Acting on ocean risk

Documenting economic, social and environmental impacts on coastal communities

Principal contributors:
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Jennifer Ross-Jones, Romain Savary and Francis Vorhies

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Executive summary

The rapid and deep changes that are being caused to the biosphere due to climate disruption and biodiversity loss undermine the future wealth, health, and prosperity of the human population. As these changes take hold and negative effects accelerate, it will be important to keep track of the full impact of such issues in order take the necessary mitigation and adaptation actions that are needed to keep our activities in proper balance with the natural world. A central aspect of this is fully understanding the changes and impact our actions are having on the ocean, which provides most of the living space for species on the planet and has a central role in regulating global temperature and climate.

In 2018 IUCN, in partnership with AXA XL, produced a landmark report on ocean risk. Not only did this report define, for the first time, what ocean risk is in terminology that resonates with the global insurance industry, but it also tracked major changes already happening in the ocean and how their effects ripple out into society. The 2018 report also postulated that the full impact of ocean risk was not only increasingly financially significant at global, regional, and national levels but remained under-assessed. It was projected that this would become an increasing challenge in the coming years both in terms of tracking impacts but also making a strong and compelling case for accelerating action to halt deterioration of the natural world.

This report is a follow on and update from the 2018 report and explores whether there is a case to answer for better analysis and understanding of ocean risk, leading to a more accurate assessment of costs and impacts. The report updates information around the five original focal areas: extreme weather events, coral bleaching, harmful algal blooms, food security via fisheries and aquaculture, and human health and disease. It also analyses this from the national perspective using the case examples from three Western Indian Ocean countries: Kenya, Mozambique, and Tanzania.

These case studies show that sea-level rise is an increasing threat on some densely populated areas and extreme weather events are likely to increase with ever greater unpredictable consequences. Mass coral bleaching events are occurring with increasing regularity and are potentially of major concern. The full extent of the impact of climate change on artisanal fisheries is as yet unquantified. Harmful algal blooms are having an increasing impact on human health especially those working in the marine environment.

The work concludes, from the global and regional observations in this report, that ocean risk is material. For many hazards, impacts are both already significant and increasing. It recommends that more in-depth assessment is urgently needed to inform policy makers, investors, insurers, and communities about the substantive and rising costs of these impacts on developing countries, and the extent to which ocean risks impact economic and subsistence activities.

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1. Introduction

The ocean has always presented humanity with a mix of substantive opportunities and serious threats. From bountiful fisheries to devastating storms, the ocean has impacted human societies and settlements for centuries. What is different today, however, is the scale of these impacts and the increasing risk of negative impacts.

Globalisation, as evidenced in the increasing scale and scope of global trade and the extraction of resources – including fish and other marine resources – is increasing our demand for ocean goods and services. Our ever-expanding technical and financial capacity is enabling us to harvest the ocean at unsustainable levels. At the same time, environmental pressures on the ocean – climate change, plastic waste, land-based pollution – are also increasing, resulting in disruptive ocean events as never seen before.

This report highlights what is known about the economic value, cost and losses associated with five major global issues: extreme weather events, coral bleaching, harmful algal blooms, food security via fisheries and aquaculture, and human health and disease.

The aim of this report is straightforward – to make the case for better assessment and management of ocean risk. This is achieved by first observing what is known about ocean risk regarding several key issues and by looking at three Western Indian Ocean countries. This is followed by a discussion of what is not known and should be known in order to better assess and manage ocean risk. The report ends with a call to develop a more strategic approach to ocean risk assessment and management at the national level.

In particular, the report hopes to stimulate discussions around the following questions:

- What are the major economic sectors at risk in the country/region?
- Who would need to be involved in national or regional-level talks? Government officials? Private sector representatives? Universities? NGOs?
- How much capacity is there already for monitoring changes in ocean-related economic trends?
- Can ocean risk management be integrated into countries national strategies and approaches to natural disaster risk reduction?

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2. Background

2.1 An expert meeting in 2017

An expert workshop exploring ocean risk took place at in 2017 at Oxford University in the UK (Laffoley et al, 2017). The experts discussed the nexus between hazards, exposure, and risks and agreed on the following relationship:

$$\frac{\text{Hazard x Exposure}}{\text{Vulnerability}} = \text{Degree of ocean risk}$$

They then proceeded to draw up an initial list of potential ocean hazards, which included the following:

Changes in ocean physics and chemistry
Methane
Acidification
Changes in ocean chemistry
Rising temperature and stratification
Ocean currents and winds
Hypoxia
Nutrient changes

The workshop explored the risks of ocean hazards and the potential impacts of these risks on coastal communities. They concluded with the recommendation that:

The true financial costs of ocean risk impacts - such as extreme storm events, coral bleaching and harmful algal blooms - is unclear, either in terms of total number of events or in terms of the total scale of impacts. This means that the impacts are not fully assessed because events are seldom isolated and they are rarely without multiplier effects. 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-sized enterprises that are often the life-blood of the economy.

This report responds to this recommendation by highlighting what is known and what yet needs to be known about ocean risks.

Human use/ocean interaction	
Pollution	Resource competition
Extraction	Military use
Ocean use change	Seismic testing
Societal disconnection	Aquaculture
Geoengineering	Bioprospecting
Change in ocean use	Pipelines and cables
Shipping	Renewable energy generation
Harmful ecosystem change	Tourism
	Recreation

2.2 An ocean connections report in 2018

The IUCN "*Ocean connections: An introduction to rising risks from a warming, changing ocean*" report (Laffoley and Baxter, 2018) report identified the societal ripple effects of climate change in innovative bubble diagrams. It set out to "explore the hazards and risks associated with ocean warming from a variety of angles, and by using innovative graphics, look at how these 'simple' temperature-related changes to the ocean can ripple out into many aspects of society."

These ripple effects are used in this report as the investigative framework for further research to identify what is known, and what is not known, about the economic risks of climate change. The ripple effect of ocean risks was investigated for 5 key areas:

- extreme weather events;
- human health and diseases;
- harmful algal blooms;
- coral bleaching; and
- food security via fisheries and aquaculture.

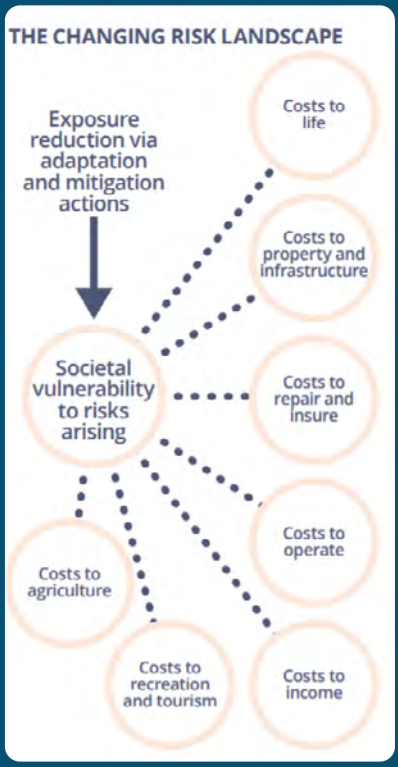
These ripple effects were set out in bubble diagrams. The right-hand sections of these diagrams – reproduced here – provided the investigative framework for further research on finding out what we know and what we should know about the changing risk landscape.

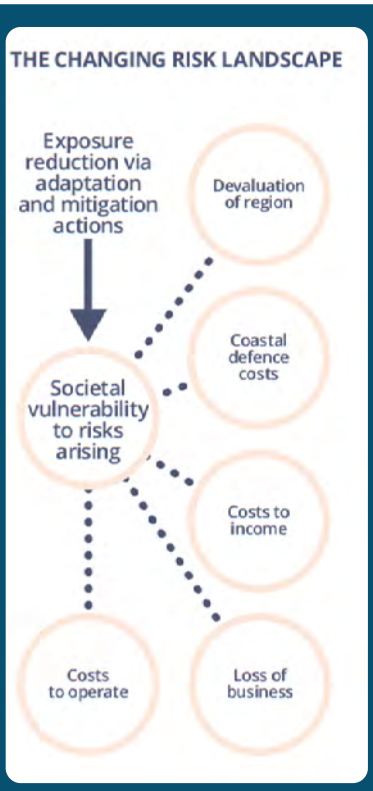
Extreme weather events

The societal vulnerability to risks arising from extreme weather events include the following costs:

- Costs to life
- Costs to property and infrastructure
- Costs to repair and insure
- Costs to operate
- Costs to income
- Costs to recreation and tourism
- Costs to agriculture

What do we know and what do we need to know about these costs?





Coral bleaching

The societal vulnerability to risks arising from coral bleaching events include the following costs:

- Devaluation of the region
- Coastal defence costs
- Costs to income
- Loss of business
- Costs to operate

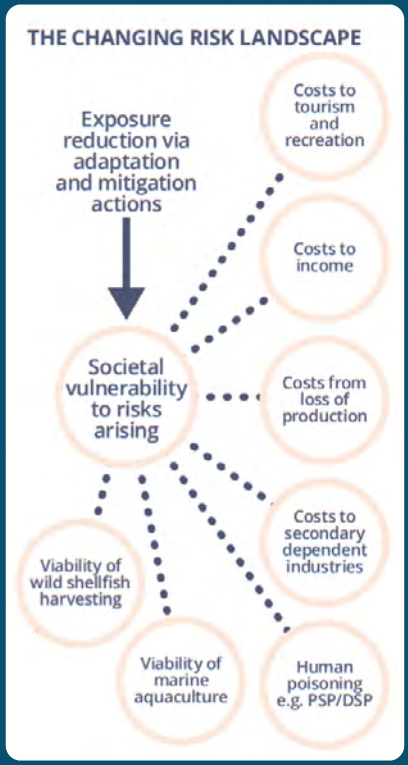
What do we know about these costs and losses and what do we need to know?

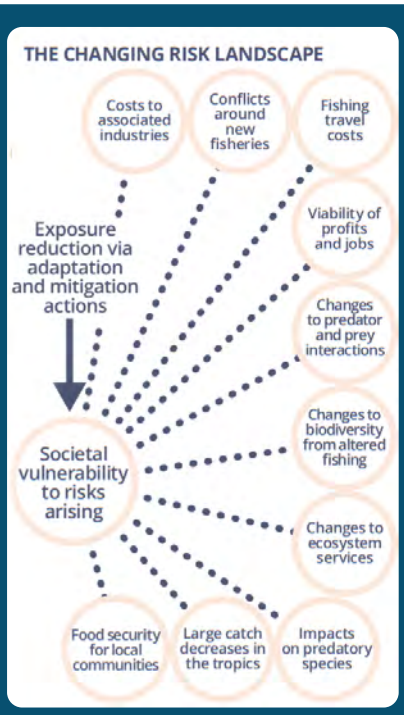
Harmful algal blooms

The societal vulnerability to risks arising from harmful algal bloom events include the following costs:

- Costs to tourism and recreation
- Costs to income
- Costs from loss of production
- Costs to secondary dependent industries
- Human poisoning, e.g. PSP/DSP
- Viability of marine aquaculture
- Viability of wild shellfish harvesting

What do we know about these costs and impacts and what do we need to know?





Food security via fisheries and aquaculture

The societal vulnerability to risks include the following costs:

- Costs to associated industries
- Conflicts around new fisheries
- Fishing travel costs
- Viability of profits and jobs
- Changes to predator/ prey interactions
- Biodiversity changes from altered fishing
- Changes to ecosystem services
- Impacts on predatory species
- Large catch decreases in the tropics
- Food security for local communities

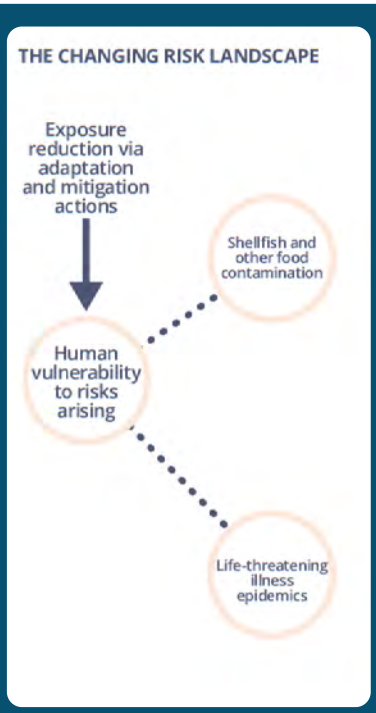
What do we know about these costs and changes and what do we need to know?

Human health and diseases

The societal vulnerability to risks arising from human health and diseases include the following costs:

- Shellfish and other food contamination
- Life-threatening illness epidemics

What do we know about contamination and illnesses - and what do we need to know?



2.3 Review of what is known

In preparation for this report, the IUCN Global Marine and Polar Programme undertook an extensive desk-based review of the available evidence of current ocean climate economic impacts. For instance, traditional sectors such as fisheries are seeing ever-increasing demands on already-declining stocks. These pressures come not only from climate impacts, but also from

overfishing and from more recent and growing sectors such as tourism and aquaculture, which are vital sources of revenue for many of the poorest communities in developing countries and regions.

Considering these challenges, it is somewhat surprising that no comprehensive figures exist on the scale and nature of economic impacts already being felt by affected local communities and others throughout the world. The research undertaken by IUCN confirms that we know a good deal about what is happening, but we still do not have a comprehensive understanding of the cumulative impacts, particularly in terms of costs. Not knowing these figures is hampering the assessments of the scale, nature, and urgency of the actual investments needed to counter these problems.

The research also highlights that several distinct areas of work related to development, disaster risk reduction, climate change and particular economic sectors each have their own distinct approaches to some aspects of ocean risk, although none comprehensively incorporate all ocean risks.

2.3.1 Disaster risk reduction and ocean risk

Globally, annual economic losses to all types of disasters due to natural hazards has increased from US$ 14 billion in 1985 to US$ 140 billion in 2014 (UNDRR, 2019). Partial information on the scale and nature of economic impacts from disasters are available from resources provided by - and supporting - global efforts on disaster risk reduction, including: the knowledge platform on disaster risk reduction[1], the disaster loss data for the Sustainable Development Goals and Sendai Framework Monitoring System[2], and the International Disasters Database (EM-DAT)[3]. Unfortunately, even with these global databases, economic data are not provided for over 60% of disaster reports in EM-DAT (CRED, 2018).

Economic data and information are most available regarding geophysical hazards (earthquakes, volcanoes, and mass movement), hydrological hazards (floods and landslides), meteorological hazards (storms and extreme temperatures) and climatological hazards (droughts and wildfires) (CRED, 2018). Biological hazards including disease, pests/infestations, biotoxins and harmful algal blooms are less commonly reported to these global platforms. In addition, many platforms are inconsistent in what and how they report, with large gaps for developing countries on economic costs and little information on many ocean risks such as coral bleaching, harmful algal blooms and human health and diseases. Impacts of disasters on economic sectors such as fisheries or tourism are rarely reported using a standardised approach or incorporated consistently into global databases.

2.3.2 Climate change and ocean risk

The IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) highlights the range of hazards and risks that have been, and will continue to be, exacerbated by climate change (IPCC, 2019). The physical changes to the ocean (temperature, oxygen, acidity and sea level) will affect all ocean and coastal ecosystems with knock-on effects on human systems and ecosystem services (fisheries, tourism, transportation/shipping, cultural services, and carbon sequestration) (IPCC, 2019). Climate change has increased the severity and extent of hazards, while population growth, coastal and ocean-based economic activities and socio-economic development have increased the exposure of people and their assets to these hazards.

Whilst adaptation actions are being taken, it seems highly likely that they will not be achieved at the speed or scale commensurate with the ocean risks now being faced, with the poorest communities likely to be the most affected.

1 https://www.preventionweb.net/knowledgebase/disaster-statistics
2 https://www.desinventar.net/
3 https://www.emdat.be/

Source: Shutterstock / yusuf madi

3. Evidence of impacts globally

3.1 Extreme weather events

Examples of extreme weather include heat waves, cold waves, extreme precipitation, and drought. To be classified as an extreme weather event, certain criteria, based on the physical, temporal, and spatial extent of the weather must be met.

Definition aside, both the frequency and magnitude of extreme weather events are growing at an alarming rate. The IPCC states with statistical confidence there has been: an increase in global average daily temperature; an overall increase in the length or number of heat waves in many regions; an increase in drought duration in southern Europe and West Africa; and a reduction in drought duration and/or frequency across central North America and north-west Australia (Field et al., 2012). The UN Office for Disaster Risk Reduction (UNDRR) reported that there were 6,602 weather-related disasters between 1998 and 2017 (Wallemacq and House, 2018).

Economic costs represent a growing problem. The World Meteorological Organisation (WMO) covered an almost 40 year range, from 1970 to 2012, and reported economic losses of US$ 2.4 trillion (Golnaraghi et al., 2014). These figures seem to be validated by other studies, which report losses of US$ 1.4 trillion, between 1980 and 2004 (Mills, 2005) and US$ 1.5 trillion between 2003 and 2013 (Baas et al., 2015).

The UNDRR estimated that economic losses were US$ 2.24 trillion from 1998 to 2017; US$ 932 billion more than those reported for the prior 20-year period (i.e. from 1978 to 1997) (Wallemacq and House, 2018).

Considered together, the reports show an overall increase in economic costs associated with extreme weather events, despite the systematic underreporting of the losses in developing countries. Surprisingly, while high-income countries reported losses from 53% of disasters between 1998 and 2017, low-income countries only reported them from 13%. No data are thus available on the losses incurred by 87% of the disasters in low income countries (Wallemacq and House, 2018).

Costs to operate

Global growth could be hindered by rising operational costs as the frequency and magnitude of extreme weather events increase. In the worst-case, this could reduce annual GDP growth by up to 1% (Wade and Jennings, 2015). The transportation departments (Venner and Zamurs, 2012) and power industries (Campbell and Lowry, 2012) are expected to be the most heavily impacted by rising maintenance costs, although very few data exist on these topics.

Costs to life

A key risk area from the potential increase in the intensity and frequency of extreme weather events is the costs to life, not only in terms of lives lost, but also people who suffer from health problems (physical injuries and psychological trauma) or displacement from their homes from an extreme weather event. The saddest and most troubling cost remains the number of fatalities caused by extreme weather events, which stands at 967,616 for the period ranging from 1900 to 2015 (Bouwer and Jonkman, 2018) and 552,766 in the period ranging from 1998 to 2017 (Wallemacq and House, 2018). In 2018 alone, extreme weather events claimed more than 13,500 victims (Swiss Re, 2018).

Costs to property and infrastructure

Extreme weather events are thought to inflict US$ 18 billion worth of damage a year to power and transport infrastructure in low- and middle-income countries. Natural disasters also cause significant disruptions to infrastructure that are thought to be worth between US$ 391 billion and US$ 647 billion a year to households and private firms. Water infrastructure systems such as reservoirs, groundwater pumps, and transmission lines are extremely vulnerable to natural disasters. However, no information currently exists on the economic cost absorbed by these sectors (Hallegatte et al., 2019).

Costs to repair and insure

In terms of annual losses, estimates since 1980 have ranged from a few billion US dollars to more than 300 billion, and still, these estimates do not include indirect and intangible losses (Handmer et al., 2012; Hoeppe, 2016). Annual material damage from extreme weather events increased 8-fold between the 1960s and the 1990s, and insured damage increased 17-fold (Mechler and Kundzewicz, 2010). More recent losses have been among the highest on record. The losses associated with extreme weather topped US$ 330 billion in 2017, of which US$ 135 billion was insured (Munich Re, 2017). While in 2018, losses amounted to US$ 165 billion, with US$ 85 billion insured. These two pay-outs represent the first and fourth largest annual pay-outs of all time. (For comparison, the previous 10-year annual average was US$ 71 billion).

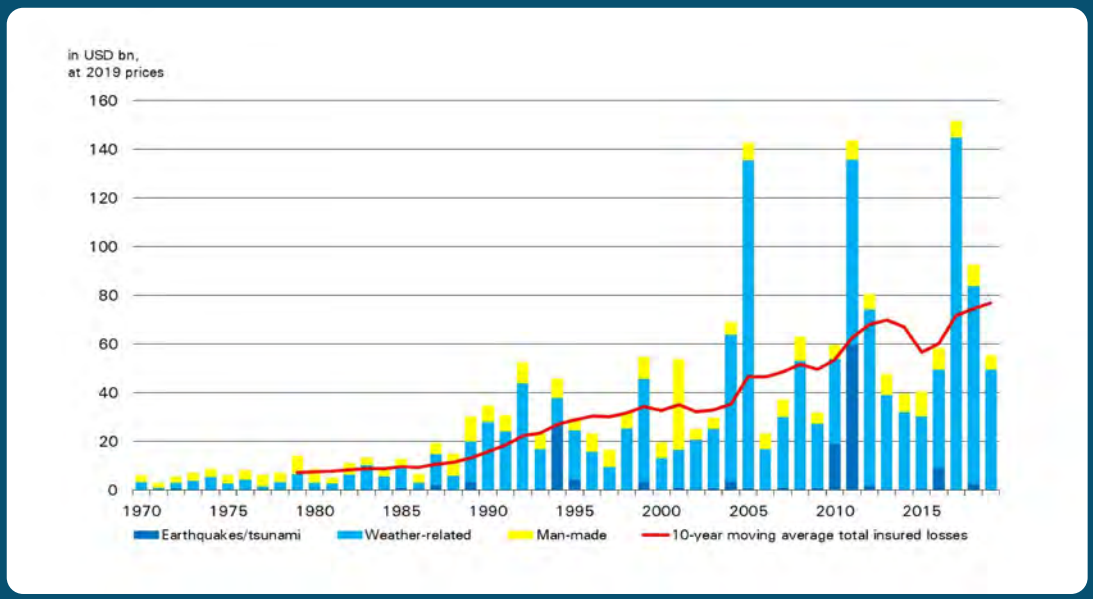


Figure 1. The increase in insured catastrophe losses between 1970 and 2018.
Source: SwissRe

Costs to income

Predicting the impact of extreme weather events on household income depends on five main criteria. Is the household a net producer or a net consumer of food? How varied/diverse are the household's current and potential income sources? What type of assets are owned by the household? Is the household able to adapt to income disruptions by reducing or smoothing their consumption? Does the household have access to credit or social safety programmes?

Even if one can calculate all of these factors, predicting the effect that extreme weather will have on household income is extremely difficult, because a socioeconomic response in society is almost always initiated. In general, though, extreme weather events tend to affect the poor more than the rich. It is much easier to calculate the costs of extreme weather events on corporate income. In the financial year of 2017, for example, 500 companies publicly stated that extreme weather events reduced their revenue (S&P Global Ratings, 2018), yet only 18 companies quantified the effect. The average reduction amounted to 6% (S&P Global Ratings, 2018).

Costs to recreation and tourism

Recreation is conducted in proximity to the home, whereas tourism involves an overnight stay. Recreational activities are not expected to be heavily impacted by extreme weather events; people will simply switch activities or seasons in which they practise their hobby. Tourism on the other hand, will be much more heavily impacted by extreme weather events. The tourism industry is one of the world's largest, accounting for 9% of global GDP and generating more than US$ 6 trillion in revenue each year (Handmer et al., 2012). The majority of assessments to date have been carried out in the Caribbean region because of its disproportionate reliance on tourism for GDP (Layne, 2017). A 2016 report from CISL reported that the costs of rebuilding tourist resorts as a result of sea level rises of 1m would be between US$ 10 billion and US$ 23.3 billion. The cost of extreme weather events for Barbados alone, were estimated to range from US$ 5.127 billion (129% of GDP) to US$ 7.648 billion (193% of GDP) (ECLAC, 2011).

3.2 Coral bleaching

Coral reefs provide a range of ecosystem services including coastal protection, recreation, and tourism. They also act as nursery grounds, supporting artisanal and commercial fisheries and they are a hotspot for novel drug discovery. Estimating the global value of coral reefs is complicated because many of the values of the services they provide overlap. Nonetheless, estimates do exist. In 1997, the annual value of coral reefs was calculated as being US$ 375 billion (Costanza et al., 1997). In 2012, this value was expressed relative to the spatial extent (in hectares per year). The average value was US$ 352,915 $ha^{-1}yr^{-1}$ although values ranged from 36,794 $ha^{-1}yr^{-1}$ to 2,129,122 $ha^{-1}yr^{-1}$ (De Groot et al., 2012). In 2014, the global service estimate was revised to between US$ 9.9 trillion and US$ 21.7 trillion (Costanza et al., 2014). Valuations of coral reefs have also been conducted at the national level. The services provided by the Great Barrier Reef, Australia for example, have been valued at between AUS$ 15 billion and AUS$ 20 billion per year (Stoeckl et al., 2014), while Hawaii's reefs contribute an estimated US$ 360 million to the economy each year (Cesar et al., 2003).

Coral bleaching (the characteristic whitening of coral resulting from the loss of its symbiotic algae) is threatening the very survival of coral reefs and the ecosystem services they provide.

The first global mass bleaching events were reported in 1998 (Aronson et al., 2002; Baird and Marshall, 1998). The second occurred in 2010 (Alemu and Clement, 2014; Krishnan et al., 2011; Moore et al., 2012). In 2015 and 2016, NASA reported that seawater temperatures were the warmest since measurements began (Northon,

2017). Seventy-five per cent of the world's reefs were affected in the latter year (Hughes et al., 2018). It is widely accepted that 20% of the world's corals are dead and that the rest are under substantial threat. In this section, we will assess the effects of coral bleaching on the value of the ecosystem services provided by the reef.

Costs to recreation and tourism

Tourism is one of the biggest industries associated with coral reefs, and is worth at least US$°36 billion to the global economy every year (Spalding et al., 2017). The average value of tourism-related income on coral reefs has been estimated to be US$ 96,300 ha^{-1} yr^{-1}. Although this varies from a few hundred US$ ha^{-1} yr^{-1} for small remote reefs to over US$ 2 million ha^{-1} yr^{-1} for heavily visited reefs in the Caribbean (De Groot et al., 2012). Such high variability makes extrapolating values to a larger scale difficult and thus, unwise. Rather, it is better to consider how bleaching will affect ecosystems at the national level. Take the Great Barrier Reef (GBR) as an example. In 2017, more than 2.3 million tourists visited the GBR generating revenue of US$ 5.2 billion for the Australian economy (Piggott-McKellar and McNamara, 2017). In a survey asking visitors whether severe bleaching events would make them more likely to choose an alternative holiday destination a large proportion answered in the affirmative: 35% of Americans, 27% of British and 55% of Chinese tourists and 37% of domestic Australian visitors (Swann and Campbell, 2016). This potential loss of tourism revenue is estimated at $1 billion (Swann and Campbell, 2016), putting at risk the 65,000 full-time jobs dependent on tourism in the region (Piggott-McKellar and McNamara, 2017).

The GBR aside, most coral reefs are in low economic countries. This renders poor and developing countries at greater risk from the loss of revenue from tourism. In some cases, reef-related revenue represents up to 40% of a countries GDP (e.g. the Maldives and Palau (Spalding et al., 2017)). Caribbean countries are also heavily reliant on reef-related tourism (Burke et al., 2011, 2004). In 2006, the direct economic benefits of reefs provided Tobago and St. Lucia $ 43.5 million (15% of GDP) and US $ 91.6 million (11% GDP), respectively. The indirect benefits (such as the provision of boats, towels and beverages) contributed an additional US$°58-86 million to Tobago, and US$ 68-102 million to St. Lucia (Burke et al., 2008).

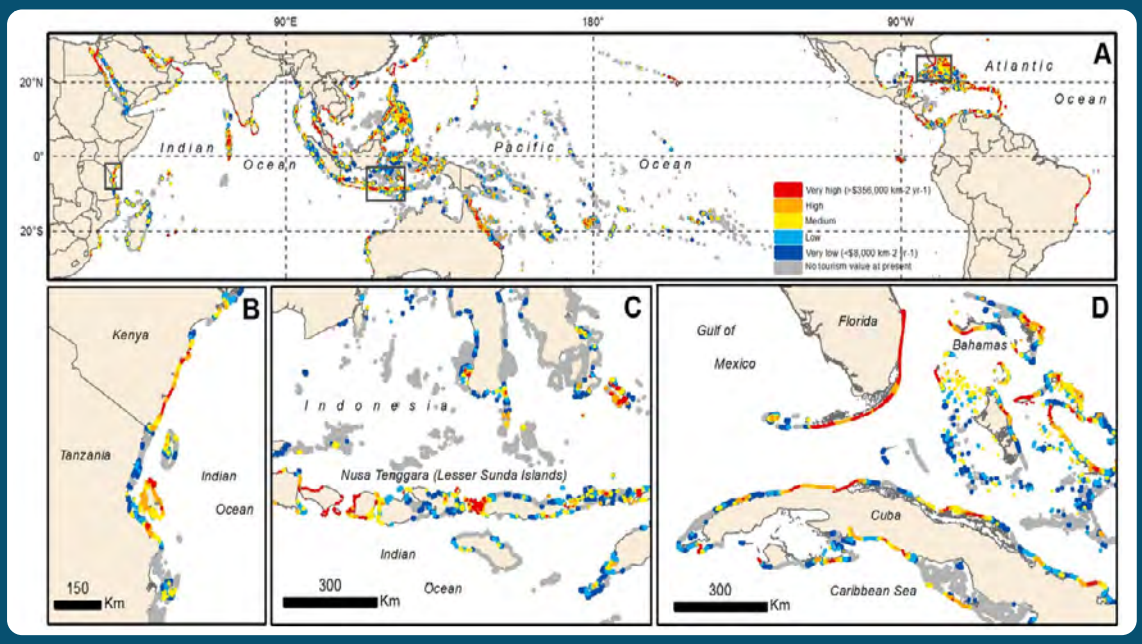


Figure 2. Tourism value of coral reefs. Red: >US$ 356,000 km^{-2} yr^{-1}; Dark blue: <$US 8,000 km^{-2} yr^{-1}); Grey: no value available at present. (Source: Spalding et al., 2017)

Coastal defence costs

Coral reefs play a critical role in wave attenuation, reducing the force of big waves, and thus protecting the coastline from flood damage and erosion (Ferrario et al., 2014; Spalding et al., 2014). In 2010, the loss of value in coastal protection from reef destruction was between US$°0.011 and US$ 0.453 million per km^2 (Barbier et al., 2010). Recently, a global assessment valued the coastal protection provided by reefs at more than US$ 4 billion (Beck et al., 2018). If all reefs were lost (a very real possibility if mass coral bleaching events continue to happen), annual damages are expected to double and terrestrial flooding would increase by 69% (Beck et al., 2018). The economic impact of this bleaching would be particularly felt in small island developing states such as Belize, Granada, Cuba, and Bahamas (Table 1).

Annual averted damages ($ millions)			Annual averted damages/GDP	
1	Indonesia	639	Cayman Islands	0.98
2	Philippines	590	Belize	0.37
3	Malaysia	452	Grenada	0.30
4	Mexico	452	Cuba	0.25
5	Cuba	401	Bahamas	0.16
6	Saudi Arabia	138	Jamaica	0.14
7	Dom. Republic	96	Philippines	0.13
8	United States	94	Antigua & Barbuda	0.13
9	Taiwan	61	Dom. Republic	0.11
10	Jamaica	46	Malaysia	0.09
11	Vietnam	42	Seychelles	0.06
12	Myanmar	33	Turks & Caicos	0.06
13	Thailand	32	Guadeloupe	0.05
14	Bahamas	14	Indonesia	0.04
15	Belize	9	Solomon Islands	0.04

Table 1. Annual benefit of reefs for flood protection by country.
Source: (Beck et al., 2018)

Costs to income

Evaluating the impacts that coral bleaching will have on income at a national or regional scale requires knowledge of the contribution of each sector to the overall economy. (Direct sectors include, for example: tourism, fisheries, protection, and indirect sectors: cultural, recreational, and research & education value). For this reason, assessments are usually conducted at the national scale. For example, many assessments have been completed in Sri Lanka (Berg et al., 1998), Hawaii (Cesar et al., 2003), the Philippines (White et al., 2000), Thailand (Seenprachawong, 2016), and Australia (Stoeckl et al., 2014). A case study from Bermuda illustrates the principles involved in assessing the costs. Sarkis et al. (2013), found that tourism provided the highest annual contribution to ecosystem service values in Bermuda, contributing US$ 406 million (56% of the total economic value; TEV), coastal protection was worth US$ 266 million (37% of TEV), recreational and cultural value was valued at US$ 37 million (5% of TEV). Amenities, fisheries, and cultural and recreational values, combined, made up the remaining 2% of TEV.

Loss of potential business

Coral reefs have often been referred to as "blue gold" when it comes to the discovery of new natural products (Leal et al., 2013). Among the most promising are potential cures for cancer, HIV, bacterial infections, and viruses. One such example is Yondelis, a potent antitumor drug, first extracted from a marine tunicate. PharmaMar the company that developed Yondelis reported $US 100 million worth of sales of this drug in 2017. It is highly likely that unidentified drugs have yet to be discovered in closely related species (Zhu et al., 2011). To date, no studies have evaluated what the loss of coral reefs may mean for the loss of blue gold.

Costs to operate

Six million fishers in 99 countries directly rely on coral reefs (Teh et al., 2013). The annual value of reef fishing exceeds US$ 5.7 billion (Cesar et al., 2003). Coral reef loss or degradation could cost the fisheries industry US$ 0.41 million km^{-2} (Barbier et al., 2010). These costs will be acutely felt in Southeast Asia where over half of all reef fishing occurs. In the Philippines alone, more than one million artisanal fishers catch almost US$ 1 billion annually (White et al., 2000). The Caribbean is also expected to suffer high losses in relation to bleaching, which are estimated to range from US$ 95 million to US$ 140 million per year (Burke et al., 2004).

Seaweed farming is an industry that is indirectly dependent on reefs. Seaweed farming occurs in the sheltered lagoons and bays created by coral reefs where 21 million tonnes of seaweed are produced worldwide each year (Hehre and Meeuwig, 2016) in an industry worth US$ 7.35 billion (FAO, 2012). China is the world's largest producer of seaweed, cultivating 60% of the world's production, while Indonesia (21%) and the Philippines (9%) also produce substantial amounts.

The marine ornamental fish trade is another sector that might be severely affected by future coral reef ecosystem degradation. This trade provides a significant source of income for low-income nations, i.e. EUR 135 million between 2000 and 2011 (Leal et al., 2016).

3.3 Harmful algal blooms (HABs)

Harmful algal blooms (HABs) are proliferations of certain noxious or toxic microalgae, macroalgae and cyanobacteria with negative impacts on aquatic ecosystems, wildlife, and human health and wellbeing (Berdalet et al., 2017). HABs can be classified as biological hazards (UNDRR, 2019). HABs can cause human fatalities, disability and illness, fish kills, mortalities and stranding of wildlife, contamination of drinking water and seafood, ecological damage through the development of anoxia or other habitat alteration (Berdalet et al., 2017). HABs cause extensive economic damage to four major economic sectors: recreation and tourism, public health, monitoring and management, and commercial fishing (Sanseverino et al., 2016). Detailed global estimates do not exist regarding the economic impact of HABs but conservative national figures suggest that annual costs exceed US$ 95 million in the USA, US$ 850 million in Europe and US$ 1 billion in Asia (Kudela et al., 2015).

Due to extensive economic losses in the past caused by HABs, many governments have implemented monitoring and management programmes (Anderson 2017; Sanseverino et al., 2016; Wang et al., 2009). This has had a positive impact in reducing the costs to public health and from disposal of toxic fishery harvests from HABs. However, these costs have largely been transferred to monitoring and mitigation costs borne by the private sector, e.g. in aquaculture (closures) or the public sector, e.g. on water quality monitoring, warning systems and clean-up/disposal (Anderson 2017; Trainer et al, 2014;

Yang et al., 2018). Other industries affected by HABs include desalination processes for water supply, due to the cost of managing biofouling and the risk of biotoxins in drinking water (Anderson, 2017; Berktay, 2011; Villacorte et al., 2015). Other industries whose operating costs are vulnerable to increase due to HABs include energy and industrial activities that use seawater for cooling. Added costs include those from biofouling and reducing the risk of invasive species introductions caused by maritime transport (Anderson, 2017).

European data about spending on annual HAB monitoring plans exceed global estimates on the annual costs of HABs: Denmark and Portugal spent about US$ 500,000, France US$ 800,000 and Spain (Galicia) US$ 1,114,000 (Anderson et al., 2001 in Sanseverino et al., 2016). This highlights the importance attributed by European governments to monitoring and managing HABs.

Since the 1980s, HABs have expanded in their range and increased in frequency, due to a combination of human introduction (e.g. aquaculture and shipping), ocean warming, marine heatwaves, oxygen loss, eutrophication, and pollution (IPCC 2019). Coastal communities are particularly vulnerable, as there are no monitoring programmes and early warning systems in place. Unfortunately, the identification of biotoxins and their toxicity require specialist skills and equipment, which are often lacking but necessary for risk management and mitigation.

Costs to income

Loss of income and jobs from beach and fisheries closures affects commercial and recreational fisheries, tourism and restaurant industries, property sales and rentals, as well as income and traditional food sources to local communities. Indigenous coastal communities are particularly vulnerable to acute and chronic exposure to HAB toxins due to the high consumption of seafood and ties to traditional and customary practices (Cisneros-Montemayor et al., 2016).

Costs to income can be assessed at an individual level by calculating the average cost of sick days taken due to illnesses arising from HAB exposure (Kouakou and Poder, 2019). This has been estimated to be between US$ 136 (Nierenberg et al., 2010) and $236 (Todd, 1995) per day.

Costs to associated industries

The fish processing industry, which includes the preservation, cooking, and production of fish meal for animal feed, is extremely valuable. By 2021, the market is projected to reach US$ 222.71 billion in value[4]. The EU estimates that 45% of the gross value of fisheries is added by the processing industry (DG MARE, 2019). The sector is an important employer, particularly for women. In 2015, 130,000 people were employed by the EU processing industry and more than EUR 30 billion was turned over by this industry (DG MARE, 2019). In Australia, AUS$ 330 million of Gross Value Added (GVA) was added by fish processing in 2017-2018, contributing AUS$165 million to total household income (FRDC, 2019). Such activities are vulnerable to disruption by fisheries closures caused by HAB events and the costs associated with monitoring and control (Anderson et al., 2017; Trainer et al., 2014). However, any loss and damage to fisheries processing industries from HAB events have not been isolated from the larger scale costs to fisheries in general.

4 https://www.prnewswire.com/in/news-releases/fish-processing-market-worth-22271-billion-usd-by-2021-582221241.html

Costs to recreation and tourism

Global costs to tourism and recreation due to HAB events are not available even though these events frequently occur in most continents. In the Caribbean, West Africa, France and China, massive noxious blooms of macroalgae have displaced tourism and recreation away from affected beaches and water bodies due to huge biomass accumulation and odours released during decomposition. Toxic blooms cause closures of beaches and recreational fisheries, and even make water-based activities unpleasant or dangerous. Visual and odour effects, as well as aerosols affecting respiration, can increase the zone of impact to extend well beyond the initial location of the HAB.

HAB outbreaks occur off the coast of Florida, USA on an almost annual basis wreaking havoc on the tourism industry. HABs of the dinoflagellate *Karenia brevis*, for example, are estimated to cost the Florida tourism industry more than US$ 20 million per year (Anderson et al., 2000), with economic losses of US$ 2.8 million and US$ 3.7 million per month assumed by the hotel and restaurant industries (Larkin and Adams, 2007). A particularly strong HAB, which occurred in the North Pacific on the coast of Washington in 2015, inflicted US$ 40 million worth of lost tourism revenue on coastal communities following the closure of popular razor clam and Dungeness crab tourist attractions (Dyson and Huppert, 2010).

Algal blooms have also become an annual summer event in the China's Yellow Sea. The "green tides" of *Ulva prolifera* are not necessarily toxic for human health, but as the bloom peaks and then declines, the decomposition releases noxious gases. The first major algal bloom of *U. prolifera* occurred in 2008, during the Beijing Olympic Games, raising international awareness about the problem. The 600 km^2 bloom lasted 46 days and required 5,000 people, 200 trucks and 1,185 fishing boats a day to eliminate algae from the sailing event area. This operation cost the organizers more than US$ 100 million (Wang et al., 2009; Ye et al., 2011), substantially higher than profits gained by the local seaweed (*Porphyra yezoensis*) aquaculture industry, which accounted for US$ 53 million (Hu et al., 2010).

Costs of human poisoning from algal biotoxins

Algal biotoxins affect 60,000 people per year with 1.5% of cases leading to death (GESAMP, 2001). The financial cost of health care caused by consuming contaminated seafood alone is estimated to be around US$ 4 billion a year (GESAMP, 2001). Globally the incidence rate of paralytic shellfish poisoning (PSP) arising from HABs increased from 1970 to 2000 (Gilbert et al., 2005; Figure 3). This increase is related to: the increase in seawater temperatures, increased shellfish consumption and higher levels of coastal eutrophication (Berdalet et al., 2015; Gilbert et al., 2005; Morabito et al., 2018). Also, more time and effort are spent monitoring the distribution of biotoxins and their impacts on human health.

The most reliable estimates of economic costs can be found in the USA. Exposure to food or water-borne poisoning is estimated to cost up to US$ 1 billion a year. Of this, US$ 350 million comes from food-borne pathogens or toxins, US$ 300 million is attributed to seafood borne disease with an unknown cause and US$ 300 million are caused by gastro-intestinal illnesses from beach recreation (Ralston et al., 2011). The proportion of illnesses that are caused by HAB-related toxins *versus* bacterial infections or other causes is not known. Most major HAB poisoning syndromes are present in the USA (Figure 4). Of these ciguatera fish poisoning has the highest costs at US$ 17-21 million per year (Anderson et al., 2000; Ralston et al., 2011).

Respiratory and digestive illnesses caused by *Karenia brevis* blooms range from US$ 0.1- 0.7 million every year, depending on the intensity and duration of the bloom (Hoagland et al., 2014, 2009).

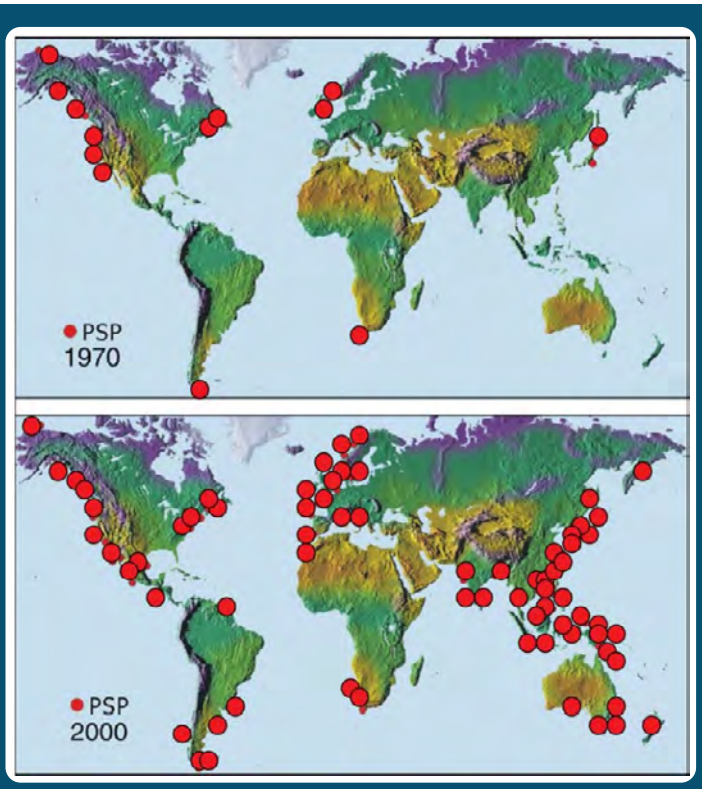


Figure 3. The global increase in Paralytic Shellfish Poisoning.
Data from 1970-2000 (Gilbert et al., 2005).

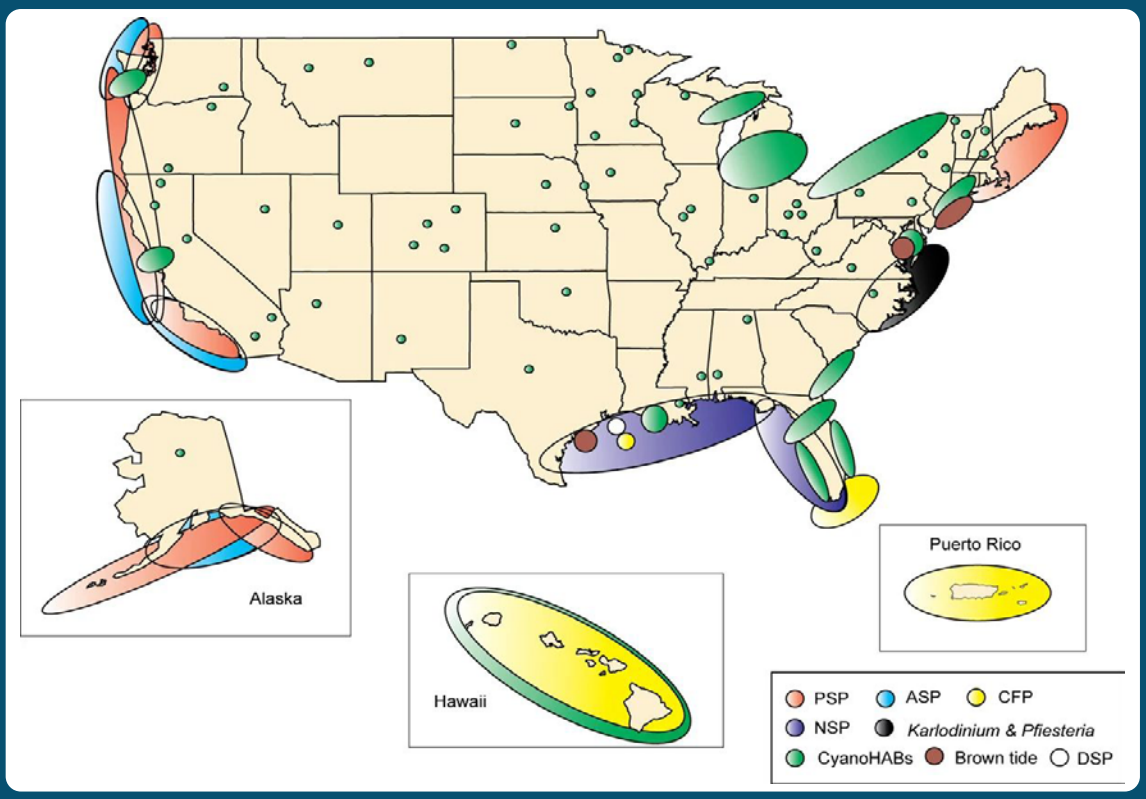


Figure 4. The national distribution of algal biotoxin syndromes in USA. Figures exclude USA territories in the Pacific and Caribbean).

Costs to fisheries and loss of production

In 2003, HABs losses to fisheries (including finfish and shellfish wild harvests and aquaculture) in European coastal waters were estimated to be more than € 800 million (Scatasta et al., 2003). Similar losses in the USA are only available at the state or regional level with annual losses of US$ 20 million reported in South West Florida and US$ 43 million in Maryland (Sanseverino, 2016).

In 2006, a HAB event off the coast of Zhejiang Province caused US$ 5.9 million in losses for local fisheries. In 2012, a HAB event off the adjacent Fujian Province coast decimated the farmed abalone industry, resulting in US$ 284 million in losses (Xinhua, 2017). In 2015/2016, a bloom of the diatom *Pseudo-nitzschia australis* broke records for extent, duration, and toxicity. The bloom, associated with an El Niño event, a marine heatwave (named "The Blob") and coastal upwelling, shut down the lucrative Dungeness crab fisheries on the West Coast of the US, causing losses of US$ 97.5 million (Dyson and Huppert, 2010).

In 2016, 40,000 tonnes of farmed salmon in Chile (12% of annual production) were lost during a HAB, dominated by the raphidophyte *Pseudochattonella*, which lasted for two weeks (Clément et al., 2016; León-Muñoz et al., 2018). The HAB was one of the worst in recent history, causing economic losses of more than US$ 800 million; a huge part of the US$ 4.3 billion economy in Chile (León-Muñoz et al., 2018).

A different algal bloom also in 2016, dominated by the floating brown macroalgae Sargassum, hit China's Yellow Sea, and caused US$ 73 million worth of losses to seaweed farmers in the Jiangsu Shoal (Xing et al., 2017).

Algal bloom in a tropical fish farm, Thailand.
Source: Shutterstock / nicepix

Costs to household income

Climate change is expected to significantly impact fishers, fish farmers and coastal inhabitants. Global losses in household income are expected to range between US$ 6-14 billion per year depending on the projected climate change scenario that is used (Lam et al., 2017). Households in developing countries are likely to suffer bigger relative losses than developed countries (estimated at US$3.9–8.4 billion for the former and US$1.6–4.2 billion for the latter). East Asia and the Pacific stand to lose the highest amount (US$6 billion per year) followed by Latin America, the Caribbean and Sub-Saharan Africa (Sumaila and Cheung, 2010).

3.4 Food security via fisheries and aquaculture

The livelihoods and food security of 520 million people (approximately 8% of the world's population) depend on fisheries and aquaculture (FAO, 2009). In addition to this, a further 200 million people are employed (both directly and indirectly) along the value chain in the two sectors (FAO, 2017). More than 3 billion obtain more than 20% of their dietary protein from the marine environment (UNDRR, 2019). Fish comprised 17% of all animal protein consumed by the human population (FAO, 2017) and capture fisheries alone are estimated to be worth US$ 220-250 billion annually (UNDRR, 2019).

Costs to associated industries

As mentioned in Section 3.3, the fish processing industry, which includes the preservation, cooking, and production of fish meal for animal feed, is extremely valuable. By 2021, the market is projected to reach US$ 222.71 billion in value[1]. The EU estimates that 45% of the gross value of fisheries is added by the processing industry (DG MARE, 2019). The sector is an important employer, particularly for women. In 2015, 130,000 people were employed by the EU processing industry and more than EUR 30 billion was turned over by this industry (DG MARE, 2019). In Australia, AUS$ 330 million of GVA was added by fish processing in 2017-2018, contributing AUS$165 million to total household income (FRDC, 2019).

Conflicts around new fisheries

Climate change will alter the distribution and abundance of commercially-important species (Cheung et al., 2010), potentially leading to escalations in the number of conflicts over marine resources (Spijkers et al., 2018). Conflicts have the potential to become extremely costly. The Council on Foreign Relations has cautioned that territorial disputes such as the on-going conflict in the South China Sea (between China, Vietnam, the Philippines, Taiwan, Malaysia and Brunei) jeopardises the US$5 trillion worth of trade passing through the South China Sea every year[5]. Co-management policies that cover large marine ecosystems on a regional basis substantially reduce the risk of resource-related conflicts (Pomeroy et al., 2007).

Fishing travel costs

Both the commercial and recreational fishing industries are affected by the price of fuel. This determines the distance travelled by boats and, therefore, has a direct impact on the amount of fish that are caught. The distribution and/or stock levels of the target species also plays an important role in determining the catch per unit effort. Overfished stocks at low densities and smaller sized individuals require boats to travel greater distances or to deeper grounds, which increases the amount of fuel used per tonne of landings (Kelleher et al., 2009). Fuel subsidies offer a controversial means of controlling these values. Annual fuel subsidies paid to the fishing industry exceed US$ 7.7 billion (Sumaila et al., 2016). A recent study called for the abolishment of such subsidies, arguing that would be beneficial for both consumers and fishers (Lancker et al., 2019).

5 https://www.cfr.org/report/exposing-chinas-actions-south-china-sea; https://international.thenewslens.com/article/69945

Viability of profits and jobs

Approximately 260 million people are employed either directly, or indirectly (i.e. in associated industries) within marine fisheries. Of these people, 22 million fall into the small-scale fisher classification (i.e. are subsistence or artisanal fishers) (Teh and Sumaila, 2011). It is possible to estimate the impact that changing fish stocks and/or catch per unit effort will have on the job market, but few studies have done it. One exception was a study conducted in West Africa by Lam et al. (2013) that estimated there would be an overall loss of 50% of jobs in fisheries by 2050, relative to the year 2000. Togo, Côte d'Ivoire, Sierra Leone, Nigeria, Ghana and Liberia were shown to be particularly high risk (Lam et al., 2012).

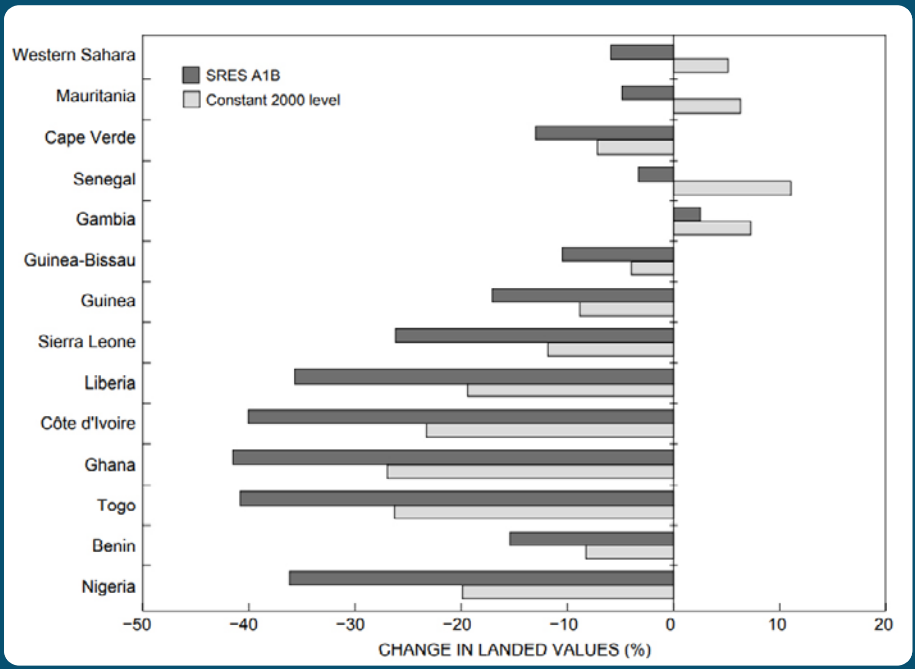


Figure 5. Annual average change in fisheries-related jobs in West Africa. Values represent average employment in the 2050s relative to the 2000s for two climate change scenarios (high: SRES A1B and low: constant 2000 level). (Lam et al., 2012).

Changes to biological interactions

There is currently no information available about the economic costs that changes in marine biodiversity and ecosystem services will have on food security. However, the increasing global demand for lower-value fish used to produce animal feed for aquaculture and/or oil is a major global concern (Garcia and Rosenberg, 2010). Removing large amounts of lower trophic level fish will have a negative impact on the stocks of large predatory fish species (e.g. tuna, cod) that they feed. On the other hand, this removal will reduce predation pressure on species that occupy the lower trophic levels (e.g. krill), which could potentially become a new food source (Garcia and Rosenberg, 2010). Predicting the costs associated with changes in predator-prey interactions is highly complex. It would require complete knowledge of seasonal fluctuations in community dynamics at a regional level (Stevenson et al., 2015); the trophic structure of the ecosystem in terms of both the abundance and spatial distribution of species (Bretagnolle and Gillis, 2010); and the dispersal and severity of threats (including fishing pressure, habitat loss or gain and the introduction of non-native species), data, which are simply not available.

Large catch decreases in the tropics

Climate change is expected to cause large-scale redistributions of the global catch potential, with 40% declines in the tropics and 30 to 70% increases in high-latitude regions predicted (Cheung et al., 2010). Temperate tunas (albacore, Atlantic bluefin, and southern bluefin) and tropical bigeye tuna are at particularly high risk of decline in the tropics (Erauskin-Extramiana et al., 2019). Such losses are predicted to reduce the maximum revenue potential of the tropics (latitudes spanning from 10°N to 10°S) by 33% (Lam et al., 2016).

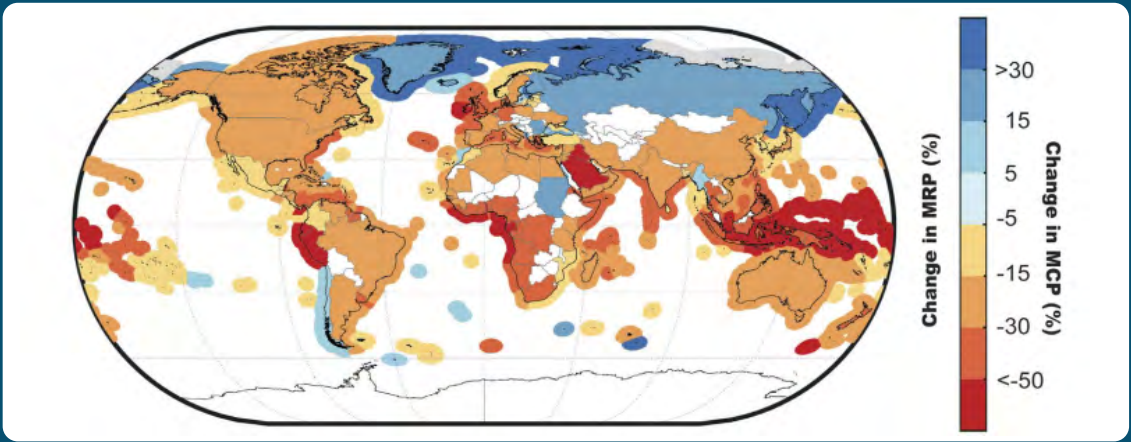


Figure 6. Impacts of climate change on maximum revenue potential (MRP) and maximum catch potential (MRC). Change in MRP/MRC is expressed as the % difference between average values in the 2050s relative to the 2000s (Lam et al., 2016).

3.5 Human health and diseases

Human exposure to marine-borne diseases can be costly, not only to infected individuals but to entire communities. Direct costs can include: death, medical diagnosis, treatment, investigation of outbreaks, and subsequent monitoring. Indirect costs can include: lost wages and productivity, migration costs, chronic pain and suffering, cost of psychological follow-up, mental health costs, and loss of recreational activities.

Globally, marine pathogens cause approximately 250 million cases of illness a year, with 5 million annual cases of gastrointestinal illness due to bathing in contaminated water in the USA alone (Ralston et al., 2011). Currently, there are no estimates for the global economic costs associated with this. There are, however, estimates available from the USA, which place figures at approximately US$ 1 billion per year (Ralston et al., 2011). A breakdown of the costs show that US$ 350 million is spent on known marine pathogens and toxins that cause food-borne diseases; US$ 300 million is spent on seafood-borne diseases with known etiology (i.e. cases with unknown pathogenic etiology are excluded from this estimation); US$30 million of damage is caused by the *Vibrio* bacteria; and US$ 300 million is spent on gastrointestinal illnesses arising from bathing in contaminated water (Ralston et al., 2011).

The two primary routes of transmission for marine borne disease are the consumption of contaminated seafood and direct exposure to marine pathogens in the marine environment. However, a third route of impact on human health - which deserves further attention - is the effect of anthropogenic pollution on the spread, transfer and potential exacerbation of marine-borne illnesses. The following outlines a few examples of the frequently reported illnesses associated with these transmission and impact routes, and the economic data currently available regarding the costs of these illnesses.

Shellfish and other food contamination

Contaminated seafood causes more illnesses per weight consumed than any other food category (CSPI, 2015; Elbashir et al., 2018). Caused by a variety of bacteria, viruses, parasites and toxins, illnesses can range from mild gastroenteritis to life-threatening symptoms (Iwamoto et al., 2010). Coastal populations are particularly vulnerable to seafood-borne illness, with an average consumption per capita that is 15 times higher than non-indigenous country populations (Cisneros-Montemayor et al., 2016).

While viruses are one of the most common cause of seafood-related infections, bacterial agents have been associated with most hospitalizations and deaths (Butt et al., 2004). Parasitic infections from seafood consumption seem more uncommon (and less costly) than bacterial or viral infections. However, the actual public health impact posed by parasites via shellfish remains unclear, largely due to severe under-reporting and the lack of data and minimal evidence of infection transmission, globally and locally (Robertson, 2007). Better monitoring is urgently required to understand the risks posed by these food-borne parasites (Singh et al., 2014).

Costs of seafood-borne illness

According to US studies, the acute health care costs resulting from marine-borne pathogens in the USA are estimated at approximately US$1 billion annually (Ralston et al., 2011). This includes US$350 million due to known marine pathogens and toxins that cause food-borne diseases; and US$300 million due to seafood-borne disease with known etiology (cases with unknown pathogenic etiology are excluded from this estimation). Most of the costs of seafood-borne illness are associated with premature deaths (US$300 million), followed by medical care (US$25 million) and lost productivity (US$15 million) (Ralston et al, 2011[6]).

Of all the marine-borne pathogens, *Vibrio* and Norovirus (Norwalk virus) are among the costliest. *Vibrio* spp. is the main species involved in seafood-and seawater-borne illness worldwide (with *Vibrio vulnificus* being the costliest). Enteric viruses, such as human noroviruses are among the most infectious, and one of the main causes of gastroenteritis worldwide (Rincé et al., 2018). Ciguatera Fish-Poisoning (discussed in section 3.3) is the most frequently reported seafood-toxin illness in the world (Friedman et al., 2017), and remains in the top five of costliest illnesses in the USA.

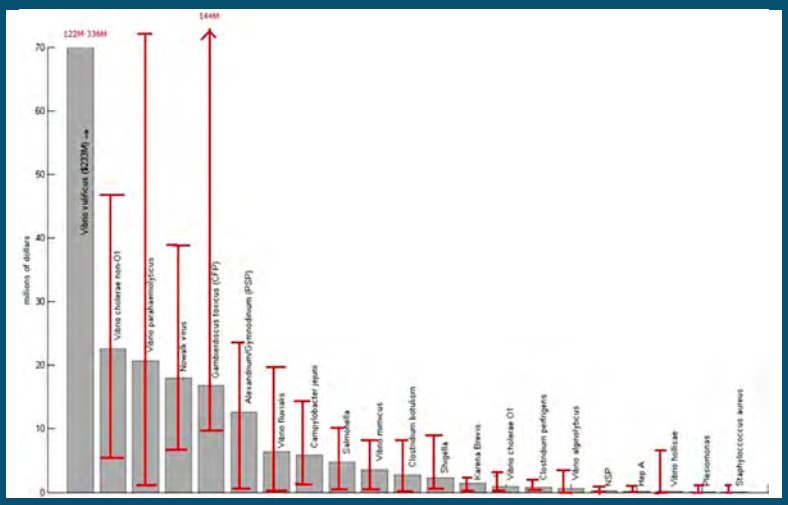


Figure 7: Overall cost of pathogen-specific, marine-borne illness in the USA
(Source: Ralston et al, 2011)

6 http://www.fao.org/food/food-safety-quality/scientific-advice/jemra/risk-assessments/vibrio0/en/

Costs of Vibrio infections

Vibrio bacterial infections are among the most costly seafood-related illnesses in the USA, and post a significant burden on the healthcare sector (Iwamoto et al., 2010). For example, in the USA alone, the annual health costs of seafood related illnesses associated with *Vibrio vulnificus*, *Vibrio parahaemolyticus*, *Vibrio alginolyticus* are estimated to be US$ 350 million (Heng et al., 2017). Studies demonstrate that premature deaths (i.e. death before the age of 75) account for a large proportion of the total treatment costs associated with seafood-related illnesses (US$ 306 million), followed by medical care (US$ 25 million), hospitalization (US$ 6 million), and loss of productivity (US$ 15 million) (Ralston et al., 2011 in Heng et al., 2017).

Despite causing a lower incidence of illness than other bacteria or pathogens, *V. vulnificus* is a leading cause of seafood-associated fatality, with approximately 95 cases reported with 85 hospitalizations and 35 deaths per year globally (Heng et al., 2017). Just in the USA, *V. vulnificus* infections account for 45 hospitalizations and 16 deaths annually (Centre for Disease Control, 2013, cited in Ralston et al, 2011). Accordingly, *V.vulnificus* is recognized as one of the costliest of all marine-borne pathogens, accounting for 66% of seafood-related illness health costs and 26% of the total health costs, one third of the total seafood-related illness and more than 85% of the costs of direct exposure to the *Vibrio* pathogen (Heng et al., 2017).

Vibrio cholerae is often transmitted by contaminated drinking water, but the consumption of fish or seafood that has been in contacted with contaminated water can also serve as a frequent transmission route. There are an estimated 1.3 to 4.0 million cases of cholera per year, with 21,000 to 143,000 deaths worldwide (Ali et al, 2015 cited in WHO, 2018e). However, the global health burden and costs of cholera remain largely unknown and possibly underestimated given that most cases are not reported and, in many cases, the specific pathway of exposure to *Vibrio cholerae* in patients remains unknown (Chowdhury et al., 2016).

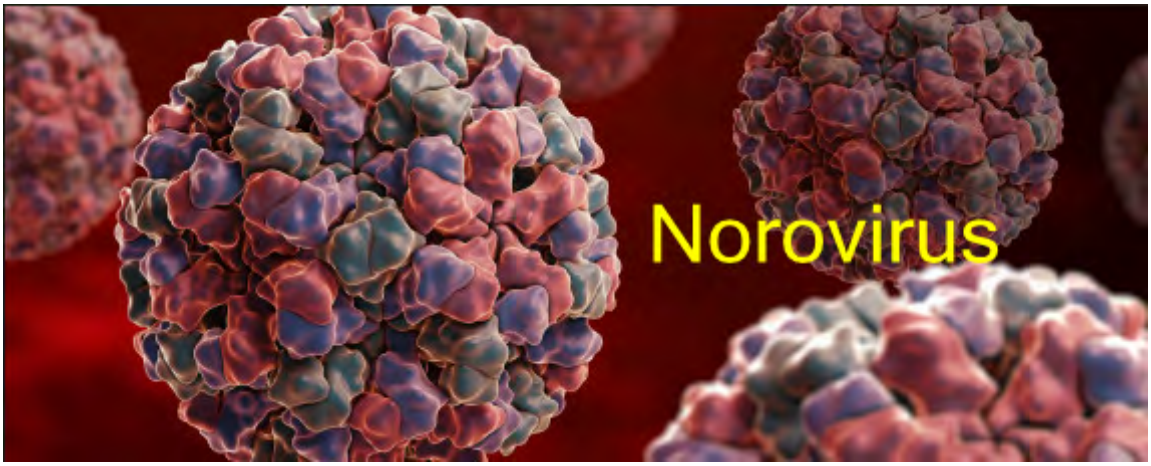
Vibrios are common in marine environmental infections especially in warmer regions, where the bacteria thrive (e.g. US southeast coast, South America, Asia), whereas there are fewer cases reported in Europe[7]. Anthropogenic warming of ocean water, increased coastal flooding and encroachment of saltwater further inland, could further increase the risk of human interaction with pathogenic *Vibrio* species, such as *V. vulnificus*, *V. cholerae*, and *V. parahaemolyticus* (Froelich and Daines, 2020).

7 https://earthobservatory.nasa.gov/images/91591/bacteria-thrive-as-ocean-warms

Costs of norovirus virus (NoV)

While rarely causing deaths, some of the milder illnesses from seafood consumption or direct recreational exposure, such as Norovirus(Norwalk virus or NoV), can also be costly.

The third most commonly reported pathogen associated with seafood in the USA (mostly from contaminated shellfish, such as molluscs and raw oysters), NoV causes 29% of all seafood-associated illnesses and 10% of hospitalisations (Iwamoto et al, 2010). In the USA alone, costs are estimated at US$18 million annually to manage an estimated 184,000 cases, making it one of the top five most costly pathogens causing marine-borne illness in the USA (Ralston et al, 2011).



Most incidence and regional distribution data are available for developed countries (including USA, Europe, Japan), with a lack of incidence data from high mortality settings and low-income countries, including for example, significant data gaps in Africa (Kreidieh et al., 2017).

In addition, while considerable global cost and loss data are available regarding NoV associated foodborne diseases, fewer studies quantify the global health and economic burden specifically associated with marine-borne sources (including cases with mild symptoms). Given the significant costs and losses associated with food-borne NoV cases, and the fact that 50% of NoV outbreaks are due to the consumption of contaminated shellfish (Alfano-Sobsey et al., 2012), we conclude that this deserves more detailed monitoring and surveillance. Further studies are recommended to understand the incidence and role exerted by NoV on the burden of diarrheal illnesses resulting from marine-borne sources.

Illnesses from direct marine exposure

With over a million bacteria characterized as being present per mL of seawater, and 10 to 100 times as many viral particles, the risks of developing an infectious disease - from recreational or occupational uses of marine water, or exposure to beach and sand sediment, zooplankton and animals - is very high, but one that remains poorly understood (Young, 2016).

Some of the human pathogens identified in bathing waters include for example: Adenovirus, Noroviruses, Enteroviruses, Hepatitis A, *Escherichia coli*, *Staphylococcus aureus*, *Bacteroides* spp., *Clostridia*, *Pseudomonas* spp., *Salmonella* spp., *Giardia* spp and *Vibrios* spp. (Young, 2016). There is also growing evidence that beach sand can also harbour harmful microbes such as pathogenic bacteria, viruses and fungi in much larger concentrations that beach water itself; however, little research has been conducted regarding the health outcomes of direct and indirect exposure to differing sand qualities (Sabino et al., 2014, Solo-Gabriele et al., 2016, Abreu et al., 2016).

Spread of marine-borne illness via ballast water

The treatment and discharge of ballast water by ocean-going vessels has the potential to significantly impact human health through the worldwide spread of aquatic invasive species, pathogens (such as *V.cholerae)* and toxic organisms, such as harmful algae. The significant transfer of ballast water (approximately 2 to 3 billion tonnes per year) from one continent to another and between oceans (Werschkun et al., 2014) poses a significant potential bacteriological risk for all international water routes. In addition, human health can be impacted through occupational and non-occupational exposure (oral, dermal and inhalation) to the disinfection-by-products (DBPs) used for ballast water treatment and disinfection, which can include chlorine (Werschkun et al., 2014). Detailed risk assessments are required to identify the incidence of transmission of pathogens and toxins causing human illness via the various exposure pathways described above; and the economic and health burden that this represents.

It is unclear from current research whether it is possible to contract the COVID-19 virus from exposure to faeces in recreational waters; there are still many unknowns regarding potential transmission of this virus via sewage and wastewater (Carducci et al., 2020).

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Anthropogenic pollution - exacerbating human illnesses

While there is significant evidence regarding the human health risks caused by bacterial and viral pathogens and marine toxins, there are much fewer studies to-date regarding how the consumption and/or exposure to anthropogenic pollutants in the marine environment affect the incidence and human health costs of marine-borne diseases. There is evidence of human infectious diseases being transferred from anthropogenic sources and spreading infections to new populations and geographic locations (Young, 2016). However, there are no data available regarding the economic and health burden that these illnesses represent.

This section outlines a few examples of anthropogenic pollution (e.g. transfer of pathogens via ballast water, synthetic organic chemicals, metals and microplastics), which have the potential to adversely impact human health, cause or exacerbate human illnesses – and which deserve further study in order to understand their scale and magnitude in light of a changing ocean climate, and the health and economic burden that they represent.

Costs of illnesses from direct marine exposure

Given that the symptoms of marine infectious diseases from direct marine exposure (e.g. gastrointestinal, respiratory, dermatologic, and ear, nose and throat infections) are mild and often self-reported, it is a challenge to understand the true incidence of infection and associated health burden (Sridhar and Deo, 2017). Some studies estimate that approximately 250 million cases of gastroenteritis occur worldwide each year (5 million in the US) as a result of bathing in contaminated water (Ralston et al, 2011), and 50 million or more cases associated with severe respiratory disease (Shuval, 2003).

While rarely causing death, there is evidence that even the milder illnesses caused by direct marine exposure can also be costly. For example, gastrointestinal illness from beach recreation in the USA is estimated to cost US$300 million, with US$30 million from direct marine exposure to the *Vibrio* species (Ralston et al., 2011).

Synthetic organic chemicals

Derived from industrial activities, synthetic organic chemicals include a wide range of chemicals, including petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), chlorobiphenyls, chlorinated dioxins, industrial solvents, pesticides and herbicides. Approximately 9% of dietary exposure to synthetic organic chemicals is from fish and shellfish caught in freshwaters, estuaries and in coastal zones (near shore versus in the open ocean) (Hellberg et al., 2012).

Classified for their persistence, bioavailability, tendency to bioaccumulate and toxicity, the consumption of synthetic organic chemicals has been linked to cause several health issues, including immune modulation (Hernrotha et al., 2018). For example, human ingestion of herbicides and pesticides has been associated with endocrine-disruption, immunosuppression and developmental problems (Fleming et al., 2006). Consumption of PAH-contaminated bivalves has also been associated with lung cancer, low birth rates, and decreased fecundity (Fleming et al., 2006). Persistent Organic Pollutants (POPs), such as PCBs and dioxins found in seafood can be particular hazardous when fish is consumed in large amounts by subsistence anglers, pregnant women and young children (Hellberg et al., 2012). While some studies report an association with prenatal exposure to PCBs and dioxins with childhood neurodevelopmental problems, other studies report no adverse effects (Nakajima et al., 2006, Hellberg et al., 2012).

Known to be immune modulators, further research is required to determine the long-term impacts of consuming seafood contaminated with synthetic organic chemicals, and the health costs that these impacts represent.

Mercury and other metals

While there are many sources of metals in the marine environment (some naturally existing, and others introduced by anthropogenic sources), the consumption of seafood is recognized as one of the major sources of non-occupational, organic mercury exposure to humans (Hellberg et al., 2012, Sheehan et al, 2014). In addition to neurodevelopmental impacts for pregnant women and foetus, the consumption of mercury can also have cardiovascular impacts on human health (Hellberg et al., 2012).

The highest human health risks of mercury are found in seafood consuming populations in coastal regions and tropical riverine populations, including south-eastern Asia, western Pacific and the Mediterranean (Fleming et al., 2016, Sheehan et al., 2014). Environmental chronic exposures have been reported in populations that depend on fishing, including in Amazonia, Coastal Peru, Seychelles, Faroe Islands, the Arctic and New Zealand (Fleming et al., 2006, Sheehan et al., 2014). At particular risk are women of reproductive age who live in low to middle-income countries (where access to information on methyl mercury content in seafood is not widely available) - and rely on seafood for at least 20% of their protein intake (estimated at approximately 400 million women worldwide (Budnik and Casteleyn, 2019). Higher risk of mercury exposure is also identified in subjects who consume self-caught fish versus store-bought fish, given their tendency to target predatory species, which contain the highest mercury concentrations (Eagles-Smith et al., 2018, Budnik and Casteleyn, 2019). It is expected that the relative exposure risk in distinctive populations is likely to change in response to globalization, population growth, resource availability (changed fisheries and “fishing down” of marine food webs), and climate change.

Other metals found in seafood include cadmium, lead and arsenic. For example, cadmium (a known human carcinogen) can bioaccumulate in the marine environment (found to bioaccumulate in shellfish, and particularly mussels, more than in fish), posing several human health risks, among the most important being proteinuria and renal failure (Fleming et al., 2006).

Overall, there is a need for more accurate information about heavy metal contaminant exposures (particularly low-level exposure) from human fish consumption, thus informing policy makers regarding the balance between fish consumption benefits and the potential adverse effects resulting from heavy metal exposure.

Microplastics

Given their high persistence in the environment, and the fact that they are accumulating in different marine ecosystems at increasing rates, microplastics (MPs) and nanoplastics (NPs) are considered an emerging issue of great concern as they may compromise human food security, food safety, and consequently human health (Barboza et al., 2018).

In addition to the absorption and transfer of chemicals and hydrophobic pollutants (such as metals and heavy metals) - which are released into the gastro-intestinal tracts of organisms when the MPs are ingested (Godoy et al., 2020) - MPs can also spread exotic invasive species and dangerous pathogens (Barboza et al., 2018). This suggests that exposure to marine plastic debris (either from marine bathing or ingestion) could increase the risk of human disease via new contamination and infection routes. For example, plastic beads (or 'nurdles') can act as rafts for harmful bacteria (including *E.coli* and *Vibrio spp.*), raising the potential for "pathogens to be transported over large distances and survive for much longer than normal" (McVeigh, 2019, Rodrigues et la., 2019). There are higher risks of human infection, particularly for children, resulting from marine bathing or exposure (e.g. ingestion) to plastic nurdles on beaches (Rodrigues et al., 2019).

To-date, the human health impacts associated with the consumption of MPs and NPs through the ingestion of shellfish, fish, salt, seaweed and other marine organisms, air or dermal exposure, remain largely unknown (Barboza et al., 2020, CIEL, 2019, Mercogliano et al., 2020). Our collective understanding of the sources, fate, exposure, bioavailability and toxicity of MPs and NPs and their associated impacts in the marine environment and for humans is limited. It is unknown to what extent pathogenic organisms can survive on plastic debris and transmit infectious diseases in humans through the consumption of seafood, and the physical and chemical toxicity thereof – which is likely dependent on size, associated chemicals and dose (Smith et al., 2018, Revel et al., 2018).

Considering the ubiquitous nature of microplastic pollution in the marine environment, the toxic effects that have been found in animals (including lipid oxidative damage in the brain), and the potential risks posed to humans through the ingestion of microplastic contaminated seafood - more research on human exposure to microplastics through the marine food web and the toxicity of the consumption of these particles to humans is of urgent priority (Barboza et al., 2020, CIEL, 2019).

The risks of plastic pollution go beyond microplastics, and these risks to human health, ecosystems, and national economies are grave and interlinked. The degradation and modification of marine and coastal systems causes negative socio-economic effects on tourism, fisheries, shipping, and human health (Raes et al., 2021). The build-up of plastic litter on beaches can have a large impact on a country's economy, wildlife, and the physical and psychological wellbeing of individuals (Jain et al., 2021). The major economic cost of this plastic debris is the reduced aesthetic appeal of coastal areas. This adversely affects the tourism industry, leading to a loss of output, revenue, and employment (Jain et al., 2021). The risks of plastic pollution on fisheries – including the broader economic dimensions of export revenue, livelihoods and employment, food security, marine ecosystems, and biodiversity – are well documented (Raes et al., 2021).

Source: Shutterstock / Marius Dobilas

4. Evidence of impacts in the Western Indian Ocean

This section takes a closer look at three Western Indian Ocean countries to see what information is available about the economic impacts of ocean risk. Though we know something about what is going on, there is a good deal that we do not know.

More complete assessments of impacts, particularly on coastal communities, is needed to inform policy makers and others about what is happening, and where mitigation measures and enhanced adaptive management are needed.

Policies in place include the *Partner States of East African Community (EAC) Disaster Risk Reduction and Management Strategy*, which looks at both natural hazards and human-induced disasters[8]. This strategy sits within the broader context of Disaster Risk Reduction (DRR), and is integrated into its programmes and planning in line with the Hyogo Framework of Action (HFA), the Sendai Framework for Disaster Risk Reduction 2015-2030 and the Africa Regional Strategy for DRR.

4.1 Impacts in Kenya

The key national disaster risk policies in Kenya are the National Disaster Risk Management Policy, approved in 2018, and is supported by the Kenya Vision 2030 Sector Plan for Drought Risk Management and Ending Drought Emergencies (UNDRR, 2019). These two documents do not specifically address several ocean risks, including coral bleaching, harmful algal blooms, fisheries and aquaculture or marine-related disease. However, local development plans, particularly at the county level, represent an opportunity for ocean risk management.

8 https://www.preventionweb.net/english/professional/policies/v.php?id=60591

Extreme weather events - Kenya

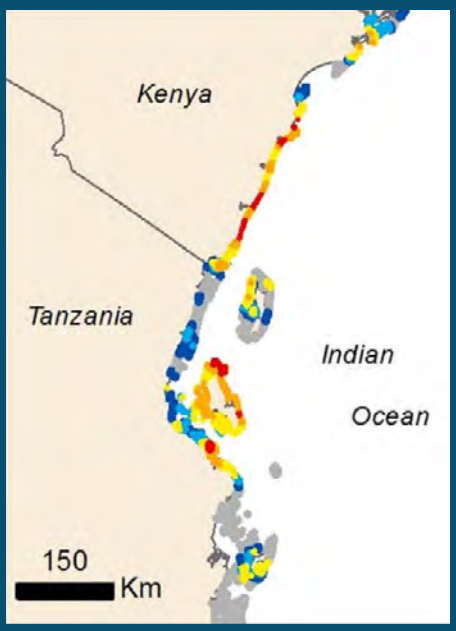
Climate change is a very real threat to Kenya. Mean seasonal temperatures have increased for the past 50 years; while average rainfall has dropped (Field et al., 2012; Funk, 2010). The rising flood and drought risks threaten coastal zones *via* sea-level rise with Mombasa - the region's largest seaport - at particular risk. They also increase health costs and place energy, infrastructure, water resources and ecosystem services at risk.[9]

Several notable extreme weather events have affected Kenya in the last 25 years. Severe floods in 1997-98 impacted 1 million people and caused US$ 0.8-1.2 billion worth of damage (Downing et al., 2009). Droughts hit the region in the years that followed (1998-2000), costing US$ 2.8 billion worth of losses in crops and livestock, forest fires, damage to fisheries, reduced hydro-power generation, reduced industrial production as well as reduced water supply (Downing et al., 2009). Droughts also hit the region in 2004-05, 2009 and 2011. Since 2014, an ongoing drought warning has been in place. The annual burden of extreme weather events is thought to be as high as US$ 0.5 billion per year, or 2 % of Kenya's GDP (Downing et al., 2009).

Tourism is Kenya's third largest economic sector after tea and coffee exports; generating US$ 6.7 billion in 2016, or 14 % of GDP (World Travel and Tourism Council, 2017). Sea-level rise is of threat to low-lying coastal tourist destinations such as Mombasa. The economic cost of sea-level rise is estimated to be US$ 7-58 million per year by 2030; a value that could rise to US$31-313 million per year by 2050 (Downing et al., 2009).

Coral bleaching - Kenya

Kenya's coastline spans some 650 km and is home to over 3.3 million people (2009); some 15 % of the total population (Payet and Obura, 2004). The majority of the coastline is covered with fringing coral reefs (Obura, 2002), which are among the most valuable in East Africa (Spalding et al., 2017). Estimates suggest coral reefs generate profits for the tourism industry worth US$ 356,000 per year, per km^2 (Spalding et al., 2017). In total, reefs could be worth US$ 2.5 billion per year or 4% of the Kenya GDP (Gudka et al., 2018).



The global mass bleaching events in 1998 and 2016 hit Kenyan reefs hard. 80% of all coral in the region are estimated to have died during the 1998 event (Obura, 2002), costing the diving industry in Mombasa alone an estimated US$ 13-20 million in lost revenue (Westmacot et al., 2000). The bleaching event of 2016 further decimated reefs, reducing hard coral cover by 20% and increasing fleshy algae coverage by almost 35%. No data are available on the economic costs incurred by the 2016 event in Kenya.

Figure 8. The economic value of coral reefs for tourism. Values range from high in red (> US$ 356,000 yr^{-1} km^{-2}) to low in dark blue (< US$ 8,000 yr^{-1} km^{-2}). (Spalding et al., 2017).

9 Global Facility for Disaster Risk Reduction country profile for Kenya https://www.gfdrr.org/en/kenya

Harmful algal blooms - Kenya

On the Kenyan coast, HAB data are limited in relation to location rather than impact (Kiteresi et al., 2013; Munga et al., 1992; Mwaluma et al., 2003; Wawiye et al., 1999)[10]. By contrast, fish kills, livestock deaths and massive wildlife deaths (e.g. flamingos) have been documented for HABs in inland lakes (HAEDAT, 2019). Marine HABS from 39 taxa have been identified in coastal waters, with particularly high densities of species associated with costly HABs such as *Pseudo-nitzschia* sp. (Kiteresi et al., 2013). HAB risks identified include cyanoHABs in salt production ponds (Ogello et al., 2014), toxic HABs where aquaculture has been proposed (Ochieng, 2015), and HAB species where dredging for port development could trigger a toxic bloom or increase the risks of HABs in ship ballast water (Adala, 2007).

In 2001, a bloom of the dinoflagellate *Karenia mikimotoi* caused mass fish mortalities on the Somali and northern Kenyan Coast (Church and Obura, 2006). Hundreds of kilometres of coastline were affected including in Kiunga National Marine Reserve (Church and Obura, 2006; Samoilys and Kanyange, 2008). Concerns about seafood safety disrupted fishing activity and reduced income as officials closed affected fishing grounds and advised the public not to consume locally caught fish. The ban on filter feeding organisms lasted several weeks. The coastal upwelling of waters, low in dissolved oxygen and high in nutrients, enhanced plankton productivity triggering the bloom, which lasted 10 days (Church and Obura, 2006). To date, no economic or other effects of marine HABs in Kenya have been quantified.

Food security via fisheries and aquaculture - Kenya

In 2004, Kenya's fishery sector was estimated to contribute 5% to the GDP, and employ 40,000 people (Fondo, 2004). By 2008, 80,000 people were directly engaged as fishers and fish farmers while the sector provided livelihoods for about 2.3 million Kenyans involved in fish processing and trade. More recent figures from the FAO highlight the continued growth of the fisheries sector, with production reaching 150,000 tonnes in 2010, and 190,000 tonnes in 2014. The market value of the latter exceeded US$ 250 million (FAO, 2016).

Approximately 80% of the marine catches in Kenya originate from shallow coastal waters and reefs, with only 20% fished offshore. Around 10,000 artisanal fishers work in Kenya (Ochiewo, 2004), using simple fishing vessels and gears such as gillnets, shark nets, beach seines, spear gun and traditional traps (McClanahan and Mangi, 2004). The value of artisanal fishing is not usually reported in official fish landings, but the 7,754 tonnes of reef-associated fin-fish that were recorded in 2006 (captured by 8,682 fishers) are estimated to have a value of US$ 9.69 million per year highlighting the importance of this industry to local economies (Samoilys et al., 2017). The impacts of climate change on Kenya's fisheries have not yet been fully analysed, but the rising number of fishers entering the fishery each year, combined with the effects of climate change, suggest that the artisanal coral reef fisheries of Kenya may be approaching their tipping point (Samoilys et al., 2017).

Kenya's maricultural industry remains undeveloped, despite it possessing 1.14 million hectares of potential farming area. If this resource were to be used, it could produce 11 million tonnes of fish a year, with an estimated worth of US$ 7.3 billion per annum[11].

10 Harmful Algae Event Database entry for Kenya http://haedat.iode.org/eventSearch.php?searchtext[countryID]=77
11 http://www.fao.org/fishery/facp/KEN/en

Human health and diseases - Kenya

The state of human health and disease prevalence along the coast of Kenya is influenced and exacerbated by high levels of poverty, low education levels, high cost of health care, a low doctor/patient ratio, lack or poor state of health infrastructure and the poor state of the environment (ASCLME, 2012a). Generally, the impact of ocean and climate change on the health of Kenya's coastal populations remains poorly documented. *Shigella* bacteria have been identified in edible fish in Kenya (David et al., 2009), but it is not clear how many confirmed cases of *shigellosis* (which is particularly prevalent in children aged between 6 months and 5 years) are linked to the consumption of contaminated seafood.

Organisms that produce biotoxins and seafood poisoning have been documented in Kenyan waters (Wawiye et al., 1999), but to date, there are no records of associated health problems or diseases. In the case of Ciguatera Fish Poisoning (CFP), there are travel advisories for tourists against this disease (which suggests CFP illnesses are a potential source of concern for human health) but again there are no reported incidences.

In general, the biggest threat to human health remains flooding (Okaka and Odhiambo, 2018). Flooding events often result in outbreaks of cholera, nonspecific diarrhoea, cryptosporidiosis, rotavirus, and typhoid and paratyphoid (Stoltzfus et al., 2014). These diseases make it difficult to differentiate marine-borne pathogens from those arising from other sources[12]. Setting up monitoring programmes should be a priority for risk mitigation in the region.

An aid worker collects health and nutrition data in Kenya.
Source: Shutterstock / marlenefrancia

12 https://www.who.int/cholera/countries/KenyaCountryProfile2010.pdf?ua=1

4.2 Impacts in Mozambique

The key national disaster risk policy in Mozambique is the Master Plan for Disaster Risk Reduction 2017-2030, which his aligned with National Development Plan, the National Agenda 2025: Visão Estratégica de Nação, the National Climate Change Mitigation and Adaptation Strategy 2013–2025, as well as the Sustainable Development Objectives. (UNDRR, 2019). Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) have been mainstreamed into district planning and budgeting systems in the eight key sectors of agriculture, health, water, social protection, roads, the environment, meteorology and energy (UNDRR, 2019).

Extreme weather events - Mozambique

The coastline of Mozambique spans 2,700 km, and houses over 60% of the population (over 13 million people). Mozambique suffers from multiple extreme weather events including periodic cyclones, droughts and floods[13]. Droughts occur in the southern region, seven out of every 10 years, while floods occur on average every two to three years. On average the country loses 1.1% of its GDP due to the impacts of droughts and floods on economic resources and activity (Irish Aid, 2018). The costs of one-off extreme events, in terms of lives lost and economic losses can be devastating. One example of this is Cyclone Idai, which hit in 2019. The cyclone triggered a deadly storm surge that killed over 1,000 people, affected 3 million more and caused US$ 2 billion worth of damage[14]. In some cities (e.g. Beira) >90% of infrastructure was lost.

Climate change predictions are severe for Mozambique's low-lying coast. Beach erosion, short-term sea-level rise, and seawater intrusion all have serious implications for coastal agriculture and fisheries. Estimates suggest that parts of the coastline could be eroded 500 metres inland, posing a serious threat to the densely populated areas (MER, 2015). Rising sea levels could cause losses of up to 4,850 km^2 (0.6% of the national land area) by 2040 (World Bank, 2010). Total annual damage losses in low-lying provinces such as Zambezia, Nampula, Sofala and Maputo are estimated to reach US$ 103 million yr^{-1} in 2040 with forced migration accounting for a large contribution of this cost (World Bank, 2010).

In terms of the cost of adaptation, the World Bank estimates the total investment required is approximately US$ 890 million yr^{-1} under a high sea-level rise scenario (World Bank, 2010). More economically viable adaptation options vary from US$ 190 million to US$ 470 million yr^{-1} depending on the climate change scenario used (World Bank, 2010).

Cyclone Idai hits the Mozambique coastline.
Source: Shutterstock / lavizzara

13 Global Facility for Disaster Risk Reduction country profile for Mozambique https://www.gfdrr.org/en/mozambique
14 https://www.africanews.com/2019/04/16/cyclone-idai-s-death-toll-stands-at-847-thousands-need-food-water-and-shelter/

Coral bleaching - Mozambique

Reef monitoring at the national level only began in Mozambique in 1999, after the first major coral bleaching event. In 1999, reefs covered 30-60% of Mozambique's coastline. In 2017, this figure had dropped to just 20-30% (Obura et al., 2017). Half of Mozambique's observed reefs exhibited medium to high levels of bleaching (>10%) during the global bleaching event in 2016 but mortality was low (< 10%) (Obura et al., 2017). The threats that climate change poses to reefs (e.g. increased seawater temperatures and terrestrial runoff after cyclones) is deemed to outweigh the impact of local communities (e.g. fishing) in Mozambique (McClanahan and Muthiga, 2017). Coral-reef related tourism is still relatively low in Mozambique, representing 0.47% of the country's GDP (Spalding et al., 2017). The benefits of coastal protection are also considered to be low in Mozambique (Beck et al., 2018). However, these statements could also reflect the paucity of data available. Substantial investment is needed in monitoring programmes in Mozambique in order to fully appreciate the economic costs and benefits provided by their reefs (Obura et al., 2017).

Fringing coral reefs dominate Mozambique's Quirimbas archipelago.
Source: Shutterstock / BlueOrange Studio

Harmful algal blooms - Mozambique

Nearshore coastal and pelagic marine surveys conducted in Mozambique have identified a variety of microalgal species that have the potential to cause HABs. These include including *Pseudo-nitzschia* spp. (the cause of Amnesic Shellfish Poisoning), *Alexandrium* spp. and *Gymnodinium* spp. (the cause of Paralytic Shellfish Poisoning), *Protoceratium* spp. and *Prorocentrum triestinum* (that produce red tides), and *Ostreopsis* spp. (the source of palytoxins associated with clupeotoxism, which causes gastrointestinal symptoms, and in severe cases, death) (Sá et al., 2013). However, few data exist about HAB occurrence, magnitude and/or frequency[15].

Mozambique does not currently have a public repository of the number of intoxications from seafood, nor does it identify the costs of illness, misdiagnosis or death (Tamele et al., 2019). Identifying such information will be paramount to managing the risks posed by climate change. In general, increases in coastal flooding events and/or the number of cyclones that hit the region increases nutrients levels, which together with increasing sea temperature are associated with increased HAB outbreaks in tropical areas.

15 Harmful Algae Event Database entry for Mozambique http://haedat.iode.org/eventSearch.php?searchtext[countryID]=105

Food security via fisheries and aquaculture - Mozambique

Mozambique's fisheries are of critical importance to national food security as about 50% of the population's protein comes from fish. The fisheries sector in Mozambique contributes an estimated 4% towards GDP, and represents 28% of foreign exports (Irish Aid, 2018). The value of Mozambique fishery exports was estimated to be worth US$ 60 million in 2014 (UNCTAD, 2017). The sector employs 95,000 people, with three to four times this number employed in the processing industry (Irish Aid, 2018).

Artisanal fishing typically contributes more to Mozambique's fishing sector than commercial fishing, with 85% of the country's fish catch being made up of small-scale fishermen (Irish Aid, 2018). Other segments in the sector include industrial and semi-industrial fishing. The latter, comprises mainly small trawlers involved in the domestic coastal shrimp fisheries. Semi-industrial fishing accounts for 2% of annual marine catches and 6% of the total value (Souto, 2014). Industrial fishing includes large vessels flagged in Mozambique and other countries, mostly targeting crustaceans such as coastal and deep-sea shrimp, which are usually processed at sea for export to Japan and Europe. This latter segment accounts for 7% of annual marine capture and 52% of total value (Oceanic Développement, 2014); 99.68% of the production is by capture. Despite Mozambique's aquaculture potential and the Government's efforts to promote the sector, it remains underdeveloped (Benkenstein, 2013).

Human health and diseases - Mozambique

Very little research work and surveillance of seafood-borne diseases has been conducted in Mozambique. Like for Kenya, the incidence of seafood diseases is difficult to estimate as most cases are reported and recorded as general diarrhoeal diseases, with little to no information about the specific pathogen responsible for the disease. Several infectious and diarrhoeal diseases are prevalent in Mozambique, including those resulting from *Vibrio* spp., *Campylobacteriosis jejuni, Clostridium* spp. (identified in Mozambique tilapia; Nol et al., 2004), Giardiasis, Rotavirus, Adenovirus, Hepatitis A/E, Salmonella and Shigella (Berger, 2018; Nhampossa et al., 2015).

Of the marine- and waterborne human infections that have been distinguished in the literature, cholera has received the most attention. In recent years, cholera outbreaks have been occurring almost every year, and have been reported in: Cabo Delgado, Gaza, Inhambane, Maputu City, Maputo, Nampula, Niassa, Sofala, Tete, and Zambezia (Berger, 2018). For example, the outbreak in 2017 resulted in 2,129 cases and four deaths[16]. Shortage of clean water and contamination of household drinking water further propagated the disease to other provinces. Severe flooding can also exacerbate the risk of cholera by displacing people and damaging infrastructure, including health facilities, which contributes to the spread of outbreaks. The projected increases in temperature and aridity forecast for Mozambique are likely to increase the spread of cholera in the future.

16 https://www.who.int/csr/don/19-february-2018-cholera-mozambique/en/

4.3 Impacts in Tanzania

The key national disaster risk policies in Tanzania include the National climate change strategy 2012, the Agriculture climate resilience plan 2014-2019, the Zanzibar Disaster Communication Strategy 2011, and the Zanzibar Disaster Management Policy, 2011[17]. The 2018 Disaster Risk Profile for Tanzania focuses on the risks from drought and flooding and does not specifically focus on ocean risk (CIMA, 2018).

Extreme weather events - Tanzania

Extreme weather events in Tanzania (flooding, droughts, cyclones, and tropical storms) have always imposed major economic costs on the country[18]. Individual annual events regularly cost Tanzania more than 1% of its GDP, reducing the country's capacity for long-term growth and placing millions of people and their livelihoods at risk (Worker and Excell, 2018).

Climate change is forecast to increase average annual temperatures by 1-2.7°C by the 2060s and by 1.5-4.5°C by the 2090s (Irish Aid, 2017). It is also anticipated to increase the intensity, frequency and unpredictably of extreme weather events in Tanzania. According to projections, the economic costs to Tanzania's main sectors could reach several billion US$ per year by the 2050s, inflicting net economic costs of a further 1-2% decline of GDP per year by 2030 (Global Climate Adaptation Partnership and partners, 2011). The economic costs associated with adapting, building adaptive capacity and enhancing resilience to potential climate-induced threats to coastlines is expected to cost between US$ 100-150 million per year (SEI, 2010).

Coral bleaching - Tanzania

Two-thirds of Tanzania's 1,000 km coastline is bordered by reefs. A World Resources Institute report on reefs at risk placed Tanzania among the 9 nations most vulnerable to reef degradation (Burke et al., 2011). According to this report, Tanzania has a low adaptive capacity, high reef dependence and high threat exposure.

For example, the 1998 bleaching event led to the loss of 80-95% of corals in Tanzania (Obura, 2002; Westmacot et al., 2000; Wilkinson et al., 1999). Economic losses to the dive industry in Zanzibar alone were estimated to be US$ 2.2 million in (Brown et al., 2011). A small decline in coral cover has been observed over the past 30 years, but has now stabilised at 35-40% (Obura et al., 2017). Some algae has been observed, which should be monitored in the future (Obura et al., 2017).

As of 2017, over 14 million Tanzanian's live in coastal regions and many of them earn their livelihood through direct or indirect connections to the reef. Tourism's economic contribution in Tanzania is relatively small, providing 0.34% of GDP, about US$ 180 million per year (Spalding et al., 2017). By contrast, one big reef-dependent industry in Tanzania is the seaweed aquaculture industry. Tanzania (Zanzibar specifically) is in the top eight countries for seaweed cultivation contributing 132,000 tonnes (0.7%) to the global production. This industry employs some 25,000 workers, the majority of which are women. Seaweed farming is only possible inside the lagoons created by coral reefs, within a narrow band of the coast, some 380-600m from the shoreline (Hedberg et al., 2018). The loss of coral reefs has the potential to disrupt this profitable industry.

17 https://www.preventionweb.net/english/countries/africa/tza/

18 Global Facility for Disaster Risk Reduction country profile for Tanzania https://www.gfdrr.org/en/tanzania

Harmful algal blooms - Tanzania

More than 20 potentially harmful algal species have been identified in the coastal waters of Tanzania (Kyewalyanga and Lugomela, 1999; Lugomela, 2006). Dominant species cover three groups associated with costly HAB events in other countries; cyanobacteria (*Trichodesmium* sp. and *Lyngbya* sp) diatoms (*Pseudo-nitzschia* sp.) and dinoflagellates (*Prorocentrum* sp. and *Gambierdiscus toxicus*) (Kyewalyanga and Lugomela, 1999; Lugomela, 2006).

HABs harm both seaweed production and farmers in Zanzibar. In February and March 2012, a cyanobacterial bloom of algae belonging to the genus *Lyngbya* stopped work in the seaweed farms in two villages in Zanzibar (IOC-UNESCO, 2016). *Lyngbya* produces several cyanotoxins, which have irritant, dermatoxic, inflammatory and neurotoxic effects and is also associated with the seafood poisoning syndrome clupeotoxism (Bláha et al., 2009; Said et al., 2018; Zanchett and Oliveira-Filho, 2013). A survey found that more than half of the seaweed farmers in Zanzibar and mainland Tanzania had suffered health problems. Fifty per cent experienced skin irritation (>120 cases), 30% (>72 cases) eye-related problems, and 20% (48 cases) had respiratory disorders (Said et al., 2018). The highest occurrence of skin irritation cases was prevalent during the warmer seasons, which resulted in lost income and productivity for these farmers. The economic burden of illnesses has not been calculated, but is likely to contribute to a decrease in seaweed productivity, harvest and income (Said et al., 2018). Farmer's children have also shown signs of health problems, which may stem from exposure during seaweed drying and preparation at home (Said et al., 2018).

Women seaweed farmers in Zanzibar face health problems arising from growing numbers of cyanobacterial blooms in seaweed farms.

Source: Imke.stahlmann / Flickr (CC BY-SA 2.0)

Food security via fisheries and aquaculture - Tanzania

Tanzania may be one of the poorest countries in the world, but it has one of the richest marine and inland fisheries, mainly because of its 1,424 km long coastline and productive inland lakes (Yusuf et al., 2015). The fishing sector plays an important role in the coastal economy of Tanzania, as well as enhancing the country's food security and local livelihoods. Small-scale fisheries in Tanzania account for 98% of total fish production and 1.3% of GDP, or US$ 12.4 million[19]. Although the contribution of small-scale fisheries to the GDP appears somewhat marginal, this sector is a vital source of food, employment and income for coastal communities (ASCLME, 2012b), supporting more than 4,000,000 Tanzanians (Sigalla, 2014). Since 1998, there has been a steady decline in the contribution of the fisheries sector to Tanzania's national GDP. This could be related to climate change and environmental degradation, decreases in fish catches, over-participation in fishing related activities, changes in species distribution and/or increases in population (Sobo, 2012).

Limited information is available on the economic costs and losses of the entire fisheries sector for Tanzania, but some information does exist on the costs and losses endured by discreet sectors such as the country's seaweed farming industry. Seaweed production for example, has fallen dramatically from 423.9 tonnes worth US$ 82,000 in 2003, to just 28 tonnes worth US$ 4,300 in 2012 due to a combination of factors linked to increasing sea temperature, epiphytic growth, including of HABs, caused by increasing sea temperature and eutrophication and disease (Msuya and Porter, 2014).

Human health and diseases - Tanzania

Several infectious and diarrheal diseases are prevalent in Tanzania, including those caused by *Campylobacter, Salmonella, Shigella, Vibrio cholerae*, Rotovirus, *Escherichia coli*, *Giardia*, Hepatitis A and intoxication biotoxins produced by HABs (ReliefWeb, 2018).

Regarding cholera, the WHO (2018) reported that 47% out of 7,000 specimens that were tested for cholera stemmed from the marine-borne *Vibrio* bacteria. Most cases that occur are reported on the coast, with five coastal regions in Tanzania among the top-eight regions by the number of cases per capita (Taylor et al., 2009 cited in Mboera et al., 2011). In 2018 alone, 66 deaths from cholera were reported (Reliefweb, 2018).

The magnitude of costs and losses resulting from cholera (attributed to climate change) is significant and considerably higher than many of the budgets currently allocated for diarrhoeal diseases in developing countries (Trærup et al., 2011). An increase in temperature of 1-2 °C is estimated to increase the risks of catching cholera in Tanzania by 29%. This would mean there would be an additional 7,809 deaths. The total cost of climate change-induced changes in cholera is expected to range from 0.32 to 1.4 percent of GDP in Tanzania by 2030 (including costs of treating the sick, productivity losses and the value of lost lives (Trærup et al., 2011). With marine-borne bacteria accounting for just under half of the cases of cholera, further monitoring is required to evaluate the incidence and prevalence of cholera cases from the marine environment and study the effects of a changed ocean environment on these figures.

19 https://iwlearn.net/resolveuid/aa54393d9cd045d7b692d629263840fa

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5. What do we still need to know?

It is clear from the global and regional observations in this report that ocean risk is material. For many hazards, impacts are increasing (IPCC, 2019; UNDRR, 2019). However, more in-depth assessment is needed to inform policy makers, investors, insurers, and communities about the substantive and rising costs of these impacts for developing countries and ocean risks to economic and subsistence activities.

5.1 Extreme weather events

What we do know is that there is plenty of information about the hazards and consequences of ocean warming for extreme weather (IPCC, 2019; UNDRR, 2019). However, when it comes to the actual figures for costs and losses of these events, information, depending on the spatial scale, sector, region and/or geographic location, is fairly disperse or in some cases not existent. For example, information regarding such costs and losses are more readily available from developed nations than developing nations and even then, the detail can be somewhat lacking.

We are also more likely to find information on the economic costs and losses of specific and discreet single extreme weather events (e.g. for a hurricane, cyclone and sea-level rise incidences) than at the global level. Sector breakdowns on economic costs and losses are dispersed and more so for developing nations, possibly due to a lack of systemization of data collection. Indeed, impacts on the informal or undocumented economy, as well as indirect effects, can be very important in some areas and sectors, but are generally not counted in reported estimates of losses. This may be more relevant for information from developing nations.

A particularly important cost that is missing is the cost of adaptation. When it comes to loss of human lives, limited information is available as to what makes up the economic costs that are associated with these lives lost, e.g. costs of hospitalization, costs of emergency and disaster responses, and other related costs. Loss of human life as well as loss of cultural heritage and ecosystem services, are also difficult to measure and monetize, and thus are also poorly reflected in estimates of losses. Such 'cost items' are often referred to as intangibles in contrast to tangibles such as tradable assets, structures, and infrastructure; although specific costs to property and infrastructure do not seem to be covered systematically and perhaps at best are covered for single extreme weather events. Information on costs and losses for these tangible assets is likely to inform insurance companies around the costs to insure for extreme weather events.

In terms of other costs to society where there is limited information, one can include costs to income that seem to be covered by costs to GDP or national income. Costs to corporate earnings (when disclosed) are also sometimes given for discreet extreme weather events although not in much detail. There is also little quantitative information available on operational costs as a result of the direct impact of extreme weather events caused by ocean warming. As regards costs to sectors, whilst some disparate information is available at the regional and national level for the tourism and agriculture, limited or very little information is

available for other sectors like energy, transport, telecommunications and construction. These would need to be determined so we can fully appreciate the severity of extreme weather events on these sectors resulting from ocean warming.

In order to fully appreciate the full range of economic impacts of extreme weather events that are caused by the onset of ocean warming, it is clear that more data collection needs to happen – not only at the global level, but also at the national level, particularly for developing countries. Specifically, more data on economic impacts and costs need to be collected or indeed determined through economic valuation methods across all affected sectors as well as for more intangible assets including cost to life, costs to ecosystem services, etc. Gaps need to be filled in for the assessment of tangible assets from property to infrastructure which could be further enabled by insurance companies, who could, in turn, also elaborate more on the costs to repair and insure. Costs to income can be specified more than via measurements of GDP, with further research applied to the informal economy.

5.2 Coral bleaching

Solid and cutting-edge research on the impact of climate change on coral reefs is essential in order to provide the best advice and solutions for the survival of these 300 million years old rainforests of the sea. Global funding of research has been increasing as the number of publications related to coral reef and climate change have increased. In a UN report, however, only US$ 19.3 million were identified as invested in research. No one for now is investing sufficiently in the research needed for reef surveys to provide long-term data and for the development of innovative ideas to maintain reef health.

With an increase in intensity of the threats to coral ecosystems, research efforts need to be funded. Unfortunately, the amount of funding for this essential research seems to have diminished in some of the most relevant institutions. For example, the Centre of Excellence for Coral Reef Studies (James Cook University in Townsville, Australia), which is a leading authority in terms of coral research and coral health will lose most of its government funding (-37%) after 2021 (Morton, 2018).

Reef countries are already adapting and will have to adapt even further to increased reef degradation. Not all reef nations are facing the same challenges, as some nations are more dependent on the reef for livelihoods and their economies than others. Most countries with a very low adaptability to reef degradation are classified as Least Developed Countries (LDCs) and/or have a recent history of conflict, such as Mozambique, Tanzania, Somalia, Eritrea, Sudan, Timor-Leste, Bangladesh and Yemen. International help and project funding should consider these vulnerable nations and put priority in helping such countries to assess and understand their economic dependence on the reef economy, as well as to reduce the different local threats to their coral reefs.

The frequency of coral bleaching events has increased so that there is insufficient time for recovery between events (IPCC, 2019; UNDRR, 2019). It is therefore essential to understand the cost of increased bleaching frequency and reduced recovery time to ensure that ocean risk management accounts for potential cascading effects of ocean warming and ocean acidification on marine ecosystems, fisheries and food security.

5.3 Harmful algal blooms

The research gaps regarding the impact of HABs on society are significant. Comprehensive and coordinated data collection and storage across affected sectors and communities needs to be facilitated. To do this effectively, data need to be characterised in order to assess the economic, public health, and sociocultural impacts of HAB events on local and regional scales using standardised approaches and units to facilitate aggregation.

Both sociocultural and economic impacts of HAB events at local and regional scales need to be more systematically and thoroughly assessed. There is a need to assess the vulnerability of actual and potential HAB-affected communities to sociocultural and economic impacts of HAB events. Due to the specialist knowledge, equipment and training needed to identify and monitor biotoxins, toxicity and attribute HABs to seafood poisoning, there is a need for increased collaboration between HAB specialists and healthcare workers.

Modelling of extreme events under a changing climate, including localized definitions of critical climate thresholds that may exacerbate HABs in the future, is required in order to better inform disaster management response. This needs to include nutrients (N, P, Si, Fe), stratification, turbulence, turbidity, pH, dissolved oxygen and specific data related to key potential HAB species as all these factors can influence toxicity of HABs and the risk of seafood poisoning. Coastal zone mapping, and vulnerability baselines are also needed to support future environmental impact assessments and guide new developments.

Information is needed on HAB events including red tides, wildlife strandings, fish kills and seafood related illness. Investigations, perhaps on behalf of insurance companies, are needed on risks to health and fisheries, especially for export produce.

It may be possible that salt workers, larger aquaculture facilities and commercial fisheries have data and records related to HABs. This needs to be further investigated. Furthermore, the medical community, hospitals and health ministries may have additional information on HAB effects related to seafood poisoning, contaminated drinking water or from other routes of exposure. In addition, the harbours and ports may have initiatives related to ballast water that can be documented or costed. The trend toward increasing desalination for drinking water supply also introduces the risk of desalination plants being exposed to biofouling and potential contamination of drinking water by biotoxins. This will require special consideration in the location and design of such plants.

In Kenya, Mozambique and Tanzania, the extensive costs from storms, drought, flooding and disease results in harmful algal blooms receiving less attention. However, the cost of HABs caused by cyanobacteria can increase as a result of drought and flooding, and are a known problem for livestock and wildlife, and for inland fisheries in Kenya and Tanzania. Marine HABs related to seafood poisoning require additional attention particularly given the occurrence of seafood poisoning events in other Western Indian Ocean nations.

5.4 Food security via fisheries and aquaculture

What we do know is that there is plenty of information about the hazards and consequences of ocean warming on fisheries as well as the subsequent impacts on food security connected with this sector. Interestingly, and perhaps as to be expected, whilst marine capture fisheries will experience negative effects from ocean warming, the aquaculture subsector is likely to experience a more positive effect owing to increased growth rates, amongst others. In East Africa, freshwater fisheries are currently larger and better documented than marine fisheries, making the quantification of cost difficult.

However, when it comes to the actual figures for costs and losses of these events, information (depending on the spatial scale, sector, region and/or geographic location) is fairly disperse or in some cases not existent. For example, information regarding such costs and losses are more readily available at the national level rather than the global level. At the same time this information typically comes from developed nations more than developing nations and even then, the detail can be somewhat lacking.

Some ocean risk areas that have been identified are lacking in information about related economic costs and losses. For example, when it comes to costs to lives and livelihoods, the information found typically only covers the decrease in household income that occurs as a result of the impacts of climate change and ocean warming on the decline of the marine capture fisheries sector. Limited information is available regarding the health costs associated with the decline of food security and loss of life. At the same time, limited information is available on the cost to lives and livelihoods for the aquaculture sectors, perhaps because for now, there are none. There is only benefit to life and livelihoods.

For some sectors, limited information exists on economic costs and losses; these include those associated with changes in marine biodiversity and ecosystem services in the fisheries and aquaculture sectors. This also encompasses costs associated with predator-prey interactions, changes to biodiversity from altered fishing and impacts on predatory species. Like costs associated with livelihoods and life, these are difficult to measure and monetize – although some estimates have been made - and thus they are also poorly reflected in estimates of losses.

In terms of grounding these costs to society at the national level within the three African countries presented - Kenya, Tanzania and Mozambique – some information is available on the contribution of fisheries to each of the country's GDP, annual landed value, export and import value and the number of jobs - most likely formal jobs - the sector provides both directly and indirectly. However, there is limited information for all three countries on the economic costs and losses of climate change and ocean warming on their fisheries sectors.

In order to fully appreciate the full picture of the economic impacts of ocean warming on the fishery sector – both marine capture and aquaculture – more data collection needs to happen – not only at the global level but also at the national level, particularly for developing countries. Specifically, more data on economic impacts and costs need to be collected and determined through economic valuation methods. These costs could also be grouped into more general categories, such as costs and losses associated with biodiversity, livelihoods, industry/business, other sectors and adaptation. It will also be essential to enable future data collection on the impacts of ocean warming connected to the informal economy relevant to subsistence fishing.

5.5 Human health and diseases

Global data on both the economic and health burden resulting from marine-borne illnesses are incomplete. This makes it difficult to attain a complete and global understanding of 1) the distribution of human pathogens through the marine food chain, 2) the transmission of these pathogens to humans, resulting in human disease, and 3) the impacts of a changed ocean climate on the transmission and incidence of human illness.

For example, while several studies exist on human pathogens in seafood (particularly shellfish), they are limited to select geographical areas, (usually developed countries, including the USA, Australia and European countries). They also focus on the most-known/monitored bacteria and viruses – usually those with the largest human health and market impact those which cause severe illness or mortality and/or those derived from commercial species (e.g.

oysters), including for example, *Vibrios* and Norovirus.

Further, monitoring and surveillance of illnesses from marine pathogens and toxins that cause mild, non-fatal symptoms – although common – continue to be underreported and under-studied, making it difficult to quantify: 1) the true incidence and human health impact, and 2) the costs and losses of these diseases on human health, globally and locally. For example, while evidence suggests that the health burden of illnesses contracted through recreational or occupational marine activities is significant, the challenge of monitoring these cases (most of which go unreported or can result in minor symptoms) confounds global and local incidence and cost analysis.

Moreover, calculating the global health burden and losses associated with specific marine-borne pathogens is a challenge due to the fact that the incidence of most marine-borne illnesses with diarrhoeal symptoms are generically reported as such, with little monitoring or misunderstanding of the specific etiology or pathogen that caused the illness or infection to begin with.

Importantly, it is also difficult to obtain estimates for indirect healthcare costs. Non-market values (such as health promotion and psychological benefits are underrepresented in local and global economic assessments, likely due to the lack of standard valuation methods for such non-market values (Legat et al., 2016).

Specific topics which merit further research include the following:

- **Morbidity and non-fatal injuries from climate related events –** Several previous studies quantify the impact on global mortality (using event-based models or average mortality models) from coastal floods and extreme storm events. However, few document the health burden and losses related to global morbidity, disease, non-fatal injuries, mental health impacts or the indirect health impacts resulting from the downstream effects of coastal climate events, such as: forced migration or displacement, reduction in fisheries and food quality (leading to malnutrition), violent conflicts and loss of recreational or occupational activities. Further research on the human health impacts of these downstream impacts, particularly in developing countries, is required.

- **Anthropogenic pollution and human health impacts** – There is a significant data gap regarding the costs and losses resulting from human illness associated with anthropogenic contaminants coming from the marine environment – and how these could change/increase in the face of a changing ocean climate. While anthropogenic contaminants have the potential to impact human health (primarily through the consumption of contaminated seafood), there is little documentation reporting the incidence of human illnesses (short-term and long-term) resulting specifically from the consumption of seafood containing synthetic chemicals, heavy metals, and microplastics. Given the prevalence of pollutants and plastic debris found in seafood, fish and bivalves sold for human consumption (Barboza et al., 2018), the nutritional importance of seafood consumption worldwide, addressing these research gaps is of critical priority.

- **Coastal governance and human health and disease –** Although not directly addressed in this Report, further research should be devoted to understanding the impact of coastal governance structures on the incidence of human disease. It would be particularly useful to identify the types of governance structures that have managed to implement effective monitoring, adaptation and mitigation strategies to reduce ocean risks to humans, particularly in the context of limiting the incidence and prevalence of marine-borne disease outbreaks.

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6. Opportunities

6.1 Economic risk

The IPCC Report on the Cryosphere and Oceans has highlighted the likelihood of significant increase in cost from ocean risks under all climate change scenarios (IPCC, 2019). These projections attempt to quantify costs of both action and inaction but also reinforce the gaps in economic data. Mitigation and adaptation measures were reported to be far less costly than the loss and damage resulting from inaction (IPCC, 2019). The 2019 Global Assessment Report on Disaster Risk Reduction highlighted the high costs of disasters and the low investment in disaster risk reduction (UNDRR, 2019). The World Bank, other multi-lateral platforms and the reinsurance industry are helping to understand and identify solutions to the challenges of addressing ocean risk (Laffoley et al., 2018; Niehörster et al., 2018).

To mitigate the economic risk of plastic pollution, policy makers and businesses should examine various guidance, tools, interventions, and instruments. Guidance on how to find and measure plastic pollution hotspots, such as the National Guidance for Plastic Pollution Hotspotting and Shaping Action (United Nations Environment Programme, 2020), can assist policy makers to understand the risks of plastic pollution and provide them with interventions and instruments on which to act (IUCN-EA-QUANTIS, 2020). Opportunities to address negative economic impacts of plastic pollution include Deposit Refund Schemes, incentives to better manage solid waste, investment in the informal sector, and circular economy business models (IUCN-EA-QUANTIS, 2020, Raes, et al, 2021).

6.2 Partners

Multilateral and national agencies - funding and implementing disaster risk reduction, poverty reduction, public health and sustainable development - all need to be involved in national or regional-level talks on ocean risk. High-level government officials may be required to provide the mandate for the necessary legislative framework and policies; however, local government, private sector partners, academia and civil society are key to achieving effective implementation. Several partnerships to support disaster risk reduction, ecosystem-based adaptation and nature-based solutions exist and could contribute to improving the consideration of ocean risk including:

- Blue Carbon Initiative (BCI)[20]
- Blue Solutions[21]
- Friends of Ecosystem-based Adaptation (FEBA)[22]
- Global Resilience Partnership
- International Partnership on Blue Carbon (IPBC)
- Ocean Risk Alliance[23]

20 www.thebluecarboninitiative.org
21 www.bluesolutions.org
22 www.iucn.org
23 www.oceanriskalliance.org/

- Ocean Unite[24]
- Panorama[25]
- Partnership for Environment and Disaster Risk Reduction (PEDRR)[26]

The Rio Conventions (e.g. United Nations Conventions on Biological Diversity, Climate Change and Combating Desertification) and other biodiversity-related conventions (e.g. CITES, Ramsar, UNESCO World Heritage Convention), also represent opportunities to incorporate ocean risk into the implementation of strategies and plans.

Successful DRR and CCA case studies repeatedly show the importance of participatory approaches that engage and empower a wide range of stakeholders (UNDRR, 2019).

6.3 Capacity

The capacity to monitor changes in ocean-related economic trends requires strengthening. This is particularly the case in order to attribute economic consequences to specific events. Improved understanding of the interaction between ocean hazards, exposure and vulnerability is required. This is best achieved through comprehensive risk assessment with the specific aim to incorporate ocean risk into the sustainable development agenda, such as through the Blue Economy. Issue-specific international capacity development mechanisms, instruments and supporting agencies include the following:

- Extreme weather: FAO, WMO, UNDRR (Database: EM-DAT)
- Coral bleaching: CORDIO, International Coral Reef Initiative (ICRI), Global Coral Reef Monitoring Network (GCRMN), Reefbase[27], UNEP, IOC-UNESCO
- Harmful Algal Blooms: IOC-UNESCO, WoRMS, ICES, PICES, IAEA and ISSHA (Database: HAEDAT[28])
- Fisheries, aquaculture and food security: FAO, WFP
- Health and disease: FAO, WHO, UNDRR (Database: Global Health Observatory[29])

6.4 Integrated approach to implementation

For some hazards, particularly extreme weather events, nature-based solutions have begun to be integrated into national strategies and approaches to disaster risk reduction (EcoDRR) and climate change adaptation (EbA). However, many ocean risks have not yet been systematically included in these initiatives.

Protected Areas and area-based conservation measures, such as locally managed marine areas, represent opportunities to achieve multiple biodiversity conservation benefits and nature-based solutions to help address development challenges. For example, recognising Blue Carbon in marine spatial planning and integrated coastal zone management is key to gaining multiple benefits from mangrove and seagrass conservation as part of ecosystem-based adaptation, climate change mitigation and disaster risk reduction. Other actions that can contribute to a more integrated approach and good governance include:

24 www.bluecarbonpartnership.org
25 https://panorama.solutions/en
26 https://pedrr.org/
27 http://www.reefbase.org/global_database/default.aspx?section=t4
28 http://haedat.iode.org/browseEvents.php
29 https://www.who.int/data/gho

- Adopt a dedicated policy and plan.
- Fully use existing legal frameworks, including SEA and EIA.
- Promote inter-agency and cross-sectoral coordination.
- Strengthen institutional capacity at all levels.
- Monitor and promote implementation and compliance.
- Adopt measures to ensure accountability, transparency, participation, and access to justice.
- Collect and share scientific information and standardised data.
- Engage communities, the private sector and the public.
- Align incentives for conservation, sustainable use and maintaining ecosystem services.
- Consider indirect and underlying drivers of ocean risk at national and transnational levels.

6.5 Financing

A key challenge for disaster risk reduction in general is to secure the necessary financing to design and implement effective mitigation measures. This also holds true for ocean risk. This is, in part, because the immediate costs of such measures are apparent and visible whereas the core benefits from these expenditures, and indeed the distribution of these benefits, are unclear and distant. Hence, risk mitigation always struggles to secure the funding needed.

One way to address this public budgeting dilemma is to identify, enhance, and communicate the potential co-benefits of disaster risk mitigation measures.[30] With respect to ocean risks, investments in mitigation measures may also generate more immediate co-benefits, which may be attractive to budgetary decision-makers as well as to the general public. These could include strategic objectives, such as:

- Improved governance and more organized social structures.
- Delivery of basic necessities (e.g. potable water, drainage, sewerage, power, and community facilities).
- Enhancing access to telephony and electronic data services.
- Reducing vulnerability to poverty.

In addition, there are several financing mechanisms which could be approached for funding ocean risk mitigation programmes. These include the following:

- Blue Action Fund[31]
- Blue Natural Capital Financing Facility[32]
- Global Risk Financing Facility[33]
- Green Climate Fund[34]
- UN REDD Programme[35]

30 http://documents.worldbank.org/curated/en/746741467986362487/pdf/WPS7633.pdf
31 https://www.blueactionfund.org/
32 https://bluenaturalcapital.org/
33 https://www.worldbank.org/en/topic/disasterriskmanagement/brief/global-risk-financing-facility
34 https://www.greenclimate.fund/
35 https://www.un-redd.org/

6.6 Ocean risk assessments

The review of ocean risk cost information available from Kenya, Mozambique and Tanzania highlighted the general unavailability of cost data to inform decision making. Carrying out ocean risk assessments could contribute to filling this gap by providing local decision-makers with the tools to help disaster risk reduction and climate change adaptation. Initial discussions - at the national level in Mozambique and county level in Kenya -suggest that there is an appetite to integrate ocean risk, blue carbon and other aspects of risk reduction and climate change adaptation into activities on the Blue Economy.

Key steps towards ocean risk assessments include:

- Embedding assessments into government administration.
- Identifying sustainable financing to carry out assessments and subsequent recommended actions.
- Identifying ocean hazards (and predicted change and variations).
- Documenting natural, cultural, and economic assets/capital exposed to ocean hazards including the Blue Economy.
- Triangulation of knowledge using participatory ocean risk mapping, geospatial data and public education to inform exposure maps.
- Analysing vulnerability and resilience.
- Incorporating recommendations into government strategies, plans and procedures.

In March 2020, IUCN organised a Western Indian Ocean Dialogues meeting that addressed two key topics – acting on ocean risk and accounting for blue carbon – in national and coastal perspectives. Taking the issues down to county level for Kenya, one of the outputs from the meeting was a map of perceived risks for the Kenyan coastal zone (see Figure 9 below).

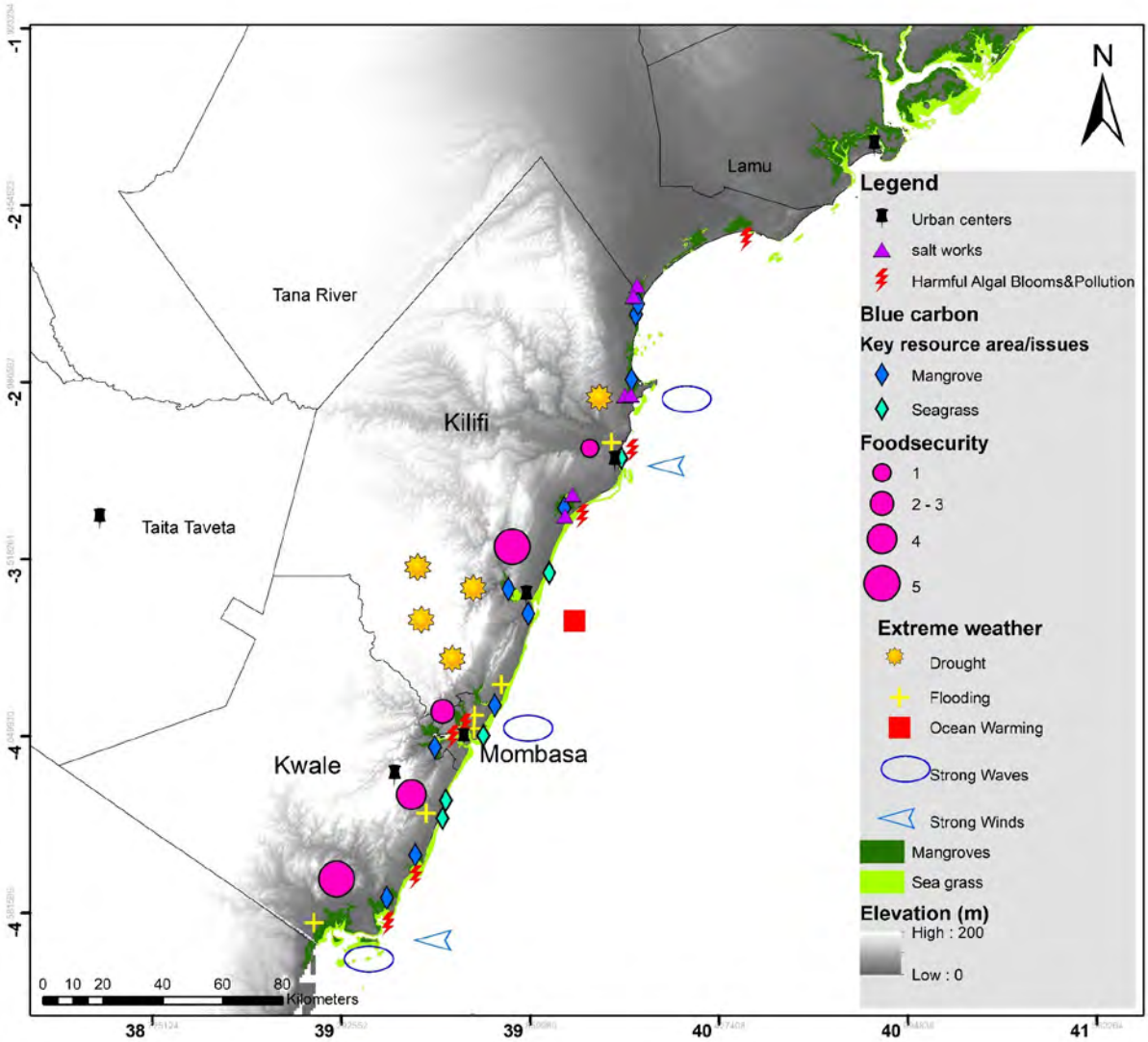

Figure 9: Perceived risk map for Kenyan coastal counties.

Source: CORDIO 2021

Source: Shutterstock / Yusnizam Yusof

7. What can be done?

Filling the knowledge gaps on the costs from ocean risks is essential and also requires gaining a deeper understanding of the interactions between natural and technological hazards (e.g. industrial pollution, toxic wastes, dam failures, transport accidents, factory explosions, fires, and chemical spills) in the face of climate change. IPCC and UNDRR have identified the complexities and interactions between multi-hazard events and cascading risks but this work has not focused on ocean risks and the Blue Economy. Natural hazards interact with technological (and geo-political) events to produce a complex risk landscape.

Most recently, the biological hazard the SARS CoV-2 virus, causing the devastating COVID-19 Pandemic, has highlighted the complex interactions between the initial biohazard and the cascading effects on economies and human well-being. This public health event has escalated into an economic shock triggering various technological hazards such as air transport and trade interruption. Ocean risks also interact with multiple hazards to expose communities and assets with poorly quantified costs to human systems and ecosystem services. Factoring uncertainty into ocean risk assessment is a significant challenge for the Blue Economy, climate change mitigation and adaptation, and disaster risk reduction.

Ocean risk is material. The livelihoods of coastal communities are at risk. National economies are at risk. Sustainable development globally is at risk. Nevertheless, our understanding of these risks and their implications for humanity is terribly limited. Most worrying is that this lack of understanding results in little, if any, efforts to mitigate these risks in order to reduce or remove the potential damage from ocean change.

This Report is intended as a wakeup call. We need to start to take ocean risk seriously and for our governments to lead a multi-stakeholder process to first assess these risks and to then to develop strategies and implement action plans to mitigate these risks.

We hope that this Report will stimulate national governments – including the three Western Indian Ocean countries highlighted in the report – to begin to act now by starting national dialogues on ocean risk leading to assessments, strategies, and action plans to mitigate these risks as part of activities on the Blue Economy. The International Union for Conservation of Nature – its Members, its Commissions, and its Secretariat – stands ready to assist and encourage national governments to act on ocean risk.

Source: Shutterstock / Caio Pederneiras

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INTERNATIONAL UNION
FOR CONSERVATION OF NATURE

WORLD HEADQUARTERS
Rue Mauverney 28
1196 Gland
Switzerland
Tel +41 22 999 0000
Fax +41 22 999 0002
www.iucn.org