Chapter 7

# Oceans and Coasts

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# Executive summary

**Human pressures on the health of the oceans have continued to increase over the last decade, in concert with the growing human population and the expanded use of ocean resources** (*well established*). Multiple stressors give rise to cumulative impacts that affect the health of marine ecosystems and diminish nature's benefits to humans. However, there has been success in the management of some pressures, with concomitant improvements in ocean health, and these provide lessons on which to build. Out of numerous existing pressures we have selected three for particular attention in this Global Environment Outlook (GEO-6) assessment: bleaching of coral reefs; marine litter; and challenges to achieving sustainable fisheries in the world's oceans. {7.1}

**Tropical coral reefs have passed a tipping point whereby chronic bleaching has killed many reefs that are unlikely to recover even over century-long timescales** *(well established)*. Coral bleaching is due to warming of the oceans, which is in turn, attributed to anthropogenic emissions of green house gases (GHGs; especially $CO_2$) since the industrial revolution. Ocean warming lags behind GHG emissions by several decades, such that the tipping point for coral reef bleaching was passed in the 1980s when atmospheric concentration of $CO_2$ exceeded about 350 parts per million (ppm). {7.3.1}

**Reef bleaching events now have a recurrence interval of about six years, while reef recovery rates are known to exceed ten years** (*established but incomplete*). This means that, on average, reefs will not have sufficient time to recover between bleaching events and so a steady downward spiral in reef health is to be expected in coming decades. The oceans SDG target 14.2 "by 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans" may not be attainable for most tropical coral reef ecosystems. {7.3.1}.

**There is evidence that reef death will be followed by loss in fisheries, tourism, livelihoods and habitats** (*inconclusive*). The demise of tropical coral reef ecosystems will be a disaster for many dependent communities and industries, and governments should, over the next decade, prepare for the eventual collapse of reef-based industries. The contributions provided by coral reefs have collectively been valued at US$29 billion, which includes their value to tourism, fisheries and coastal protection. Losses to these sectors have not yet been documented but there is significant risk that losses will occur over the next decade. {7.4.1}.

**Fisheries and aquaculture are estimated to be worth US$362 billion in 2016, with aquaculture contributing US$232 billion** (*established but incomplete*). Mariculture is expanding but most of the increase is in aquaculture, especially inland aquaculture (*established*). Aquaculture provides more than 10 per cent of the total tonnage of fish production and this proportion is increasing. Together fisheries and aquaculture support between 58-120 million livelihoods, depending on how part-time employment and employment in secondary processing is counted. The large majority of livelihoods are provided by small-scale fisheries and this has been stable for over a decade, yet commercial harvesting accounts for the large majority of commodity value, including more than US$80 billion per year exported from developing countries to international markets. {**Table 7.1**, 7.3.2}.

**Fish, high in protein and micronutrients important for health, currently provide 3.1 billion people with over 20 per cent of their dietary protein, with higher proportions in many areas of the world where food insecurity is widespread** (*established but incomplete*). To meet future challenges of food security and healthy populations, in addition to using all natural products harvested for food more efficiently, more fish, invertebrates and marine plants will have to be taken as food from the oceans and coasts, so both capture fisheries and aquaculture are expected to expand. {7.5.2}.

**It is possible to keep capture fisheries sustainable, but this requires significant investments in monitoring, assessment and management and strong local community-based approaches** (*established but incomplete*). Likewise, sustainable aquaculture requires knowledge and care in management of operations. {7.6}.

**Reviews show wide variation among countries in the sustainability of their fisheries and aquaculture, with factors such as overall wealth to invest in fisheries research and management, while avoiding capacity-enhancing subsidies, strongly affecting the ability to keep large-scale fisheries sustainable** (*established but incomplete*). For small-scale fisheries coherence of the social structures and cultural practices that promote effective community self-regulation strongly affect sustainability. {7.5.2}

**The ecosystem approach to fisheries has been widely adopted in national and regional policies and operational guidance on actions to manage the footprint of fisheries has been provided by the Food and Agriculture Organization of the United Nations (FAO)** (*inconclusive*). Despite the acknowledgement of the large footprint of fisheries on marine ecosystems and its full uptake in policy, measures to minimize the ecosystem effects of fishing have had mixed success. However, as with sustainability of exploitation of target species, in general the ecosystem footprint of by-catches, discards and negative habitat impacts of fishing gear is declining in the parts of world with sufficient economic resources to invest in fisheries monitoring and gear technologies that improve selectivity of harvest and reduce habitat impacts. This approach is also being applied in aquaculture, with comparable objectives and rapid uptake by the industry. {7.4.2}

**The amount of marine litter continues to increase – an estimated 8 million tons (Mt) of plastics enters the ocean each year, as a result of the mismanagment of domesic waste in coastal areas** (*established but incomplete*). Marine litter has been found at all ocean depths. Without intervention, the quantity of plastic in the ocean is expected to increase to 100-250 Mt by 2025. {7.3.3}.

**Plastic particles are increasingly being found in the digestive systems of marine organisms including fish and shellfish consumed by humans** (*established but incomplete*). The human health risks of ingesting seafood contaminated with plastic are unclear. There is well-documented evidence of physical damage to marine organisms from both entanglement in marine litter and ingestion of plastic. Some plastic contains potential toxins and can also adsorb and concentrate toxic substances from the surrounding seawater. However, there is currently no evidence of serious toxic effects to marine biota from these pollutants. Marine litter can also provide a means of transport for the spread of pathogens and invasive species (*well established*). {7.4.4}.

**The economic, social and environmental costs of marine litter are continually increasing and include the direct economic costs of clean-up and loss of revenue from industries such as tourism and fishing** (*unresolved*). Social and health costs are more difficult to quantify beyond local scales, as are environmental costs such as reduction in ecosystem function and services. {7.4.4}.

## 7.1 Introduction

The world's oceans comprise more than 70 per cent of the Earth's surface. More than 1.9 billion people lived in coastal areas in 2010, and the number is expected to reach 2.4 billion by 2050 (Kummu *et al.* 2016). Twenty of the 30 megacities[1] are located on coasts, and these megacities are expected to increase in population faster than non-urban areas (Kummu *et al*. 2016). The three fastest-growing coastal megacities are Lagos, Nigeria (4.17 per cent population growth rate), Guangzhou, China (3.94 per cent) and Dhaka, Bangladesh (3.52 per cent) (Grimm and Tulloch eds. 2015).

### 7.1.1 Welcome to the ocean

The health and livelihoods of many people are directly linked to the ocean through its resources and the important aesthetic, cultural and religious benefits it provides. Seafood provides at least 20 per cent of the animal protein supply for 3.1 billion people globally (Food and Agriculture Organization of the United Nations [FAO] 2016a). This is particularly important for economically disadvantaged coastal areas and communities. Coastal ecosystems also provide numerous benefits not readily monetized, such as coastal stabilization, regulation of coastal water quality and quantity, biodiversity and spawning habitats for many important species. The ocean is an integral part of the global climate system (Intergovernmental Panel on Climate Change [IPCC] 2013), contributing to the transport of heat, which influences temperature and rainfall across the planet. About 50 per cent of global primary production occurs in the ocean (Mathis *et al.* 2016). The ocean also provides a reservoir of additional economically important resources such as aggregates and sand, renewable energy and biopharmaceuticals. However, people, their livelihoods and the many indirect benefits the ocean provides are being affected by the deteriorating health of marine and coastal ecosystems, from causes including pollution, climate change, overfishing, and habitat and biodiversity loss.

By definition a healthy ocean would be one in which the basic ecosystem function and structure are intact, thereby:

- able to support livelihoods and contribute to human well-being;
- resilient to current and future change.

The full range of benefits can only continue to be enjoyed if marine and coastal ecosystems are functioning and used within environmental limits, in a way that does not cause severe or irreversible harm. However, sustainable use of marine and coastal ecosystems is challenged by many drivers of change (see Chapter 2), and by the competing pressure on natural resources and the complexities of governance and multiple, often conflicting, uses **(Figure 7.1).** Coastal states have rights and obligations within their marine jurisdiction (United Nations 1982). However, the ocean imposes special challenges on the exercise of jurisdiction. Ocean currents can carry chemicals, waste, emerging organic pollutants and pathogens beyond areas under national maritime boundaries, and marine organisms and seabirds may not stay within an area under the jurisdiction of a state. Coordination of governance measures is particularly difficult in areas beyond national jurisdiction, where a large number of institutions and agreements regulate sectoral issues such as shipping, fishing and seabed mining.

Not only must states cooperate across borders, they must also integrate decision-making across the various uses of marine and coastal ecosystems. The interlinkages between ocean conditions and marine life, and the spatially dynamic ocean processes mean that the activities of any single industry sector may have far-reaching impacts. These may disrupt the livelihoods of people who have received no benefits from the industry that has caused the impact. Similarly, benefits expected from conservation measures taken in one sector or jurisdiction may be reduced or negated by lack of action in other sectors or jurisdictions.

Global challenges such as climate change and ocean acidification must also be addressed. Climate change impacts ocean temperature, sea-ice extent and thickness, salinity, sea level rise and extreme weather events. Although climate change impacts vary at regional levels and therefore require adaptive management actions at local and regional scales (Von Schuckmann *et al*. 2016), these efforts need to be coordinated at larger scales, and lessons and best practices shared efficiently.

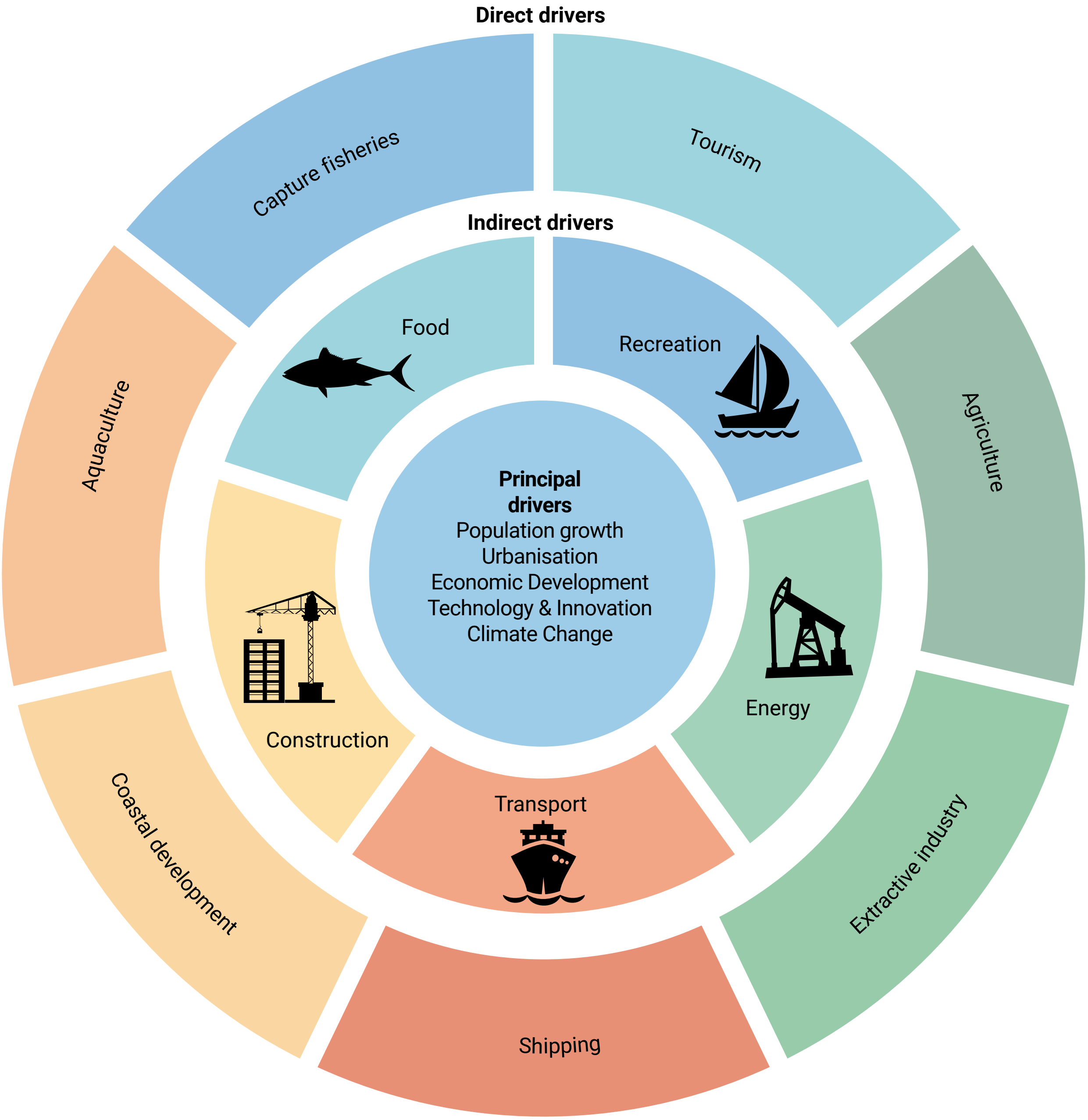
### 7.1.2 Focus of this chapter

Oceans have many uses, and there are too many linkages among marine ecosystems and between the land and adjacent seas to review them all in this chapter. *The First Global Integrated Marine Assessment* (A/RES/70/235; Inniss and Simcock eds. 2016) and reports of the Intergovernmental Panel on Climate Change (IPCC 2013) have provided recent comprehensive reviews of the state of the ocean. Therefore, three topics have been selected here that warrant particular attention – tropical coral reefs, fishing and debris entering the marine environment. Several topics of emerging or particular interest – mercury, sand mining, deep sea mining and ocean noise – are also briefly considered.

The rationale for selecting the three main topics stems from resolutions adopted by the United Nations Environmental Assembly (UNEA) at its second session in May 2016, which included specific mention of coral reefs in Resolution UNEP/EA.2/Res.12 (UNEA 2016a), and marine litter in Resolution UNEP/EA.2/Res.11 (UNEA 2016b). Marine litter was also included in a special Decision CBD/COP/DEC/XIII/10 of the Conference of the Parties to the Convention on Biological Diversity (CBD) (CBD 2016) and in Decision BC 13/17 of the Conference of the Parties to the Basel Convention (2017) . Fisheries have linkages to multiple Sustainable Development Goals (SDGs) and they also intersect the cross-cutting themes identified in Chapter 4 (notably gender, health, food systems, climate change, polar regions, and chemicals and waste).

1 Cities with populations of more than 10 million.

**Figure 7.1: Generalized schematic showing the drivers and pressures relevant to the marine environment**




The central circle represents major high-level drivers of change in human demands on the ocean. The inner ring represents the types of societal needs promoted by the drivers, and the outer ring represents the industry sectors addressing the needs, for which policies are commonly established. The needs expressed through sector actions are the relevant pressures.

## 7.2 Pressures

Human activities can alter the ocean and its resources in many ways, particularly through activities that are land-based. Part V of the *First Global Integrated Marine Assessment* (Inniss and Simcock eds. 2016) describes both the societal benefits and major impacts of human activities, whether directly through resource extraction (e.g. fish, hydrocarbons, sand) or indirectly (e.g. seabed impacts of fishing gear or mining operations). The report also documents the economic value and number of livelihoods supported by each industry sector **(Table 7.1)**

The footprints of many ocean industries overlap (**Table 7.1**: column 4) and sometimes multiple sectors use the same resource for different purposes (e.g. fish for ecotourism, versus food for a coastal community; see also Halpern *et al.* 2012).

**Table 7.1: Estimates of economic value, employment and major environmental impacts of the major ocean-related industries**

| Sector [and World Ocean Assessment chapter] | Economic value or scale of operation | Employment/ livelihoods | Major environmental impacts if inadequately regulated |
|---|---|---|---|
| Fishing [9,11,12] | US$362 billion (includes mariculture and freshwater aquaculture – approx. US$28 billion but accounting not fully separated) | 58-120 million (depending on how part-time employment and secondary processing employment are counted) | Changes of food web structure and function if top predators or key forage species are depleted or fishing is highly selective.<br>By-catches of non-targeted species, some of which can sustain only very low mortality rates (e.g. sea turtles, many seabirds and small cetaceans).<br>Gear impacts on seabed habitats and benthos, especially structurally fragile habitats (e.g. corals, sponges).<br>Continued fishing of lost fishing gear. |
| | Competent IGOs | | |
| Shipping [17] | 50,500 billion ton-miles of cargo;<br>2.05 billion passenger trips | > 1.25 million seafarers | Shipping disasters and accidents that may result in release of cargos, fuel and loss of life. Toxicity of cargos ranges from nil to severe.<br>Chronic and episodic release of fuel and other hydrocarbons.<br>Infrequent loss of containers with toxic contents.<br>Discharge of sewage, waste and 'grey water'.<br>Transmission of invasive species through ballast water and bilge water.<br>Use of anti-fouling paints.<br>Noise from ships.<br>Maritime transport responsible for about 3 per cent of global greenhouse gas emissions. |
| | Competent IGO – and conventions – IMO and MARPOL | | |
| Ports [18] | 5.09 billion tons of bulk cargo | Technology development has made consistent dockworker statistics unavailable | Concentration of shipping and potential environmental impacts of shipping.<br>Need for dredging and access to deep water passages.<br>Impacts on seabed and coastline from construction of infrastructure.<br>Noise. |
| | Competent IGO – IMO and MARPOL conventon, but mostly local jurisdiction | | |
| Offshore hydrocarbon industries [21] | US$500 billion (at US$50 per barrel) | 200,000 workers in offshore production | Release of hydrocarbons particularly during blowouts or platform disasters, with potential for very large volumes to enter marine systems, with high persistence impacting on tourism and aesthetic and cultural values.<br>Oiling of marine and coastal organisms and habitats.<br>Contaminants entering food webs and potential human food sources<br>Chronic release of chemicals used in operations.<br>Episodic release of dispersants during spill clean-up.<br>Local smothering of benthos.<br>Noise from seismic surveys and shipping.<br>Disturbances of biota during decommissioning. |
| Other marine-based energy industries [2] | 7.36 MW (megawatts) produced | 7-11 job-years per MW generated | Competition for space for infrastructure and displacement of biota.<br>Localized mortality of benthos due to infrastructure.<br>Mortality of birds, fish in energy turbines and windmills.<br>Noise and physical disturbance during construction and decommissioning of infrastructure. |
| | Competent IGO – primarily local jurisdiction | | |
| Marine-based mining [23] | US$5.0-5.4 billion | 7,100–12,000 (incomplete) | Mortality, displacement or extinction of marine species, particularly benthos.<br>Destruction of seabed habitat, esp. if fragile or sensitive.<br>Creation of sediment plumes and deposition of sediments.<br>Noise.<br>Potential contamination of food chains from deep-sea mining.<br>Creation of microhabitats vulnerable to sediment concentration and anoxia [23.3]. |
| | Competent IGO – ISA | | |
| Marine-based tourism [27] | US$2.3 trillion (35 per cent of coarse estimate of all tourism, including multiplier effects) | Not estimated due to lack of common treatment of multiplier effects. Overall tourism considered to comprise 3.3 per cent of global workforce, but breakout of marine and not-marine not consistent. | Construction of coastal infrastructure changing habitats, increasing erosion, mortality and displacement of biota, noise.<br>Contamination of coastal waters by waste and sewage.<br>Disturbance of organisms by increased presence of people, especially diving in high-diversity habitats, and watching marine megafauna.<br>Increased mortality due to recreational fishing. Increases boating with all the impacts of shipping on local scales. |
| | Competent IGO – none | | |

IGO: Intergovernmental organisations; IMO: International Maritime Organization; ISA: International Seabed Authority; MARPOL: the International Convention for the Prevention of Pollution from Ships.

*Sources:* Unless indicated otherwise, all information is taken from the First Global Integrated Marine Assessment (United Nations 2016), with chapter(s) indicated in first column. For some industries, economic value is recorded so differently by different countries that global economic value cannot be estimated meaningfully, and other indicators of scale of the industry are used. Reporting year also not standardized for all rows, but all estimates are 2012 or later. Table entries should be taken as indicative of global scale with large variation regionally and nationally. IMO (2015).

Developing effective management strategies therefore requires policies that can address cumulative impacts and not just separate sectoral footprints (Halpern *et al.* 2008).

## 7.3 State

### 7.3.1 Coral bleaching crisis 2015-17

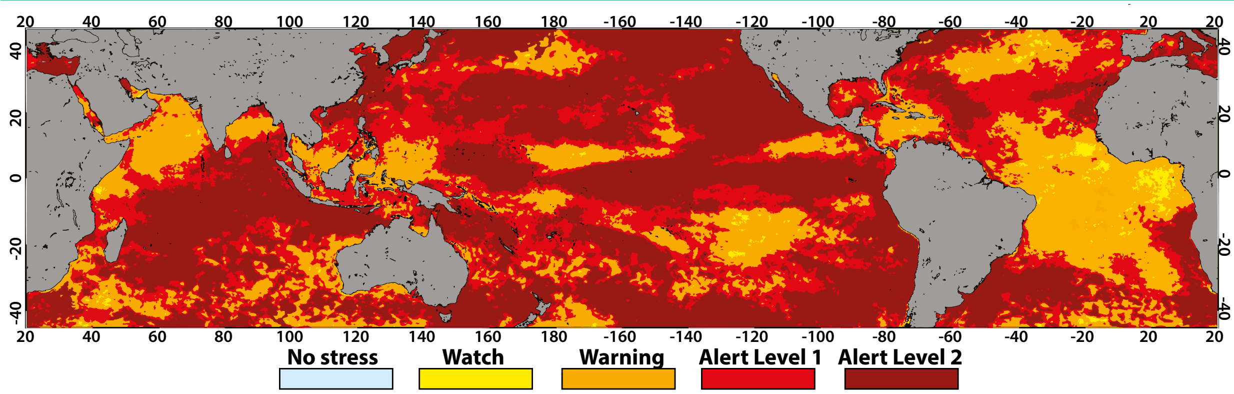
Tropical coral reefs[2] are among the most biodiverse ecosystems on earth, hosting approximately 30 per cent of all marine biodiversity (Burke *et al.* 2012). The 'Coral Triangle' region, which includes Indonesia, Malaysia, Philippines, Timor-Leste, Papua New Guinea and Solomon Islands, is the area of greatest biodiversity, hosting more than 550 species of hard corals (c.f. 65 coral species in the Caribbean and Atlantic region). Globally, coral reefs cover an area of around 250,000 $km^2$. Due to multiple human pressures, including pollution, fishing and coral bleaching, the current state of reef health is very poor at many sites.

Coral bleaching occurs when corals are stressed by changes in conditions such as temperature, light or nutrients, causing them to expel symbiotic algae living in their tissues, revealing their white skeltons. Large-scale coral reef bleaching events attributed to warmer surface ocean temperatures have been regularly reported over the last two decades and climate research reveals that the recurrence interval between events is now about six years (Hughes *et al*. 2018). The 2015 northern hemisphere and 2015-2016 southern hemisphere summers were the hottest ever recorded and caused the worst coral bleaching on record. The United States National Oceanic and Atmospheric Administration (NOAA) declared 2015 as the beginning of the third global coral bleaching event, following similar events in 1998 and 2010. Still ongoing, this third event is the longest and most damaging recorded, to date affecting 70 per cent of the world's reefs, with some areas experiencing annual bleaching **(Figure 7.2)**. Australia's Great Barrier Reef has been particularly hard hit, with more than 50 per cent of the reef impacted since 2016 (Australia, Great Barrier Reef Marine Park Authority [GBRMPA] 2017).

The severity of bleaching varies both within reefs and between regions, and some areas that have not previously experienced bleaching have been impacted in this latest event. A recent initiative to identify the 50 reef areas most likely to survive beyond the year 2050 has been announced, with the goal of encouraging governments to set these areas aside for protection and conservation (https://50reefs.org).

The recently published summary of IPCC Fifth Assessment Report, O'Neill *et al*. (2017) concluded that there "is robust evidence (from recent coral bleaching) of early warning signals that a biophysical regime shift already may be underway". Veron *et al.* (2009) predicted the coral reef bleaching tipping point (an abrupt change in state that occurs when a threshold value is exceeded) would occur once global atmospheric $CO_2$ reached 350 ppm. This value was reached in about 1988, but because ocean warming lags behind global atmospheric $CO_2$ levels (Hansen *et al.* 2005) it has taken almost 30 years for the impact of this level of $CO_2$ to be revealed. The lag effect is due to the slow rate of global ocean circulation compared with the rapid rate of rising $CO_2$ levels. In effect, the ocean is currently responding to $CO_2$ levels of decades ago and the balance of evidence indicates that a tipping point for coral bleaching has now been passed (Hoegh-Guldberg *et al.* 2007; Frieler *et al.* 2013). The Veron *et al.* (2009) 350 ppm tipping point, reached 29 years ago, may have been the death sentence for many corals. And given that global atmospheric $CO_2$ levels are now in excess of 400 ppm, there are serious implications for the very survival of coral reefs. Recent modelling suggests more than 75 per cent of reefs will experience annual severe bleaching before 2070, even if pledges made following the 2015 Paris Climate Change Conference (COP 21) become reality (van Hooidonk *et al.* 2016; UNEP 2017). Experts agree that the coral reefs that survive to the end of the 21st century will bear little resemblance to those we are familiar with today (Hughes *et al.* 2017).

**Figure 7.2: Map showing the maximum heat stress during the 2014-17 (still ongoing at the time of writing) period of the global coral bleaching event**




Alert Level 2 heat stress indicates widespread coral bleaching and significant mortality. Level 1 heat stress indicates significant coral bleaching. Lower levels of stress may have caused some bleaching as well.

*Source:* United States National Oceanic and Atmospheric Administration (NOAA) (2017).

2 Tropical coral reefs do not include deep, cold-water reefs or temperate rocky reefs.

### 7.3.2 Fisheries

***Capture fisheries***

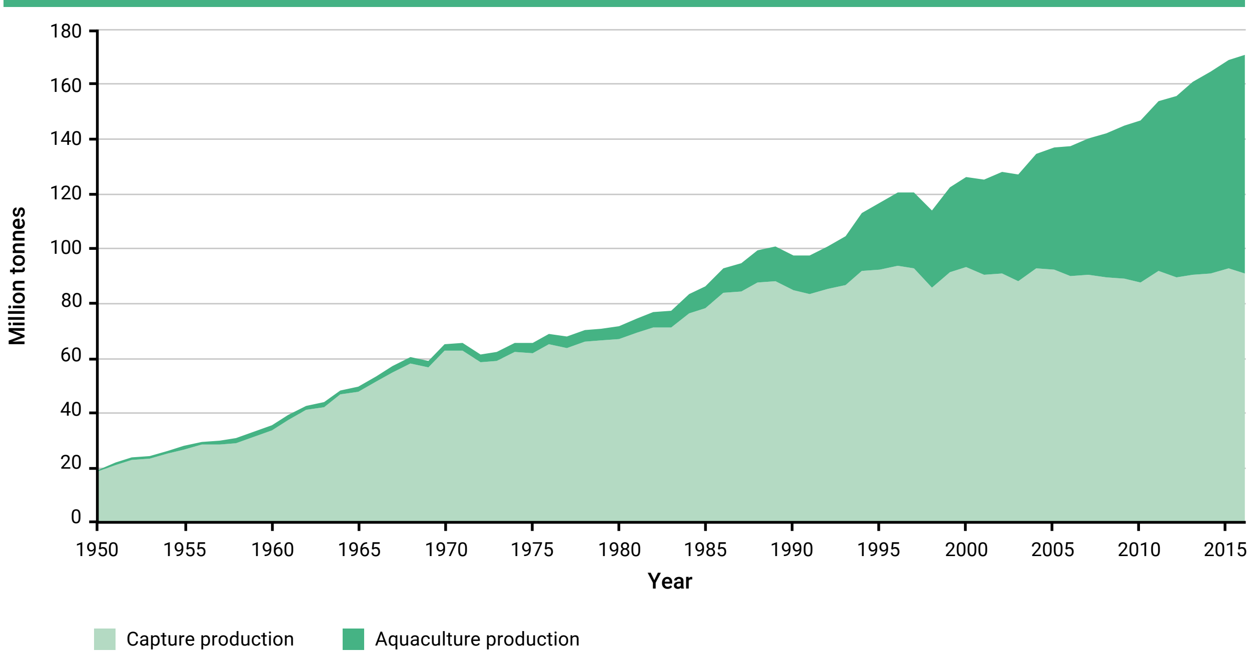
In addition to changes in ocean status due to natural variation and climate change, people change the state of the ocean by removing resources from it. Most widespread and largest in magnitude is the harvesting of fish and other marine organisms for human consumption and some industrial uses (e.g. feed for aquaculture).

The ocean is an increasingly important source of food (International Labour Organisation [ILO] 2014). Total production from capture fisheries and mariculture[3] exceeded 170 million (metric) tons by 2017 and the mariculture contribution continues to grow (FAO 2018a). Fish provide more than 20 per cent of dietary protein to over 3.1 billion people, with this percentage high in coastal areas where food security concerns are also high. Moreover, the micronutrients in fish are an important contribution to human health, and are difficult to replace in areas where availability of fish is declining (Roos *et al*. 2007; FAO and World Health Organization [WHO] 2014; Thilsted *et al.* 2014).

Capture fisheries have been stable at around 90 million tons for over 15 years, whereas production from culture facilities has continued to increase **(Figure 7.3)** There are debates about the sustainability of present levels of fishing, with disagreements about many fundamental points regarding stock status, causes of trends and effectiveness of management measures (Worm *et al.* 2009; Froese *et al.* 2013; Melnychuk *et al.* 2016). Some fishing crises have become textbook stories of harm from diverse combinations of overexpansion of fishing capacity and effort, unmanaged technological innovation, politicized or non-precautionary decision-making, and ineffective science, management and governance. In addition, interactions of environmental change and stock dynamics in the face of inertia in management decisions played central roles in the collapse of the cod fisheries in eastern Canada (Rose 2007; Rice 2018), and fisheries for Pacific small pelagic species off Peru and Chile (Chavez *et al*. 2008).

The large volume of literature on fisheries sustainability contains many cases of both unsustainable expansion, and successes in managing exploitation rates and rebuilding previously depleted stocks. For countries where capacity and political will exist to assess stock status and fishing mortality, and implement monitoring, control and surveillance measures, trends from 1990 to the present indicate that overfishing is usually avoided (Hilborn and Ovando 2014; Melnychuk *et al.* 2016). However, the reviews also show wide variation among countries, with factors such as overall wealth to invest in fisheries research and management while avoiding capacity-enhancing subsidies, strongly affecting the ability to keep fisheries sustainable. In the large majority of cases where jurisdictions have resources for sufficient research and management, and have implemented effective governance, fishing mortality has been constrained or reduced to sustainable rates, and stocks are assessed as either healthy or recovering from historical overfishing **(Figure 7.4)**. However, where significant funding for resource assessments and monitoring, control and surveillance measures are not made available, overfishing, illegal, unreported or unregulated (IUU)[4] fishing and resource depletion continue and may be expanding.

**Figure 7.3: World capture fisheries and aquaculture production**

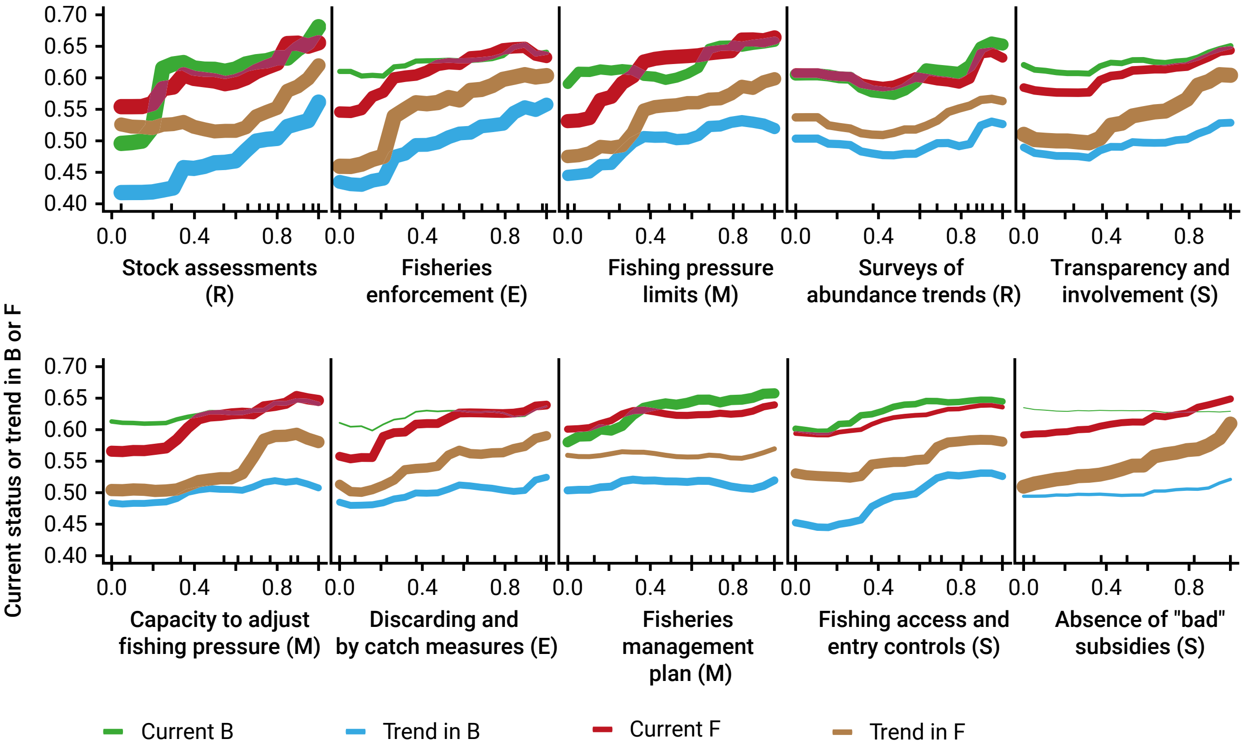



*Source:* FAO (2018a).

3 For this report 'aquaculture' is a general term used for raising fish and shellfish in captivity for eventual human consumption, whereas 'mariculture' is the portion of aquaculture practised in marine, coastal and estuarine areas.

4 Illegal, unreported and unregulated (IUU) fishing is a broad term which includes: fishing and fishing-related activities conducted in contravention of national, regional and international laws; non-reporting, misreporting or under-reporting of information on fishing operations and their catches.

**Figure 7.4: Status of fish stocks and fishing mortality as influenced by various factors of science, management and governance. Higher relative scores on vertical axis reflect better stock status relative to theoretically 'ideal' management**




Effects of fisheries management attributes in research (R), management (M), enforcement (E), and socioeconomics (S) dimensions on the current status and trends of biomass (B) and fishing mortality (F). Line thickness reflects the different importance of each dimension on the relationship of the x and y variable.

*Source:* Melnychuk *et al*. 2016

In addition, fisheries are still expanding geographically, with management jurisdictions scrambling to keep pace. Causes include:

- effort displaced from jurisdictions trying to reduce exploitation on stocks within their authority,
- a continued increase in fishing capacity of fleets based in Asia (although fleet capacity of other jurisdictions is decreasing), and
- overall increases in efficiency of fishing on global scales (Bell, Watson and Ye 2017; Jacobsen, Burgess and Andersen 2017).

Spatial realignment of fishing effort will occur as stocks move in response to changes in ocean conditions due to anthropogenic global warming (Cheung, Watson and Pauly 2013), but the details of species' redistributions is uncertain (Barange *et al.* 2014; Johnson *et al.* 2016; Salinger *et al.* 2016) and management strategies appropriate for such dynamics are in the early stages of development (Schindler and Hilborn 2015; Creighton *et al*. 2016).

Fisheries have expanded to many oceanic seamounts, where accumulated biomass of long-lived, slow-growing fishes, such as orangy roughy and oreos, are often depleted even before the regional fisheries management organizations/bodies can collect sufficient information to assess sustainable harvest levels (FAO 2009a; Koslow *et al.* 2016). As fish stocks in polar

### Box 7.1: Fisheries in the polar oceans

The polar oceans were not identified as a GEO-6 Region, but many of the sectors listed in **Table 7.1** are also present in one or both polar regions. Estimates of economic value and livelihoods supported are incomplete, but marine resources remain essential to the livelihoods of over 150,000 Inuit in the North American Arctic (Inuit Circumpolar Council 2011). Commercial fishing in the Arctic Ocean is under moratorium by the United States of America and Canada within their national jurisdictions, and in the international Arctic waters the initial Canada–Russian Federation–United States of America moratorium was recently joined by China, Denmark (for Greenland), the European Union, Iceland, Japan and Republic of Korea.[5] For the polar areas under Norwegian and Russian jurisdiction, fisheries are managed by the national authorities and regularly assessed by the International Council for Exploration of the Seas (ICES).

In the Southern Ocean, commercial fisheries for toothfish, icefish and krill have been prosecuted under Commission for the Conservation of Antarctic Marine Living Resources' (CCAMLR) regulatory framework since 1982. The toothfish and krill fisheries expanded rapidly, with krill catches less than a third of the precautionary catch limit (Commission for the Conservation of Antarctic Marine Living Resources [CCAMLR] 2016). Toothfish and icefish fisheries have been certified as sustainable (by the Marine Stewardship Council, an independent body), with substantial progress in deterring IUU (Österblom and Bodin 2012). The legal fisheries produced annual revenue of over US$200 million (toothfish) and US$70 million krill over five years (Hoshino and Jennings 2016). CCAMLR has periodic independent reviews of its performance (e.g. CCAMLR 2016). Polar oceans are experiencing the most rapid climate change and northern livelihoods are being impacted in many detrimental ways (Inuit Circumpolar Council 2011). For example, seasonal access of indigenous fishers to sea-ice fisheries has become problematic as sea ice thins and disappears. Opportunities for mining seabed, hydrocarbon resources and commercial shipping will require development of appropriate policies to ensure any benefits flow to local inhabitants.

latitudes become more available to commercial fisheries through a combination of melting sea ice and improved technologies for harvesting, overfishing could be a particular threat, if not carefully regulated **(Box 7.1)**. Such fisheries can expand rapidly, challenging the capabilities of management jurisdictions (Swan and Gréboval 2005), with regional fisheries management organizations/bodies playing a major role as fisheries expand in areas beyond national jurisdiction.

Where overfishing has been reduced or eliminated, or new fisheries have been constrained within sustainable levels, a wide mix of measures have been used (Melnychuk *et al.* 2016; Garcia *et al.* 2018). Efforts to constrain total catches (number and sizes of fishing vessels, days fishing, etc.) are almost universally present and technological innovation is at least monitored if not managed. Where science and management resources allow, the regulatory measures are usually informed by biologically based management reference points and harvest control rules (Inniss and Simcock eds. 2016). However, top-down management based on scientific assessments and advice is not essential in all types of fisheries. In small-scale community-based fisheries community management is often effective, as long as the coherence with traditional cultural practices is high (FAO 2015). In all scales of fisheries, co-management and inclusiveness of industry participants in management can pay off in greater compliance and lower management costs (Gray 2005; Dichmont *et al*. 2016; Leite and Pita 2016).

Small-scale fisheries have been a cornerstone of livelihoods and food security in many parts of the world for centuries but only recently have been recognized as a major consideration in fisheries status and trends. (FAO 2005; SDG 14.b.a; FAO 2018b). Providing nearly 80 per cent of the employment in fisheries globally (FAO 2016a) they often operate in circumstances where centralized top-down managment would be both very expensive and culturally intrusive (FAO 2015;FAO 2016b). After extensive consultation globally, guidelines for the performance

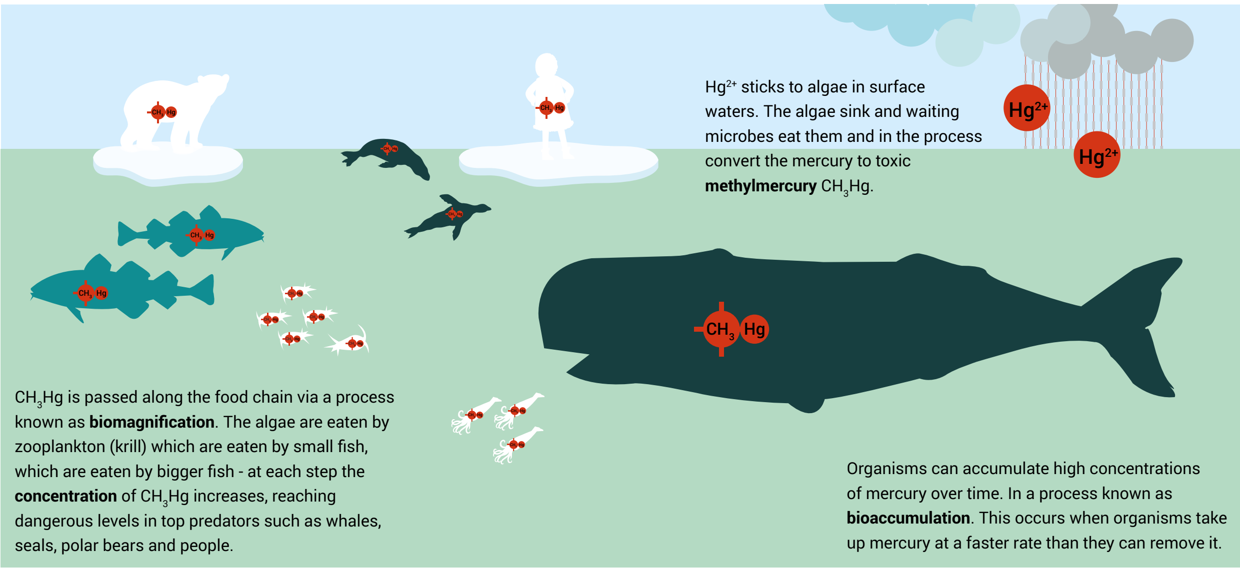
### Box 7.2: Mercury in the marine environment

The World Health Organization places mercury in the top ten chemicals of major public health concern (WHO 2017). This is because mercury, especially in the form of methylmercury, is a powerful neurotoxin, which even at low concentrations can affect fetal and childhood development and cause neurological damage (Karagas *et al*. 2012; Ha *et al*. 2017). Epidemiological studies of elevated prenatal methylmercury exposure in populations from the Faroe Islands and New Zealand have found some adverse developmental impacts (Grandjean *et al*. 1997; Crump *et al*. 1998). However, studies in the Seychelles and the United Kingdom of Great Britain and Northern Ireland found that the regular consumption of ocean fish during pregnancy did not pose a developmental risk (Myers *et al*. 2003; Daniels *et al*. 2004; van Wijngaarden *et al*. 2017). Further research on the United Kingdom cohort found that seafood intake during pregnancy (>340 g per week) improved developmental, behavioural and cognitive outcomes (Hibbeln *et al*. 2007), suggesting other nutrients present in fish such as long-chain polyunsaturated fatty acids (Strain *et al*. 2008) or selenium (Ralston and Raymond 2010) may obscure or counteract the negative effects of the methylmercury.

The health benefits of eating fish are well established (FAO and WHO 2011; FAO and WHO 2014); however, due to high methylmercury levels in some seafood and the uncertainty regarding risk, many countries have advisories suggesting that pregnant women should limit their intake of fish to species that record low concentrations of mercury (Taylor *et al*. 2018). Generally, the fish to be avoided are predatory species such as shark, tuna and swordfish and long-lived fish such as orange roughy due to the processes of biomagnification and bioaccumulation (United States Food and Drug Administration 2017).

[5] 2017 Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean.

**Figure 7.5: Biomagnification and bioaccumulation of methylmercury in the food chain**




*Source:* Baker, Thygesen and Roche (2017).

and governance of small-scale fisheries are already leading to improvements in these fisheries (FAO 2015; FAO 2016b).

***Emergence of mariculture***

Although capture fisheries plateaued in the early 2000s, mariculture continues to expand and, if current trends continue, will soon surpass them (**Figure 7.4**; FAO 2018a). Large-scale mariculture of market-oriented, high-value fish and shellfish such as tuna, salmon, mussels, oysters and other bivalves, now contributes significantly to the economies of most coastal developed countries. Small-scale mariculture is also expanding through less-developed countries and economies in transition. Freshwater and marine culture which use fish-processing by-products and low-value fish as feed, create both new markets for low-value fisheries products and some potential for market competition as mariculture demand for feedstocks increases. Data on production from small-scale operations are incomplete, especially for community consumption, as these products do not enter the market.

Populations reliant on marine organisms for nutrition may have particularly high exposures to methylmercury and persistent organic pollutants and these risks are highest in areas where food security is not assured (Gribble *et al*. 2016).

In addition, climate change may lead to changes in emissions of mercury, for instance through its release from long-term storage in the frozen peatlands of the northern hemisphere (UNEP 2013; Schuster *et al.* 2018). This has the potential to increase input of mercury into the oceans.

### 7.3.3 Marine litter

Marine litter is a growing problem, that has serious impacts on marine organisms, habitats and ecosystems (Secretariat of the Convention on Biological Diversity [SCBD] 2016). Litter has been found at all ocean depths and on the ocean floor (Pham *et al.* 2014) and on the shores of even the most remote Pacific islands (Lavers and Bond 2017). Three-quarters of all marine

litter is composed of plastic. This includes microplastics of less than 5 mm in size, which are either purposefully manufactured (primary microplastics) for use in various industrial and commercial products (e.g. pellets, microbeads in cosmetics), or are the result of weathering of plastic products and synthetic fibres that can produce micro- and nanoplastic particles (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection [GESAMP] 2015; Gigault *et al.* 2016). Weathering can also release the chemical additives that are used in plastic manufacture (Jahnke *et al*. 2017).

Based on global solid waste data, population density and economic status, Jambeck *et al.* (2015) estimate that 275 million tons of plastic waste were generated in 192 coastal countries in 2010, of which 4.8 to 12.7 (8) million tons may have washed into the ocean **(Figure 7.6)**. They calculate that without global intervention, the quantity of plastic in the ocean could increase to 100-250 million tons by 2025. Sources of marine litter can generally be correlated with the efficiency of solid waste management and wastewater treatment (Schmidt *et al.* 2017).

It is generally accepted that a large proportion of the plastic entering the ocean originates on land. It makes its way into the marine environment via storm water run-off, rivers or is directly discharged into coastal waters (Cozar *et al.* 2014; Wang *et al.* 2016). Uncollected waste is thought to be the major source, with lesser amounts coming from collected waste re-entering the system from poorly operated or located formal and informal dumpsites (see 5.2.5). There is less information on the percentage of plastic coming from ocean-based sources, but we do know that lost fishing gear is a problem. This includes gear that is lost as a result of fishing method, washed overboard during storms or is intentionally discarded (Macfadyen, Huntington and Cappell 2009).

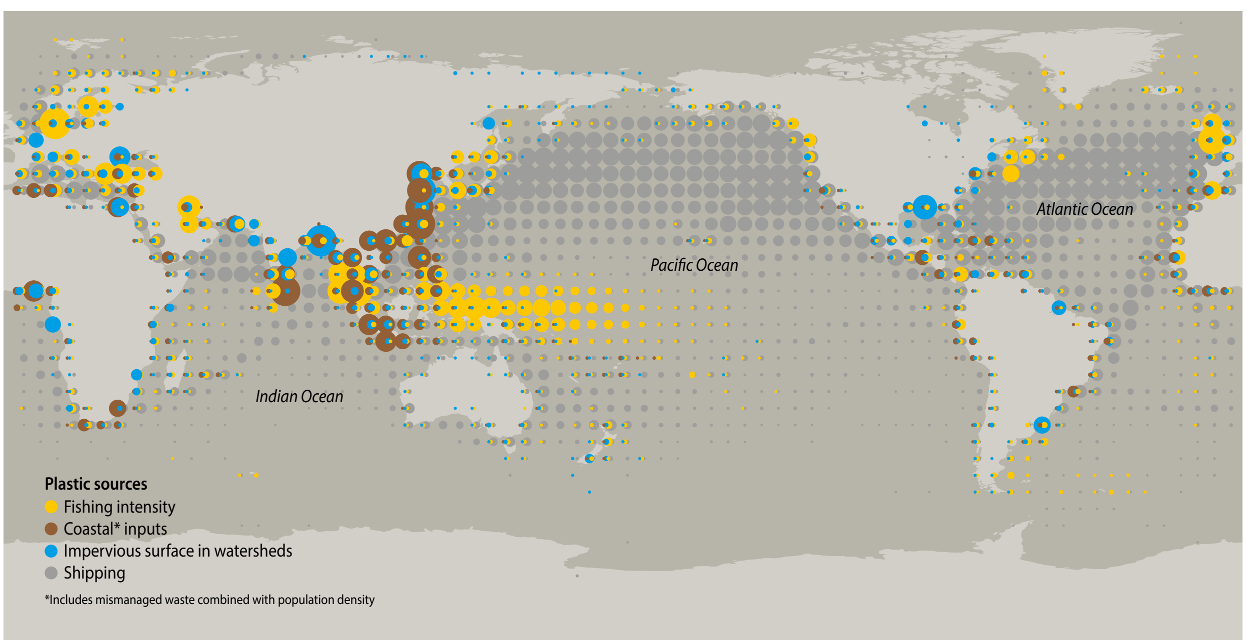
## 7.4 Impacts

### 7.4.1 Social and economic consequences of death of coral reefs

Coral reefs are of major importance for 275 million people located in 79 countries who depend on reef-associated fisheries as their major source of animal protein (Wilkinson *et al.* 2016). The contributions provided by coral reefs have collectively been valued at US$29 billion per annum, in the form of tourism (US$11.5 billion), fisheries (US$6.5 billion) and coastal protection (US$10.7 billion) (Burke *et al.* 2012). Bleaching of corals in the Great Barrier Reef alone could cost the Australian economy US$1 billion pa in lost tourism revenue (Willacy 2016). The total annual economic value of coral reefs in the United States of America has been valued at US$3.4 billion (Brander and Van Beukering 2013).

Coral reefs that have been degraded by the compounding effects of pollution from land or repeated bleaching events, are less able to provide the benefits on which local communities depend (Cinner *et al.* 2016). Once corals have died, they no longer grow vertically upwards, so the reefs gradually erode. Dead reefs become submerged under rising sea level and are less effective in providing shoreline protection from wave attack during storms. Dead corals not only lack the aesthetic appeal that is fundamental to reef tourism, they also sustain a less biodiverse fish community (Jones *et al.* 2004). This results in reduced tourist activity and reduced income from fisheries, which can threaten the livelihoods of local communities. Living coral reefs are also important religious symbols for some communities (Wilkinson *et al.* 2016).

**Figure 7.6: Global map of potential marine plastic input to the oceans based on human activities and watershed characteristics**




*Source:* Map produced by GRID-Arendal (2016a) based on data from Halpern *et al*. (2008), Watson *et al*. (2012) and Jambeck *et al*. (2015).

### 7.4.2 Capture fisheries

The initial impact of fishing on the target species is to reduce abundance from the unfished level. This reduction, in turn, is expected to produce increases in population productivity as density-dependence pressures are reduced, so both growth and energy reserves are available for spawning increase. This reasoning underpins basic fisheries science (Beverton and Holt 1957; Ricker 1975) and the concept of a Maximum Sustainable Yield (MSY) is entrenched in the United Nations Convention on the Law of the Sea (UNCLOS). This concept is a global norm for fisheries management, when the rate of removals by fisheries has maximized productivity without depleting the size of the spawning population sufficiently to impair production of recruits. If the exploitation rate increases beyond this level, spawning potential is diminished faster than productivity is enhanced, and overfishing occurs. The current global outcomes of fishing on target species were summarized in Section 7.3.2.

The impacts of fishing on marine ecosystems are well documented and have been studied for several decades (Jennings and Kaiser 1998; Gislason and Sinclair 2000). Major impacts include:

- by-catches of non-target species in fishing operations
- impacts of fishing gear on seabed habitats and sedentary benthic communities
- alteration of food webs through reduction in abundance of either top predators potentially allowing release of prey populations, or depletion of prey populations leading to decreased productivity of predator populations.

The pathways of these impacts are well described, and have been central in the development of the ecosystem approach to fisheries. This was entrenched in the United Nations Fish Stocks Agreement and has been widely adopted in national and regional policies (Rice 2014). FAO has provided operational guidance on actions to manage fisheries' footprint (FAO 2003) and updates, and it has been taken into the Code of Conduct on Responsible Fishing (FAO 2005; FAO 2011).

Despite acknowledgement of fisheries' large footprint on marine ecosystems, and the full uptake in policy, measures to minimize the ecosystem effects of fishing have had mixed success. There appears to be overall progress, as two global reviews a decade apart found estimates of global annual discards from fisheries to have declined from 27 million tons in 1994 to 7.3 million tons in 2004 (Alverson *et al.* 1994; Kelleher 2005). However, substantial discarding remains in many fisheries, particularly small mesh fisheries for species such as shrimp in less-developed countries, where incentives for reduction of discards and by-catch are absent or ineffective (FAO 2016a; FAO 2016b). Moreover, even where by-catches of highly vulnerable species have been reduced, levels still present population concerns for some sharks and seabirds (Campana 2016; Northridge *et al.* 2017).

Similarly, the footprint of fishing gear on sea floor habitat and benthic communities is being taken seriously by fisheries management organizations at national and regional scales. This concern has increased, prompting the adoption in the United Nations General Assembly of Resolution 61/105 in 2007, which required all regional fisheries management organizations (RFMOs) to identify marine ecosystems in their jurisdiction that would be vulnerable to bottom-contacting gear and to either protect them from harm or close them to such fishing. The evidence for policy effectiveness of this approach is examined in Chapter 14. However, despite all relevant RFMOs acting to comply with this requirement (Rice 2014), regional studies find that well over 50 per cent of fishable seabed has been impacted by fishing gear more often than benthic communities can recover fully from the disturbance, and repeated impacts remain common (Eigaard *et al.* 2017).

### 7.4.3 Mariculture

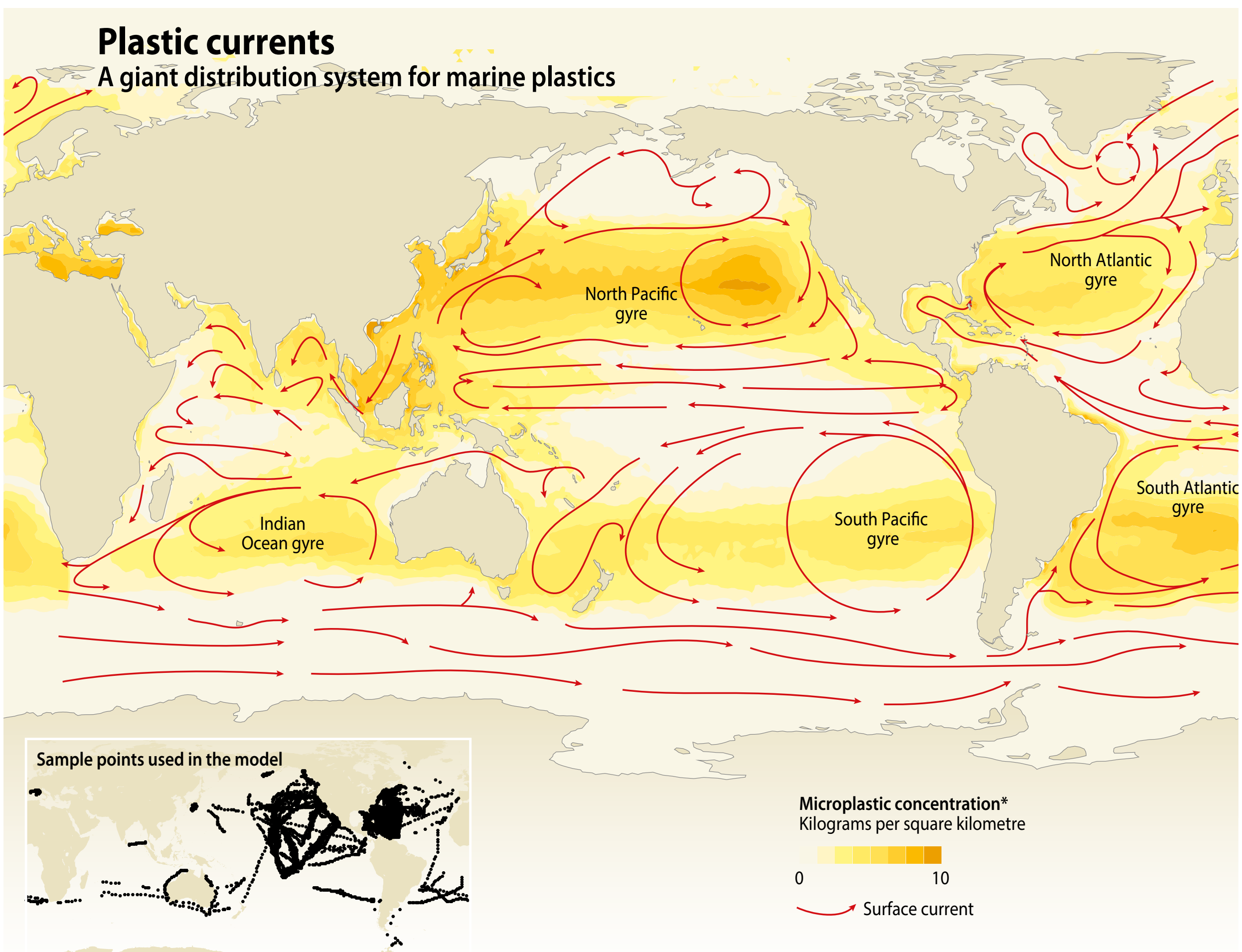
Mariculture has a substantial impact on the marine ecosystem, and documentation of these effects is growing. Conversion of mangroves for mariculture has resulted in widespread habitat loss with far-reaching implications for dependent species. In open, dense culture facilities, antibiotics and other medications used to prevent disease are carried by currents and tides well outside the waters in the culture area. Excessive feed sinking through the cages can accumulate on the sea floor, decompose and reduce oxygen levels. These and other effects, such as being vectors or resources for parasites and diseases, or increasing risks of non-adaptive gene-flow and invasive species, can be managed through careful, albeit sometimes costly operations (Bernal and Oliva 2016). However, the ecosystem approach is also being applied in aquaculture, with comparable objectives and rapid uptake by industry (FAO 2010).

### 7.4.4 Marine litter

Although the greatest accumulation of marine litter is in coastal environments (Derraik 2002), plastic (including microplastic) is distributed worldwide in the ocean, with increased accumulation in the convergence zones of each of the five subtropical gyres (Cozar *et al.* 2014; Van Sebille *et al.* 2015; Yang *et al.* 2015; see **Figure 7.7**).

Plastic pollution has been recognized for decades as a threat to marine biodiversity (Gray 1997). One of the most visible impacts is death or injury of marine life from entanglement with derelict fishing gear and plastic packaging. Many animals also ingest litter, either accidently or intentionally when it is mistaken for food. This can cause starvation due to intestinal blockage or lack of nutritian (UNEP and GRID-Arendal 2016). Recent reviews have found that a growing number of turtles, marine mammals and seabirds are endangered or killed by floating litter (Thiel *et al.* 2018; O'Hanlon *et al.* 2017).

**Figure 7.7: Plastic litter in the open ocean**




*Source:* GRID-Arendal (2016b), based on data from Van Sebille *et al.* (2015)

Microplastics are now appearing in food consumed by humans; however, the impact on human health is uncertain (GESAMP 2015; Halden 2015). Plastic particles have been found in the intestines of fish from all oceans and in products such as sea salt (e.g. Yang *et al.* 2015; Güven *et al*. 2017). There are currently no standard methods for assessing the health risks of ingesting plastic particles. For fish at least, people do not generally consume their digestive tract where plastic accumulates, so intake is probably limited. In instances where people consume whole organisms, such as mussels and oysters, ingestion rates could be higher (Van Cauwenberghe and Janssen 2014; Li *et al*., 2018). Moreover, the aesthetic and restorative value of the ocean for people is well known, but there is evidence that the presence of marine litter can undermine the psychological benefits generally provided (Wyles *et al.* 2015).

Some plastic products contain dangerous chemicals (e.g. fire retardants) and plastic marine litter can also attract chemicals from the surrounding seawater (e.g. UNEP 2016; UNEP and GRID-Arendal 2016). However, the fraction of chemicals contained in plastic or sorbed to plastic in the ocean, is currently considered to be small compared to the chemicals found in seawater and organic particles that originate from other land-based sources of pollution (Koelmans *et al.* 2016). There are currently no proven toxic effects of chemicals sorbed by plastic particles found across a range of marine biota, but more data are needed to fully understand the relative importance of exposure to sorbed chemicals from microplastics compared with other exposure pathways (Ziccardi *et al.* 2016).

The economic and social costs of marine litter include indirect effects such as interfering with small-scale fishing opportunities, tourism and recreation (Watkins *et al.* 2017). These costs are generally unquantified but may fall disproportionately on those with livelihoods most closely tied to coastal activities. Some direct economic costs include the cost of beach cleanup and accidents related to navigation hazards or fouling (UNEP 2016). The European Union has estimated that every year up to €62 million are lost to the fishing industry from damage to vessels and gear and reduced catch due to ghost fishing (abandoned gear that continues to catch marine organisms as it drifts) and up to €630 million is spent on beach cleaning (Acoleyen *et al.* 2013).

### 7.4.5 Emerging Issues for the Ocean

Exploitation of the ocean is expanding and a number of key emerging issues will need to be addressed by policy makers as this exploitation continues.

**Box 7.3: Coastal sand mining**

Around the globe, coastal and nearshore areas are being mined for construction sand and gravel. These are non-renewable resources, although deposits are replenished by a number of processes including erosion of the coast, riverine transport of sediments and biological production (Woodroffe *et al*. 2016) and landward sediment transport. Sand and gravel are the second most-used natural resource on our planet, after water. Annual sand and gravel consumption is estimated at around 40-50 billion tons (5.2-6.6 tons per person per year, or c.20 kg per person per day), 26 billion tons of which is used for making concrete (Peduzzi 2014).

Most sand comes from the erosion of mountains by rivers and glaciers. It is estimated that all the Earth's rivers deliver around 12.6 billion tons of sediment to the sea each year (Syvitski *et al*. 2005). Consequently, humans are currently using sand at a rate four-times that at which it is being produced by nature. Desert sand cannot be used as an aggregate because the grains are too smooth and rounded from constant motion over desert dunes.

Many European countries have been mining sand from offshore sand banks for several decades (Baker *et al*. 2016). The practice is expanding rapidly in other parts of the world, but the exact volume mined is currently uncertain. The act of dredging the seabed kills organisms in the mined area and the plume of disturbed mud can blanket the seabed and smother sea life in surrounding areas. Illegal and poorly regulated sand mining on beaches (and in rivers) is causing major damage to ecosystems and landscapes (Larson 2018). For example, in Kiribati, beach mining has increased vulnerability to coastal inundation (Ellison 2018) and in central Indonesia, sand mining is one of the identified threats to seagrass beds (Unsworth *et al*. 2018).

Actions to reduce the global 'sand mining footprint' include conserving existing buildings and substituting recycled material for sand and gravel in new projects. It is also possible to replace sand in concrete with 15-70 per cent of incinerator ash, depending on the use (Rosenberg 2010). Research into developing desert-sand-based concrete is expanding and new products are currently being trialled (Material District 2018).

Improved knowledge of sandy environments and their dependent ecosystems is needed in order to make the wisest use of remaining sand and gravel resources (Peduzzi 2014). There is no mention of seabed mining or coastal erosion in the SDG indicators.

## Box 7.4: Deep sea mining

Commercial deep sea mining has not yet begun, but the International Seabed Authority (ISA) has currently entered into 15-year contracts with companies for exploration of polymetallic nodules (the Clarion Clipperton Fracture Zone and the Central Indian Basin), polymetallic sulphides (South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge) and cobalt-rich ferromanganese crusts (Western Pacific Ocean). In addition, a number of Pacific Island nations with potential deep sea mineral resources have issued exploration licences or are updating relevant policies before doing so.

Globally, deep sea mineral deposits are becoming more attractive to mining companies as they search for higher grade ore bodies (Secretariat of the Pacific Community [SPC] 2013a; SPC 2013b). These include: (1) manganese nodules that exist as cobble- to boulder-sized rocks scattered over broad areas of the abyssal ocean floor at depths exceeding 5,000 m; (2) cobalt-rich crusts formed on the flanks of seamounts and other volcanic sea floor features; and (3) massive sulphide deposits that are formed in association with hydrothermal vents found along sea floor spreading ridges, back arc-basins and submarine volcanic arcs. Benthic communities inhabiting these environments are globally unique and host many endemic species (Beaudoin and Smith 2012). Interest in mining these deposits is most advanced in relation to massive sulphide deposits located in the south-west Pacific, but many unanswered questions remain about the environmental impacts (Boschen *et al.* 2013).

Potential impacts of deep sea mining are poorly studied, but are generally assumed to include (1) direct impacts on the benthic communities where nodules/ore deposits are removed; (2) impacts on the benthos due to mobilization, transport and redeposition of sediment over potentially broad areas; and (3) impacts in the water column in cases where mining vessels discharge a plume of sediment near the sea surface, thus affecting photosynthesizing biota and pelagic fish (Morgan, Odunton and Jones 1999; Sharma 2001). A seabed disturbance experiment in the Peru Basin found very little recovery of benthic fauna 26 years after mimicking mining operations (Marcon *et al*. 2016). Lack of knowledge and understanding has been argued as one reason for countries to proceed with caution in developing these resources (Van Dover 2011; Van Dover *et al.* 2017). In the context of deep sea mining, the world has a unique opportunity to make wise decisions about an industry before it has started.

The ISA is responsible for ensuring effective protection of the marine environment from harmful effects of deep sea mining in areas beyond national jurisdiction (in accordance with Part XI of the United Nations Convention on the Law of the Sea). The Authority is in the process of developing the Mining Code, which contains rules, regulations and procedures to regulate prospecting, exploration and exploitation of marine minerals in the area (International Seabed Authority [ISA] 2017).

Many states with potential deep sea minerals have developed or are developing policies to regulate this new industry. These include a range of initiatives – for example, the Secretariat of the Pacific Community Regional Legislative and Regulatory Framework for Deep Sea Minerals Exploration and Exploitation (SPC 2013b), Cook Islands National Seabed Minerals Policy (Cook Islands Seabed Minerals Authority 2014) and the Tuvalu Seabed Mining Act 2014 (Tuvalu 2014).

## Box 7.5: Anthropogenic ocean noise

There is increasing concern regarding the potential impact of anthropogenic acoustic noise on marine life. This is noise generated by a range of activities including shipping, seismic surveys, military operations, wind farms, channel dredging and aggregate extraction (Inger *et al*. 2009). Large commercial ships generate noise in the frequency range from 10 to 1,000 Hz, which coincides with frequencies used by marine mammals for communication and navigation (Richardson *et al*. 1995). There is evidence that low-frequency noise has increased significantly in the deep ocean since the 1950s (Andrew *et al*. 2002; McDonald *et al*. 2006; Chapman and Price 2011). However, some recent observations have shown a constant level or slightly decreasing trend in low-frequency noise (Andrew *et al*. 2011; Miksis-Olds and Nichols 2016). There is limited information on noise levels in the shallower water of the continental shelf (Harris *et al*. 2016).

Evolutionary adaptations that have allowed many marine species to detect sound may now make them vulnerable to noise pollution (Popper and Hastings 2009). Sound energy dissipates as a function of the distance squared, so proximity to the sound source is a major factor for calculating impact. Early research on noise and marine mammals focused on high-frequency sound, such as ship sonar, which had been implicated in whale strandings (e.g. Fernández *et al*. 2005). More recently, researchers have tried to determine the impacts of common, low-frequency sounds on marine mammals. Although it is difficult to determine the impact of anthropogenic noise on marine mammals, there is general consensus that it can cause adverse effects, from behavioural changes to strandings (Götz *et al*. 2009). A review by Cox *et al*. (2016) on the impact of ocean noise on fish behaviour and physiology determined that certain sounds can disrupt communication and interfere with predator-prey interactions. Low-frequency noise has also been found to impact crustaceans, producing changes in behaviour and ecological function (Tidau and Briffa 2016).

There are increasing concerns about the long-term and cumulative effects of noise on marine biodiversity (CBD 2012). The CBD (operational paragraph 3 of Decision XIII/10) calls for improved assessment of noise levels in the ocean, further research, development and transfer of technologies and capacity-building and mitigation (CBD 2016). The European Union Marine Strategy Framework Directive 2017/848 (European Commission 2017) has recently provided criteria and methodological standards to ensure that introduced noise does not adversely affect the marine environment and proposed standardized methods for monitoring and assessment.

The United Nations Convention on the Law of the Sea makes no specific mention of anthropogenic noise, but if the introduction of noise into the marine environment is likely to have a negative impact on the environment, it may be considered a form of pollution under UNCLOS. Delegates at the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (ICP-19, 2018) disussed recognizing underwater noise as a form of transboundary pollution to be mitigated and addressed through an United Nations General Assembly resolution.

## 7.5 Response

Governance approaches and policy instruments that address impacts on the marine environment are quite varied. General discussion of these policy approaches is provided here while the effectiveness of specific examples is explored in Chapter 14 (Part B).

### 7.5.1 Coral reefs

Since the increased frequency of coral bleaching is attributed to global anthropogenic climate change, only a global policy response can address the root cause of the problem. The term 'coral reefs' is not mentioned in the SDG indicators, including SDG 14 "Conserve and sustainably use the oceans, seas and marine resources for sustainable development". Aichi Target 10 is related to coral reefs conservation: "By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning." The oceans SDG target 14.2 – "by 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans" – may not be attainable for most tropical coral reef ecosystems. The resilience of coral reefs is affected by cumulative human impacts (e.g. fishing, coastal pollution, sediment run-off, invasive species), hence these impacts must be curbed to sustain reefs into the future.

Nations dependent upon reef-based fisheries, tourism and other sectors will need to develop policies for a transition to post-reef economies within the next decade, including dealing with associated cultural trauma, especially in cases where reef degradation is most rapid and spatially widespread. In addition, low-lying coral atoll countries will need to develop policies for a transition to environments where the natural benefits of coral reefs to people are much reduced or no longer available. Given that some reef habitat may be in locations where the impacts of climate change will be less severe, and where corals might survive, reef-owning nations should consider taking immediate action to protect all known coral reef habitat from any non-subsistence uses (i.e. establish all reefs as total no-take, no-go conservation zones) until such time as the location of reefs that are most likely to survive becomes known (Beyer *et al*. 2018). Studies show that where 'no-take' MPAs have been established, reef ecosystem resilience is improved (Steneck *et al.* 2018).

The challenge is to evolve from local management and monitoring towards the multiscale governance of addressing drivers, thresholds and feedbacks at relevant scales. Coral reef management must adapt to embrace new approaches such as resilience and ecosystem-based management, including the manipulation of ecosystems, bio-engineering of heat-resistant coral species as well as building new international institutions and partnerships to tackle the global aspects of the decline in coral reefs (Hughes *et al.* 2017).

### 7.5.2 Fishing

***Policies and measures to manage fisheries impacts on ecosystems***

The impacts of fisheries on species not delivered to markets (collectively called by-catch) on the sea floor and its biota, and on marine ecosystem structure and function, have been studied since before the 1980s. Measures to manage all these types of impacts are known and feasible, and can keep them within safe ecological limits (FAO 2009a). These include technologies and practices that make fishing gear more selective for target species, discourage by-catches of marine birds, mammals and reptiles, and avoid or reduce impacts of fishing gear on the sea floor (FAO 2009a; FAO 2009b). Guidance on how, and under what conditions, to apply all these measures has been available for well over a decade (FAO 2003), and has been expanded and updated regularly (e.g. FAO and World Bank 2015). Significant global policy commitments have been made to avoid or mitigate such ecosystem effects of fishing (Rice 2014).

Spatial measures have had a role in fisheries management for over a century and the growing establishment of marine protected areas (MPAs) has accelerated the interest in spatial management approaches. Many ecological and governance factors appear to influence the effectiveness of MPAs and their incremental value to other measures (Rice *et al.* 2012). Overall there is growing awareness that they can help to keep fisheries sustainable, particularly with regard to protection of sensitive habitat features or contributing to improving the status of fish stocks when conventional fisheries management measures are not being implemented effectively. However, MPAs also have a wide range of social and economic impacts that need to be considered on a case-by-case basis (FAO 2007). In addition, conflicting results are found with regard to MPA benefits such as 'spillover effects', and studies of their impacts on coastal livelihoods and implications for food security have produced mixed results (FAO 2016b).

Fisheries are being impacted by climate change in many ways, well documented in IPCC's Fifth Aseessment Report, Working Group I (IPCC 2013), and the subject of an upcoming IPCC special report on oceans and cryosphere, expected late in 2019. As temperature and salinity profiles change with global warming, the distribution and productivity of important target species is already being reflected in changes in distribution of fishery catches. Moreover, environmental changes are impacting stock productivity of fish and making them available at different places and/or at different times of the year, with impacts on large-scale mobile fisheries (which may have to fish in different places or at different times) and small-scale fisheries with lower mobility (which may have to adapt to changing species available for harvest). Depending on the cultural practices associated with fishing, these challenges may be disruptive to address.

Ocean acidification is a potential threat to many species, particularly in early life stages, including many shellfish, as calcium carbonate for shell formation is less available in seawater of higher acidity. Estimates of losses from ocean acidification are highly variable, but some projections suggest losses over US$100 billion by 2100 (Narita, Redhanz and Tol 2012; Lemasson *et al.* 2017). Acidification is considered a particularly serious threat in polar areas (Tarling *et al.* 2016), and should be an important consideration.

## Box 7.6: Examples of existing global policy commitments to sustainable fisheries using an ecosystem approach (dates of agreements in brackets)

United Nations Convention on the Law of the Sea Articles 61(4) and 119(1) both make explicit reference to sustainability of associated and dependent species, and many articles in parts V, VI and VII refer to sustainable fisheries [1982].

United Nations Fish Stocks Agreement Article 5.3.d: Develop data-collection and research programmes to assess the impact of fishing on non-target and associated or dependent species and their environment, and adopt plans necessary to ensure the conservation of such species and to protect habitats of special concern [1995].

Aichi Target 6: By 2020, all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem-based approaches, so that overfishing is avoided; recovery plans and measures are in place for all depleted species; fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems; and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits [2010].

United Nations General Assembly 61/105 Paragraph 80: Calls upon states to take action immediately, individually and through regional fisheries management organizations and arrangements, and – consistent with the precautionary approach and ecosystem approaches – to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts, hydrothermal vents and cold-water corals, from destructive fishing practices, recognizing the immense importance and value of deep sea ecosystems and the biodiversity they contain [2006]. This resolution has been followed by several updates.

SDG Target 14.4: By 2020, effectively regulate harvesting and end over-fishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics [2016].

***Social and economic benefits of fishing***

The benefits and opportunities for development presented by fisheries is important to different large-scale and small-scale fisheries (LSF and SSF). Some SSF have severely depleted the stocks they exploit, as have some LSF, and some of the most destructive fishing practices, including fishing with dynamite and poisons, are restricted to SSF. The geographic scale of LSF means that even modest by-catch rates or habitat impacts of fishing gear can result in substantial pressure on species taken as by-catch and seabed features (FAO 2009a; FAO 2018a).

SSF and LSF differ in the magnitude of the market value of their catches, and in the employment created, livelihoods supported and social distribution of the benefits provided from fishing. As a generalization with occasional exceptions, LSF provide greater direct economic revenues, but also require much greater capital investment in fishing vessels, gear and processing capacity. On the other hand, employment for the same volume of catch is usually much greater in SSF, especially since significant additional jobs are created in shore-based small-scale market and processing, with sometimes multiple layers of these secondary employment opportunities. These multiplication factors also apply to LSF, which can create substantial coastal employment in rural areas, but data are rarely collected systematically, so total employment created in all types of fisheries is probably underestimated.

Gender roles also differ between LSF and SSF. Most open ocean fishers are men. Women generally fish on shallow reefs and tidal flats, and in mangroves and coastal estuaries (Lambeth *et al.* 2014). Women often predominate in the post-harvest processing, marketing and trading of fish. These roles are often omitted from data-collection efforts, and overlooked in conventional government or aid programmes that support fishing and fishers (Siason *et al.* 2010). However, when all of the industry workforce is counted, women make up nearly 50 per cent (World Bank 2012; **Table 7.2**).

These issues of magnitude and distribution of revenue and employment created by LSF and SSF present complex choices to policymakers. In developing countries, SSF potentially contribute substantially to development and equitable distribution of livelihoods from fishing. This does not mean that earnings from fishing alone are sufficient to sustain households at a level above the poverty line or above a country's minimum wage (FAO 2016a), and these fisheries are particularly vulnerable to outside threats from factors such as climate

**Table 7.2: Global capture fisheries employment**

| | Small-scale fisheries | | | Large-scale fisheries | | | Total |
|---|---|---|---|---|---|---|---|
| | Marine | Inland | Total | Marine | Inland | Total | |
| Number of fishers (millions) | 13 | 18 | 31 | 2 | 1 | 3 | 34 |
| Number of post-harvest jobs (millions) | 37 | 38 | 75 | 7 | 0.5 | 7.5 | 82.5 |
| Total | 50 | 56 | 106 | 9 | 1.5 | 10.5 | 116.5 |
| Percentage of women | 36% | 54% | 46% | 66% | 28% | 62% | 47% |

*Source:* World Bank (2012).

change (Barange *et al*. 2014; Guillotreau, Campling and Robinson 2012). LSF have greater opportunity to generate revenues for participants and governments (World Bank 2012), but are at greater risk of concentrating the wealth and opportunity generated among a small number of individuals (Olson 2011). How available fish harvests are distributed between SSF and LSF consequently has major consequences for development, employment and revenue generation, which need to be considered fully in any comprehensive fisheries policies.

***Fisheries and SDGs and the Aichi Targets***

Fisheries have important roles in meeting both SDGs 1 and 2 (end poverty and hunger) as well as SDG 14 (conserve and sustainably use the ocean and its resources). To meet global food security needs, dietary protein from marine sources will have to increase by 50 per cent and likely much more (Rice and Garcia 2011). Some combination of innovative harvest strategies that increase harvest of food sources with presently low market value and ensure their distribution to appropriate markets (e.g. Garcia *et al.* (2012) and expansion of mariculture production will be essential to meeting SDG 2, and can contribute to improving employment and livelihoods supported by-production of marine food (SDG 1). These needs pose challenges for SDG 14, as plans for advancing this goal usually involve discussions of reducing the pressure from fisheries on marine ecosystems, rebuilding depleted stocks, ending over- and IUU fishing, and greatly expanding the coverage of no-take MPAs. These goals can be pursued in unison, but only if planning for expanded catches and mariculture production, including its offshore expansion, is done very carefully, with full ecosystem impacts considered in each case. If the 'conserved' part of SDG 14 is interpreted as complementary with 'sustainably used', systems altered from their pristine state are considered 'conserved' as long as major structural properties and functional processes are not altered beyond safe ecological limits as specified in Aichi Target 6. Such careful planning for expansion of food production from the sea could also contribute to SDGs 3 (health and well-being), 5 (gender equity) and 12 (sustainable consumption and production patterns), as long as these factors are part of the benefits sought from the increased food production.

Aichi Target 6 also focuses directly on fishing. In much more detail than SDG 14, it spells out all the ecological factors related to fishing that need to be made sustainable by 2020, including catch levels of all stocks, commitments to rebuilding depleted stocks, management of by-catches and habitat impacts of fishing gear, and establishing resilient ecosystem structure and function.

### 7.5.3 Marine litter

Policy responses to marine plastics are growing and range from global instruments such as MARPOL, UNCLOS and the Honolulu Commitment and Strategy, through regional action plans such as the Regional Plan on Marine Litter Management in the Mediterranean (UNEP/MAP 2015), and specific product bans (e.g. single-use plastic bags) at municipal or national levels. Marine litter has been incorporated into SDG target 14.1 indicator 14.1.1 as a composite indicator that includes (i) the index of coastal eutrophication and (ii) floating plastic litter density. The third United Nations Assembly (UNEA-3) adopted resolution UNEP/EA.3/Res.7 which includes the establishment of an open-ended ad hoc expert group to further examine the barriers to and options for combating marine plastic litter and microplastics from all sources, especially land-based sources (UNEA 2017). The first meeting of the expert group was held in Nairobi, Kenya from 29 to 31 May 2018.

Cleaning up coasts and beaches can provide environmental and economic benefits (e.g. Orange County California estimated an economic benefit of more than US$140 million could be generated annually from the increased number of visitors attracted to cleaner beaches (Leggett *et al.* 2014). However, cleaning up the open ocean does not currently appear to be a practical solution to marine litter. The cost of the ship-time alone needed to clean the litter concentrated in 1 per cent (approximately one million km$^2$) of the Central Pacific Gyre is estimated to be between US$122 million and US$489 million (NOAA Office of Response and Restoration 2012). Large-scale booms may be effective at trapping surface litter in small areas. The trail of a 600 m long boom by the NGO Ocean Cleanup recently began offshore California. If succcessful, the boom will be deployed in the open ocean of the North Pacific gyre (Stokstad 2018).

Research suggests that up to 95 per cent of the plastic entering the ocean does not remain in the surface waters (Eriksen *et al*. 2014). However, there is a major knowledge gap in understanding the behaviour and breakdown of plastic in the ocean and where it eventually ends up (Cozar *et al.* 2014). Therefore, efforts to address marine litter should focus primarily on its prevention at source through sustainable consumption and production patterns, sound waste management, wastewater treatment and resource recovery using the priciples of a circular economy (Eriksen *et al.* 2014; UNEP 2016).

## 7.6 Conclusions

The oceans are impacted by numerous human activities and the most serious impacts are related to climate change, land-based pollution and fishing. Within the impacts of climate change, our assessment has mentioned several issues: ocean acidification; sea level rise; changes to bottom water formation; the distribution of many fish and invertebrate species; and ocean circulation. The most dramatic and immediate impact of climate change on the oceans in recent years (GEO-6 cycle) is the bleaching and death of coral reefs. Pollution, particularly from plastic, is a major concern for many marine and coastal ecosystems. In relation to the fisheries sector, the chapter highlights concerns of overfishing, climate change impacts on species distribution patterns and the rise of aquaculture. We therefore summarize some key findings:

1. Tropical coral reefs have passed a tipping point whereby chronic bleaching has killed many reefs that are unlikely to recover even over centuries-long timescales. Reef death will be followed by loss of fisheries, tourism livelihoods and habitats. The demise of tropical coral reef ecosystems will be a disaster for many dependent communities and industries. Even if reef-owning nations take immediate action to protect their coral reefs from non-subsistence uses, there is a major risk that many reef-based industries will collapse over the next decade.

7

2. Marine litter has been found across all oceans and at all depths. Micro- and nano-plastics are now documented in the food web, including in seafoods consumed by humans. Marine litter has increased, with an estimated 8 million tons per year of plastics entering the ocean, mainly from land-based sources. If nations do not take action to prevent litter from entering the ocean, it will continue to accumulate and compromise ecosystem health and human food security. Prevention involves ensuring recovery and recycling of all used plastic products, encouraging communities to reduce the volume of rubbish generated, and improving solid waste management and wastewater treatment. Cleaning up the oceans is not a sustainable option without action to stop litter from entering the oceans.

3. To meet future challenges of food security and healthy populations, in addition to using all natural products harvested for food more efficiently, more fish, invertebrates and marine plants will have to be taken as food from the oceans and coasts, so both capture fisheries and mariculture must expand while preserving sustainability. It is possible to keep capture fisheries sustainable, but this requires significant investments in monitoring, assessment and management (at national, regional and international levels) and/or strong local community-based approaches. Sustainable mariculture requires knowledge and care in management of operations. Without sound bases in knowledge and governance of fisheries and mariculture, patterns of overexploitation, environmental damage and resource depletion are likely, and neither food security nor health goals will be met.

# References




Acoleyen, M., Laureysens, I., Lambert, S., Raport, L., van Sluis, C., Kater, B. *et al.* (2013). *Final Report: Marine Litter Study To Support The Establishment of an Initial Quantitative Headline Reduction Target - SFRA0025.* European Commission. http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/pdf/final_report.pdf.

Alverson, D.L., Freeberg, M.H., Murawaski, S.A. and Pope, J.G. (1994). *A Global Assessment of Fisheries Bycatch and Discards.* FAO Fisheries Technical Paper. Rome. http://www.fao.org/docrep/003/t4890e/t4890e00.htm.

Andrew, R.K., Howe, B.M. and Mercer, J.A. (2011). Long-time trends in ship traffic noise for four sites off the North American west coast. *The Journal of the Acoustical Society of America* 129(2), 642-651. https://doi.org/10.1121/1.3518770.

Andrew, R.K., Howe, B.M., Mercer, J.A. and Dzieciuch, M.A. (2002). Ocean ambient sound: Comparing the 1960s with the 1990s for a receiver off the California coast. *Acoustics Research Letters Online* 3(2), 65-70. https://doi.org/10.1121/1.1461915.

Australia, Great Barrier Reef Marine Park Authority (2017). *Reef health*. http://www.gbrmpa.gov.au/about-the-reef/reef-health.

Baker E., Gaill F., Karageorgis A., Lamarche G., Narayanaswamy B., Parr J. *et al.* (2016). Offshore mining industries.In *The First Global Integrated Marine Assessment - World Ocean Assessment I.* United Nations. chapter 23. http://www.un.org/Depts/los/global_reporting/WOA_RPROC/Chapter_23.pdf

Baker, E.K., Thygesen, K. and Roche, C. (2017). Why we need action on mercury now. [Grid-Arendal https://news.grida.no/why-we-need-action-on-mercury-now (Accessed: June 2018).

Barange, M., Merino, G., Blanchard, J.L., Scholtens, J., Harle, J., Allison, E.H. *et al.* (2014). Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nature Climate Change* 4(3), 211-216. https://doi.org/10.1038/nclimate2119.

Basel Convention (2017). *BC-13/17: Work Programme and Operations of the Open-ended Working Group for the biennium 2018–2019.* Basel Convention. https://www.informea.org/en/decision/work-programme-and-operations-open-ended-working-group-biennium-2018–2019.

Beaudoin, Y.C. and Smith, S. (2012). Habitats of the Su Su Knolls hydrothermal site, eastern Manus Basin, Papua New Guinea.In *Seafloor Geomorphology as Benthic Habitat.* Harris, P. and Baker, E. (eds.). Elsevier. 843-852. https://www.researchgate.net/publication/284781274_Habitats_of_the_Su_Su_Knolls_Hydrothermal_Site_Eastern_Manus_Basin_Papua_New_Guinea

Bell, J.D., Watson, R.A. and Ye, Y. (2017). Global fishing capacity and fishing effort from 1950 to 2012. *Fish and Fisheries* 18(3), 489-505. https://doi.org/10.1111/faf.12187.

Bernal, P. and Olivia, D. (2016). Aquaculture.In *The First Global Integrated Marine Assessment - World Ocean Assessment I.* Innis, L. and Simcock, A. (eds.). United Nations. chapter 12. http://www.un.org/Depts/los/global_reporting/WOA_RPROC/Chapter_12.pdf

Beverton, R.J.H. and Holt, S.J. (1957). *On The Dynamics of Exploited Fish Populations.* 1st edn. London: Her Majesty's Stationery Office. https://trove.nla.gov.au/work/13338365?q&sort=holdings+desc&_=1539166792028&versionId=25601182.

Beyer, H.L., Kennedy, E.V., Beger, M., Chen, C.A., Cinner, J.E., Darling, E.S. *et al.* (2018). Risk-sensitive planning for conserving coral reefs under rapid climate change. *Conservation Letters*, e12587. https://doi.org/10.1111/conl.12587.

Boschen, R.E., Rowden, A.A., Clark, M.R. and Gardner, J.P.A. (2013). Mining of deep-sea seafloor massive sulfides: A review of the deposits, their benthic communities, impacts from mining, regulatory frameworks and management strategies. *Ocean & Coastal Management* 84, 54-67. https://doi.org/10.1016/j.ocecoaman.2013.07.005.

Brander, L. and Van Beukering, P. (2013). *The Total Economic Value of U.S. Coral Reefs: A Review of The Literature.* Silver Spring, MD: National Oceanographic and Atmospheric Administration (NOAA) Coral Reef Conservation Programme (CRCP). https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/other_crcp_publications/TEV_US_Coral_Reefs_Literature_Review_2013.pdf.

Burke, L., Reytar, K., Spalding, M. and Perry, A. (2012). *Reefs at Risk Revisited in the Coral Triangle.* Washington, DC: World Resources Institute. http://pdf.wri.org/reefs_at_risk_revisited_coral_triangle.pdf.

Campana, S.E. (2016). Transboundary movements, unmonitored fishing mortality, and ineffective international fisheries management pose risks for pelagic sharks in the Northwest Atlantic. *Canadian Journal of Fisheries and Aquatic Sciences* 73(10), 1599-1607. https://doi.org/10.1139/cjfas-2015-0502.

Chapman, N.R. and Price, A. (2011). Low frequency deep ocean ambient noise trend in the Northeast Pacific Ocean. *The Journal of the Acoustical Society of America* 129(5), EL161-EL165. https://doi.org/10.1121/1.3567084.

Chavez, F.P., Bertrand, A., Guevara-Carrasco, R., Soler, P. and Csirke, J. (2008). The northern Humboldt Current System: Brief history, present status and a view towards the future. *Progress in Oceanography* 79(2–4), 95-105. https://doi.org/10.1016/j.pocean.2008.10.012.

Cheung, W.W., Watson, R. and Pauly, D. (2013). Signature of ocean warming in global fisheries catch. *Nature* 497(7449), 365-368. https://doi.org/10.1038/nature12156.

Cinner, J.E., Pratchett, M.S., Graham, N.A.J., Messmer, V., Fuentes, M.M.P.B., Ainsworth, T. *et al.* (2016). A framework for understanding climate change impacts on coral reef social–ecological systems. *Regional environmental change* 16(4), 1133-1146. https://doi.org/10.1007/s10113-015-0832-z.

Commission for the Conservation of Antarctic Marine Living Resources (2016). *Toothfish fisheries*. https://www.ccamlr.org/en/fisheries/toothfish-fisheries.

Convention on Biodiversity (2012). Scientific Synthesis on the Impacts of Underwater Noise on Marine and Coastal Biodiversity and Habitats- Note by the Executive Secretary. UNEP/CBD/SBSTTA/16/INF/12 *19th ASCOBANS Advisory Committee Meeting*. 20-22 March 2012. https://www.cbd.int/doc/meetings/sbstta/sbstta-16/information/sbstta-16-inf-12-en.doc

Convention on Biological Diversity (2016). *XIII/10. Addressing impacts of marine debris and anthropogenic underwater noise on marine and coastal biodiversity: Decision adopted by the Conference of the Parties to the Convention on Biological Diversity. CBD/COP/DEC/XIII/10.* Cancun. https://www.cbd.int/doc/decisions/cop-13/cop-13-dec-10-en.pdf.

Cook Islands Seabed Minerals Authority (2014). *Cook Islands National Seabed Minerals Policy.* https://www.seabedmineralsauthority.gov.ck/PicsHotel/SeabedMinerals/Brochure/Cook%20Islands%20Seabed%20Minerals%20Policy%20.pdf.

Cox, K.D., Brennan, L.P., Dudas, S.E. and Juanes, F. (2016). Assessing the effect of aquatic noise on fish behavior and physiology: A meta-analysis approach. *Proceedings of Meetings on Acoustics* 27(1). https://doi.org/10.1121/2.0000291.

Cozar, A., Echevarria, F., Gonzalez-Gordillo, J.I., Irigoien, X., Ubeda, B., Hernandez-Leon, S. *et al.* (2014). Plastic debris in the open ocean. *Proceedings of the National Academy of Sciences* 111(28), 10239-10244. https://doi.org/10.1073/pnas.1314705111.

Creighton, C., Hobday, A.J., Lockwood, M. and Pecl, G.T. (2016). Adapting management of marine environments to a changing climate: a checklist to guide reform and assess progress. *Ecosystems* 19(2), 187-219. https://doi.org/10.1007/s1002.

Crump, K.S., Kjellström, T., Shipp, A.M., Silvers, A. and Stewart, A. (1998). Influence of prenatal mercury exposure upon scholastic and psychological test performance: Benchmark analysis of a New Zealand cohort. *Risk Analysis* 18(6), 701-713. https://doi.org/10.1111/j.1539-6924.1998.tb01114.x.

Daniels, J.L., Longnecker, M.P., Rowland, A.S., Golding, J. and ALSPAC Study Team-University of Bristol Institute of Child Health (2004). Fish intake during pregnancy and early cognitive development of offspring. *Epidemiology* 15(4), 394-402. https://doi.org/10.1097/01.ede.0000129514.46451.ce.

Derraik, J.G.B. (2002). The pollution of the marine environment by plastic debris: A review. *Marine pollution bulletin* 44(9), 842-852. https://doi.org/10.1016/S0025-326X(02)00220-5.

Dichmont, C.M., Dutra, L.X.C., Owens, R., Jebreen, E., Thompson, C., Deng, R.A. *et al.* (2016). A generic method of engagement to elicit regional coastal management options. *Ocean & Coastal Management* 124, 22-32. https://doi.org/10.1016/j.ocecoaman.2016.02.003.

Eigaard, O.R., Bastardie, F., Hintzen, N.T., Buhl-Mortensen, L., Buhl-Mortensen, P., Catarino, R. *et al.* (2017). The footprint of bottom trawling in European waters: Distribution, intensity, and seabed integrity. *ICES Journal of Marine Science* 74(3), 847-865. https://doi.org/10.1093/icesjms/fsw194.

Ellison, J.C. (2018). Pacific Island beaches: Values, threats and rehabilitation.In *Beach Management Tools-Concepts, Methodologies and Case Studies.* Botero C., Cervantes O. and Finkl, C. (eds.). Cham: Springer. 679-700. https://link.springer.com/chapter/10.1007/978-3-319-58304-4_34

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C. *et al.* (2014). Plastic pollution in the world's oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PLoS One* 9(12), e111913. https://doi.org/10.1371/journal.pone.0111913.

European Commission (2017). *Commission Decision (EU) 2017/848 of 17 May 2017 laying down Criteria and Methodological Standards on Good Environmental Status of Marine Waters and Specifications and Standardised Methods for Monitoring and Assessment, and repealing Decision 2010/477/EU.* European Union. https://publications.europa.eu/en/publication-detail/-/publication/a7523a58-3b91-11e7-a08e-01aa75ed71a1/language-en.

Fernández, A., Edwards, J.F., Rodriguez, F., De Los Monteros, A.E., Herraez, P., Castro, P. *et al.* (2005). "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (family Ziphiidae) exposed to anthropogenic sonar signals. *Veterinary Pathology* 42(4), 446-457. https://doi.org/10.1354/vp.42-4-446.

Food and Agriculture Organization of the United Nations (2003). *Fisheries Management 2: The Ecosystem Approach to Fisheries.* FAO Technical Guidelines for Responsible Fisheries. Rome. http://www.fao.org/3/a-y4470e.pdf.

Food and Agriculture Organization of the United Nations (2005). *Increasing The Contribution of Small-Scale Fisheries To Poverty Alleviation and Food Security.* FAO Technical Guidelines For Responsible Fisheries. Rome. http://www.fao.org/tempref/docrep/fao/008/a0237e/a0237e00.pdf.

Food and Agriculture Organization of the United Nations (2007). *Marine Protected Areas as as a Tool for Fisheries Management (MPAs).* Rome. http://sih.ifremer.fr/content/download/5924/43589/file/MPA_FAO_website_Sep_2007.pdf.

Food and Agriculture Organization of the United Nations (2009a). *International guidelines for the management of deep-sea fisheries in the high seas*. http://www.fao.org/docrep/011/i0816t/i0816t00.htm.

Food and Agriculture Organization of the United Nations (2009b). *FAO/UNEP Expert Meeting on Impacts of Destructive Fishing Practices, Unsustainable Fishing, and Illegal, Unreported and Unregulated (IUU) Fishing on Marine Biodiversity and Habitats.* FAO Fisheries and Aquaculture. Rome. http://www.fao.org/docrep/012/i1490e/i1490e00.pdf.

Food and Agriculture Organization of the United Nations (2010). *Aquaculture Development 4. Ecosystem Approach to Aquaculture.* FAO Technical Guidelines for Responsible Fisheries Rome. http://www.fao.org/docrep/013/i1750e/i1750e.pdf.

Food and Agriculture Organization of the United Nations (2011). *Code of Conduct for Responsible Fisheries.* Rome. http://www.fao.org/3/a-v9878e.pdf.

Food and Agriculture Organization of the United Nations (2015). *Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication.* Rome: Food and Agriculture Organization. http://www.fao.org/policy-support/resources/resources-details/en/c/418453/.

Food and Agriculture Organization of the United Nations (2016a). *The State of World Fisheries and Aquaculture 2016: Contributing to Food Security and Nutrition for All.* Rome. http://www.fao.org/3/a-i5555e.pdf.

Food and Agriculture Organization of the United Nations (2016b). *Technical and Socio-Economic Characteristics of Small-Scale Coastal Fishing Communities, and Opportunities for Poverty Alleviation and Empowerment.* FAO Fisheries and Aquaculture. Rome. http://www.fao.org/3/a-i5651e.pdf.

Food and Agriculture Organization of the United Nations (2018a). *The State of World Fisheries and Aquaculture: Meeting the Sustainable Development Goals.* Rome. http://www.fao.org/3/i9540en/I9540EN.pdf.

Food and Agriculture Organization of the United Nations (2018b). *Policy support and governance: Sustainable small-scale fisheries*. http://www.fao.org/policy-support/policy-themes/sustainable-small-scale-fisheries/en/ (Accessed: 1 October 2018).

Food and Agriculture Organization of the United Nations and World Bank (2015). *Aquaculture Zoning, Site Selection and Area Management under the Ecosystem Approach To Aquaculture.* http://www.fao.org/3/a-i5004e.pdf.

Food and Agriculture Organization of the United Nations and World Health Organisation (2011). *Report of the Joint FAO/WHO Expert Consultation on the Risks and Benefits of Fish Consumption.* Rome, 25–29 January. http://www.fao.org/docrep/014/ba0136e/ba0136e00.pdf

Food and Agriculture Organization of the United Nations and World Health Organization (2014). *Conference Outcome Document: Rome Declaration on Nutrition.* Second International Conference on Nutrition. Rome. www.fao.org/3/a-ml542e.pdf.

Frieler, K., Meinshausen, M., Golly, A., Mengel, M., Lebek, K., Donner, S.D. *et al.* (2013). Limiting global warming to 2 °C is unlikely to save most coral reefs. *Nature Climate Change* 3(2), 165-170. https://doi.org/10.1038/nclimate1674.

Froese, R., Zeller, D., Kleisner, K. and Pauly, D. (2013). Worrisome trends in global stock status continue unabated: a response to a comment by RM Cook on "What catch data can tell us about the status of global fisheries". *Marine Biology* 160(9), 2531-2533. https://doi.org/10.1007/s00227-013-2185-9.

Garcia, S.M., Kolding, J., Rice, J., Rochet, M.-J., Zhou, S., Arimoto, T. *et al.* (2012). Reconsidering the consequences of selective fisheries. *Science* 335(6072), 1045-1047. https://doi.org/10.1126/science.1214594.

Garcia, S.M., Ye, Y., Rice, J. and Charles, A.T. (2018). *Rebuilding of Marine FisheriesPart 1: Global Review.* FAO Fisheries and Aquaculture Technical Paper 630/1. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/ca0161en/CA0161EN.pdf.

Gigault, J., Pedrono, B., Maxit, B. and Ter Halle, A. (2016). Marine plastic litter: The unanalyzed nano-fraction. *Environmental science: Nano* 3(2), 346-350. https://doi.org/10.1039/C6EN00008H.

Gislason, H. and Sinclair, M.M. (2000). Ecosystem effects of fishing. *ICES Journal of Marine Science* 57(3), 466–467. https://doi.org/10.1006/jmsc.2000.0742.

Götz, T., Hastie, G., Hatch, L.T., Raustein, O., Southall, B.L., Tasker, M. *et al.* (2009). *Overview of the Impacts of Anthropogenic Underwater Sound in the Marine Environment.* OSPAR Biodiversity Series. London: OSPAR Commission. https://tethys.pnnl.gov/sites/default/files/publications/Anthropogenic_Underwater_Sound_in_the_Marine_Environment.pdf.

Grandjean, P., Weihe, P., White, R.F., Debes, F., Araki, S., Yokoyama, K. *et al.* (1997). Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. *Neurotoxicology and teratology* 19(6), 417-428. https://doi.org/10.1016/S0892-0362(97)00097-4.

Gray, J.S. (1997). Marine biodiversity: Patterns, threats and conservation needs. *Biodiversity and Conservation* 6(1), 153-175. https://doi.org/10.1023/A:1018335901847.

Gray, T.S. (ed.) (2005). *Participation in Fisheries Governance*. Dordrecht: Springer. https://www.springer.com/gp/book/9781402037771.

Gribble, M.O., Karimi, R., Feingold, B.J., Nyland, J.F., O'Hara, T.M., Gladyshev, M.I. *et al.* (2016). Mercury, selenium and fish oils in marine food webs and implications for human health. *Journal of the Marine Biological Association of the United Kingdom* 96(1), 43-59. https://doi.org/10.1017/S0025315415001356.

GRID-Arendal (2016a). *Plastic input into the ocean*. http://www.grida.no/resources/6906.

GRID-Arendal (2016b). *Plastic currents*. Grid-Arendal http://www.grida.no/resources/6913.

Grimm, M. and Tulloch, J. (eds.) (2015). *The megacity state:The world's biggest cities shaping our future*. Munich: Allianz SE. https://www.allianz.com/content/dam/onemarketing/azcom/Allianz_com/migration/media/press/document/Allianz_Risk_Pulse_Megacities_20151130-EN.pdf.

Guillotreau, P., Campling, L. and Robinson, J. (2012). Vulnerability of small island fishery economies to climate and institutional changes. *Current Opinion in Environmental Sustainability* 4(3), 287-291. https://doi.org/10.1016/j.cosust.2012.06.003.

Güven, O., Gökdağ, K., Jovanović, B. and Kıdeyş, A.E. (2017). Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. *Environmental Pollution* 223, 286-294. https://doi.org/10.1016/j.envpol.2017.01.025.

Ha, E., Basu, N., Bose-O'Reilly, S., Dórea, J.G., McSorley, E., Sakamoto, M. *et al.* (2017). Current progress on understanding the impact of mercury on human health. *Environmental Research* 152, 419-433. https://doi.org/10.1016/j.envres.2016.06.042.

Halden, R.U. (2015). Epistemology of contaminants of emerging concern and literature meta-analysis. *Journal of Hazardous Materials* 282, 2-9. https://doi.org/10.1016/j.jhazmat.2014.08.074.

Halpern, B.S., Longo, C., Hardy, D., McLeod, K.L., Samhouri, J.F., Katona, S.K. *et al.* (2012). An index to assess the health and benefits of the global ocean. *Nature* 488(7413), 615-620. https://doi.org/10.1038/nature11397.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'agrosa, C. *et al.* (2008). A global map of human impact on marine ecosystems. *Science* 319(5865), 948-952. https://doi.org/10.1126/science.1149345.

Hansen, J., Nazarenko, L., Ruedy, R., Sato, M., Willis, J., Del Genio, A. *et al.* (2005). Earth's energy imbalance: Confirmation and implications. *Science* 308(5727), 1431-1435. https://doi.org/10.1126/science.1110252.

Harris, P., Philip, R., Robinson, S. and Wang, L. (2016). Monitoring anthropogenic ocean sound from shipping using an acoustic sensor network and a compressive sensing approach. *Sensors* 16(3), 415. https://doi.org/10.3390/s16030415.

Hibbeln, J.R., Davis, J.M., Steer, C., Emmett, P., Rogers, I., Williams, C. *et al.* (2007). Maternal seafood consumption in pregnancy and neurodevelopmental outcomes in childhood (ALSPAC study): An observational cohort study. *The Lancet* 369(9561), 578-585. https://doi.org/10.1016/S0140-6736(07)60277-3.

Hilborn, R. and Ovando, D. (2014). Reflections on the success of traditional fisheries management. *ICES Journal of Marine Science: Journal du Conseil* 71(5), 1040-1046. https://doi.org/10.1093/icesjms/fsu034.

Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E. *et al.* (2007). Coral reefs under rapid climate change and ocean acidification. *Science* 318(5857), 1737-1742. https://doi.org/10.1126/science.1152509.

Hoshino, E. and Jennings. S. (2016). *The value of marine resources harvested in the CCAMLR Convention Area – an assessment of GVP.* Tasmania: Conservation of Antarctic Marine Living Resources. https://www.ccamlr.org/en/ccamlr-xxxv/10.

Hughes, T.P., Anderson, K.D., Connolly, S.R., Heron, S.F., Kerry, J.T., Lough, J.M. *et al.* (2018). Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science* 359(6371), 80-83. https://doi.org/10.1126/science.aan8048.

Hughes, T.P., Barnes, M.L., Bellwood, D.R., Cinner, J.E., Cumming, G.S., Jackson, J.B. *et al.* (2017). Coral reefs in the Anthropocene. *Nature* 546(7656), 82-90. https://doi.org/10.1038/nature22901

Hughes, T.P., Barnes, M.L., Bellwood, D.R., Cinner, J.E., Cumming, G.S., Jackson, J.B. *et al.* (2017). Coral reefs in the Anthropocene. *Nature* 546(7656), 82-90. https://doi.org/10.1038/nature22901.

Inger, R., Attrill, M.J., Bearhop, S., Broderick, A.C., James Grecian, W., Hodgson, D.J. *et al.* (2009). Marine renewable energy: Potential benefits to biodiversity? An urgent call for research. *Journal of Applied Ecology* 46(6), 1145-1153. https://doi.org/10.1111/j.1365-2664.2009.01697.x.

Inniss, L. and Simcock, A. (eds.) (2016). *The First Global Integrated Marine Assessment: World Ocean Assessment I*. New York, NY: United Nations. http://www.un.org/depts/los/global_reporting/WOA_RegProcess.htm.

Intergovernmental Panel on Climate Change (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J. *et al.* (eds.). Cambridge, MA: Cambridge University Press. http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf.

International Labour Organization (2014). *Report of the UN Secretary-General on Oceans and Law of the Sea, 2014.* Geneva. http://www.un.org/depts/los/general_assembly/contributions_2014/ILO.pdf.

International Seabed Authority (2017). *Selected Decisions and Documents of The Twenty-Third Session.* Kingston: International Seabed Authority. https://www.isa.org.jm/sites/default/files/files/documents/en_3.pdf.

Inuit Circumpolar Council (2011). *A Circumpolar Inuit Declaration on Resource Development Principles in Inuit Unaat*. http://www.inuitcircumpolar.com/uploads/3/0/5/4/30542564/declaration_on_resource_development_a3_final.pdf (Accessed: 27 July 2016).

Jacobsen, N.S., Burgess, M.G. and Andersen, K.H. (2017). Efficiency of fisheries is increasing at the ecosystem level. *Fish and Fisheries* 18(2), 199-211. https://doi.org/10.1111/faf.12171.

Jahnke, A., Arp, H.P.H., Escher, B.I., Gewert, B., Gorokhova, E., Kühnel, D. *et al.* (2017). Reducing uncertainty and confronting ignorance about the possible impacts of weathering plastic in the marine environment. *Envronmental Science & Technology Letters* 4(3), 85-90. https://doi.org/10.1021/acs.estlett.7b00008.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A. *et al.* (2015). Plastic waste inputs from land into the ocean. *Science* 347(6223), 768-771. https://doi.org/10.1126/science.1260352.

Jennings, S. and Kaiser, M.J. (1998). The effects of fishing on marine ecosystems. *Advances in Marine Biology* 34, 201-352. https://doi.org/10.1016/S0065-2881(08)60212-6.

Johnson, J.E., Welch, D.J., Maynard, J.A., Bell, J.D., Pecl, G., Robins, J. *et al.* (2016). Assessing and reducing vulnerability to climate change: Moving from theory to practical decision-support. *Marine Policy* 74, 220-229. https://doi.org/10.1016/j.marpol.2016.09.024.

Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) (2015). *Sources, Fate and Effects of Microplastics in the Marine Environment: A Global Assessment*. Kershaw, P.J. (ed.). London: International Maritime Organization. http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/pdf/GESAMP_microplastics%20full%20study.pdf.

Jones, G.P., McCormick, M.I., Srinivasan, M. and Eagle, J.V. (2004). Coral decline threatens fish biodiversity in marine reserves. *Proceedings of the National Academy of Sciences* 101(21), 8251-8253. https://doi.org/10.1073/pnas.0401277101.

Karagas, M.R., Choi, A.L., Oken, E., Horvat, M., Schoeny, R., Kamai, E. *et al.* (2012). Evidence on the human health effects of low-level methylmercury exposure. *Environmental Health Perspectives* 120(6), 799-806. https://doi.org/10.1289/ehp.1104494.

Kelleher, K. (2005). *Discards in The World's Marine Fisheries: An Update.* FAO Fisheries Technical Paper. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/008/y5936e/y5936e00.htm.

Koelmans, A.A., Bakir, A., Burton, G.A. and Janssen, C.R. (2016). Microplastic as a vector for chemicals in the aquatic environment: Critical review and model-supported reinterpretation of empirical studies. *Environmental Science & Technology* 50(7), 3315-3326. https://doi.org/10.1021/acs.est.5b06069.

Koslow, J.A., Auster, P., Bergstad, O.A., Roberts, J.M., Rogers, A., Vecchione, M. *et al.* (2016). Biological communities on seamounts and other submarine features potentially threatened by disturbance. In *The First Global Integrated Marine Assessment: World Ocean Assessment I*. Innis, L. and Simcock, A. (eds.). United Nations. chapter 51. http://www.un.org/depts/los/global_reporting/WOA_RPROC/Chapter_51.pdf

Kummu, M., De Moel, H., Salvucci, G., Viviroli, D., Ward, P.J. and Varis, O. (2016). Over the hills and further away from coast: Global geospatial patterns of human and environment over the 20th–21st centuries. *Environmental Research Letters* 11(3), https://doi.org/10.1088/1748-9326/11/3/034010.

Lambeth, L., Hanchard, B., Aslin, H., Fay-Sauni, L., Tuara, P., Rochers, K.D. *et al.* (2014). An overview of the involvement of women in fisheries activities in Oceania.In *Global Symposium on Women in Fisheries.* Williams M.J., Chao N.H., Choo P.S., Matics K., Nandeesha M.C., Shariff M. *et al.* (eds.). Penang: ICLARM — The World Fish Center. 21-33.

Larson, C. (2018). Asia's hunger for sand takes toll on ecology. *Science* 359(6379), 964-965. https://doi.org/10.1126/science.359.6379.964

Lavers, J.L. and Bond, A.L. (2017). Exceptional and rapid accumulation of anthropogenic debris on one of the world's most remote and pristine islands. *Proceedings of the National Academy of Sciences* 114(23), 6052-6055. https://doi.org/10.1073/pnas.1619818114.

Leggett, C., Scherer, N., Curry, M., Bailey, R. and Haab, T. (2014). *Final Report: Assessing the economic Benefits of Reductions in Marine Debris: A Pilot Study of Beach Recreation in Orange County, California.* https://marinedebris.noaa.gov/sites/default/files/publications-files/MarineDebrisEconomicStudy_0.pdf.

Leite, L. and Pita, C. (2016). Review of participatory fisheries management arrangements in the European Union. *Marine Policy* 74, 268-278. https://doi.org/10.1016/j.marpol.2016.08.003.

Lemasson, A.J., Fletcher, S., Hall-Spencer, J.M. and Knights, A.M. (2017). Linking the biological impacts of ocean acidification on oysters to changes in ecosystem services: A review. *Journal of Experimental Marine Biology and Ecology* 492, 49-62. https://doi.org/10.1016/j.jembe.2017.01.019.

Li, H.-X., Ma, L.-S., Lin, L., Ni, Z.-X., Xu, X.-R., Shi, H.-H. *et al.* (2018). Microplastics in oysters Saccostrea Cucullata along the Pearl River Estuary, China. 236, 619-625. https://doi.org/10.1016/j.envpol.2018.01.083.

Macfadyen, G., Huntington, T. and Cappell, R. (2009). *Abandoned, Lost Or Otherwise Discarded Fishing Gear.* UNEP Regional Seas Reports and Studies No.185; FAO Fisheries and Aquaculture Technical Paper, No. 523. Rome: Food and Agriculture Organization of the United Nations and the United Nations Environment Programme. http://www.fao.org/docrep/011/i0620e/i0620e00.htm.

Marcon, Y., Purser, A., Janssen, F., Lins, L., Brown, A. and Boetius, A. (2016). Megabenthic community structure within and surrounding the DISCOL Experimental Area 26 years after simulated manganese nodule mining disturbance. *EU FP7 MIDAS Final Meeting*. Gent, 3-7 October 2016. http://epic.awi.de/44161/

Material District (2018). *Finite: A more sustainable alternative to concrete made from desert sand*. [Material District https://materia.nl/article/finite-concrete-desert-sand/ (Accessed: October 2018).

McDonald, M.A., Hildebrand, J.A. and Wiggins, S.M. (2006). Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. *The Journal of the Acoustical Society of America* 120(2), 711-718. https://doi.org/10.1121/1.2216565.

Melnychuk, M.C., Peterson, E., Elliott, M. and Hilborn, R. (2016). Fisheries management impacts on target species status. *Proceedings of the National Academy of Sciences* 114(1), 178-183. https://doi.org/10.1073/pnas.1609915114.

Miksis-Olds, J.L. and Nichols, S.M. (2016). Is low frequency ocean sound increasing globally? *The Journal of the Acoustical Society of America* 139(1), 501-511. https://doi.org/10.1121/1.4938237.

Morgan, C.L., Odunton, N.A. and Jones, A.T. (1999). Synthesis of environmental impacts of deep seabed mining. *Marine Georesources and Geotechnology* 17(4), 307-356. https://doi.org/10.1080/106411999273666.

Myers, G.J., Davidson, P.W., Cox, C., Shamlaye, C.F., Palumbo, D., Cernichiari, E. *et al.* (2003). Prenatal methylmercury exposure from ocean fish consumption in the Seychelles child development study. *The Lancet* 361(9370), 1686-1692. https://doi.org/10.1016/S0140-6736(03)13371-5.

Narita, D., Rehdanz, K. and Tol, R.S.J. (2012). Economic costs of ocean acidification: A look into the impacts on global shellfish production. *Climatic Change* 113(3-4), 1049-1063. https://doi.org/10.1007/s10584-011-0383-3.

Northridge, S., Coram, A., Kingston, A. and Crawford, R. (2017). Disentangling the causes of protected-species bycatch in gillnet fisheries. *Conservation Biology* 31(3), 686-695. https://doi.org/10.1111/cobi.12741.

O'Hanlon, N.J., James, N.A., Masden, E.A. and Bond, A.L. (2017). Seabirds and Marine Plastic Debris in the Northeastern Atlantic: A Synthesis and Recommendations for Monitoring and Research. *Environmental Pollution* 22, 1291-1301. https://doi.org/10.1016/j.envpol.2017.08.101.

O'Neill, B.C., Oppenheimer, M., Warren, R., Hallegatte, S., Kopp, R.E., Pörtner, H.O. *et al.* (2017). IPCC reasons for concern regarding climate change risks. *Nature Climate Change* 7(1), 28-37. https://doi.org/10.1038/nclimate3179.

Olson, J. (2011). Understanding and contextualizing social impacts from the privatization of fisheries: An overview. *Ocean & Coastal Management* 54(5), 353-363. https://doi.org/10.1016/j.ocecoaman.2011.02.002.

Österblom, H. and Bodin, Ö. (2012). Global cooperation among diverse organizations to reduce illegal fishing in the Southern Ocean. *Conservation Biology* 26(4), 638-648. https://doi.org/10.1111/j.1523-1739.2012.01850.x.

Peduzzi, P. (2014). Sand, rarer than one thinks. *Environmental Development* 11, 208-218. https://doi.org/10.1016/j.envdev.2014.04.001.

Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., Amaro, T., Bergmann, M., Canals, M. *et al.* (2014). Marine litter distribution and density in European seas, from the shelves to deep basins. *PLoS One* 9(4), e95839. https://doi.org/10.1371/journal.pone.0095839.

Popper, A.N. and Hastings, M.C. (2009). The effects of anthropogenic sources of sound on fishes. *Journal of fish biology* 75(3), 455-489. https://doi.org/10.1111/j.1095-8649.2009.02319.x

Ralston, N.V. and Raymond, L.J. (2010). Dietary selenium's protective effects against methylmercury toxicity. *Toxicology* 278(1), 112-123. https://doi.org/10.1016/j.tox.2010.06.004.

Rice, J. (2014). Evolution of international commitments for fisheries sustainability. *ICES Journal of Marine Science* 71(2), 157-165. https://doi.org/10.1093/icesjms/fst078.

Rice, J., Moksness, E., Attwood, C., Brown, S.K., Dahle, G., Gjerde, K.M. *et al.* (2012). The role of MPAs in reconciling fisheries management with conservation of biological diversity. *Ocean & Coastal Management* 69, 217-230. https://doi.org/10.1016/j.ocecoaman.2012.08.001.

Rice, J.C. and Garcia, S.M. (2011). Fisheries, food security, climate change, and biodiversity: characteristics of the sector and perspectives on emerging issues. *ICES Journal of Marine Science* 68(6), 1343-1353. https://doi.org/10.1093/icesjms/fsr041.

Richardson, W.J., Greene, C.R., Malme, C.I. and Thomson, D.H. (1995). *Marine Mammals and Noise.* San Diego, CA: Academic Press. https://www.elsevier.com/books/marine-mammals-and-noise/richardson/978-0-08-057303-8.

Ricker, W.E. (1975). *Computation and Interpretation of Biological Statistics of Fish Populations.* Bulletin of the Fisheries Research Board of CanadaEnvironment Canada. http://www.dfo-mpo.gc.ca/Library/1485.pdf.

Roos, N., Wahab, M.A., Chamnan, C. and Thilsted, S.H. (2007). The role of fish in food-based strategies to combat vitamin A and mineral deficiencies in developing countries. *The Journal of Nutrition* 137(4), 1106-1109. https://doi.org/10.1093/jn/137.4.1106.

Rose, G.A. (2007). *Cod: The Ecological History of the North Atlantic Fisheries.* St. John's, Newfoundland: Breakwater Books. http://www.breakwaterbooks.com/books/cod-the-ecological-history-of-the-north-atlantic-fisheries/.

Rosenberg, A. (2010). *Using fly ash in concrete.* [National Precast Concrete Association https://precast.org/2010/05/using-fly-ash-in-concrete/.

Salinger, J., Hobday, A., Matear, R., O'Kane, T., Risbey, J., Dunstan, P. *et al.* (2016). Chapter one-decadal-scale forecasting of climate drivers for marine applications. *Advances in Marine Biology* 74, 1-68. https://doi.org/10.1016/bs.amb.2016.04.002.

Schindler, D.E. and Hilborn, R. (2015). Prediction, precaution, and policy under global change. *Science* 347(6225), 953-954. https://doi.org/10.1126/science.1261824.

Schmidt, C., Krauth, T. and Wagner, S. (2017). Export of plastic debris by rivers into the sea. *Environmental Science & Technology* 51(21), 12246-12253. https://doi.org/10.1021/acs.est.7b02368.

Schuster, P.F., Schaefer, K.M., Aiken, G.R., Antweiler, R.C., Dewild, J.F., Gryziec, J.D. *et al.* (2018). Permafrost stores a globally significant amount of mercury. *Geophysical Research Letters* 45(3), 1463-1471. https://doi.org/10.1002/2017GL075571.

Secretariat of the Convention on Biological Diversity (2016). *Marine Debris: Understanding, Preventing and Mitigating the Significant Adverse Impacts on Marine and Coastal Biodiversity.* CBD Technical Series No. 83. Montreal. https://www.cbd.int/doc/publications/cbd-ts-83-en.pdf.

Secretariat of the Pacific Community (ed.) (2013a). *Deep Sea Minerals: Sea Floor Massive Sulphides, a Physical, Biological, Environmental, and Technical Review*. http://dsm.gsd.spc.int/public/files/meetings/TrainingWorkshop4/UNEP_vol1A.pdf.

Secretariat of the Pacific Community (2013b). *Deep Sea Minerals: Deep Sea Minerals and the Green Economy.* Baker, E. and Beaudoin, Y. (eds.). https://www.researchgate.net/publication/260596769_Deep_Sea_Minerals_and_the_Green_Economy.

Sharma, R. (2001). Indian Deep-sea Environment Experiment (INDEX): An appraisal. *Deep Sea Research Part II: Topical Studies in Oceanography* 48(16), 3295-3307. https://doi.org/10.1016/S0967-0645(01)00041-8.

Steneck, R.S., Mumby, P.J., MacDonald, C., Rasher, D.B. and Stoyle, G. (2018). Attenuating effects of ecosystem management on coral reefs. *Science Advances* 4(5), eaao5493. https://doi.org/10.1126/sciadv.aao5493.

Stokstad, E. (2018). Controversial plastic trash collector begins maiden ocean voyage. Science Magazine http://www.sciencemag.org/news/2018/09/still-controversial-plastic-trash-collector-ocean-begins-maiden-voyage.

Strain, J.J., Davidson, P.W., Bonham, M.P., Duffy, E.M., Stokes-Riner, A., Thurston, S.W. *et al.* (2008). Associations of maternal long-chain polyunsaturated fatty acids, methyl mercury, and infant development in the Seychelles child development nutrition study. *NeuroToxicology* 29(5), 776-782. https://doi.org/10.1016/j.neuro.2008.06.002.

Swan, J. and Gréboval, D. (2005). *Overcoming Factors of Unsustainability and Overexploitation in Fisheries: Selected Papers on Issues and Approaches.* Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/009/a0312e/A0312E00.htm.

Syvitski, J.P.M., Vörösmarty, C.J., Kettner, A.J. and Green, P. (2005). Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science* 308(5720), 376-380. https://doi.org/10.1126/science.1109454.

Tarling, G.A., Peck, V.L., Ward, P., Ensor, N.S., Achterberg, E., Tynan, E. *et al.* (2016). Effects of acute ocean acidification on spatially-diverse polar pelagic foodwebs: Insights from on-deck microcosms. *Deep Sea Research Part II: Topical Studies in Oceanography* 127, 75-92. https://doi.org/10.1016/j.dsr2.2016.02.008.

Taylor, C.M., Emmett, P.M., Emond, A.M. and Golding, J. (2018). A review of guidance on fish consumption in pregnancy: Is it fit for purpose? *Public Health Nutrition* 21(11), 2149-2159. https://doi.org/10.1017/S1368980018000599.

Thiel, M., Luna-Jorquera, G., Álvarez-Varas, R., Gallardo, C., Hinojosa, I.A., Luna, N. *et al.* (2018). Impacts of Marine Plastic Pollution from Continental Coasts to Subtropical Gyres—Fish, Seabirds, and Other Vertebrates in the SE Pacific. *Frontiers in Marine Science* 5(238). https://doi.org/10.3389/fmars.2018.00238.

Thilsted, S.H., James, D., Toppe, J., Subasinghe, R. and Karunasagar, I. (2014). Maximizing the contribution of fish to human nutrition. *ICN2 Second International Conference on Nutrition*. Food Agriculture Organizationof the United Nations and World Health Organization http://www.fao.org/3/a-i3963e.pdf

Tidau, S. and Briffa, M. (2016). Review on behavioral impacts of aquatic noise on crustaceans. *Proceedings of Meetings on Acoustics* 27(010028). https://doi.org/10.1121/2.0000302.

*Tuvalu Seabed Mining Act 2014,* 2014 (Tuvalu, P.o.). https://www.tuvalu-legislation.tv/cms/images/LEGISLATION/PRINCIPAL/2014/2014-0014/TuvaluSeabedMineralsAct_1.pdf.

United Nation Environment Programme (2013). *Global Mercury Assessment 2013: Sources, Emissions, Release and Environmental Transport.* Nairobi. http://wedocs.unep.org/bitstream/handle/20.500.11822/7984/-Global%20Mercury%20Assessment-201367.pdf?sequence=3&isAllowed=y.

United Nations (1982). *United Nations Convention on the Law of the Sea (LOSC).* http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm.

United Nations, General Assembly (2016). *70/235. Oceans and the law of the sea: Resolution adopted by the General Assembly on 23 December 2015.* https://undocs.org/A/RES/70/235.

United Nations Environment Assembly of the United Nations Environment Programme (2016a). *2/12. Sustainable Coral Reefs Management. UNEP/EA.2/Res.12.* http://wedocs.unep.org/bitstream/handle/20.500.11822/11187/K1607234_UNEPEA2_RES12E.pdf?sequence=1&isAllowed=y.

United Nations Environment Assembly of the United Nations Environment Programme (2016b). *2/11. Marine Plastic Litter and Microplastics. UNEP/EA.2/Res.11.* http://wedocs.unep.org/bitstream/handle/20.500.11822/11186/K1607228_UNEPEA2_RES11E.pdf?sequence=1&isAllowed=y.

United Nations Environment Assembly of the United Nations Environment Programme (2017). *3/7. Marine Litter and Microplastics. UNEP/EA.3/Res.7.* https://papersmart.unon.org/resolution/uploads/k1800210.english.pdf

United Nations Environment Programme (2016). *Marine Plastic Debris and Microplastics: Global Lessons and Research To Inspire Action and Guide Policy Change.* Nairobi. https://wedocs.unep.org/rest/bitstreams/11700/retrieve.

United Nations Environment Programme (2017). *Coral Bleaching Futures: Downscaled Projections of Bleaching Conditions for the World's Coral Reefs, Implications of Climate Policy and Management Responses.* Nairobi. http://wedocs.unep.org/bitstream/handle/20.500.11822/22048/Coral_Bleaching_Futures.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme and GRID-Arendal (2016). *Marine Litter Vital Graphics.* Nairobi: United Nations Environment Programme and GRID-Arendal. https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/11/original/MarineLitterVG.pdf?1488455779.

United Nations Environment Programme World Conservation Monitoring Centre (2015). *Marine Litter Assesment in the Mediterranean 2015. A Report of the Mediterranean Action Plan.* https://wedocs.unep.org/bitstream/handle/20.500.11822/7098/MarineLitterEng.pdf?sequence=1&isAllowed=y.

United States Food and Drug Administration (2017). *Eating fish: What pregnant women and parents should know*. https://www.fda.gov/Food/ResourcesForYou/Consumers/ucm393070.htm (Accessed: June 2018.

United States National Oceanic and Atmospheric Administration (2012). *How much would it cost to clean up the pacific garbage patches?* NOAA Coral Reef Watch https://response.restoration.noaa.gov/about/media/how-much-would-it-cost-clean-pacific-garbage-patches.html.

United States National Oceanic and Atmospheric Administration (2017). *Global warming and recurrent mass bleaching of corals. Coral Reef Watch*. https://coralreefwatch.noaa.gov/satellite/publications_hughes-etal_nature_20170316.php (Accessed: June 2017).

Unsworth, R.K.F., Ambo-Rappe, R., Jones, B.L., La Nafie, Y.A., Irawan, A., Hernawan, U.E. *et al.* (2018). Indonesia's globally significant seagrass meadows are under widespread threat. *Science of the Total Environment* 634, 279-286. https://doi.org/10.1016/j.scitotenv.2018.03.315.

Van Cauwenberghe, L. and Janssen, C.R. (2014). Microplastics in bivalves cultured for human consumption. *Environmental Pollution* 193, 65-70. https://doi.org/10.1016/j.envpol.2014.06.010.

Van Dover, C.L. (2011). Tighten regulations on deep-sea mining. *Nature* 470(7332), 31-33. https://doi.org/10.1038/470031a.

Van Dover, C.L., Ardron, J.A., Escobar, E., Gianni, M., Gjerde, K.M., Jaeckel, A. *et al.* (2017). Biodiversity loss from deep-sea mining. *Nature Geoscience* 10, 464–465. https://doi.org/10.1038/ngeo2983.

Van Hooidonk, R., Maynard, J., Tamelander, J., Gove, J., Ahmadia, G., Raymundo, L. *et al.* (2016). Local-scale projections of coral reef futures and implications of the Paris Agreement. *Scientific reports* 6(39666). https://doi.org/10.1038/srep39666.

Van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Van Franeker, J.A. *et al.* (2015). A global inventory of small floating plastic debris. *Environmental Research Letters* 10(12), 124006. https://doi.org/10.1088/1748-9326/10/12/124006.

Van Wijngaarden, E., Thurston, S.W., Myers, G.J., Harrington, D., Cory-Slechta, D.A., Strain, J.J. *et al.* (2017). Methyl mercury exposure and neurodevelopmental outcomes in the Seychelles Child Development Study Main cohort at age 22 and 24 years. *Neurotoxicology and teratology* 59, 35-42. https://doi.org/10.1016/j.ntt.2016.10.011.

Veron, J., Hoegh-Guldberg, O., Lenton, T., Lough, J., Obura, D., Pearce-Kelly, P. *et al.* (2009). The coral reef crisis: The critical importance of< 350ppm $CO_2$. *Marine Pollution Bulletin* 58(10), 1428-1436. https://doi.org/10.1016/j.marpolbul.2009.09.009.

Von Schuckmann, K., Palmer, M.D., Trenberth, K.E., Cazenave, A., Chambers, D., Champollion, N. *et al.* (2016). An imperative to monitor Earth's energy imbalance. *Nature Climate Change* 6(2), 138-144. https://www.nature.com/articles/nclimate2876.

Wang, J., Kiho, K., Ofiara, D., Zhao, Y., Bera, A., Lohmann, R. *et al.* (2016). Marine debris.In *The First Global Integrated Marine Assessment - World Ocean Assessment I.* Innis, L. and Simcock, A. (eds.). chapter 25. http://www.un.org/depts/los/global_reporting/WOA_RPROC/Chapter_25.pdf

Watkins, E., ten Brink, P., Sirini Withana, M.K., Russi, D., Mutafoglu, K., Schweitzer, J.-P. *et al.* (2017). The socio-economic impacts of marine litter, including the costs of policy inaction and action.In *Handbook on the Economics and Management of Sustainable Oceans.* Nunes, P.A.L.D., Svensson, L.E. and Markandya, A. (eds.). Edward Elgar Publishing. chapter 14. 296-319. https://www.elgaronline.com/view/9781786430717.00024.xml

Watson, R.A., Cheung, W.W.L., Anticamara, J.A., Sumaila, R.U., Zeller, D. and Pauly, D. (2012). Global marine yield halved as fishing intensity redoubles. *Fish and Fisheries* 14(4), 493-503. https://doi.org/10.1111/j.1467-2979.2012.00483.x.

Wilkinson, C., Salvat, B., Eakin, C.M., Brathwaite, A., Francini-Filho, R., Webster, N. *et al.* (2016). Tropical and sub-tropical coral reefs.In *The First Global Integrated Marine Assessment: World Ocean Assessment I*. Simcock, A. and Innis, L. (eds.). chapter 43. http://www.un.org/depts/los/global_reporting/WOA_RPROC/Chapter_43.pdf

Woodroffe, C.D., Hall, F.R., Farrell , J.W. and Harris, P.T. (2016). Calcium carbonate production and contribution to coastal sediments.In *The First Global Integrated Marine Assessment: World Ocean Assessment I*. Innis, L. and Simcock, A. (eds.). Cambridge, MA: Cambridge University Press. chapter 7. http://www.un.org/Depts/los/global_reporting/WOA_RPROC/Chapter_07.pdf

World Bank (2012). *Hidden Harvest:The Global Contribution of Capture Fisheries.* Washington, DC: World Bank. http://documents.worldbank.org/curated/en/515701468152718292/pdf/664690ESW0P1210120HiddenHarvest0web.pdf.

World Health Organization (2017). *Mercury and health: Key facts*. http://www.who.int/news-room/fact-sheets/detail/mercury-and-health (Accessed: June 2018).

Worm, B., Hilborn, R., Baum, J.K., Branch, T.A., Collie, J.S., Costello, C. *et al.* (2009). Rebuilding global fisheries. *Science* 325(5940), 578-585. https://doi/org/10.1126/science.1173146.

Wyles, K.J., Pahl, S., Thomas, K. and Thompson, R.C. (2016). Factors that can undermine the psychological benefits of coastal environments: Exploring the effect of tidal state, presence, and type of litter. *Environment and behavior* 48(9), 1095-1126. https://doi.org/10.1177/0013916515592177.

Yang, D., Shi, H., Li, L., Li, J., Jabeen, K. and Kolandhasamy, P. (2015). Microplastic pollution in table salts from China. *Environmental science & technology* 49(22), 13622-13627. https://doi.org/10.1021/acs.est.5b03163.

Ziccardi, L.M., Edgington, A., Hentz, K., Kulacki, K.J. and Kane Driscoll, S. (2016). Microplastics as vectors for bioaccumulation of hydrophobic organic chemicals in the marine environment: A state-of-the-science review. *Environmental toxicology and chemistry* 35(7), 1667-1676. https://doi.org/10.1002/etc.3461.

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