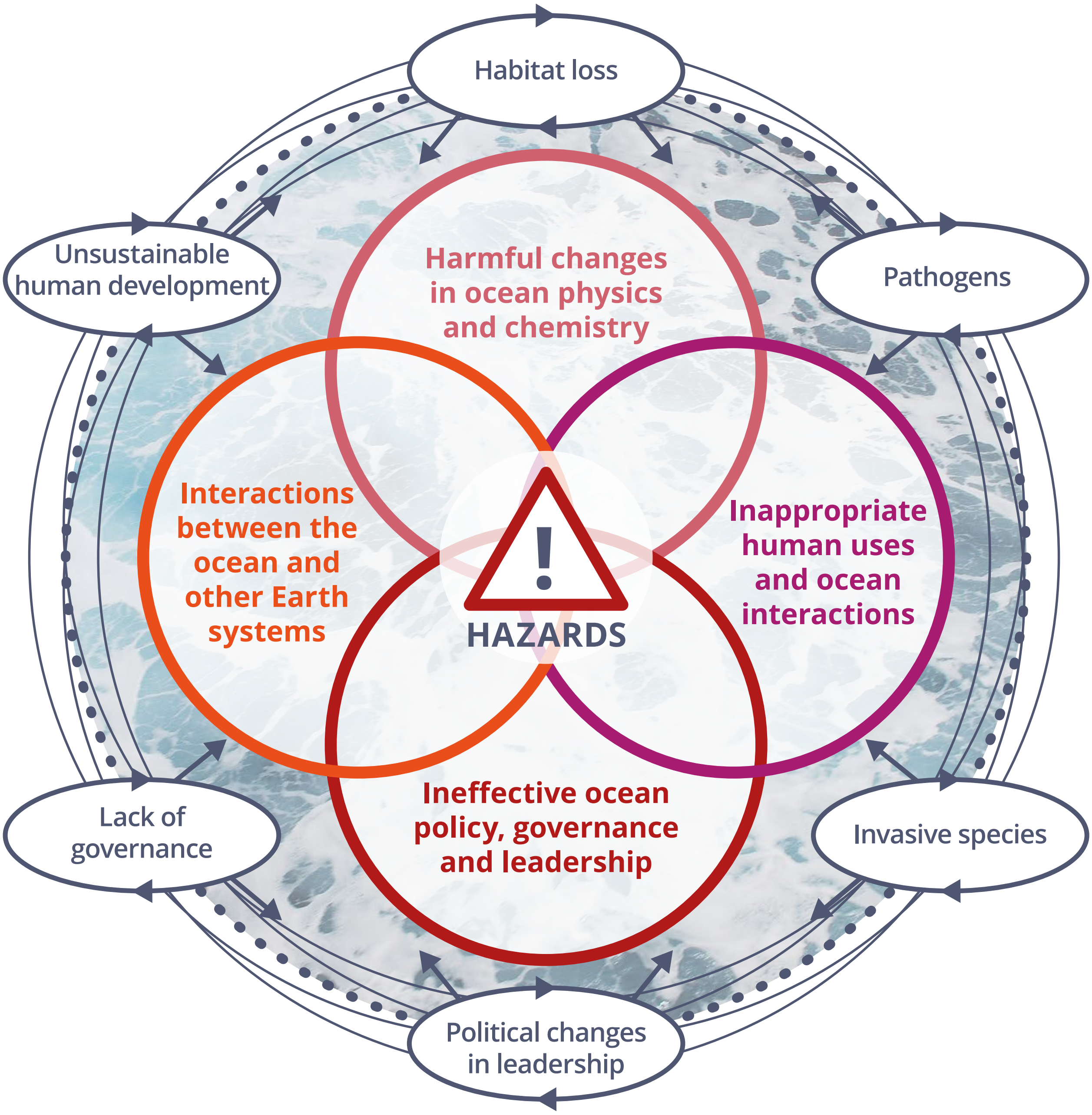


Figure 2. **Constituent inter-related aspects that form four key dimensions driving the formation of significant ocean hazards.**

Changes in ocean physics and chemistry	Human use / ocean interaction
Methane Acidification Rising temperature and stratification Ocean currents and winds Hypoxia Nutrient changes Freshwater input via polar ice melt	Pollution Extraction Ocean use change Societal disconnection Geoengineering Shipping Harmful ecosystem change Resource competition Military use Seismic testing Aquaculture Bio-prospecting Pipelines and cables Renewable energy generation Tourism Recreation
Ocean policy and governance	**Ocean / Earth system interaction (terrestrial/atmosphere ocean interaction)**
Piracy Political leadership Territorial conflicts Political priorities Lack of policies / legislation Loss of nations	Agriculture Sea-level rise Sea incursion as a result of storm surges Loss of nations Weather system change Ultraviolet El Niño Sea ice loss
Cross-cutting (across multiple sections)	
Habitat loss Pathogens Invasive species Political changes in leadership Lack of governance Unsustainable human development	

Table 1. **Factors that contribute towards each of the four dimensions driving the formation of significant hazard[2].**

The determination of the dimensions and component factors set out above is important because it ensures that key hazards are considered in identifying risk. However, an additional and significant threat lies in the interaction of many of these factors and the essential interconnectivity of the whole ocean.

There is a great deal of complexity, interconnectivity and knock-on effects which have yet to be fully resolved. For example:

- melting of glaciers and land-based ice is largely a consequence of rising temperatures and wind, leading to the reduction of the ice albedo effect and the associated hazard of sea-level rise;
- temperature rise, leading to melting of polar sea ice which impacts ocean currents and exposes hazards from new shipping routes and increased shipping, which in turn leads to an increased hazard of invasive species; and
- marine 'aquatic' heatwaves leading to hazards such as the loss of coral reefs, which leads to a loss of their barrier function to coastal erosion and protection from storm surges.

There are also new problems emerging that will complicate further assessments of ocean risk. These include:

- changes in how we use the ocean – with the addition of pipelines and cables, wave and tidal energy generation, and aquaculture;
- increasing extraction of rare earth metals – with ever increasing demand and technological capabilities; and
- resource competition due to, for example, mass migration, and over-population.

Alongside new threats there are as yet undefined issues that could lead to further problems down the line, but which are difficult to assess at present, e.g.:

- advances in geoengineering (deliberate large-scale intervention in the Earth's natural systems to counteract climate change) that pose a hazard to the ocean: one example is iron fertilization; and
- nanotechnology.

Our predictive capacity on hazards is also limited by the gaps in our knowledge. The models used to identify tipping points, for example, are only as good as what is known – and so we get caught out when events move outside the parameters of current models. A serious threat lies in the lack of scientific funding, which would help us to fill in the gaps and improve our predictive ability. The lack of governance, implementation and enforcement are also all significant threats, which exacerbate the problems faced. Finally, a basic lack of ocean literacy – understanding the role of the ocean at an Earth system level – compounds the difficulty in recognizing the hazards that exist.

Ocean risk

To most people risk has a simple meaning, but in other sectors more sophisticated perspectives have been arrived at which define risk in more detail. The ocean community will need to take a more sophisticated approach to risk in coming years as the true scale of ocean-driven climate change and impacts become apparent. In the finance industry, for example, risk has taken on many different dimensions related to the probability that an actual return on an investment will be lower than the anticipated return. Financial risk is accordingly often divided into the following categories: basic risk, capital risk, country risk, default risk, delivery risk, economic risk, exchange rate risk, interest rate risk, liquidity risk, operations risk, payment system risk, political risk, refinancing risk, reinvestment risk, settlement risk, sovereign risk, and underwriting risk.

Risk **noun**

1. a situation involving exposure to danger, or hazard.

For ocean warming and associated stressors (such as ocean acidification and ocean deoxygenation), the degree to which the impacts of a hazard can be ameliorated or negated through avoidance, adaptation or mitigation actions is the degree to which any risks arising are manageable or not.

3. Defining ocean risk

Ocean Risk = f (Hazard, Exposure, Vulnerability)

Ocean risk is a function (f) of exposure to hazards arising from ocean change, and impacts resulting from external or internal vulnerabilities, which may or may not be avoided, reduced or adapted to through pre-emptive action. Assessments of ocean risk need to reflect both the gross changes now being driven by climate change, future changes 'locked' into the climate system, as well as changes to the ocean from the consequences of overfishing, pollution, etc. (Figure 3).

The definition of ocean risk, also and importantly, will create a common language between the insurance and private sectors on the one hand, and the conservation and marine science sectors on the other. How much is actually 'manageable risk', as opposed to greater uncontrolled impacts on society, determines the degree of changes needed in lifestyles, livelihoods and in political decision-taking and action.

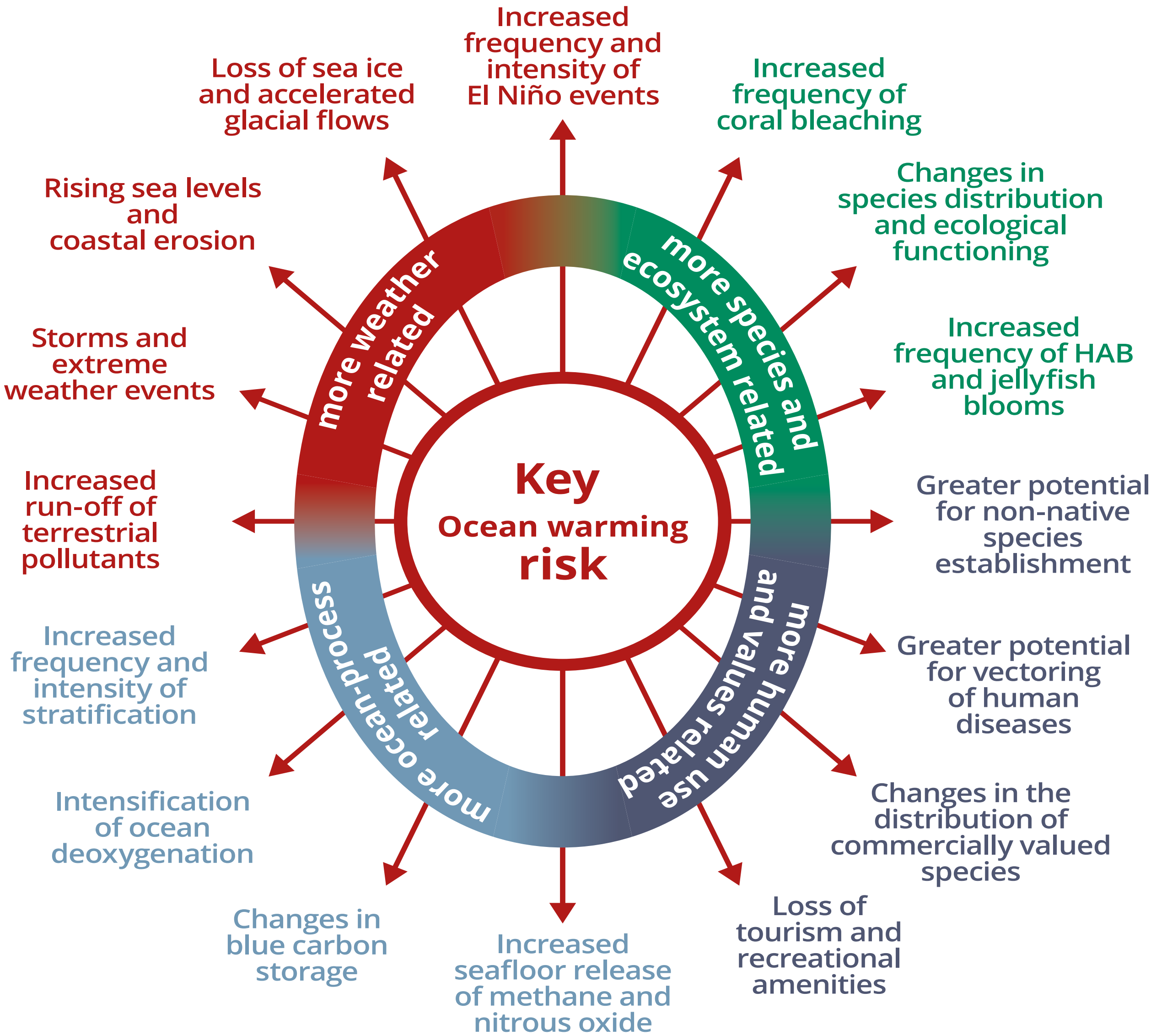


Figure 3. Associated hazards (coloured ovals) that can drive the formation of ocean risk.

4. Vulnerability to ocean risk

Understanding vulnerability is a key part of understanding ocean risk and the ability to lessen our exposure to it. This is because the degree of ocean risk relates to the likelihood of a hazard occurring, the exposure to the hazard, and the vulnerability of exposure to the hazard (i.e. overall ability to address the hazard).

Where there is exposure to a hazard and where the vulnerability to that hazard is high, the degree of ocean risk will also be high. If there is no possibility of exposure to a hazard arising from ocean change, there is no associated ocean risk. Six areas contribute towards our growing vulnerability to ocean risk (Table 2).

INHERENT OCEAN SYSTEM SENSITIVITY Primary production variability High connectivity in the ocean Dying coral reefs Rate/speed of change – running out of time Feedback loops are long Interconnectivity of ocean/whole ocean vs management, e.g. straddling stocks Cumulative impacts Tipping points largely unknown Ecosystem regime shift (and the challenge of reversing those changes that take place)	**INADEQUACY OF SCIENCE** Lack of resources/funding Lack of real time data, observations, and knowledge Current scientific models and related issues (communications, data governance, no sharing, open access, speed of publication, collaboration, lack of data overlap) Lack of scientists Lack of transparency in commercial data (e.g. fish, oil) Usability / accessibility of science Capacity	**CHALLENGES AND ISSUES RELATED TO POLITICAL WILL AND COMMUNICATIONS** Political cycles out of time with biological processes Funding cuts for science Long-term view needed but short-term view taken Ocean literacy Faith-based decision making Feedback loops are long Multinationals/abuses beyond law/politics Not enough laws, e.g. high seas legislation Reactive to hazards not proactive Lack of preparedness for risk Humanitarianism and environmental disconnect Governance vacuum Inadequate transparency of decision making Making-it-worse decisions
CHALLENGES AND ISSUES AROUND GOVERNANCE AND IMPLEMENTATION Not enough implementation Poacher / gamekeeper Humanitarian and environmental disconnect Lack of governance Governance vacuum Lack of integration of best practice Lack of planning for coastal cities Lack of good / adequate planning Push back on regulation Enforcement Liability Jurisdictions Regulations Lack of regulation for technology	**VULNERABILITY DUE TO SOCIAL GAPS** Capacity in developing nations People don't want bad news – the 'ostrich head-in-the sand' effect Lack of appreciation that humans impact the ocean, and vice versa Low priority for poor (disenfranchised); rich and powerful beyond the law High levels of some developing nation engagement but lack of funds / opportunities / power Lack of recognition of the value of the ocean beyond the economic Invisibility of ocean – disconnection Hazards making poor poorer Ocean literacy, one ocean, e.g. El Niño effect from Pacific to Indian Ocean Urbanization Historical use of ocean Freedom of the high seas Resistance to change Lack of shared language between sectors Not getting enough attention as a crisis Perception that we can fix anything – technology hero Public under-informed	**FINANCIAL AND ECONOMIC CHALLENGES** Incomplete framework between finance community and delivery initiatives Short-term monetization of ocean resource Non-sustainable economic practice Pricing of / trade in natural capital Profiteering Rights and assignments of assets Economic need / drive trumps good planning – Wild West mentality
CROSS-CUTTING Communication Ocean literacy Urgency and scale		

Table 2. Six interrelated areas that drive vulnerability to ocean risks, and accordingly increase the likelihood of hazards occurring[3]. Summary points are explained in more detail in the text below.

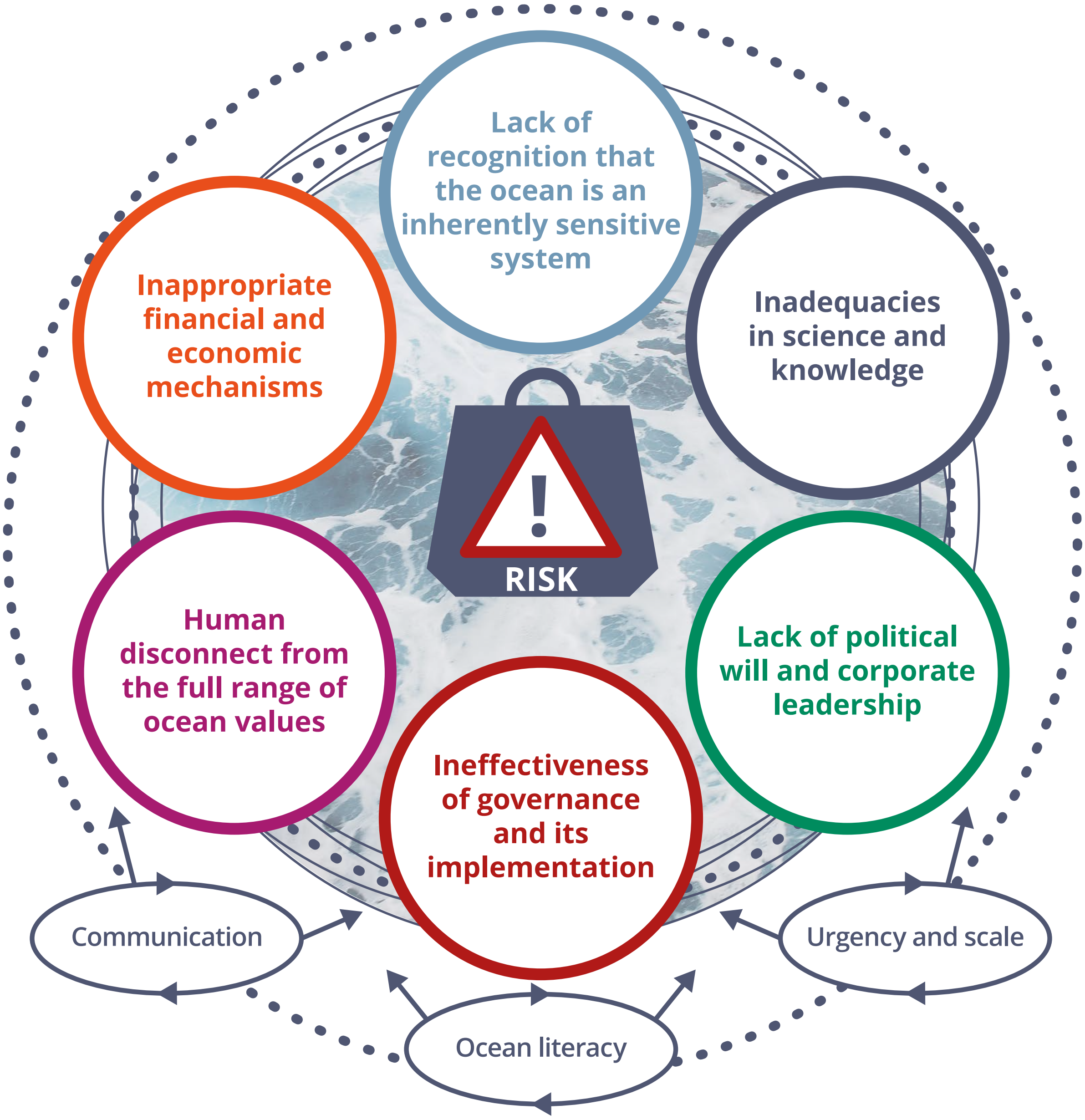


Figure 4. The six interrelated areas that drive human vulnerability to ocean risk, set alongside the challenges of effective communication, adequate ocean literacy and the necessary urgency and scale of response.

Fundamental to the level of vulnerability is having the capacity to respond, but it is becoming clear that we are more vulnerable than we think, because the ocean is far more connected than the terrestrial realm and subject to the cumulative effects of multiple stressors such as ocean warming, ocean acidification and ocean deoxygenation. This is in turn exacerbated by our lack of understanding of how stressors interact with one another / together. There are inherent biological sensitivities in the ocean system to environmental change – for example primary production, which is influenced by eutrophication, stratification, temperature, and which itself has massive consequences for the ocean system. The feedback loops of change within the ocean are long but the scale of change can be much faster than has been generally anticipated.

It is inherent in ocean sensitivity that when a system changes it is very difficult for it to get back to its original state – i.e. regime shift occurs. As an example of interconnectivity, the Indian Ocean is becoming much warmer at deeper levels due to the El Niño effect in the Pacific Ocean. In addition to the direct impact humankind has on the ocean (for example from extraction), it is our indirect impacts which also contribute to overall vulnerability. For example, all of the following are increasing human vulnerability to ocean risk:

- A persistence in doing the wrong thing / continuing with damaging behaviour.
- The short-term optimization and monetization of the ocean – extracting a profit from an essential natural resource for the benefit of a few.
- A lack of common ownership, the allocation of individual rights and lack of accountability.
- Inadequate governance, implementation and enforcement including a lack of law governing two-thirds of the ocean (high seas).
- Short-term decision making and disjointed responsibility.
- The lobbying of powerful actors with a vested interest in the freedom to exploit.

Alongside these aspects another overarching vulnerability is a lack of scientific knowledge and funding. We certainly know enough about the problems to act, but for solutions to be created and be more effective we need to better understand areas such as interconnectivity to improve crisis response readiness and the ability to avert risk. The scientific models are hindered by a lack of both knowledge, and long-term and real-time data. We cannot test the models as we do not have the fundamental data to plug into them. There is also poor data governance and too much data-locking (the failure to adequately share data being gathered). The reviewing process is too slow and holds up the sharing of important information, and although we need more data, recognized standards must be in place to make it possible to combine data in a consistent way to be useful.

The lack of adequate scientific funding and resources compounds and drives the current model of scientific research around short-term examination and publication, with a lack of cross-communication and sharing of material. Flaws and gaps in communications are also a common theme – for example, between scientists, with governments, and between sectors. This – as with the definition of hazard – is compounded by very poor ocean literacy, the fundamental understanding about the role of the ocean at an Earth system level and its feedback effect on humans. These issues are summarized in Figure 4.

5. The emerging realities of risks arising from a warming, and changing ocean

To most people the idea of the consequences of climate change evokes images of flooding and storms, as is frequently portrayed in the media, and the notion of rising risks and impacts on vulnerable people, communities, and sometimes to society as a whole. The relationship between hazards and risk from ocean warming, however, is complex, as highlighted in the previous sections.

Individual hazards arising from ocean warming can affect humans through a variety of different mechanisms and these in turn can increase the degree of risk in many different ways (Table 3). The complex relationship between hazards and resultant risks is why changes being driven by ocean warming are likely to impact many people, especially as the 'locked in' changes arising from our impacts on the existing climate system increasingly take hold in the coming decades.

A changing ocean

Changes underway in the state of the ocean and how it functions because of climate change are exacerbating existing problems and creating new hazards which, if they go unmanaged, will result in greater or even new risks to people and the environment. Given the fact that the ocean acts as the greatest regulator for the planet (Figure 5), the notion that 'only vulnerable communities at the coast' will be impacted or are 'at risk' needs to be dispelled. They may be the first to be impacted and indeed in some places are already suffering significant consequences, but ocean risk will extend well beyond just coastal communities. This is because the influence of the ocean on the climate drives associated widespread impacts inland, across continents, and touches many more people's lives in ways that most have probably not even thought of yet.

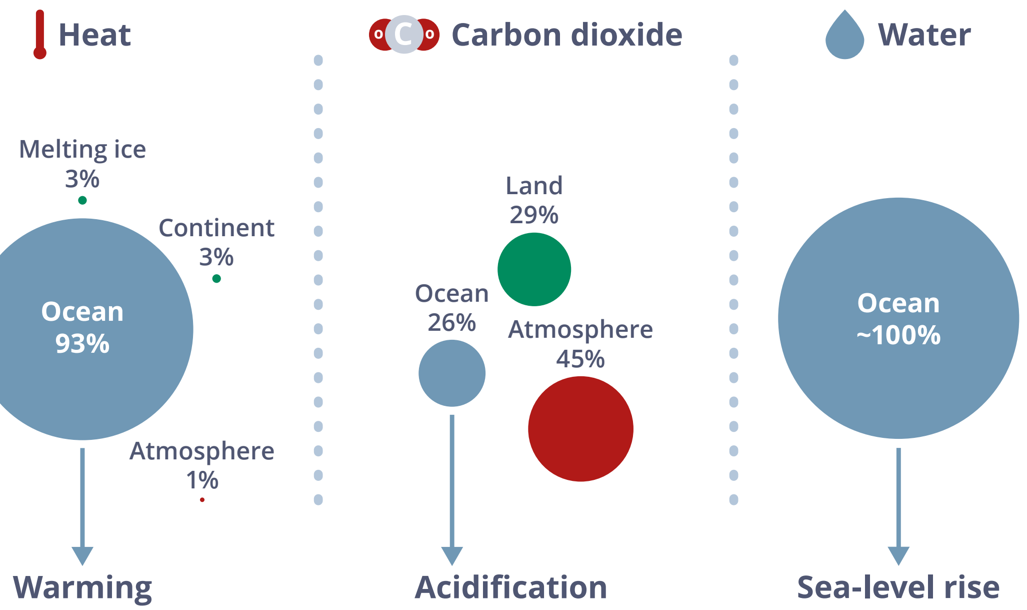


Figure 5. **The distribution of heat, carbon dioxide and ice-melt water in the main Earth reservoirs and consequences for the ocean (Source: J-P Gattuso).**

Ocean warming hazard	Examples of human exposure	Examples of increased risks
Impacts on ecologically and/or commercially important species and ecosystems	Via changes in ecosystem composition and functionality and from changes in distribution and abundance of species	• Risk to dependent fishing industries • Risk to operating costs • Risk to income • Risk to political and management frameworks • Risk to secondary industries • Risk to tourism viability and income • Risk to human health • Risk to dependent marine species • Risk of coastal flooding • Risk of coastal erosion
Vibrio bacteria	Via range expansion of vibrios	• Risk to life • Risk to human health • Risk to tourism viability and income
Regional marine heat waves	Via gross changes to ecosystems – e.g. increased frequency of coral bleaching leading to mass coral reef die-off, and mass kelp forest die-off	• Risk to tourism viability and income • Risk to coastal defences • Risk to ecosystem functioning and existence • Risk to resource-dependent industries, e.g. fisheries • Risk to regional reputation and worth
Storms, hurricanes and typhoons	Via exposure to more extreme precipitation, winds, and storm surges	• Risk to life • Risk to built infrastructure and habitations • Risk to human health • Risk to coastal defences • Risk to earnings • Risk to tourism viability and income • Risk of coastal flooding • Risk to viability of coastal defences • Risk to operating costs
Sea-level rise (SLR)	Via ice melt and thermal expansion	• Risk to life • Risk to built infrastructure and habitations • Risk of coastal flooding • Risk to viability of coastal defences • Risk to operating costs • Risk to human health
Harmful algal blooms (HABs)	Via new or increased frequency and extent of blooms	• Risk to human health • Risk to shellfish fisheries • Risk to operating costs • Risk to aquaculture production • Risk to secondary industries
Non-native marine species	Via species extending their ranges into new regions or being introduced by vectors and having a better chance at establishment	• Risk to fishing and aquaculture industries • Risk to operating costs • Risk to tourism
El Niño events	Via increased frequency of severe events	• Risk to life • Risk to fisheries • Risk to agriculture • Risk to marine ecosystem health • Risk to human health
Ocean deoxygenation	Via warming of waters and increased stratification in the water column	• Risk to fisheries • Risk to dependent recreational industries • Risk to regional productivity • Risk to marine ecosystem health
Methane hydrates	Via warming melting the gas hydrate and releasing more methane into the water and air	• Risk of exacerbating regional deoxygenation • Risk of increasing powerful greenhouse gas emissions • Risk of destabilizing seabed areas leading to underwater landslides

Table 3. **The relationship between hazards from ocean warming, ways in which humans are exposed to such hazards, and the areas where increases in risks are likely or already happening.**

The challenge is that the assessment of risks from ocean warming has to be set against a sliding scale

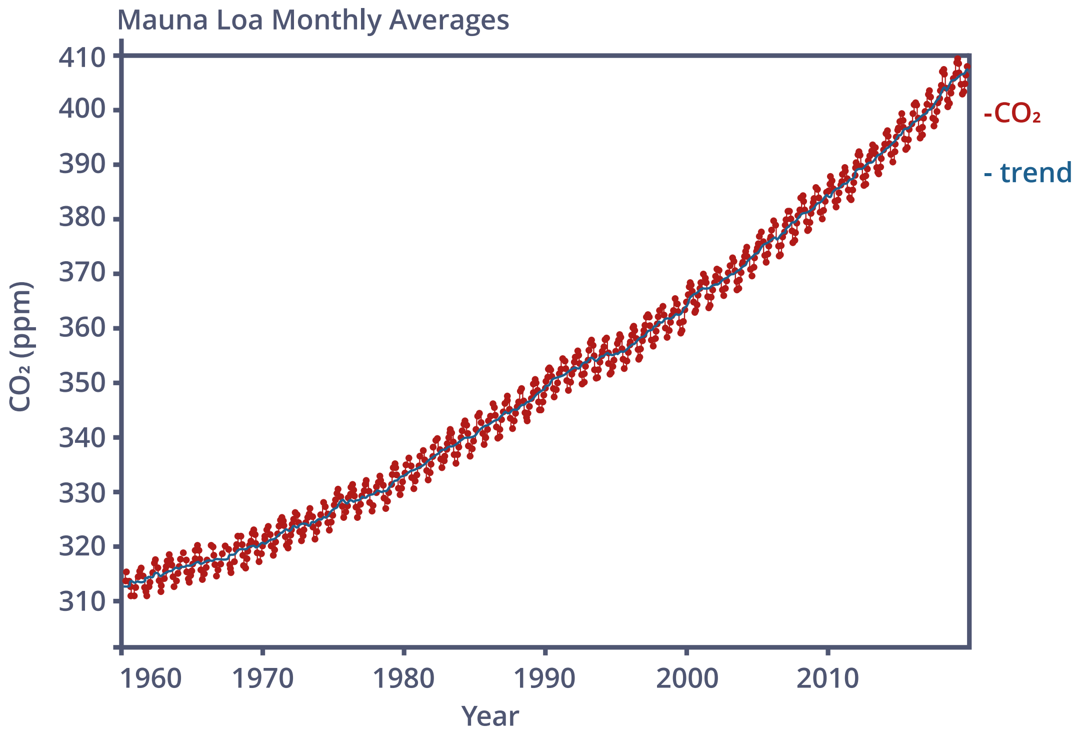


Figure 6. **Progressive and continuing emissions of carbon dioxide recorded at Mauna Loa, Hawaii (Source: NOAA).**

of increasing impacts from climate change. In recent years, as evidence of change and acceleration in resulting trends in climate change have emerged, more serious consideration needs to be given to assessing and acknowledging ocean-related risks arising from the hazards of ocean warming and ocean-related systems including the weather. At the core of this is the level of CO_2 in the atmosphere that continues to rise unabated and which in turn drives further change (Figure 6). How the continuing increase of greenhouse gas emissions interacts with the ocean-climate system in the future, to drive progressive and increasingly rapid changes to a

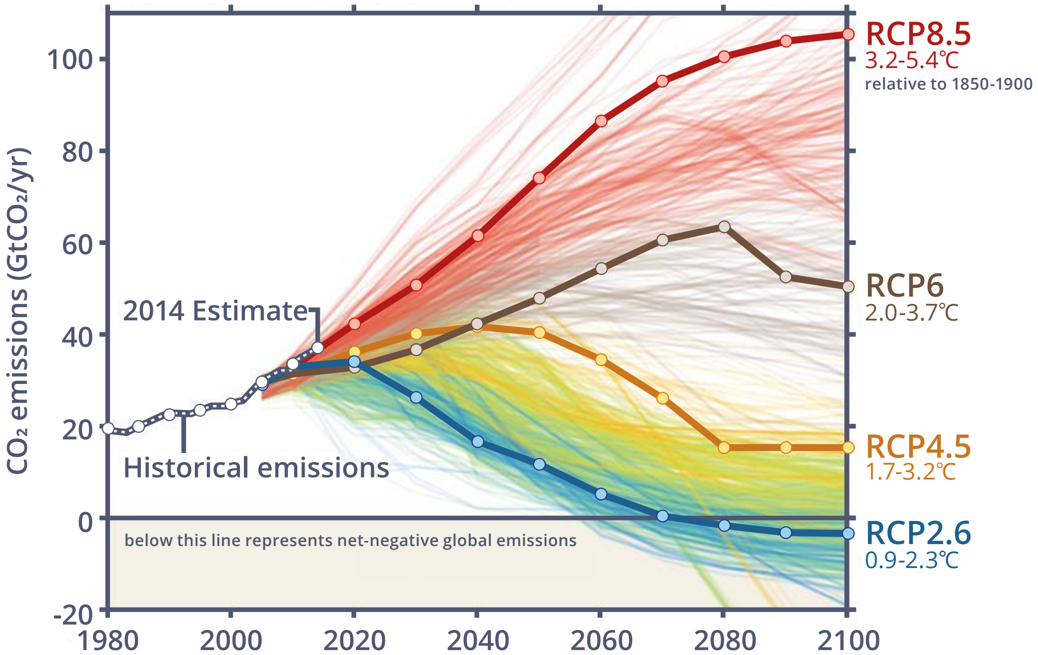


Figure 7. **Carbon dioxide emission pathways until 2100 and the extent of net negative emissions and bioenergy with carbon capture and storage (BECCS) in 2100. (© 2014 Springer Nature. Fuss et al., 2014[4])**

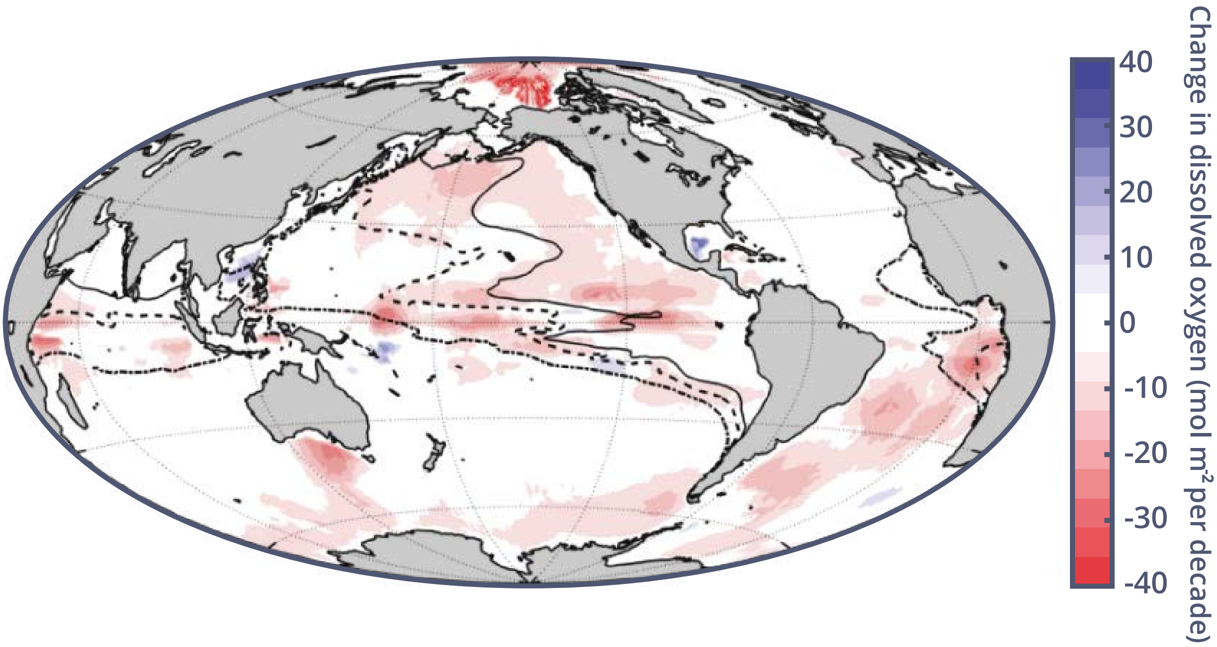


Figure 8. **Dissolved oxygen and apparent oxygen utilization changes per decade since 1960. During that period the ocean has lost on average 2% of its oxygen but not uniformly (© 2017, Springer Nature. Schmidtko, Stramma, and Visbeck, 2017[5])**

level that has serious impacts, will determine the levels of ocean risk that can be ameliorated and managed now and especially in the coming decades (Figure 7).

One of the challenges in assessing the degree of risk arising from ocean warming is that ocean warming is but one of the major climate-related stressors that are now acting together on the ocean and driving change. Another stressor which is itself partly a consequence of ocean warming is ocean deoxygenation (Figure 8).

This is, at its simplest, due to the fact that warmer water holds less gases including oxygen. There is now a recordable trend in reductions in oxygen held in ocean water across the globe (about 2%), but with regional hot-spots where reductions of as much as 33% are being recorded since the 1960s.

Furthermore, alongside deoxygenation and ocean warming, and compounding future assessments of the degree of risk arising from the changing ocean is ocean acidification (Figure 9). Ocean acidification is a phenomenon resulting from the increasingly elevated levels of CO_2 in the atmosphere dissolving in ocean water

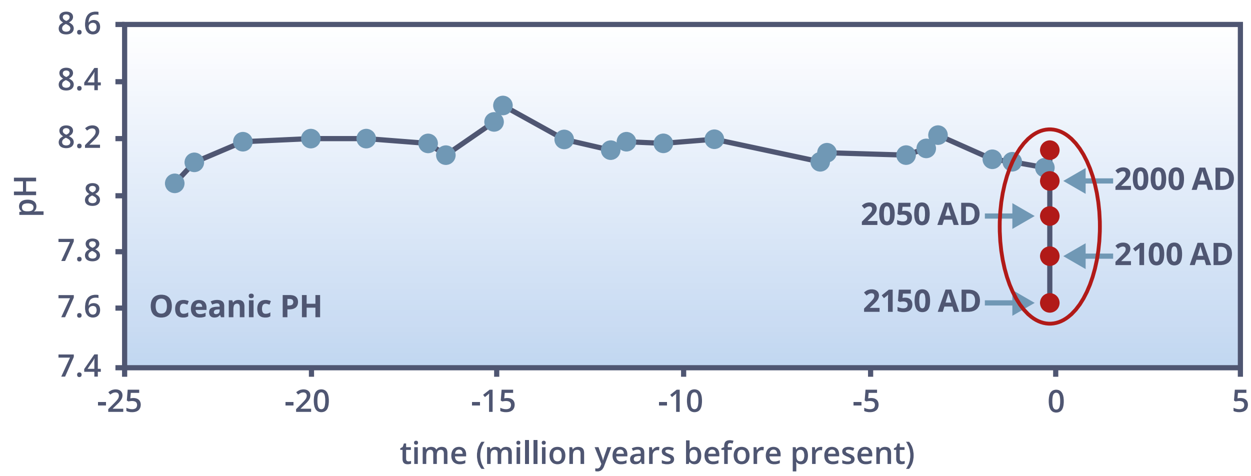


Figure 9. **The changes in ocean pH over the last 25 million years. Significant changes are now occurring at a rate and to a level not experienced by marine organisms for around 60 million years (Source: Carol Turley)**

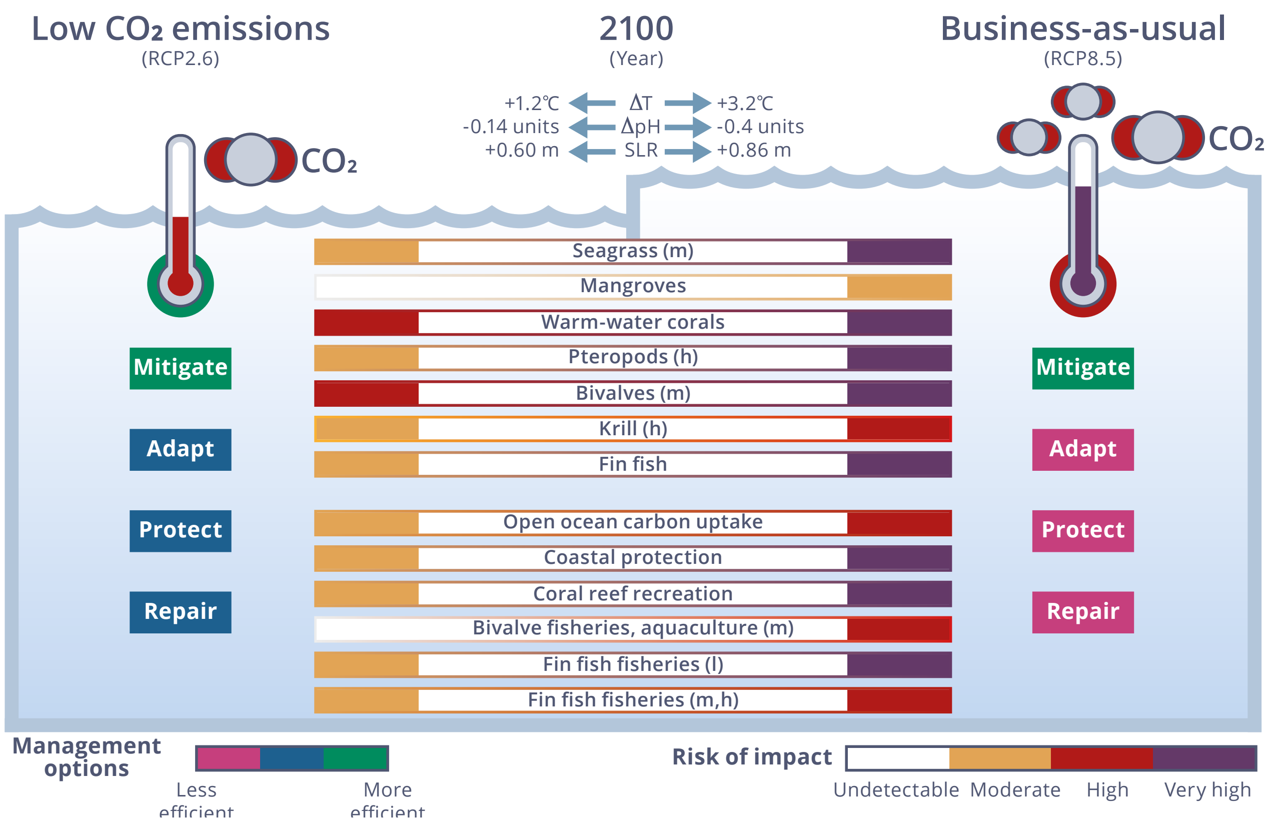


Figure 10. Changes in ocean physics and chemistry and impacts on organisms and ecosystem services according to stringent (RCP2.6) and business-as-usual (RCP8.5) carbon dioxide scenarios . h - high latitude; m - mid latitude; l - low latitude (Adapted from: Gattusso et al., 2015[7]).

Consequences of a warming ocean

Temperature is fundamental to the functioning of the ocean. When it changes beyond accepted norms this causes a cascade of consequences. A recent study by IUCN involving 80 leading scientists revealed a wide range of implications for species in the ocean including:

- Loss of breeding grounds on land and at sea
- Impacts on breeding successes
- Changes in foraging strategies
- Sex ratio shifts
- Seasonality shifts leading to mismatches in prey and predator occurrences
- Poleward movement of fish shifting from 10s to 100s of km per decade
- Species invasions and local extinctions
- Shifts in community structure
- Shifts in fishing grounds of target species
- Reduction in the physical size of species in response to food and nutrient limitations
- Reduction in size of fish leading to reduced fecundity, altered trophic interactions and decreased fisheries yield
- Potential increases in bycatch when overlaps of distributions of target and non-target species increases
- Whole marine ecosystem shifts as species respond to shifting boundaries in ocean temperature and decoupling of community structure

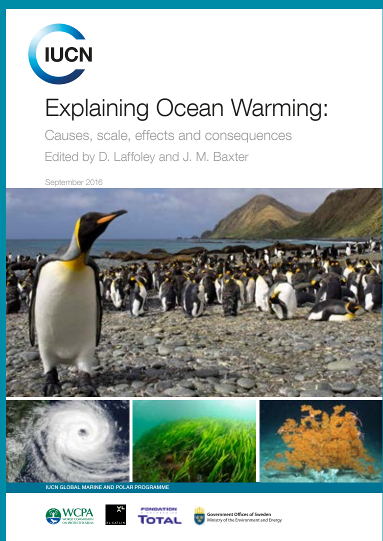


Figure 11. Major implications of a warming ocean which is beginning to alter species, ecosystems and ecological processes (Summarized from: Laffoley and Baxter, 2016[6]).

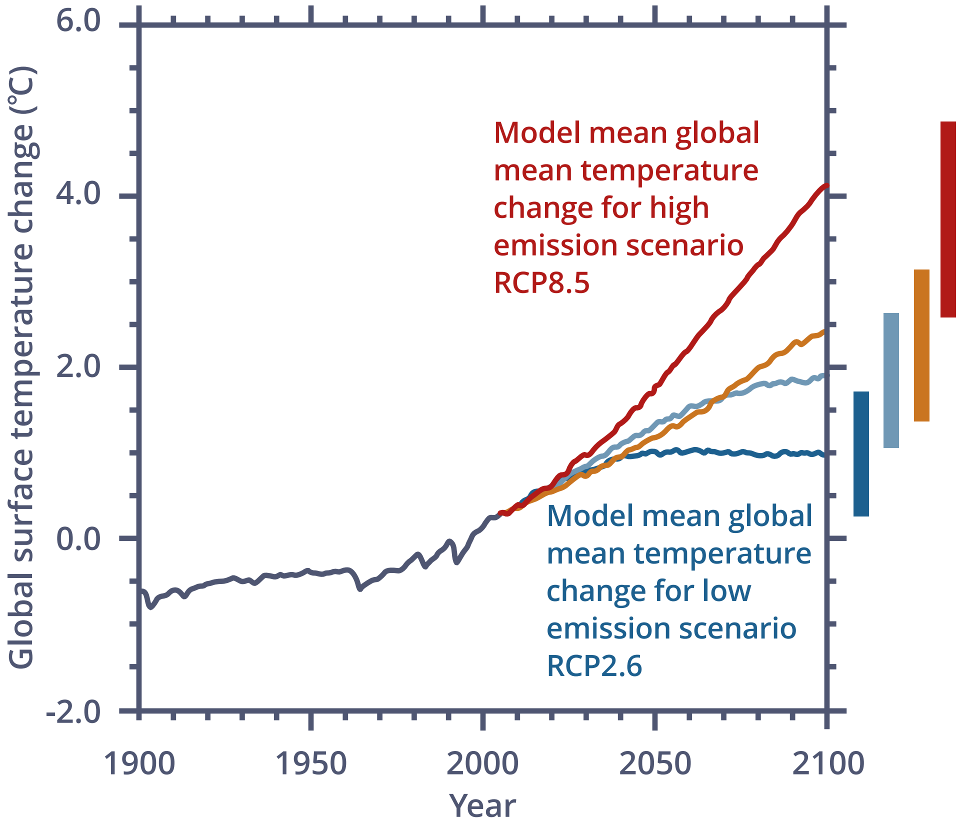


Figure 12. **Observed and projected changes in global average temperature under four emissions pathways. The vertical bars at right show likely ranges in temperature change by the end of the century, while the lines show projections averaged across a range of climate models (dark blue RCP2.6; light blue RCP4.5; orange RCP6.0; red RCP8.5). Changes are relative to the 1986-2005 average. (Source: IPCC, 2013, FAQ 12.1, Figure 1.[8]).**

and forming carbonic acid thus tending towards more acidic conditions. This makes it harder for organisms to grow carbonate skeletons and shells, which in turn has the potential to affect many other aspects of life in the ocean.

What is evident from recent research is that the ocean is already too warm (Figure 10) and tending towards acidic conditions that are too much for some marine species, and as progressive locked-in changes occur, not only will more species be affected, but the opportunities to take mitigation and adaptation actions will reduce.

The real and urgent question is therefore when will we reach tipping points where mitigation and adaptation actions to reduce the risks arising are no longer an option, and risks to humans and our ocean life support systems become unmanageable? It is becoming increasingly clear that this may be sooner than some think (Figures 11 and 12), and the issue is what action must be taken to avoid reaching such tipping points. This is the difference between communities and governments having become used to simply buying themselves out of problems that arise – perhaps through disaster recovery – and negative, progressive and permanent changes being wrought on the environment on which people depend, and that no amount of money can rectify.

6. Case studies in ocean warming and cost implications to society

This section explores ocean risk from five differing perspectives, using a combination of diagrams showing how changes to the ocean ripple out to cause potential risks to society, coupled with an associated narrative drawn and updated from the IUCN Ocean Warming report. The diagrams are illustrative of the major links between changes to the ocean.

The five case studies are the impacts of ocean warming and change on:

- Weather and extreme storm events
- Human health and diseases
- Harmful algal blooms
- Coral bleaching
- Food security via fisheries and aquaculture

Weather and extreme storm events

As the ocean warms the atmosphere above is being affected. Changes in air-sea interactions are being seen around the planet, in many cases leading to enhancement or shifting of extreme weather. Until recently it was believed that, in terms of the global mean temperature, this upward trend in near-surface atmospheric temperature may have slowed. However, it is now likely that this was an artefact of measurements of sea surface temperature (SST) becoming more common from ocean buoys than ship engine intakes, with the former tending to record cooler values than the latter.

The upper ocean acts as a major heat engine for the atmosphere of the planet: it absorbs solar energy that is then transferred to the atmosphere. Over much of the ocean its surface is warmer than the atmosphere above it, driving a heat flux to the atmosphere. This addition of heat and moisture to the atmosphere helps stimulate the formation of mid-latitude storminess linked to more severe hurricanes, or changes to the character of the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), or monsoons, linked to tropical ocean changes.

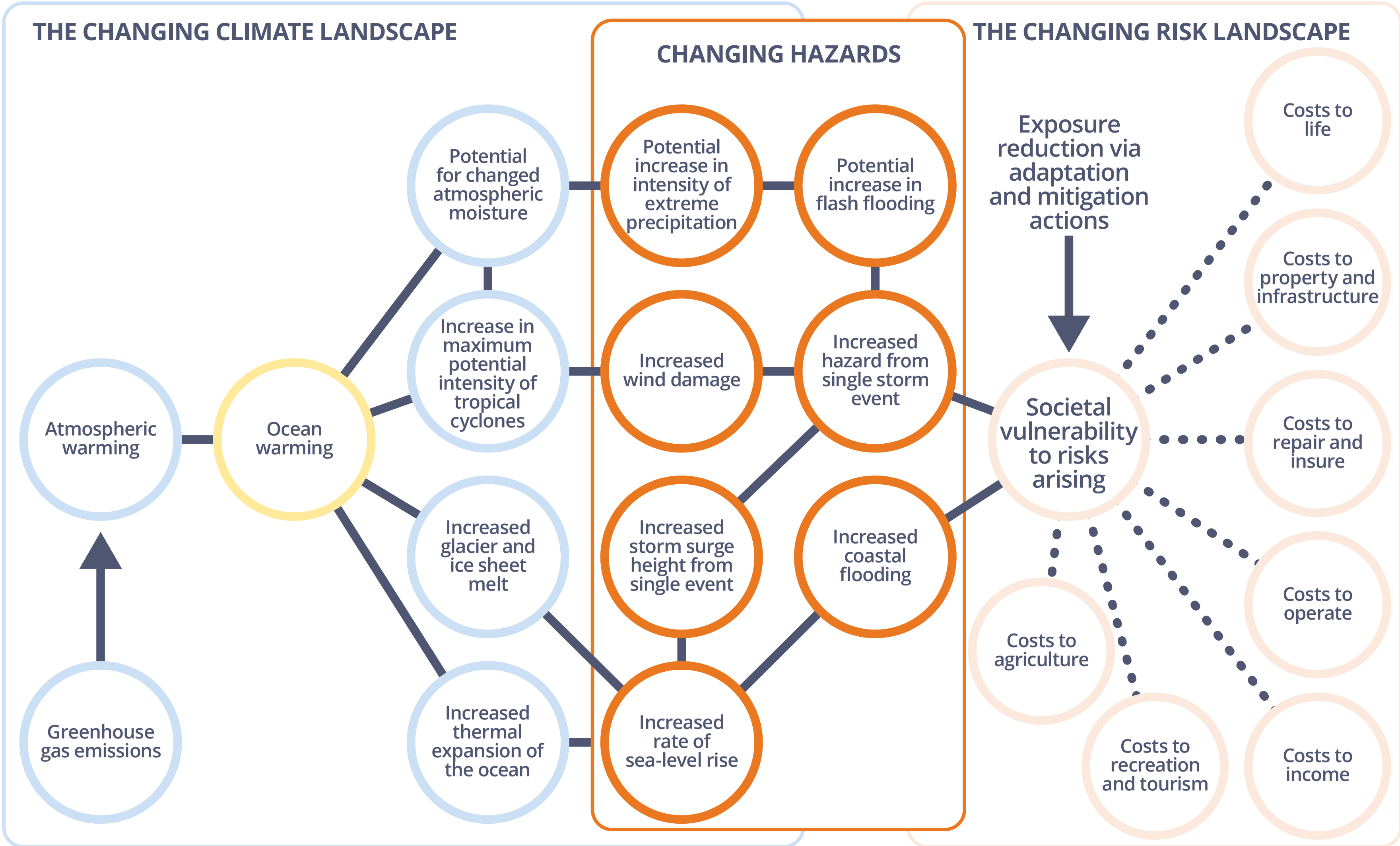
The consequences for society of changing weather patterns due to the warming of the ocean are considerable. There have already been changes to precipitation patterns in several areas of the planet resulting from large-scale atmospheric connections to ocean warming. These can be increases in rainfall in some mid-latitude and monsoon areas, but decreases over various subtropical regions. Both will have impacts on crop yields over many important food producing areas such as Australia, North America, and India.

Since the 1990s the atmosphere in the Polar Regions has been warming at about twice the average rate of global warming, this being greatest in the Arctic and around the Antarctic Peninsula, known as polar amplification. Polar amplification has had profound impacts on the climatology of the high-latitude ocean resulting in effects on sea ice cover. Arctic sea ice cover in late summer has declined by over 13% per decade since 1979, and by about 3% in late winter.

If these trends continue, then there is the possibility that as soon as 2025-2040, little Arctic sea ice could remain in late summer in some years. This may lead to the recreation of a relatively warm water connection between the North Pacific and North Atlantic as summer ice disappears, allowing species movement and mixing. More generally in polar regions the increasing ocean temperatures are linked to greater melt and higher fluxes of icebergs from both Greenland and Antarctica. Ocean warming will increase the stratification of the ocean by making the mixed layer less dense than it is currently. Mixing between surface and deeper waters will therefore most likely become harder to initiate over large parts of the ocean. This will slow the supply of sub-surface nutrients to the surface waters, generally decreasing marine primary productivity.

Water supplies are also impacted by these ocean-induced weather changes. Where droughts are occurring in regions that are semi-arid even in good years, water supplies often rely on a limited

The ripple effect - connections between ocean warming, extreme storm events such as hurricanes, and risks and costs to society



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number of sources. Decreases in the flows of major rivers put at risk the water needs of large human populations. In regions where storms are increasing in number or severity, flooding can be a major risk, whether inland or coastal. Risk is not just associated with food security and flooding. It appears likely that the probability of strong hurricanes occurring will increase, posing a significant risk to economic development, housing, as well as life in areas subject to landfall of such storms. While the consequences are especially severe for developing countries, even developed nations such as the United States are still subject to major dislocation.

Climate models are still not able to reproduce tropical cyclones, so there is some doubt about whether the number of such storms will increase, as expected. North-west Europe faced a series of unusually severe winter storms during the 1990s (at least in the context of the previous few decades), and any changes in jet-stream activity – which are clearly related in part to ongoing climate change – have serious economic, societal and ecological implications for the densely-populated northern mid-latitudes. It is often stated that continued warming of the tropical ocean should also lead to more frequent occurrence of tropical ocean-atmosphere processes such as El Niño, as the basic state of the ocean is more conducive to such events being initiated. However, climate models are still not sufficiently good in reproducing temporal patterns of El Niño frequency for this to be certain.

Human health and diseases

Given that 44% of the current global population live near the coast, and 8 out of 10 of the world's largest cities are coastal, the lives of billions of people are influenced by the planet's coastal seas. There is a range of mechanisms where climate change can influence the ocean and thus directly or indirectly affect human health and welfare.

A relatively less well recognized issue about climate change is how a warming ocean can influence human health through changes in the geographic locations and the resulting risk of transmission of pathogens and biologically-produced toxins from the marine environment.

Evidence suggests that observed warming could affect many vector-borne diseases through a range of mechanisms such as altering disease, vector, or reservoir distributions, or by increasing outbreak probability and risk of disease transmission. Links between disease outbreaks and climate variability vary greatly by region, but overall global patterns are apparent: of 17 common communicable human diseases, 12 (71%) are weakly to strongly affected by changes in rainfall and temperature. Practically all of these cases are, however, associated with terrestrial or freshwater systems, with rather less known about implications in marine systems.

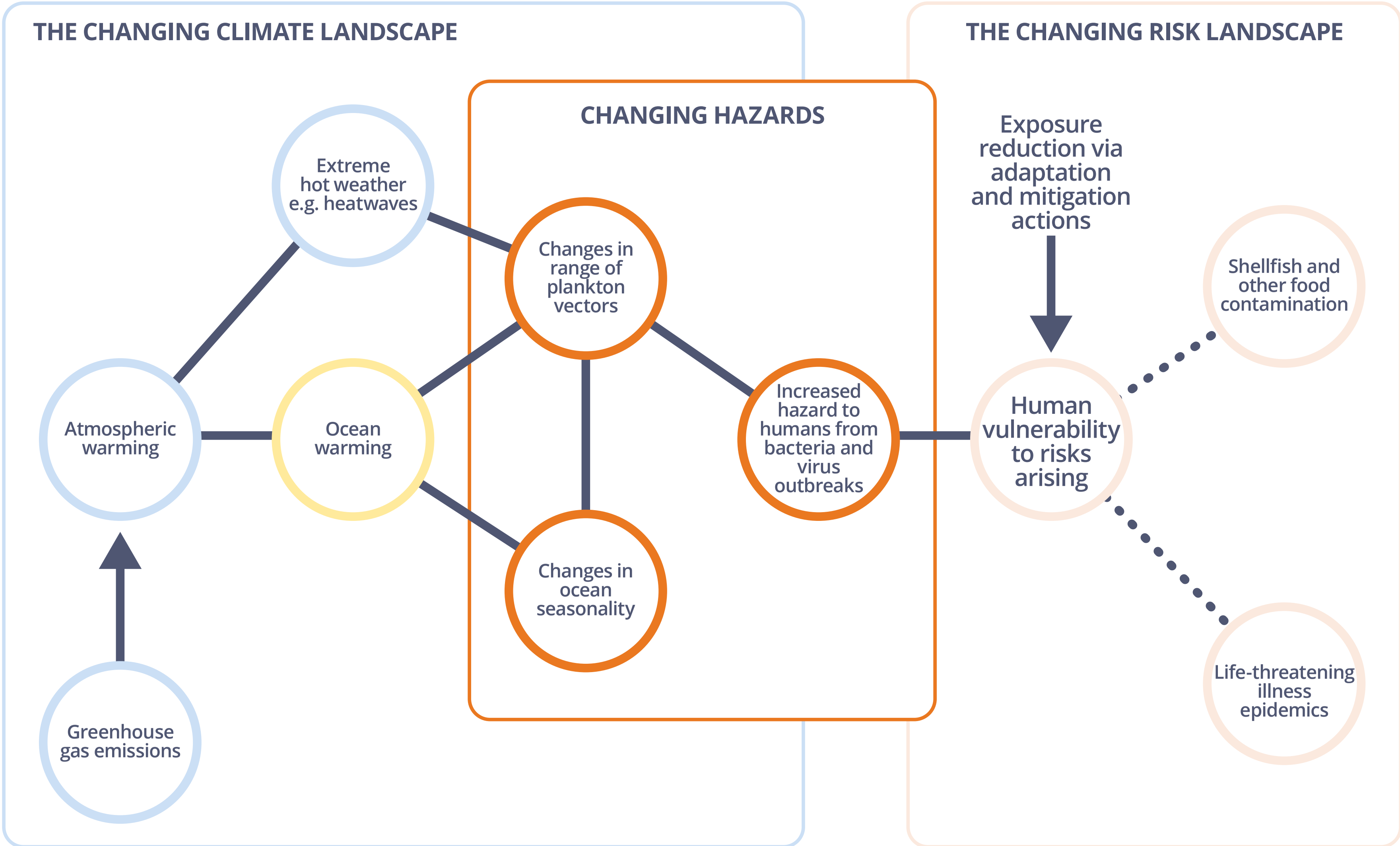
There are numerous studies linking climate variability in coastal systems to increases in vector-borne diseases of humans, but these are typically indirect effects of SST variability on the terrestrial climate, which in turn affects disease prevalence and transmission by terrestrial vectors and reservoirs, such as mosquitos and sand flies, or freshwater animals, such as snails.

The potential for climate-related spread of human diseases through marine systems is less reported, and has received comparatively little attention. There is evidence for increases in infectious diseases in marine organisms world-wide, and a recent review of seafood safety suggested early signs of emergence of "tropical" human diseases into historically temperate seas, but rigorously proven linkages with anthropogenic climate change (driving both ocean warming and acidification) remain elusive. Marine systems, like freshwater systems, also have the possibility of disease transmission through wounds encountering infected water.

Many marine-based human pathogens are sensitive to sea temperature variability. Harmful algal blooms are one set of pathogens. Another is the *Vibrio* bacterium in oysters, whose infection incidence rises dramatically with increased sea temperature. The human impact of the species *Vibrio vulnificus* infection is severe, as 30% to 48% of people die after contracting this bacterium. *Vibrio*-related illnesses have about doubled for every 1°C increase in maximum water temperature. Thus, once above a minimum survival temperature, infection rate is more closely related to maximum temperatures.

The global distributions of key human pathogens (bacteria, viruses, protozoa, fungi and other parasites) follow the same latitudinal diversity gradient as most animals and plants. Greater species richness of pathogens in the tropics is

The ripple effect - connections between ocean warming, human health, and risks and costs to society



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related to climatic variables. Global warming could drive the expansion of pathogens into historically cold regions with increasing temperatures (i.e. cold-temperate and boreal regions), but may also result in a reduced prevalence in the warmest parts of the historical ranges of these diseases.

The best projections of future geography of human disease come from terrestrial systems, where decades of detailed experimental work have refined our understanding of the specific thermal limits and optimum conditions for survival, growth, reproduction and transmission of various human diseases, such as malaria. This depth of experimental knowledge is largely lacking for diseases associated within the marine realm, making the modelling of future risk difficult, with high uncertainty in projected outcomes.

As it is now clear that latitudinal movement of species is happening between 1.5 and 5 times faster in open marine systems than on land, it is possible that where a pathogen survives in marine conditions this could provide the quickest route for its spread to new regions. There is now compelling evidence, for example, of the links between climate variability, climate change (e.g. via increases in strength of El Niño events), native plankton dynamics, bacterial dynamics in the wild, and cholera disease epidemics.

Harmful algal blooms (HABs)

Microscopic unicellular planktonic algae form the basis, either directly or indirectly, of all marine food webs leading to edible fish. Through the process of photosynthesis these microscopic floating plants provide 50% of the oxygen humans breathe and constitute a major consumer of anthropogenically produced atmospheric CO_2. The ability of the ocean to act as a sink for anthropogenic CO_2 relies on its conversion by phytoplankton into particulate organic matter and subsequent partial loss to the deep ocean (the so-called biological pump).

Any reduction in net ocean CO_2 uptake caused by shifts in ocean circulation or reduced phytoplankton growth in surface waters could lead to an acceleration in the rate of increase in atmospheric CO_2 and global warming. Increased recognition of phytoplankton as a climate driver is well demonstrated by commercial interests exploring options such as ocean fertilization to combat anthropogenic climate change through enhanced phytoplankton production.

While considerable progress has been made in understanding the physics of climate change, understanding the impacts on biological communities is in its infancy. There will be winners and losers from climate change, but predicting how individual species and consequently ecosystems will respond poses a formidable challenge to assessing risk. Not all trophic levels are responding to the same extent or in the same way, and where zooplankton or fish grazers are differentially impacted by ocean warming, this may have cascading impacts on the structure of marine food webs. While the collapse of the North Atlantic cod fishery has been widely attributed to overfishing, an underlying climate driven regime shift in its preferred zooplankton prey is also thought to have played a key role. Because of their short generation times and longevity, many phytoplankton are expected to respond rapidly to current climate change. However, our knowledge of the potential of marine microalgae to adapt is very limited.

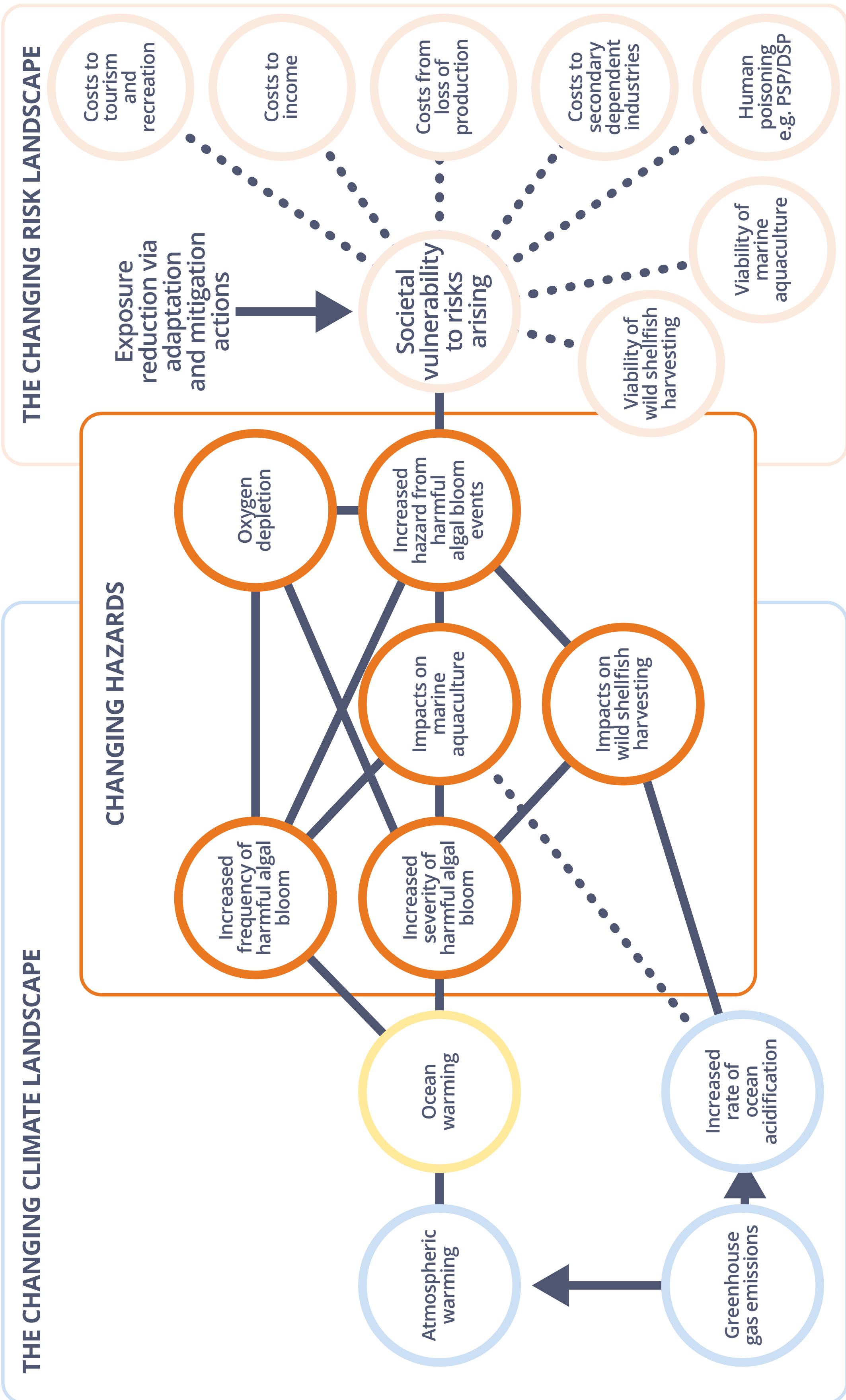
The greatest problems for human society are posed by being confronted with a new level of uncertainty, such as for seafood security and safety for an ever-growing human population. Under favourable environmental conditions of light, temperature, salinity, water column stability and nutrients, algal populations of only a few cells can quickly multiply into dense blooms containing millions of cells per litre which can discolour the sea water (sometimes referred to as ‘red tides’).

Most plankton blooms appear to be beneficial to human society in that they drive food chains leading to commercial fisheries as well as serve as a sink for anthropogenically produced CO_2. Ocean fertilization experiments suggest that at various times in the Earth’s history, proliferation of algal blooms which gobbled up CO_2 and then sank to the bottom of the sea, thus capturing the greenhouse gases, may have contributed to a cooling of climate.

Under exceptional conditions algae may become so densely concentrated that they deplete the oxygen in the water upon their demise. This can cause indiscriminate kills of fish and invertebrates in sheltered bays. Prolonged low oxygen conditions, such as those caused by excessive nutrient pollution from human activities into coastal waters, can lead to oxygen dead zones that fail to support marine life.

A different phenomenon is the production, by certain species of dinoflagellates, diatoms and

The ripple effect - links between ocean warming, harmful algal blooms, and risks and costs to society



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cyanobacteria, of potent neurological toxins which can find their way through fish and shellfish to humans. When humans eat seafood contaminated by these microalgal toxins, they may suffer a variety of gastrointestinal and neurological illnesses, including Paralytic, Diarrhetic, Amnesic, or Neurotoxic Shellfish Poisoning and Ciguatera Fish Poisoning. Human drinking-water supplies can be contaminated by cyanobacterial toxins.

Algal bloom species show a perplexing diversity of biomass and toxicity patterns, ranging from species that can cause toxicity problems even at very low cell concentrations, to species that are basically non-toxic but whose nuisance value derives from their high biomass production.

In addition to trying to predict how global phytoplankton abundance may respond, special attention has also focused on the behaviour of so-called HABs. Persistent near-monospecific algal blooms have sometimes been referred to as ecosystem disruptive algal blooms (EDABs), in which toxic or unpalatable algal species disrupt grazing of phytoplankton by zooplankton and thus diminish nutrient supply via recycling. Ecosystems affected by pollution or climate change are considered more prone to introduction of non-native species through ballast water discharges or climate-driven invasions than mature stable ecosystems.

Coral bleaching

Shallow water coral reefs are ecologically and economically important marine ecosystems, found across the world's tropical and sub-tropical oceans. In addition to their inherent beauty, reefs provide a variety of social, economic and cultural services to coastal communities and visitors with an estimated value of US$9.8 trillion per year. Despite covering less than 0.1% of the ocean floor, reefs are the most biodiverse marine ecosystem – comparable to rainforests. These 'Rainforests of the Sea' provide habitat and feeding grounds for over 25% of all marine fish species and myriad of other marine animals, and yet they are under imminent threat due to the rapidly changing ocean climate landscape, driving increased hazards and significant risks.

The services provided by coral reefs can be severely disrupted by a wide range of chronic and acute environmental disturbances. Most important are the impacts of global stressors resulting from increases in anthropogenic atmospheric CO_2. These include thermal stress (linked to coral bleaching and disease); ocean acidification (reducing the growth of corals and the strength of reefs); tropical storms (which can physically damage reefs); and sea-level rise (with which coral reef growth may not be able to keep up, and which could increase sediments, nutrients, and toxic pollutants on reefs). Such cumulative impacts on coral reef ecosystems potentially have dramatic consequences for the many services they provide and the numerous people who rely upon those services.

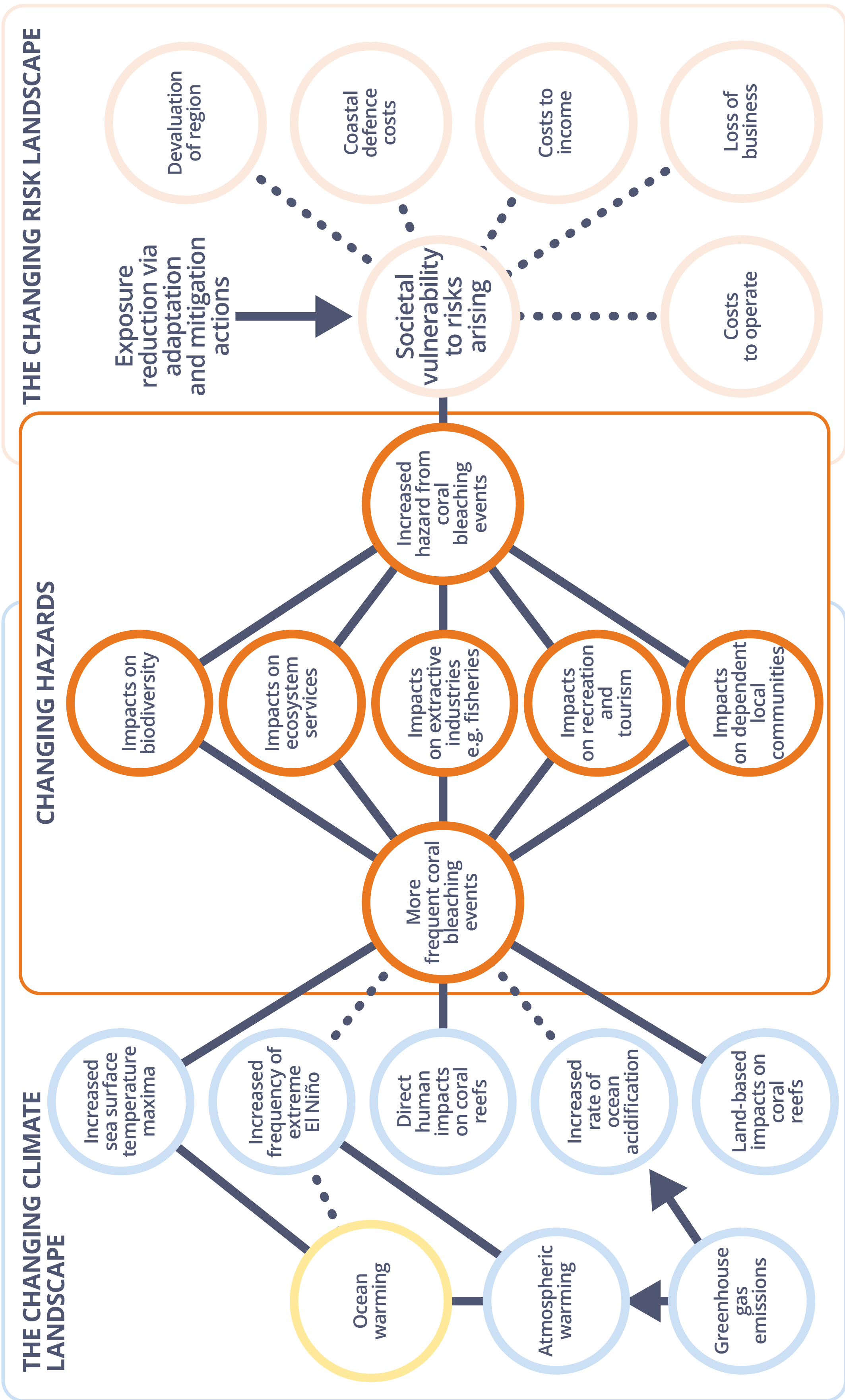
The three-dimensional structure formed by corals not only supports complex ecosystems, but also dissipates wave energy to protect coastlines from erosion and damage. Coastal protection and recreational activities (including tourism) provide the greatest economic benefits from coral reefs. Coral reef organisms have also been the source of numerous important drugs and medical treatments.

Coral reefs are a key indicator ecosystem for the impacts of climate change on the marine environment – thermal stress events related to ocean warming have and are predicted to result in dramatic impacts on coral reefs. Corals thrive in conditions close to their upper temperature limits, maximizing growth and reproduction. Exceeding these temperature thresholds, however, can result in coral bleaching – impacting coral growth and reproduction; increasing susceptibility to diseases; and even leading to death. The rapid recurrence of regional- and global-scale bleaching events reflects the serious impact the current trajectory of ocean warming is having on both short- and long-term persistence of healthy coral reefs.

Such events reduce the cover and diversity of corals, and flatten the three-dimensional structure coral reefs provide. This destroys habitat for resident animals while also reducing coastal protection. Tropical cyclones also can flatten structures, causing the same downstream effects on coral ecosystems and the human populations they support and protect. This can be compounded by ocean acidification that weakens reef structures.

Ocean warming has accelerated during the past century and is predicted to continue, resulting in more frequent and severe coral bleaching and disease outbreaks (Figure 13). Unless the cause of

The ripple effect - connections between ocean warming, coral bleaching, and risks and costs to society



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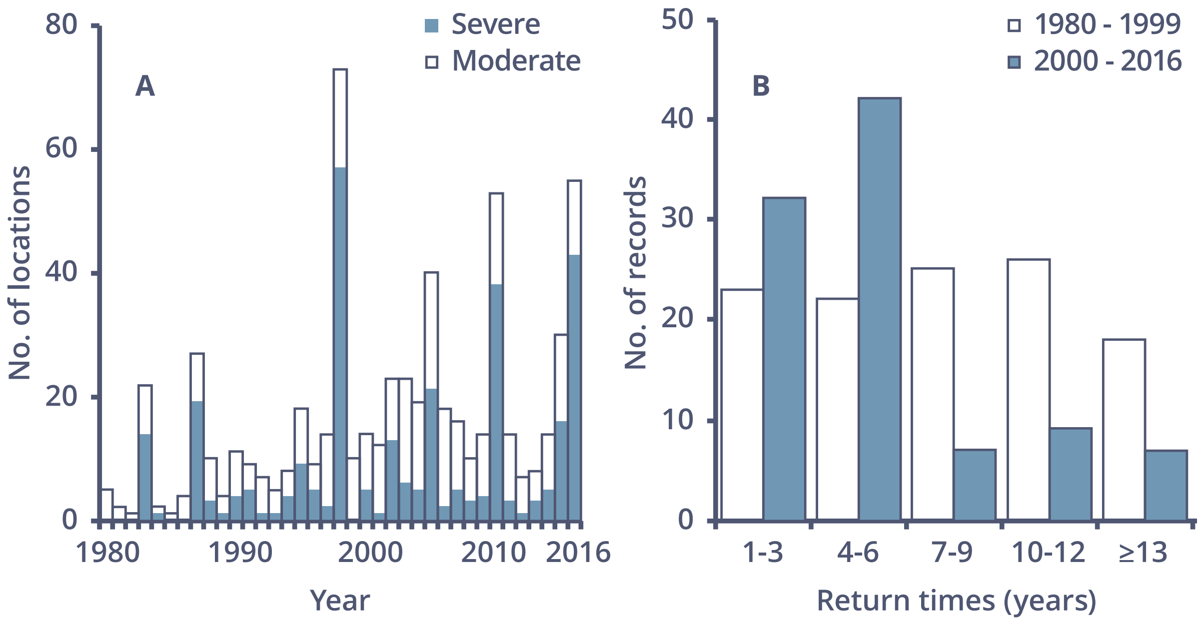


Figure 13. Temporal patterns of recurrent coral bleaching. (A) The number of 100 pantropical locations that have bleached in each year from 1980 to 2016. Blue bars indicate severe bleaching affecting >30% of corals, and white bars depict moderate bleaching of <30% of corals. An increase in severe events is recorded in the last decade. (B) Frequency distribution of return times (number of years) between successive severe bleaching events from 1980 to 1999 (white bars) and 2000 to 2016 (blue bars). Corals are now bleaching at the same location faster than they can recover and repair themselves (redrawn from: Hughes et al., 2018[9]).

this warming (CO_2 emissions) is urgently reduced, bleaching is likely to strike almost all the world's coral reefs every year by 2050. This will result in severe coral mortality, as is now occurring around the world, and destroy most of the world's coral reef ecosystems.

Because the worst bleaching is occurring in the tropics and the most rapid acidification is at high latitudes, there will be no refuge for corals from the impacts of rising atmospheric CO_2. While corals appear to have been able to adapt to past rates of ocean warming, there is no evidence that they can keep up with the present accelerating rise in ocean temperature.

Global stressors often act synergistically (e.g. acidification weakens reef structure increasing susceptibility to storm damage; thermal stress slows coral growth and kills corals), increasing the impact on reefs. Loss of coral reefs would affect the services provided by the ecosystem, including coastal protection, fish habitat and tourism. Costs from the loss of coral reef services are estimated to reach US$1 trillion each year by 2100. The greatest losses will likely fall on those people who rely upon reef services for day-to-day subsistence – typically the poorest coastal nations.

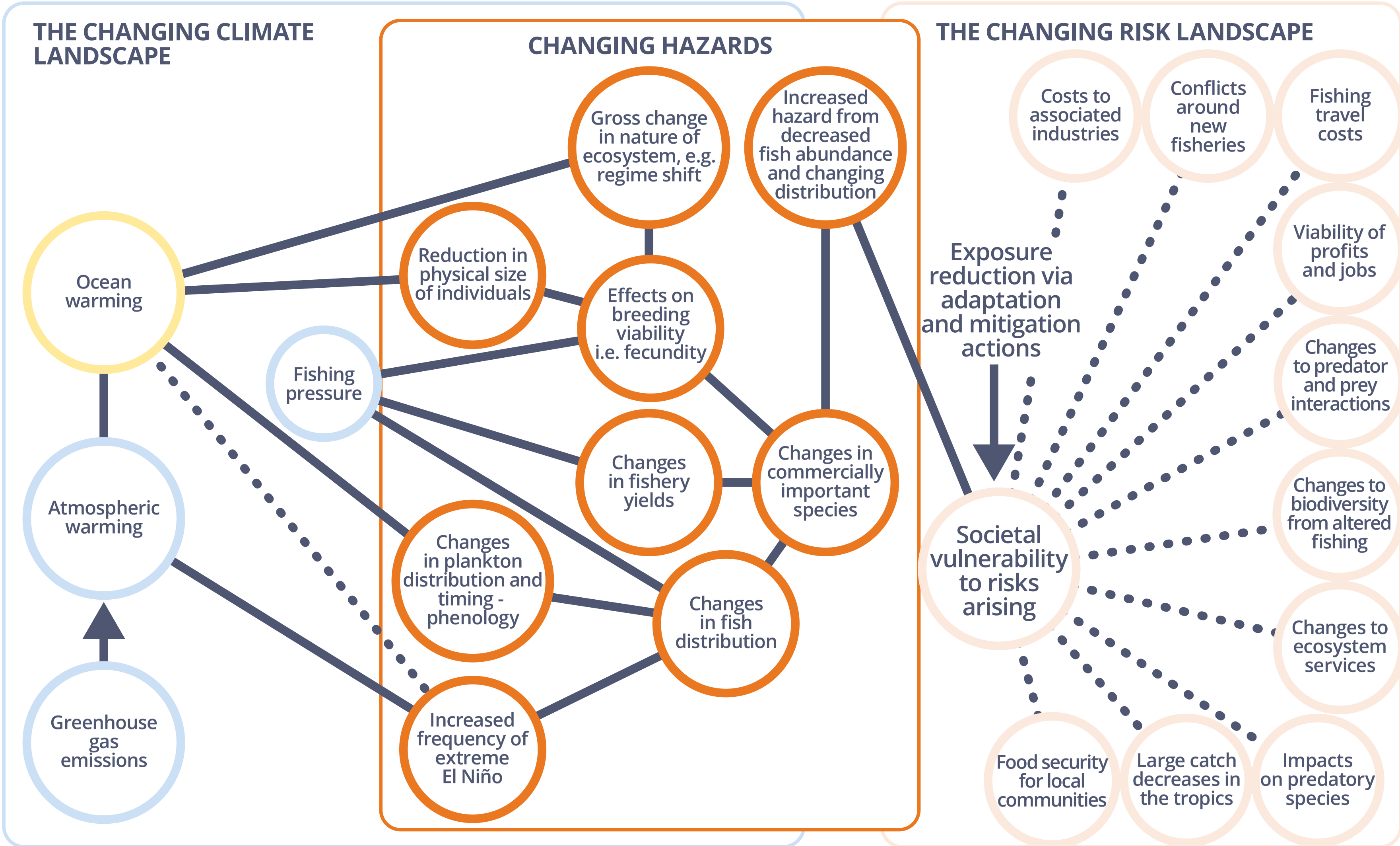
Food security via fisheries and aquaculture

Fisheries and aquaculture play a vital but often poorly acknowledged role in global food and nutrition security. The ~130 million tonnes of fish currently produced from marine and freshwater capture fisheries and aquaculture used directly for human consumption provide 4.3 billion people with about 15% of their average per capita intake of animal protein. Furthermore, about 10% of the world's population – predominantly from developing and emergent countries – rely heavily on fisheries and aquaculture for the income needed to buy food.

In recent decades, total production from capture fisheries has levelled off at about 90 million tonnes per year because most marine resources are now fully exploited, and in some cases over-exploited. Approximately 75% of capture fisheries production is used directly for food. Rapid development of aquaculture has met the remainder of the demand.

Efforts towards better management of capture fisheries and technical improvements in aquaculture in the future could be affected by ocean warming. Warming is expected to have significant impacts on the structure and function of ecosystems. For

The ripple effect - connections between ocean warming, fisheries, and risks and costs to society



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example, differential shifts in the distributions or abundances of species in response to higher SST are likely to change prevailing predator-prey relationships, whilst increases in SST at higher latitudes may enable some species to use a wider range of habitats. There will be winners and losers. Overall, however, the consequences of ocean warming are likely to pose additional risks to the initiatives underway to supply more than 200 million tonnes of fish for human consumption by 2050.

There is every reason to believe that ocean warming will reduce or redistribute the benefits of marine fisheries and aquaculture in those regions of the world with a high dependence on fisheries for food security and livelihoods. The *availability* of fish will vary because of changes in fish habitats, fish stocks and the distributions of species. The *stability* of supply will be altered by changes in seasonality, increased variance in ecosystem productivity and increased variability in catches. *Access* to fish will be affected by changes in opportunities to derive livelihoods from marine fisheries and aquaculture, *utilization* of fish will be affected because some communities will need to adjust to species not consumed traditionally, and increased prevalence of aquatic diseases and HABs are likely to render some fish production inedible more frequently.

The effects on food security are likely to be greatest in tropical and subtropical countries (Figure 14) where the largest reductions in fisheries production are generally expected to occur. However, as profound as the effects of ocean warming on productivity of marine fisheries are likely to be in many of these countries, population growth and the quality of resource management will probably have a much greater influence on availability of fish per capita for the next few decades. This implies that governments must identify effective ways of minimizing and filling the gap between the amount of fish readily available and the quantities of fish required for good nutrition of national populations.

Ocean warming can also be expected to affect plans for the expansion of aquaculture both directly and indirectly. The main direct impacts are likely to be caused by alterations in the suitability of areas for growing particular species, driven by higher SST. Fish aquaculture in temperate regions, where much of the present-day production occurs, is expected to be affected negatively by ocean warming. Salmon

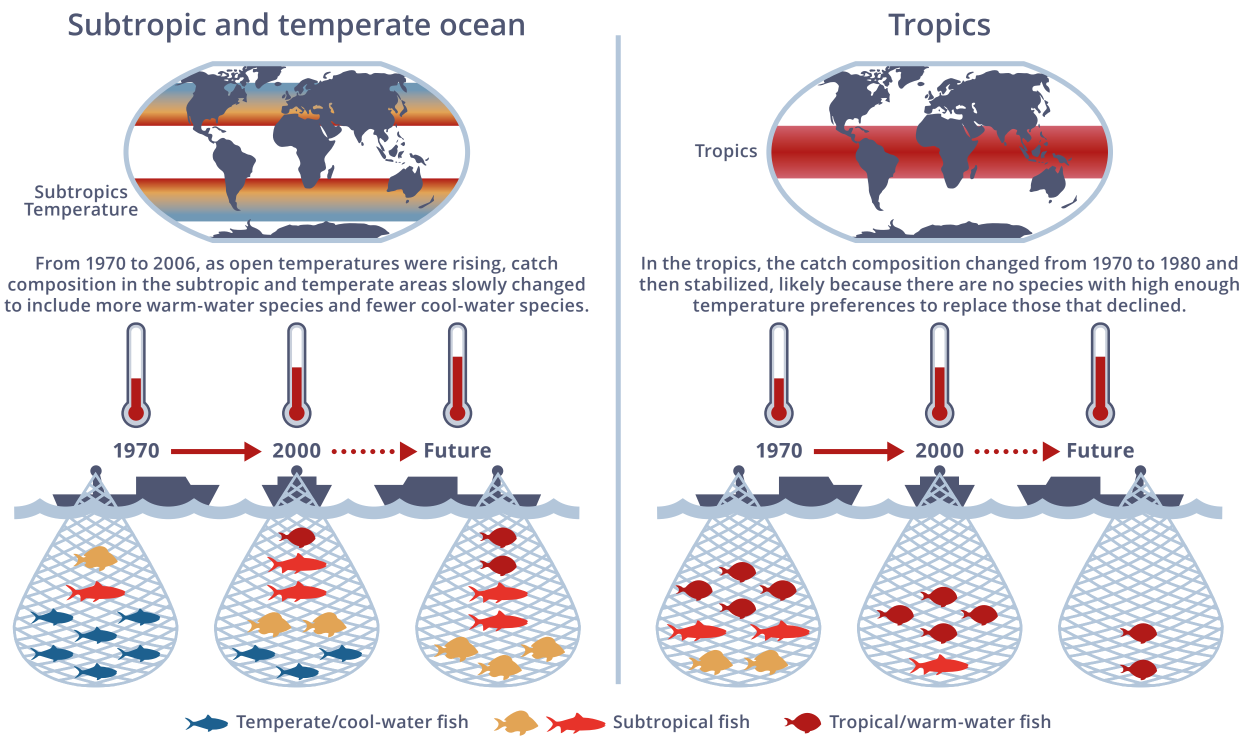

Figure 14. **Marine species are gradually moving away from the equator into cooler waters, and, as a result, species from warmer waters are replacing those traditionally caught in many fisheries world-wide. Scientific studies show that this change is related to increasing ocean temperatures. (Adapted from: Warming oceans are reshaping fisheries[10].)**

farming and the emerging culture of cod (*Gadus morhua*) need to operate within a relatively narrow range of temperatures for optimal performance. These temperatures are expected to be exceeded more often in the future.

Changes are also expected to occur in prime locations for farming tropical and sub-tropical marine finfish, such as groupers, snappers and cobia, as SST increases. Where temperatures begin to exceed the thermal optima for these species, aquaculture operations will need to move to higher latitudes. The effects of a warmer ocean, manifested through changes in current patterns, and in salinity, run-off of nutrients and dispersal of pollutants resulting from higher rainfall, are also likely to reduce the productivity of other aquaculture operations in tropical areas.

One of the main indirect effects of ocean warming on aquaculture is expected to be more frequent disease outbreaks arising from redistribution of existing pathogens and increased virulence of previously dormant pathogens. Another indirect threat to aquaculture from warmer, more nutrient-rich, coastal waters is an increase in the frequency of HABs. Possible shortages in the supply of fish used to make the fish meal and fish oil ingredients in aquaculture feeds is one potential indirect impact not expected to unduly disrupt the expansion of marine fish farming. Recent modelling suggests that technological developments should reduce the dependence of aquaculture on fish meal.

7. Ocean connections: the need for significant action on ocean risk

In 1956 the influential meteorologist Carl-Gustav Rossby, now considered by some as the 'father' of ocean warming, speculated that over the course of a few centuries vast amounts of heat might be buried in the oceans or emerge, perhaps greatly affecting the planet's climate. He warned that "Tampering can be dangerous. Nature can be vengeful. We should have a great deal of respect for the planet on which we live".

His theory has been borne out as the consequences of increasing human activities have indeed injected vast quantities of heat into the ocean, in so doing, shielding humanity on land, up to now, from the worst effects of climate change. This regulating function, however, happens at the cost of profound alterations to the ocean's physics and chemistry that lead especially to ocean warming and acidification, and consequently sea-level rise.

In light of this perspective it is somewhat surprising how late in the day ocean issues have been addressed in international climate policy. The Paris COP meeting of 2015 marked a turning point where the true role of the ocean was placed centre-stage. From a scientific perspective it is heartening to see the last round of IPCC studies expanded to give greater treatment to ocean impacts and including ocean warming[11]. At the international policy level parties to the Paris Agreement are now acknowledging the ocean, but a striking number do not. At the national level ocean issues are evident in risk assessments but as with science aspects the key risk they pose has yet to be truly acknowledged (Table 4).

Ocean warming connected	Topic	Status
D	Flooding and coastal change risks to communities, businesses and infrastructure	MORE ACTION NEEDED
D	Risks to health, well-being and productivity from high temperatures	MORE ACTION NEEDED
I	Risk of shortages in the public water supply, and for agriculture, energy generation and industry	MORE ACTION NEEDED
D	Risks to natural capital, including terrestrial, coastal, marine and freshwater ecosystems, soils and biodiversity	MORE ACTION NEEDED
I	Risks to domestic and international food production and trade	MORE ACTION NEEDED
D	New and emerging pests and diseases, and invasive non-native species, affecting people, plants and animals	RESEARCH PRIORITY

NOW → RISK MAGNITUDE → FUTURE

LOW | MEDIUM | HIGH

Table 4. **The direct (D) and indirect (I) relationship between ocean warming and the UK's assessment of the top six areas of inter-related climate change risks for the country (Adapted from: UK Climate Change Risk Assessment 2017 Synthesis Report[12]).**

It is hoped that the IPCC Special Report on the Oceans and Cryosphere[13] will take the bold step and acknowledge the key risk that ocean warming presents to humanity. There is, however, a long way to go on recognizing the severity of the challenges we face. Almost two thirds of FTSE 100 companies for example are not reporting on the risk of climate change in their annual reports[14], with only 48% FTSE 100 aligned to the United Nations' Sustainable Development Goals (SDGs) – a much lower proportion than the index's French and Spanish counterparts, for example.

The surge seen in CO_2 emissions in 2016[15] was 50% higher than the average for the past 10 years which risks making global temperature targets largely unattainable. According to the 2017 edition of the National Oceanic and Atmospheric Administration's (NOAA) report card[16] Arctic temperatures are increasing at a phenomenal rate – double the rate of global temperatures. Some have noted that this is so fast that climate change has 'outrun' a computer designed to measure it in Alaska[17]. In 2017 the lowest ever measurement for maximum winter sea ice area was recorded at both poles during the near four decades of observations[18].

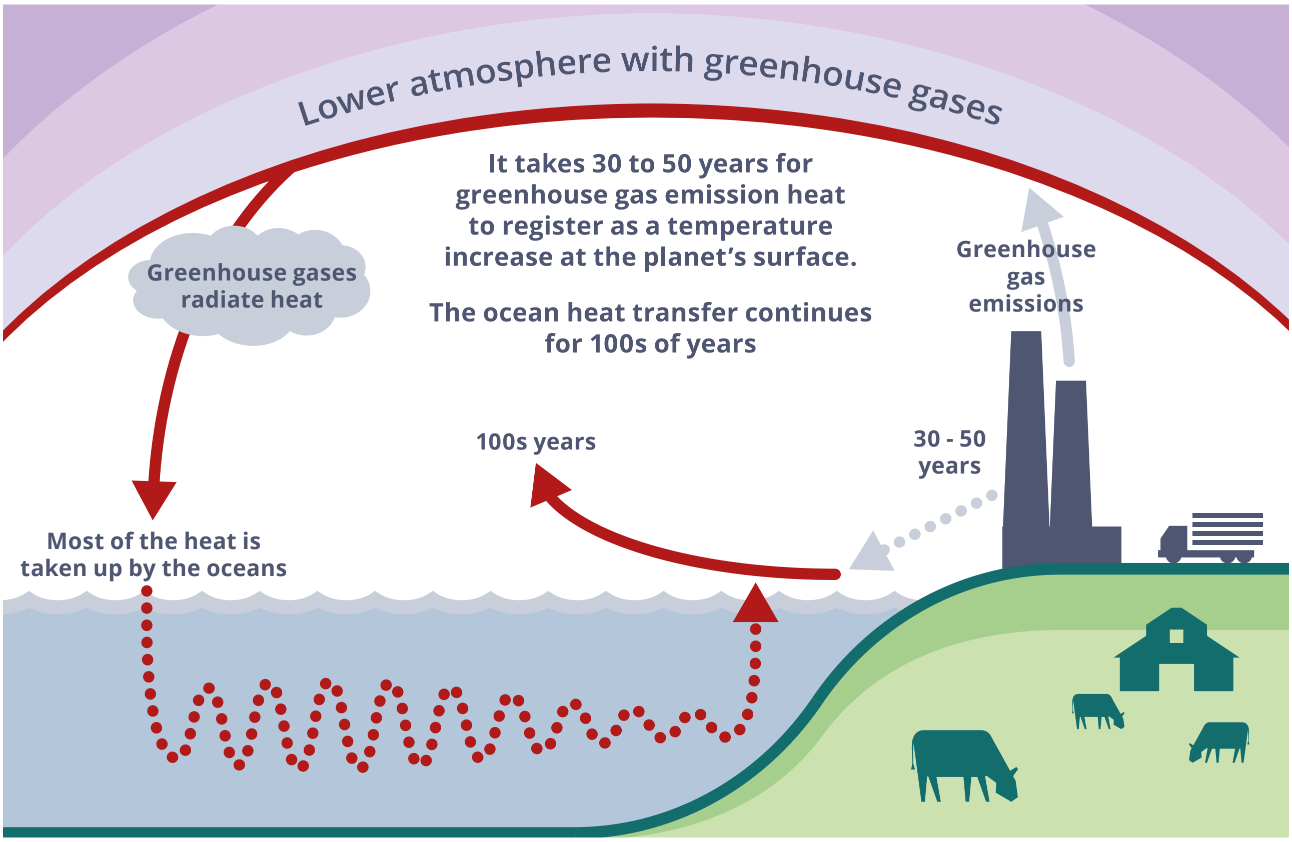

Figure 15. The time it takes due to climate system inertia (due to the ocean heat delay/lag) for an emission to result in a temperature increase registering at the Earth's surface.

It is key that sustained and increased attention is paid to the trends and issues affecting the ocean that in turn drive changes on land. There is an urgency to this given the central role the ocean plays in climate, weather and well-being issues. This is driven in part by the time it takes for any actions we may take on reducing CO_2 emissions to feed through the atmosphere/ocean system. Some estimate that there is a 30 – 50 years lag between changes in emissions and then coming through the climate ocean system (Figure 15). It is also driven in part by the realization that we are still not ahead of the rising CO_2 issue in the atmosphere.

The World Meteorological Organization noted in November 2017 that 2017 is 'very likely' to be in the top three warmest years in the absence of the El Niño phenomenon and that the long-term trend of warming driven by human activities continues unabated[19]. As for the ocean, one of the latest studies from the end of 2017 (Figure 16) shows that it is heating up faster than expected – regardless of how you measure, who does the measurements, when or where the measurements are taken, the ocean is warming. There is a growing urgency for greater ambition and action to stem these changes.

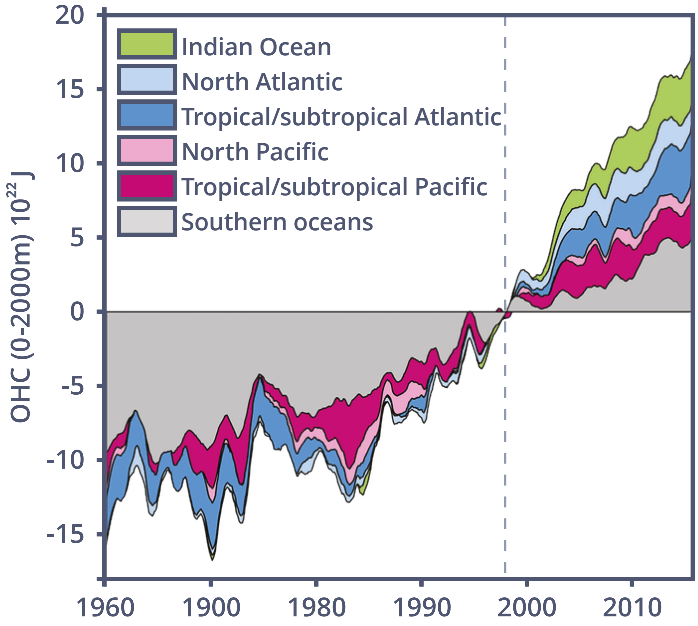

Figure 16. **Ocean heat content (OHC) changes from 1960 to 2015 for different ocean basins for 0 – 2,000 m depths. Time series is relative to the 1997-1999 base period and smoothed by a 12-month running filter. The curves are additive, and the ocean heat content changes in different ocean basins are shaded in different colours (From: Cheng et al., 2017[20]).**

Humanity is pumping climate-warming CO_2 into the atmosphere 10 times faster than at any point in the past 66 million years[21] resulting in the conditions for the next mass extinction event to occur. When we look back over geological timescales (Figure 17) we see the same symptoms of warming, acidification and anoxia linked the major extinction events.

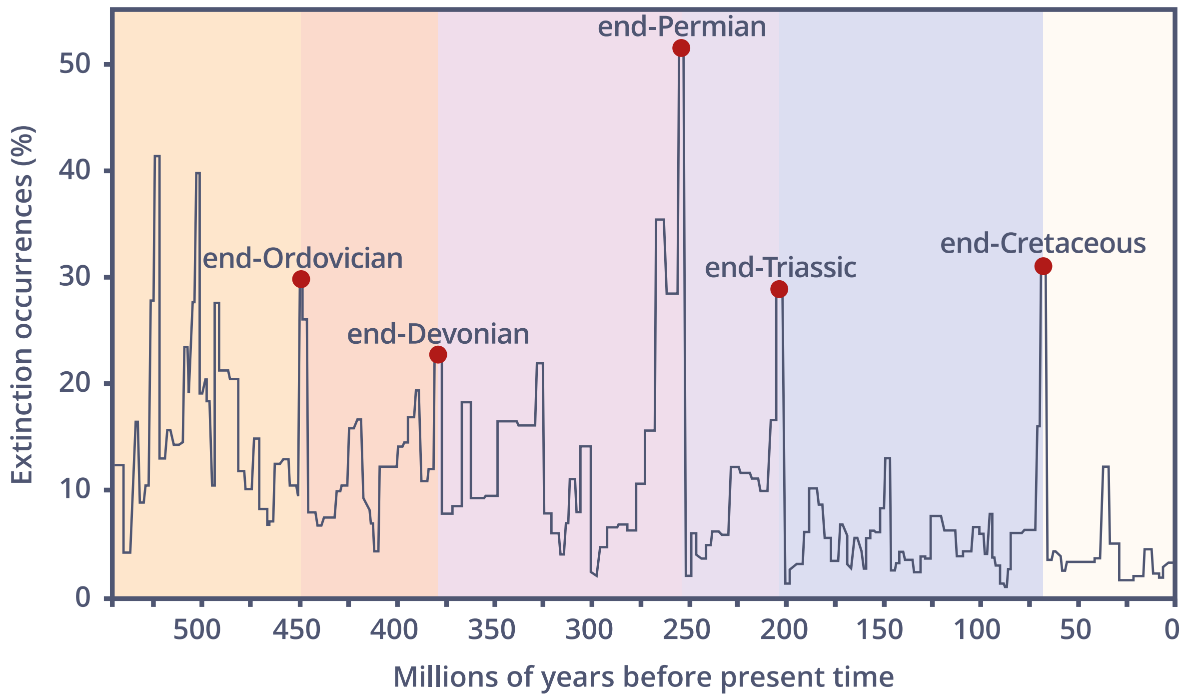

Figure 17. **Percentage extinction occurrences as reflected in the fossil record have fluctuated throughout Earth's history. Sudden and dramatic losses of biodiversity, called mass extinctions, have been linked to greenhouse gas driven hothouse and ocean events such as acidification, warming and deoxygenation. (Image source: Biodiversity Crisis[22])**

In the meantime, the costs of inaction build. There is no readily accessible comprehensive analysis of the costs of the impacts society is bearing because of ocean warming and change. The fragmentary information points to significant costs. The consequences of the 2017 hurricane season in the USA are being blamed for a loss of 33,000 jobs in the leisure and hospitality sector, compared to an expected rise in the same month of 90,000 jobs. Whilst this decline is not expected to be a long-term trend it does highlight the vulnerability of sectors to such impacts. More broadly weather-related costs continue to rise – in 2017 in the USA alone there were nine weather and climate disasters accounting for some US$16.4bn in damages.

Alongside the high economic impacts from recent extreme storm events, other single event economic losses related to ocean warming impacts already run from the tens to hundreds of millions of dollars[23]. Major outbreaks of Paralytic Shellfish Poisoning in 2012 and 2015 along 200km of coastline of Tasmania triggered a global product recall and loss to the local economy of AU$ 23million. A single coral bleaching event in South-east Asia suggested an economic loss of services to dive tourists in the order of US$49-74 million for the six-month period during and following bleaching, whilst more recently the 2016 unusually strong El Niño pattern triggered the largest ever reported algal blooms and aquaculture fish kills in Chile causing losses of US$ 800million. If all the costs were added up the resulting annual losses total would be truly gigantic – and all indicators point to it rising further in the future as continued progressive change occurs to the ocean and atmosphere.

Perhaps as worrying are the consequences ocean warming and particularly rising sea levels (Figure 18) and increased storminess may bring to the global populations and the world's poorest communities.

The hazard of rising sea levels

- Anthropogenically-forced ocean thermal expansion and ice sheet melting, along with a much smaller contribution from changes in land-water storage, have led to a global mean sea-level rise of 3.3 ± 0.4 mm yr^{-1} over the last two decades, most likely the fastest in at least 2800 years.
- Projections indicate that under a moderate climate change scenario a further global mean rise of 0.54 ± 0.19 m could occur by the end of the century, although significant regional variability will exist.
- Many risks will accompany sea-level rise, including increased flooding of coastal land (causing saline incursion to freshwater systems and groundwater, thus reducing potable water for drinking and irrigation), a growth in coastal erosion rates, a decline in mangroves and saltmarshes, and die-off of coral reefs and deeper-water seagrass beds.
- Coasts will bear the brunt of the effects of changes in sea level. While there is much evidence that coastal ecosystems can cope with rapid changes in sea level, particularly through recent glacial cycles, the pace of sea-level rise anticipated for the next 100 years may exceed the resilience of coastal habitats to track the changing coastlines.
- A longer-term consequence of rapidly rising sea level may be the total loss of some habitats, such as the drowning of coral reefs and light-attenuation loss of seagrass beds, a phenomenon last seen during rapid post glacial sea-level rise due to collapsing ice sheets and meltwater release.

Figure 18. The hazard of rising sea levels and the risks this holds for society, ecosystems and species (Laffoley and Baxter, 2016[24]).

By the year 2100 it has been estimated that 2 billion people – about one-fifth of the world's population – could become refugees (Asia Development Bank[25]). Many coastal communities will be displaced by sea-level rise (Figure 19) causing resettlement bottlenecks as they seek and have to wait for decisions on more habitable land elsewhere being allocated. At the same time the swelling global population (estimated to top 11 billion by then) will require even more arable land whilst it is being lost through inundation from rising sea levels. The Pope[26] amongst others has led calls for changes in people's lifestyle and the use of resources, noting what was needed is better management of the planet's abundant resources and prevention of waste.

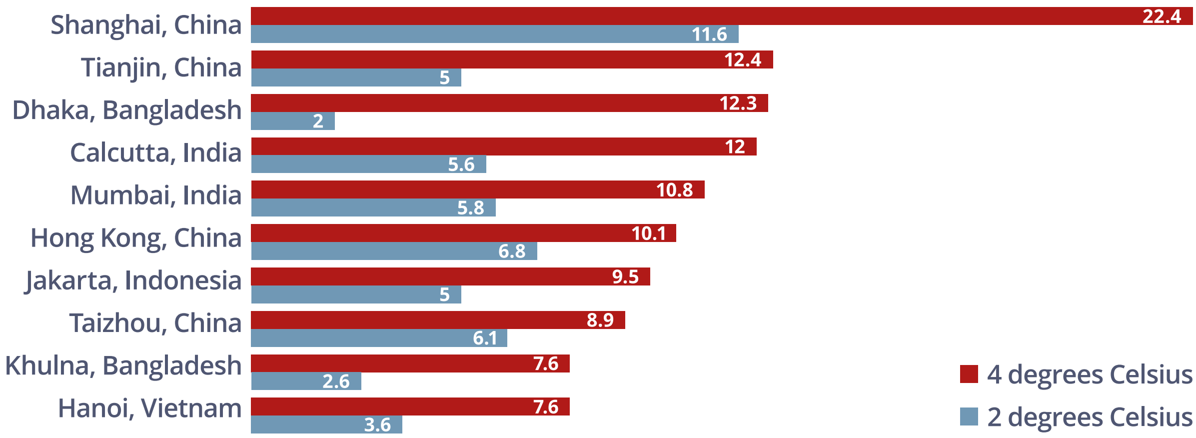

Figure 19. Population at risk in cities lying below the locked-in sea level rise, based on two differing warming levels (Image: Climate Central[27]).

In the Asia-Pacific region large temperature increases are likely because of a continued reliance on fossil fuels. Whilst rising sea levels are a key part of the impact, the expected rise in temperature would be so severe that it would make it almost impossible for people to live outside, prompting migration on a massive scale (Figure 20).

In Europe researchers found "a highly statistically significant relationship" between the number of asylum applications logged by the EU and average temperatures in the maize growing regions of countries like Pakistan[29]. Researchers found that when temperatures deviated from the moderate optimum of 20°C that is best for agriculture in food growing areas of 103 countries, more

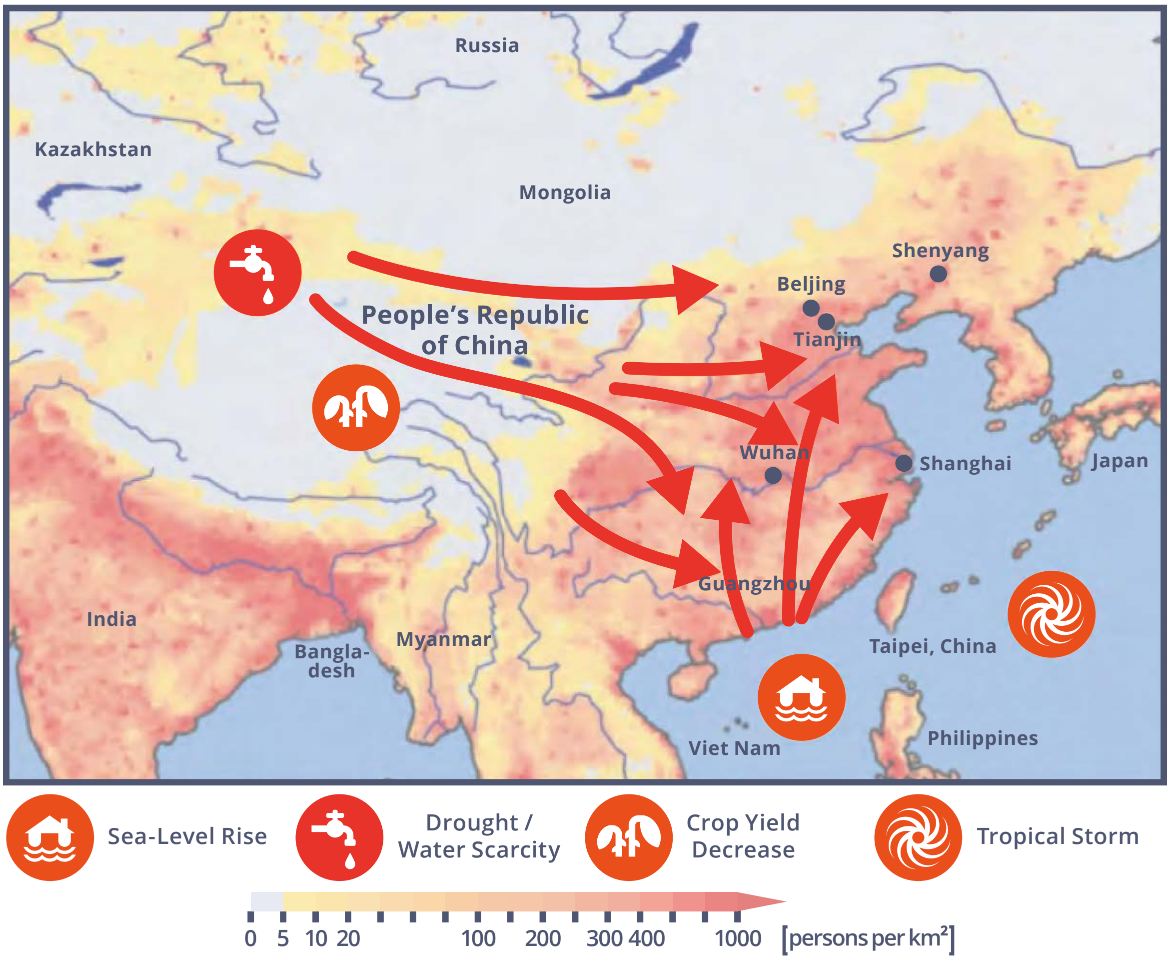

Figure 20. Climate impacts and possible migration routes in China 2100 (Image: ADB[28]).

people sought refuge abroad. Looking ahead to the rest of this century, it is predicted that if temperature rises linked to climate change are limited to 1.8°C above pre-industrial levels, then applications for asylum would increase by 28%. However, if CO_2 emissions continue at their present rate and temperatures rise by up to 4.8°C, then applications could rise by 188%, meaning an extra 660,000 people seeking refuge each year in the EU.

Finally, one of the indirect impacts causing increasing concern is changes to rainfall and heat patterns influenced by ocean events such as El Niño. Sustained drought leads to forest fires and landslides displacing or killing people and destroying property, whilst some coastal cities such as Cape Town being at much greater risk of running out of drinking water. Increased heat also brings other problems including loss of life, failures in electricity grids (due to air conditioner demand), and damage to crops. It is suggested that the recent upward trend in maximum summer temperatures for cities like Sydney, which has experienced temperatures as high as 47°C, may become the new norm[30].

The need to acknowledge the ocean hazards from ocean warming and the scale and intensity of the ocean risks that arise has never been stronger or more urgent. As demonstrated in the examples above the way ocean warming interacts with terrestrial and weather systems, and the synergistic impacts that result, point to the fact that immediate action now needs to be taken to understand, to act and to reduce the underlying drivers of change. At the same time planning and preparing for even greater impacts in the future needs to be put in place as a matter of urgency, devising innovative and effective solutions in the meantime to offset the worst consequences if possible.

8. Conclusions

Several issues emerge from this report that should form some of the next steps to help address ocean risk from ocean warming:

Financial impacts

The true financial costs of ocean warming impacts such as from extreme storm events, coral bleaching and HABs is unclear. Moving forward, it will be important to gather more consistent and in-depth facts on the true scale of what is happening, including the knock-on effects on small to medium size enterprises that are often the life-blood of the economy.

Ocean risk scenario planning

There is a need to think through what is actually happening on ocean risk, and what may still happen if we either continue business as usual or reduce emissions of CO_2 in line with the Paris Agreement. In the latter case, due to lag effects, change will still happen, and the risks will still be there for decades. Plotting these two scenarios would be very helpful to future planning and communication activities.

Ocean risk action at local levels

Mobilizing known solutions and accelerating their application will be critical steps to help build and rebuild ocean resilience. This in turn can both insure against risk and help communities better cope with risk (e.g. rebuilding natural coastal defences). Looking at how such solutions can be better mobilized at the local coastal scale through practical projects would be helpful – removing barriers to implementation and speeding up application.

Policy integration and action

It would be helpful for new work to look at how ocean risk intersects with the SDGs and other global and regional commitments. This is both from the view of better recognition of the problems but also as routes through which awareness and solution-orientated action can be achieved.

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