Summary of the First Global Integrated Marine Assessment

I. Introduction[1]

Let us consider how dependent on the ocean we are. The ocean is vast: it covers seven tenths of the planet, is on average about 4,000 metres deep and contains 1.3 billion cubic kilometres of water (97 per cent of all the water on the surface of the Earth). There are, however, 7 billion people on Earth. This means that each one of us has just one fifth of a cubic kilometre of ocean as our portion to provide us with all the services that we get from the ocean. That small, one fifth of a cubic kilometre portion generates half of the annual production of the oxygen that each of us breathes, and all of the sea fish and other seafood that each of us eats. It is the ultimate source of all the freshwater that each of us will drink in our lifetimes.

The ocean is a highway for ships that carry the goods that we produce and consume. The seabed and the strata beneath it hold minerals and oil and gas deposits that we increasingly need to use. Submarine cables across the ocean floor carry 90 per cent of the electronic traffic of communications, financial transactions and information exchange. Our energy supply will increasingly rely on sea-based wind turbines and wave and tidal power from the ocean. Large numbers of us take our holidays by the sea. The seabed is a rich repository for archaeology.

That one fifth of a cubic kilometre also suffers from the sewage, garbage, spilled oil and industrial waste which we collectively allow to go into the ocean every day. Demands on the ocean continue to rise together with the world's population. By the year 2050, it is estimated that there will be 10 billion people on Earth. Our portion, or our children's portion, of the ocean will then have shrunk to one eighth of a cubic kilometre. That reduced portion will still have to provide each of us with oxygen, food and water, while still suffering from the pollution and waste that we allow to enter the ocean.

The ocean is also home to a rich diversity of animals, plants, seaweeds and microbes, from the largest animal on the planet (the blue whale) to plankton and bacteria that can only be seen with powerful microscopes. We use some of those directly, and many more contribute indirectly to the benefits that we derive from the ocean. Even those organisms without any apparent connection with humans are part of the biodiversity whose value we have belatedly recognized. However, our relationship with the ocean and its creatures works both ways. We intentionally exploit many components of that rich biodiversity and increase the mortality of other components, even though we are not deliberately harvesting them. Carelessly (for example, through the input of waste material) or because of an initial lack of knowledge (for example, through the ocean acidification from increased emissions of carbon dioxide), we are altering the environment in which those organisms live. All those actions are affecting their ability to thrive and, sometimes, even to survive.

The impacts of humanity on the ocean are parts of our inheritance and future. They have helped to shape our present and will shape not only the future of the ocean and its biodiversity as an integral physical and biological system, but also the ability of the ocean to provide the services that we use now, that we will increasingly need to use in the future and that are vital to each of us and to human well-being overall.

Managing our uses of the ocean is therefore vital. The successful management of any activity, however, requires an adequate understanding of the activity and of the context in which it takes place. Such an understanding is needed even more when management

[1] In the present summary, the chapters referred to in footnotes are chapters of parts II to VII of the first global integrated marine assessment. When placed at the end of a paragraph, such footnotes apply to all preceding paragraphs up to the previous such footnote.

tasks are split among many players: unless each knows how the part they play fits into the overall pattern, there are risks of confusion, contradictory actions and failure to act. Managing the human uses of the ocean has inevitably to be divided among many players. In the course of their activities, individuals and commercial enterprises that use the ocean on a constant basis take decisions that affect the human impacts on the ocean.[2]

The United Nations Convention on the Law of the Sea[3] establishes the legal framework within which all activities in the oceans and seas must be carried out. National Governments and regional and global intergovernmental organizations all have their parts to play in regulating those activities. However, each of those many players tends to have a limited view of the ocean that is focused on their own sectoral interests. Without a sound framework in which to work, they may well fail to take into account the ways in which their decisions and actions interact with those of others. Such failures can add to the complexity of the manifold problems that exist.

It is therefore not surprising that, in 2002, the World Summit on Sustainable Development recommended that there be a regular process for global reporting and assessment of the state of the marine environment, including socioeconomic aspects, or that the General Assembly accepted that recommendation. In its resolution 64/71, the Assembly adopted the recommendation that the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects should review the state of the marine environment, including socioeconomic aspects, on a continual and systematic basis by providing regular assessments at the global and supraregional levels and an integrated view of environmental, economic and social aspects.

Those regular reviews of the state of the ocean, the way in which the many dynamics of the ocean interact and the ways in which humans are using it should enable the many people and institutions involved in human uses to position their decisions more effectively in the overall context of the ocean. The First Global Integrated Marine Assessment, also known as the first World Ocean Assessment, is the first outcome of the Regular Process. It is divided into seven parts, which are described in detail below. The present part (part I, the summary) provides: (a) a summary of the organization of the Process and the Assessment; (b) a short description of the 10 main themes that have been identified; (c) a more detailed description of each of those themes, based on the content of parts II to VII; and (d) indications of the most serious gaps in our knowledge of the ocean and related human activities, as well as in the capacities to engage in some activities and to assess them all, drawing on the content of parts III to VII.[4]

II. Background to the Assessment: the ocean around us

The starting point is the four main ocean basins of our planet: the Arctic Ocean, the Atlantic Ocean, the Indian Ocean and the Pacific Ocean.[5] Even though they have different names, they form one single interconnected ocean system. The basins have been created over geological times by the movement of the tectonic plates across the Earth's mantle. The tectonic plates have differing forms at their edges, giving broad or narrow continental shelves and varying profiles to the continental slopes leading down to the continental rises and the abyssal plains. Geomorphic activity in the abyssal plains between the continents gives rise to abyssal ridges, volcanic islands, seamounts, guyots (plateau-like seamounts), rift-valley segments and trenches. Erosion and sedimentation (either submarine or riverine, when the sea level was lower during the ice ages) have

[2] See chaps. 1 and 3.
[3] United Nations, *Treaty Series*, vol. 1833, No. 31363.
[4] See chaps. 1 and 2.
[5] The Southern Ocean is formed by the southernmost parts of the Atlantic, Indian and Pacific Ocean basins. The first World Ocean Assessment does not consider enclosed seas, such as the Caspian Sea or the Dead Sea.

created submarine canyons, glacial troughs, sills, fans and escarpments. Around the ocean basins, there are marginal seas, more or less separated from the main ocean basins by islands, archipelagos or peninsulas, or bounded by submarine ridges and formed by various processes.[6]

The water of the ocean mixes and circulates within those geological structures. Although the proportion of the different chemical components dissolved in seawater is essentially constant over time, that water is not uniform: there are very important physical and chemical variations within the seawater. Salinity varies according to the relative balance between inputs of freshwater and evaporation. Differences in salinity and temperature of water masses can cause seawater to be stratified into separate layers. Such stratification can lead to variations in the distribution of both oxygen and nutrients, with an obvious variety of consequences in both cases for the biotas sensitive to those factors. A further variation is in the penetration of light, which controls where the photosynthesis on which nearly all ocean life depends can take place. Below a few tens of metres at the coastal level or a few hundred meters in the clearer open ocean, the ocean becomes dark and there is no photosynthesis.[7]

Superimposed on all this is a change in the acidity of the ocean. The ocean absorbs annually about 26 per cent of the anthropogenic carbon dioxide emitted into the atmosphere. That gas reacts with the seawater to form carbonic acid, which is making the ocean more acid.

The ocean is strongly coupled with the atmosphere, mutually transferring substances (mostly gases), heat and momentum at its surface, forming a single coupled system. That system is influenced by the seasonal changes caused by the Earth's tilted rotation with respect to the sun. Variations in sea-surface temperature among different parts of the ocean are important in creating winds, areas of high and low air pressure and storms (including the highly damaging hurricanes, typhoons and cyclones). In their turn, winds help to shape the surface currents of the ocean, which transport heat from the tropics towards the poles. The ocean surface water arriving in the cold polar regions partly freezes, rendering the remainder more saline and thus heavier. That more saline water sinks to the bottom and flows towards the equator, starting a return flow to the tropics: the meridional overturning circulation, also called the thermohaline circulation. A further overall forcing factor is the movements generated by the tidal system, predominantly driven by the gravitational effect of the moon and sun.[8]

The movements of seawater help to control the distribution of nutrients in the ocean. The ocean enjoys both a steady (and, in some places, excessive) input from land of inorganic nutrients needed for plant growth (especially nitrogen, phosphorus and their compounds, but also lesser amounts of other vital nutrients) and a continuous recycling of all the nutrients already in the ocean through biogeochemical processes, including bacterial action. Areas of upwelling, where nutrient-rich water is brought to the surface, are particularly important, because they result in a high level of primary production from photosynthesis by phytoplankton in the zone of light penetration, combining carbon from atmospheric carbon dioxide with the other nutrients, and releasing oxygen back into the atmosphere. Whether in the water column or when it sinks to the seabed, that primary production constitutes the basis on which the oceanic food web is built, through each successive layer up to the top predators (large fish, marine mammals, marine reptiles, seabirds and, through capture fisheries, humans).[9]

The distribution of living marine resources around the world is the outcome of that complex interplay of geological forms, ocean currents, nutrient fluxes, weather, seasons and sunlight. Not surprisingly, the resulting distribution of living resources reflects that complexity. Because some ocean areas have high levels of primary production, the density of living marine resources in those areas and the contiguous areas to which

[6] See chap. 1.
[7] See chaps. 1 and 4.
[8] See chaps. 1 and 5.
[9] See chaps. 1 and 6.

currents carry that production is also high. Some of those areas of dense living marine resources are also areas of high biological diversity. The general level of biological diversity in the ocean is also high. For example, just under half of the world's animal phyla are found only in the ocean, compared to one single phylum found only on land.

Human uses of the ocean are shaped not only by the complex patterns of the physical characteristics of the ocean, of its currents and of the distribution of marine life, but also by the terrestrial conditions that have influenced the locations of human settlements, by economic pressures and by the social rules that have developed to control human activities — including national legislation, the law of the sea, international agreements on particular human uses of the sea and broader international agreements that apply to both land and sea.[10]

III. Carrying out the Assessment

A. Organization

To carry out the complex task of assessing the environmental, social and economic aspects of the ocean, the General Assembly has established arrangements capable of bringing to bear the many different skills needed. After the holding of two international workshops to consider modalities for the Regular Process, the Assembly started the first phase in 2006, the Assessment of Assessments. This examined more than 1,200 ocean assessments — some regional, others global, some as thematically restricted as the status and trend of a single fish stock or pollutant in a specific area, others as broad as integrated assessments of entire marine ecosystems. The Assessment of Assessments resulted in conclusions on good practice in that field and in recommendations on how the task of carrying out fully integrated assessments might be approached.

The General Assembly set up an Ad Hoc Working Group of the Whole, which examined those conclusions and recommendations and put proposals to the Assembly. In 2009, the Assembly approved the framework for the Regular Process developed in that way. The framework consists of: (a) the overall objective for the Regular Process; (b) a description of the scope of the Regular Process; (c) a set of principles to guide its establishment and operation; and (d) best practices on key design features for the Regular Process, as identified in the Assessment of Assessments. The framework also provided that capacity-building, the sharing of data and information and the transfer of technology would be crucial elements.

Between 2009 and 2011, the General Assembly set up, on the recommendation of the Ad Hoc Working Group of the Whole, the main institutional arrangements for the Regular Process, namely:

(a) The Ad Hoc Working Group of the Whole of the General Assembly on the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects, which has overseen and guided the Process, meeting at least once a year. In 2011, the Working Group established a Bureau to put its decisions into practice during intersessional periods;

(b) The Group of Experts of the Regular Process, which has the task of carrying out assessments within the framework of the Regular Process at the request of the Assembly and under the supervision of the Working Group. The Group of Experts is collectively responsible for its work on the Assessment. It consists of 22 members, for a maximum possible membership of 25, who are appointed through the regional groups within the Assembly. The work of the Group members has been either voluntary or supported by their parent institutions;

(c) The Pool of Experts, which provides a pool of skilled support to assist with the wide range of issues that an assessment of the ocean, integrated across ecosystem

[10] See chaps. 33 and 34.

components, sectors and environmental, social and economic aspects, has to cover. The members of the Pool have been nominated by States through the chairs of the regional groups within the Assembly and are allocated tasks by the Bureau on the recommendations of the Group of Experts. The work of the Pool members has been either voluntary or supported by their parent institutions;

(d) The secretariat of the Regular Process, which has been provided by the Division for Ocean Affairs and the Law of the Sea of the United Nations. No additional staff were recruited specifically for this work, as it was to be carried out within the overall resource level of the Division;

(e) Technical and scientific support for the Regular Process, which has been available, as a result of invitations from the Assembly, from the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP), the International Maritime Organization, the Food and Agriculture Organization of the United Nations (FAO), and the International Atomic Energy Agency;

(f) Workshops, which have been held as forums where experts could make an input to the planning and development of the Assessment. Eight workshops have been held around the world to consider the scope and methods of the Assessment, the information available in the region where each was held and capacity-building needs in that region;

(g) A website (www.worldoceanassessment.org), which has been established to make information about the Assessment available and to provide a means of communication among members of the Group of Experts and of the Pool of Experts.

In its resolution 68/70 adopted on 9 December 2013, the General Assembly took note of the guidance to contributors adopted by the Bureau of the Ad Hoc Working Group of the Whole (A/68/82 and Corr.1, annex II). In that guidance, it is stated that contributors are expected to act in their personal capacity as independent experts, and not as representatives of any Government or any other authority or organization. They should neither seek nor accept instructions from outside the Regular Process regarding their work on the preparation of the Assessment, although they are free to consult widely with other experts and with government officials, in order to ensure that their contributions are credible, legitimate and relevant.

The Group of Experts proposed a draft outline for the first global integrated assessment of the marine environment. After detailed dialogue, revision and consideration by the Working Group, the outline was submitted in the report on the work of the Ad Hoc Working Group of the Whole (A/67/87, annex II)and adopted by the General Assembly on 11 December 2012 in its resolution 67/78. On 29 December 2014, the Assembly took note in its resolution 69/245 of the updated outline contained in annex II to A/69/77. The chapters have been prepared by writing teams of one or more members. Conveners from the Group of Experts or the Pool of Experts have led those teams. One or more lead members from the Group of Experts has overseen the preparation of (or, in some cases, prepared) each draft chapter. In some cases, the draft chapters have been reviewed by one or more commentators and, in all cases, by the Group of Experts as a whole. Synthesis chapters (drawing together the main points from each part) and the present summary have been prepared by members of the Group of Experts.

Notwithstanding the generous support of the hosts of the workshops and other support described in chapter 2, the production of the first World Ocean Assessment has been constrained by lack of resources. Apart from the costs of the workshops met by host States, support for the website from Australia and Norway and support by Australia, Belgium, Canada, China, the Republic of Korea, the United Kingdom of Great Britain and Northern Ireland and the United States of America for the travel costs of the members of the Group of Experts from those countries, outgoings have been met from a voluntary trust fund set up by the Secretary-General of the United Nations. Donations to that trust fund from Belgium, China, Côte d'Ivoire, Iceland, Ireland, Jamaica, New

Zealand, Norway, Portugal, and the Republic of Korea have amounted to $315,000. Generous support to the Regular Process has also been provided, financially and technically, by the European Union, the Intergovernmental Oceanographic Commission and UNEP.[11]

B. Structure of the Assessment

The Assessment is divided into the seven parts described below.

Part I: summary

The summary describes how the Assessment has been carried out, the overall assessment of the scale of human impact on the ocean, the overall value of the ocean to humans and the main pressures on the marine environment and human economic and social well-being. As guides for future action, it also sets out the gaps (general or partial) in knowledge and in capacity-building.

Part II: context of the Assessment

Chapter 1 is a broad, introductory survey of the role played by the ocean in the life of the planet, the ways in which the ocean functions, and humans' relationships to the ocean. Chapter 2 explains in more detail the rationale for the Assessment and how it has been produced.

Part III: assessment of major ecosystem services from the marine environment (other than provisioning services)

Ecosystem services are those processes, products and features of natural ecosystems that support human well-being. Some (fish, hydrocarbons or minerals) are part of the market economy. Others are not marketed. Part III looks at the non-marketed ecosystem services that the ocean provides to the planet. It considers, first, the scientific understanding of those ecosystem services and then the Earth's hydrological cycle, interactions between air and sea, primary production and ocean-based carbonate production. Finally, it looks at aesthetic, cultural, religious and spiritual ecosystem services (including some cultural objects that are in trade). Where relevant, it draws heavily on the work of the Intergovernmental Panel on Climate Change, with the aim of using the work of the Panel, not of duplicating or challenging it.

Part IV: assessment of the cross-cutting issues of food security and food safety

Part IV, which covers the one cross-cutting theme selected for examination, examines all aspects of the vital function of the ocean in providing food for humans. It draws substantially on information collected by FAO. The economic significance of employment in fisheries and aquaculture and the relationship those industries have with coastal communities are addressed, including gaps in capacity-building for developing countries.

Part V: assessment of other human activities and the marine environment

All other human activities that can impact on the ocean (other than those relating to food production) are covered in part V of the Assessment. To the extent that the available information allows, each chapter describes the location and scale of the activity, the economic benefits, employment and social role, environmental consequences (where appropriate), links to other activities and gaps in knowledge and capacity-building.

Part VI: assessment of marine biological diversity and habitats

[11] See chap. 2.

Part VI: (a) gives an overview of marine biological diversity and what is known about it; (b) reviews the status and trends of, and pressures on, marine ecosystems, species and habitats that have been scientifically identified as threatened, declining or otherwise in need of special attention or protection; (c) examines the significant environmental, economic and social aspects of the conservation of marine species and habitats; and (d) identifies gaps in capacity to identify marine species and habitats that are recognized as threatened, declining or otherwise in need of special attention or protection, and to assess the environmental, social and economic aspects of the conservation of marine species and habitats.

Part VII: overall assessment

Finally, part VII considers the overall way in which the various human impacts cumulatively affect the ocean, and the overall benefits that humans draw from the ocean.[12]

IV. Ten main themes

Ten main themes emerge from the detailed examination set out in parts III to VI of the first World Ocean Assessment. The order in which they are presented does not reflect any assessment of the order of importance for action. The present Assessment has been prepared on the basis of the outline, in which it is stated that the First Global Integrated Marine Assessment will not include any analysis of policies. In the light of the dialogue in the Working Group, that limitation has been understood to include the prioritization of actions or the making of recommendations (A/69/77, annex II).

Theme A

Climate change and related changes in the atmosphere have serious implications for the ocean, including rises in sea level, higher levels of acidity in the ocean, the reduced mixing of ocean water and increasing deoxygenation. There are many uncertainties here, but the consensus is that increases in global temperature, in the amount of carbon dioxide in the atmosphere and in the radiation from the sun that reaches the ocean have already had an impact on some aspects of the ocean and will produce further significant incremental changes over time. The basic mechanisms of change are understood but the ability to predict the detail of changes is limited. In many cases, the direction of change is known, but uncertainty remains about the timing and rate of change, as well as its magnitude and spatial pattern.[13]

Theme B

The exploitation of living marine resources has exceeded sustainable levels in many regions. In some jurisdictions, various combinations of management measures, positive incentives and changes to governance have allowed those historical trends to be reversed, but they persist in others. Where fisheries have imposed levels of mortality on fish stocks and wildlife populations above sustainable levels for some considerable time, those stocks have become depleted. Overexploitation has also brought about changes to ecosystems (for example, overfishing of herbivorous fish in parts of the Caribbean has led to the smothering of corals by algae). Overexploitation can also make fish stocks less productive by reducing the numbers of spawning fish, with adverse effects often amplified by the removal of the larger, older fish, which produce disproportionately more eggs of higher quality than younger, smaller individuals. At the same time, reproductive success is also being reduced by pollution, loss of habitat and other forms of disturbance, including climate change. All those factors result, more generally, in

[12] See chap. 1.
[13] See also paras. 44-72 below.

declining biological resources with important implications for food security and biodiversity.[14]

Theme C

With regard to the cross-cutting issue of food security and food safety (part IV), fish products are the major source of animal protein for a significant fraction of the world's population, particularly in countries where hunger is widespread. Globally, the current mix of the global capture fisheries is near the ocean's productive capacity, with catches on the order of 80 million tons. Ending overfishing (including illegal, unreported and unregulated fishing) and rebuilding depleted resources could result in a potential increase of as much as 20 per cent in yield, but this would require addressing the transitional costs (especially the social and economic costs) of rebuilding depleted stocks. In some areas, pollution and dead zones are also depressing the production of food from the sea. Small-scale fisheries are often also a critical source of livelihoods, as well as of food, for many poor residents in coastal areas. Rebuilding the resources on which they depend and moving to sustainable exploitation will potentially have important benefits for food security. The contribution of aquaculture to food security is growing rapidly and has greater potential for growth than capture fisheries, but it brings with it new or increased pressures on marine ecosystems.[15]

Theme D

There are clear patterns in biodiversity around the world. The pressures on marine biodiversity are increasing, particularly near large population centres and in areas, such as the open ocean, that have so far suffered only limited impacts. Crucial areas for biodiversity, the so-called biodiversity hotspots, often overlap with the areas critical for the provision of ecosystem services by the ocean. In some of those hotspots, the ecosystem services create the conditions for high biodiversity, while in others, both the rich biodiversity and the ecosystem services result independently from the local physical and oceanographic conditions. In both cases, many of those hotspots have become magnets for human uses, in order to take advantage of the economic and social benefits that they offer. This creates enhanced potential for conflicting pressures.[16]

Theme E

Increased use of ocean space, especially in coastal areas, create conflicting demands for dedicated marine space. This arises both from the expansion of long-standing uses of the ocean (such as fishing and shipping) and from newly developing uses (such as hydrocarbon extraction, mining and the generation of renewable energy conducted offshore). In most cases, those various activities are increasing without any clear overarching management system or a thorough evaluation of their cumulative impacts on the ocean environment, thus increasing the potential for conflicting and cumulative pressures.[17]

Theme F

The current, and growing, levels of population and industrial and agricultural production result in increasing inputs of harmful material and excess nutrients into the ocean. Growing concentrations of population can impose, and in many areas are imposing, levels of sewage discharge that are beyond the local carrying capacity and which cause harm to human health. Even if discharges of industrial effluents and emissions were restrained to the lowest levels in proportion to production that are currently practicable, continuing growth in production would result in increased inputs to the ocean. The growing use of plastics that degrade very slowly result in increased quantities reaching the ocean and have many adverse effects, including the creation of

[14] See also paras. 73-87 below.
[15] See also paras. 88-96 below.
[16] See also paras. 97-108 below.
[17] See also paras. 109-122 below.

large quantities of marine debris in the ocean, and negative impacts on marine life and on the aesthetic aspects of many ocean areas, and thus consequent socioeconomic effects.[18]

Theme G

Adverse impacts on marine ecosystems come from the cumulative impacts of a number of human activities. Ecosystems, and their biodiversity, that might be resilient to one form or intensity of impact can be much more severely affected by a combination of impacts: the total impact of several pressures on the same ecosystem often being much larger than the sum of the individual impacts. Where biodiversity has been altered, the resilience of ecosystems to other impacts, including climate change, is often reduced. Thus the cumulative impacts of activities that, in the past, seemed to be sustainable are resulting in major changes to some ecosystems and in a reduction in the ecosystem services that they provide.[19]

Theme H

The distribution around the world of the benefits drawn from the ocean is still very uneven. In some fields, this unevenness is due to the natural distribution of resources in areas under the jurisdiction of the various States (for example, hydrocarbons, minerals and some fish stocks). The distribution of some benefits is becoming less skewed: for example, the consumption of fish per capita in some developing countries is growing; the balance between cargoes loaded and unloaded in the ports of developing countries is moving closer to those in developed countries in tonnage terms. In many fields, however, including some forms of tourism and the general trade in fish, an imbalance remains between the developed and developing parts of the world. Significant differences in capacities to manage sewage, pollution and habitats also create inequities. Gaps in capacity-building hamper less developed countries in taking advantage of what the ocean can offer them, as well as reduce their capability to address the factors that degrade the ocean.[20]

Theme I

The sustainable use of the ocean cannot be achieved unless the management of all sectors of human activities affecting the ocean is coherent. Human impacts on the sea are no longer minor in relation to the overall scale of the ocean. A coherent overall approach is needed. This requires taking into account the effects on ecosystems of each of the many pressures, what is being done in other sectors and the way that they interact. As the brief summary above of the many processes at work in the ocean demonstrates, the ocean is a complex set of systems that are all interconnected. In all sectors, albeit unevenly, there has been a progressive, continuing development of management: from no regulation to the regulation of specific impacts, to the regulation of sector-wide impacts and finally to regulation taking account of aspects of all relevant sectors.

Such a coherent approach to management requires a wider range of knowledge about the ocean. Many of the gaps in the knowledge that such an integrated approach requires are identified in the present Assessment. There are also widespread gaps in the skills needed to assess the ocean with respect to some aspects (for example, the integration of environmental, social and economic aspects). In many cases, there are gaps in the resources needed for the successful application of such knowledge and skills. Gaps in capacity-building are identified briefly at the end of the present summary, and in more detail in parts III to VI.[21]

[18] See also paras. 123-151 below.
[19] See also paras. 152-166 below.
[20] See also paras. 167-186 below.
[21] See also paras. 187-196 below.

Theme J

There is the delay in implementing known solutions to problems that have already been identified as threatening to degrade the ocean further. In many fields, it has been shown that there are practicable, known measures to address many of the pressures described above. Such pressures are continuously degrading the ocean, thereby causing social and economic problems. Delays in implementing such measures, even if they are only partial and will leave more to be done, mean that we are unnecessarily incurring those environmental, social and economic costs.[22]

Conclusion

The 10 themes are described in more detail in section V below. As explained above, the order in which the themes are presented does not represent any judgement on their priority. Elements in those themes overlap, and the same issue may be relevant to more than one theme. The identification of knowledge gaps and capacity-building gaps follows in the final two sections of the summary.

V. Further details on the 10 main themes

A. Impacts of climate change and related changes in the atmosphere

Changes

Major features of the ocean are changing significantly as a result of climate change and related changes in the atmosphere. The work of the Intergovernmental Panel on Climate Change has been used, where climate is concerned, as the basis of the present assessment, as required in the outline (A/69/77, annex II).

Sea-surface temperature

The Intergovernmental Panel on Climate Change has reaffirmed in its fifth report its conclusion that global sea-surface temperatures have increased since the late nineteenth century. Upper-ocean temperature (and hence its heat content) varies over multiple time scales, including seasonal, inter-annual (for example, those associated with the El Niño-Southern Oscillation), decadal and centennial periods. Depth-averaged ocean-temperature trends from 1971 to 2010 are positive (that is, they show warming) over most of the globe. The warming is more prominent in the northern hemisphere, especially in the North Atlantic. Zonally averaged upper-ocean temperature trends show warming at nearly all latitudes and depths. However, the greater volume of the ocean in the southern hemisphere increases the contribution of its warming to the global heat content.

The ocean's large mass and high heat capacity enable it to store huge amounts of energy, more than 1,000 times than that found in the atmosphere for an equivalent increase in temperature. The earth is absorbing more heat than it is emitting back into space, and nearly all that excess heat is entering the ocean and being stored there. The ocean has absorbed about 93 per cent of the combined extra heat stored by warmed air, sea, land, and melted ice between 1971 and 2010. During the past three decades, approximately 70 per cent of the world's coastline has experienced significant increases in sea-surface temperature. This has been accompanied by an increase in the yearly number of extremely hot days along 38 per cent of the world's coastline. Warming has also been occurring at a significantly earlier date in the year along approximately 36 per cent of the world's temperate coastal areas (between 30° and 60° latitude in both hemispheres). That warming is resulting in an increasingly poleward distribution of many marine species.[23]

[22] See also paras. 197-202 below.
[23] See chap. 5.

Sea-level rise

It is very likely that extreme sea-level maxima have already increased globally since the 1970s, mainly as a result of global mean sea-level rise. That rise is due in part to anthropogenic warming, causing ocean thermal expansion and the melting of glaciers and of the polar continental ice sheets. Globally averaged sea level has thus risen by 3.2 mm a year for the past two decades, of which about a third is derived from thermal expansion. Some of the remainder is due to fluxes of freshwater from the continents, which have increased as a result of the melting of continental glaciers and ice sheets.

Finally, regional and local sea-level changes are also influenced by natural factors, such as regional variability in winds and ocean currents, vertical movements of the land, isostatic adjustment of the levels of land in response to changes in physical pressures on it and coastal erosion, combined with human perturbations by change in land use and coastal development. As a result, sea levels will rise more than the global mean in some regions, and will actually fall in others. A 4°C warming by 2100 (which is predicted in the high-end emissions scenario in the report of the Intergovernmental Panel on Climate Change) would lead, by the end of that period, to a median sea-level rise of nearly 1 metre above the 1980 to 1999 levels.[24]

Ocean acidification

Rising concentrations of carbon dioxide in the atmosphere are resulting in increased uptake of that gas by the ocean. There is no doubt that the ocean is absorbing more and more of it: about 26 per cent of the increasing emissions of anthropogenic carbon dioxide is absorbed by the ocean, where it reacts with seawater to form carbonic acid. The resulting acidification of the ocean is occurring at different rates around the seas, but is generally decreasing the levels of calcium carbonate dissolved in seawater, thus lowering the availability of carbonate ions, which are needed for the formation by marine species of shells and skeletons. In some areas, this could affect species that are important for capture fisheries.[25]

Salinity

Alongside broad-scale ocean warming, shifts in ocean salinity (salt content) have also occurred. The variations in the salinity of the ocean around the world result from differences in the balance between freshwater inflows (from rivers and glacier and ice-cap melt), rainfall and evaporation, all of which are affected by climate change. The shifts in salinity, which are calculated from a sparse historical observing system, suggest that at the surface, high-salinity subtropical ocean regions and the entire Atlantic basin have become more saline, while low-salinity regions, such as the western Pacific Warm Pool, and high-latitude regions have become even less saline. Since variations in salinity are one of the drivers of ocean currents, those changes can have an effect on the circulation of seawater and on stratification, as well as having a direct effect on the lives of plants and animals by changing their environment.[26]

Stratification

Differences in salinity and temperature among different bodies of seawater result in stratification, in which the seawater forms layers, with limited exchanges between them. Increases in the degree of stratification have been noted around the world, particularly in the North Pacific and, more generally, north of 40ºS. Increased stratification brings with it a decrease in vertical mixing in the ocean water column. This decreased mixing, in turn, reduces oxygen content and the extent to which the ocean is able to absorb heat and carbon dioxide, because less water from the lower layers is brought up to the surface, where such absorption takes place. Reductions in vertical

[24] See chap. 4.
[25] See chaps. 5-7.
[26] See chaps. 4 and 5.

mixing also impact the amount of nutrients brought up from lower levels into the zone that sunlight penetrates, with consequent reductions in ecosystem productivity.[27]

Ocean circulation

The intensified study of the ocean as part of the study of climate change has led to a much clearer understanding of the mechanisms of ocean circulation and its annual and decadal variations. As a result of changes in the heating of different parts of the ocean, patterns of variation in heat distribution across the ocean (such as the El Niño-Southern Oscillation) are also changing. Those changes in patterns result in significant changes in weather patterns on land. Water masses are also moving differently in areas over continental shelves, with consequent effects on the distribution of species. There is evidence that the global circulation through the open ocean may also be changing, which might lead, over time, to reductions in the transfer of heat from the equatorial regions to the poles and into the ocean depths.

Storms and other extreme weather events

Increasing seawater temperatures provide more energy for storms that develop at sea. The scientific consensus is that this will lead to fewer but more intense tropical cyclones globally. Evidence exists that the observed expansion of the tropics since approximately 1979 is accompanied by a pronounced poleward migration of the latitude at which the maximum intensities of storms occur. This will certainly affect coastal areas that have not been exposed previously to the dangers caused by tropical cyclones.[28]

Ultraviolet radiation and the ozone layer

The ultraviolet (UV) radiation emitted by the sun in the UV-B range (280-315 nanometres wavelength) has a wide range of potentially harmful effects, including the inhibition of primary production by phytoplankton and cyanobacteria, changes in the structure and function of plankton communities and alterations of the nitrogen cycle. The ozone layer in the Earth's stratosphere blocks most UV-B from reaching the ocean's surface. Consequently, stratospheric ozone depletion since the 1970s has been a concern. International action (under the Montreal Protocol on Substances that Deplete the Ozone Layer)[29] to address that depletion has been taken, and the situation appears to have stabilized, although with some variation from year to year. Given those developments and the variations in the water depths to which UV-B penetrates, a consensus on the magnitude of the ozone-depletion effect on net primary production and nutrient cycling has yet to be reached. There is, however, a potential effect of ultraviolet on nanoparticles.[30]

Implications for human well-being and biodiversity

Changes in seasonal life cycles in the ocean

It has been predicted under some climate change scenarios that up to 60 per cent of the current biomass in the ocean could be affected, either positively or negatively, resulting in disruptions to many existing ecosystem services. For example, modelling studies of species with strong temperature preferences, such as skipjack and bluefin tuna, predict major changes in range and/or decreases in productivity.[31]

The effects are found in all regions. For example, in the North-West Atlantic, the combination of changes in feeding patterns triggered by overfishing and changes in climate formed the primary pressures thought to have brought about shifts in species composition amounting to a full regime change, from one dominated by cod to one

[27] See chaps. 1 and 4-6.
[28] See chap. 5.
[29] United Nations, *Treaty Series*, vol. 1522, No. 26369.
[30] See theme F above and chap. 6.
[31] See chaps. 42 and 52.

dominated by crustacea. Even in the open ocean, climate warming will increase ocean stratification in some broad areas, reduce primary production and/or result in a shift in productivity to smaller species (from diatoms of 2-200 microns to picoplankton of 0.2-2 microns) of phytoplankton. This has the effect of changing the efficiency of the transfer of energy to other parts of the food web, causing biotic changes over major regions of the open ocean, such as the equatorial Pacific.[32]

Loss of sea ice in high latitudes and associated ecosystems

The high-latitude ice-covered ecosystems host globally significant arrays of biodiversity, and the size and nature of those ecosystems make them critically important to the biological, chemical and physical balance of the biosphere. Biodiversity in those systems has developed remarkable adaptations to survive both extreme cold and highly variable climatic conditions.

High-latitude seas are relatively low in biological productivity, and ice algal communities, unique to those latitudes, play a particularly important role in system dynamics. Ice algae are estimated to contribute more than 50 per cent of the primary production in the permanently ice-covered central Arctic. As sea-ice cover declines, this productivity may decline and open water species may increase. The high-latitude ecosystems are undergoing change at a rate more rapid than in other places on earth. In the past 100 years, average Arctic temperatures have increased at almost twice the average global rate. Reduced sea ice, especially a shift towards less multi-year sea ice, will affect a wide range of species in those waters. For example, owing to low reproductive rates and long lifetimes, some iconic species (including the polar bear) will be challenged to adapt to the current fast warming of the Arctic and may be extirpated from portions of their range within the next 100 years.[33]

Plankton

Phytoplankton and marine bacteria carry out most of the primary production on which food webs depend. The climate-driven increases in the temperature of the upper ocean that had been predicted are now causing shifts in phytoplankton communities. This may have profound effects on net primary production and nutrient cycles over the next 100 years. In general, when smaller plankton account for most net primary production, as is typically the case in oligotrophic open-ocean waters (that is, areas where levels of nutrients are low), net primary production is lower and the microbial food web dominates energy flows and nutrient cycles. Under such conditions, the carrying capacity for currently harvestable fish stocks is lower and exports of organic carbon, nitrogen and phosphorus to the deep sea may be smaller.

On the other hand, as the upper ocean warms, the geographic range of nitrogen-fixing plankton (diazotrophs) will expand. This could enhance the fixation of nitrogen by as much as 35-65 per cent by 2100. This would lead to an increase in net primary production, and therefore an increase in carbon uptake, and some species of a higher trophic level may become more productive.

The balance between those two changes is unclear. A shift towards less primary production would have serious implications for human food security and the support of marine biodiversity.[34]

Fish stock distribution

As seawater temperatures increase, the distribution of many fish stocks and the fisheries that depend upon them is shifting. While the broad pattern is one of stocks moving poleward and deeper in order to stay within waters that meet their temperature preference, the picture is by no means uniform, nor are those shifts happening in

[32] See chaps. 6 and 36A.
[33] See chaps. 36G, 36H and 37.
[34] See chap. 6.

concert for the various species. Increasing water temperatures will also increase metabolic rates and, in some cases, the range and productivity of some stocks. The result is changes in ecosystems occurring at various rates ranging from near zero to very rapid. Research on those effects is scattered, with diverse results, but as ocean climate continues to change, those considerations are of increasing concern for food production. Greater uncertainty for fisheries results in social, economic and food security impacts, complicating sustainable management.[35]

Seaweeds and seagrasses

Cold-water seaweeds, in particular kelps, have reproductive regimes that are temperature-sensitive. Increase in seawater temperature affects their reproduction and survival, which will consequently affect their population distribution and harvest. Kelp die-offs have already been reported along the coasts of Europe, and changes in species distribution have been noted in Northern Europe, Southern Africa and Southern Australia, with warm-water-tolerant species replacing those that are intolerant of warmer water. The diminished kelp harvest reduces what is available for human food and the supply of substances derived from kelp that are used in industry and pharmaceutical and food preparation.

Communities with kelp-based livelihoods and economies will be affected. For seagrasses, increased seawater temperatures have been implicated in the occurrence of a wasting disease that decimated seagrass meadows in the north-eastern and north-western parts of the United States. Changes in species distribution and the loss of kelp forest and seagrass beds have resulted in changes in the ways that those two ecosystems provide food, habitats and nursery areas for fish and shellfish, with repercussions on fishing yields and livelihoods.[36]

Shellfish productivity

Because of the acidification of the ocean, impacts on the production by shellfish of their calcium carbonate shells has already been observed periodically at aquaculture facilities, hindering production. As acidification intensifies, this problem will become more widespread, and occur in wild, as well as in cultured, stocks. However, like all other ocean properties, acidification is not evenly distributed, so that the effects will not be uniform across areas and there will be substantial variation over small spatial scales. In addition, temperature, salinity and other changes will also change shellfish distributions and productivity, positively or negatively in different areas. As with fishing, the course of those changes is highly uncertain and may be disruptive to existing shellfish fisheries and aquaculture.[37]

Low-lying coasts

Sea-level rise, due to ocean warming and the melting of land ice, poses a significant threat to coastal systems and low-lying areas around the world, through inundations, the erosion of coastlines and the contamination of freshwater reserves and food crops. To a large extent, such effects are inevitable, as they are the consequences of conditions already in place, but they could have devastating effects if mitigation options are not pursued. Entire communities on low-lying islands (including States such as Kiribati, Maldives and Tuvalu) have nowhere to retreat to within their islands and have therefore no alternative but to abandon their homes entirely, at a cost they are often ill-placed to bear. Coastal regions, particularly some low-lying river deltas, have very high population densities. Over 150 million people are estimated to live on land that is no more than 1 metre above today's high-tide levels, and 250 million at elevations within five metres of that level. Because of their high population densities, coastal cities are particularly

[35] See chaps. 36A-H and 52.
[36] See chaps. 14 and 47.
[37] See chaps. 5, 11 and 52.

vulnerable to sea-level rise in concert with other effects of climate change, such as changes in storm patterns.[38]

Coral reefs

Corals are subject to "bleaching" when the seawater temperature is too high: they lose the symbiotic algae that give coral its colour and part of its nutrients. Coral bleaching was a relatively unknown phenomenon until the early 1980s, when a series of local bleaching events occurred, principally in the eastern tropical Pacific and Wider Caribbean regions. Severe, prolonged or repeated bleaching can lead to the death of coral colonies. An increase of only 1°C to 2°C above the normal local seasonal maximum can induce bleaching. Although most coral species are susceptible to bleaching, their thermal tolerance varies. Many heat-stressed or bleached corals subsequently die from coral diseases.

Rising temperatures have accelerated bleaching and mass mortality during the past 25 years. The bleaching events in 1998 and 2005 caused high coral mortality at many reefs, with little sign of recovery. Global analysis shows that this widespread threat has significantly damaged most coral reefs around the world. Where recovery has taken place, it has been strongest on reefs that were highly protected from human pressures. However, a comparison of the recent and accelerating thermal stress events with the slow recovery rate of most reefs suggests that temperature increase is outpacing recovery.

Losses of coral reefs can have negative effects on fish production and fisheries, coastal protection, ecotourism and other community uses of coral reefs. Current scientific data and modelling predict that most of the world's tropical and subtropical coral reefs, particularly those in shallow waters, will suffer from annual bleaching by 2050, and will eventually become functionally extinct as sources of goods and services. This will have not only profound effects on small island developing States and subsistence fishermen in low-latitude coastal areas, but also locally significant effects even in major economies, such as that of the United States.[39]

Submarine cables

Submarine cables have always been at risk of breaks from submarine landslides, mainly at the edge of the continental shelf. As the pattern of cyclones, hurricanes and typhoons changes, submarine areas that have so far been stable may become less so and thus produce submarine landslides and consequent cable breaks. With the increasing dependence of world trade on the Internet, such breaks (in addition to breaks from other causes, such as ship anchors and bottom trawling) could delay or interrupt communications vital to that trade.[40]

Eutrophication problems

Where there are narrow continental shelves, some wind conditions can bring nutrient-rich, oxygen-poor water up into coastal waters, and produce hypoxic (low-oxygen) or even anoxic conditions (the implications of which are described under theme F). Changes in ocean circulation appear to be enhancing those effects. Examples of this can be found on the western coasts of the American continent immediately north and south of the equator, the western coast of sub-Saharan Africa and the western coast of the Indian subcontinent.[41]

Opening of Arctic shipping routes

Although the number of ships transiting Arctic waters is currently low, it has been escalating for the past decade, and the retreat of the polar sea ice as a result of

[38] See chap. 4.
[39] See chaps. 34, 36D and 43.
[40] See chap. 19.
[41] See chaps. 6 and 20.

planetary warming means that there are increasing possibilities for shipping traffic between the Atlantic and Pacific Oceans around the north of the American and Eurasian continents during the northern summer. The movement of species between the Pacific and the Atlantic demonstrates the scale of the potential impact. Those routes are shorter and may be more economic, but shipping brings with it increased risks of marine pollution both from acute disasters and chronic pollution and the potential introduction of invasive non-native species. The very low rate at which bacteria can break down spilled oil in polar conditions and the general low recovery rate of polar ecosystems mean that damage from such pollution would be very serious. Furthermore, the response and clear-up infrastructure found in other ocean basins is largely lacking today around the Arctic Ocean. Those factors would make such problems even worse. Over time, the increased commercial shipping traffic through the Arctic Ocean and the noise disturbance it creates may also displace marine mammals away from critical habitats.[42]

B. Higher mortality and less successful reproduction of marine biotas

Captures of fish stocks at levels above maximum sustainable yield

Globally, the levels of capture fisheries are near the ocean's productive capacity, with catches on the order of 80 million tons. Exploitation inevitably reduces total population biomass through removals. As long as the fish stock can compensate through increased productivity because the remaining individuals face less competition for access to food and therefore grow faster and produce more progeny, then fishing can be sustained. However, when the rate of exploitation becomes faster than the stock can compensate through increasing growth and reproduction, the removal level becomes unsustainable and the stock declines.

The concept of "maximum sustainable yield", entrenched in international legal instruments such as the United Nations Convention on the Law of the Sea and the Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks,[43] is based on the inherent trade-off between increasing harvests and decreasing the ability of a smaller resulting population to compensate for the removals.

At present, about one quarter of all assessed fish stocks are being overfished and more are still recovering from past overfishing. This is undermining the contribution that they could make to food security. Ending overfishing is a precondition for allowing stocks to rebuild. Other stocks may still be categorized as "fully exploited" despite being on the borderline of overfishing. Those could produce greater yields if effectively managed.

There are only a few means available to increase yields. Ending overfishing, eliminating illegal, unreported and unregulated fishing, bringing all fishery yields under effective management and rebuilding depleted resources may result in an increase of as much as 20 per cent in potential yield, provided that the transitional economic and social costs of rebuilding depleted stocks can be addressed.

Overfishing can also undermine the biodiversity needed to sustain marine ecosystems. Without careful management, such impacts on biodiversity will endanger some of the most vulnerable human populations and marine habitats around the world, as well as threaten food security and other important socioeconomic aspects (such as livelihoods).[44]

[42] See chaps. 20 and 36G.
[43] United Nations, *Treaty Series*, vol. 2167, No. 37924.
[44] See chaps. 10, 11 and 15.

Impacts of changes in breeding and nursery areas

Changes in breeding and nursery areas are best documented for the larger marine predators. For seabirds, globally, the greatest pressure is caused by invasive species (mainly rats and other predators acting at breeding sites). That pressure potentially affects 73 threatened seabird species — 75 per cent of the total and nearly twice as many as any other single threat. The remaining most significant pressures are fairly evenly divided between those faced mainly at breeding sites, namely problematic native species, human disturbance and the loss of historical breeding and nursery sites to urban development (commercial, residential or infrastructural), and those faced mainly at sea, particularly by-catch in longlines, gillnets and trawl fisheries, when birds are foraging or moulting, migrating or in aggregations. The ingestion of marine plastic debris is also significant. For marine reptiles, decades of overharvesting of marine turtle eggs on nesting beaches have driven the long-term decline of some breeding populations. In some areas, tourist development has also affected reproductive success at historical turtle nesting beaches. All this has rendered them more vulnerable to fishery by-catch and other threats. Similar pressures apply to marine mammals.[45]

Levels of by-catch (non-target fish, marine mammals, reptiles and seabirds), discards and waste

Current estimates of the number of overfished stocks do not take into account the broader effects of fishing on marine ecosystems and their productivity. In the past, large numbers of dolphins drowned in fishing nets. This mortality greatly reduced the abundance of several dolphin species in the latter half of the twentieth century. Thanks to international efforts, fishing methods have changed and the by-catch has been reduced significantly. Commercial fisheries are the most serious pressure at sea that the world's seabirds face, although there is evidence of some reductions of by-catch in some key fisheries. Each year, incidental by-catch in longline fisheries is estimated to kill at least 160,000 albatrosses and petrels, mainly in the southern hemisphere. For marine reptiles, a threat assessment scored fishery by-catch as the highest threat across marine turtle subpopulations, followed by harvesting (that is, for human consumption) and coastal development.

The mitigation of those causes of mortality can be effective, even though the lack of reliable data can hamper the targeting of mitigation measures. Depending on the particular species and fishery methods, mitigation may include the use of acoustic deterrents, gear modifications, time or area closures and gear switching (for example, from gillnets to hooks and lines). In particular, the global moratorium on all large-scale pelagic drift-net fishing called for by the General Assembly in 1991 was a major step in limiting the by-catch of several marine mammal and seabird species that were especially vulnerable to entanglement.[46]

Impact of hazardous substances and eutrophication problems on reproduction and survival

Each of the reviews of regional biodiversity in part VI of the present Assessment reported at least some instances of threats from hazardous substances. To give some examples, in the South Pacific, localized declines in species densities, assemblages and spatial distributions are being observed, particularly in areas close to population centres where overfishing, pollution from terrestrial run-off and sewage and damage from coastal developments are occurring. In the North Atlantic, impacts on the benthos have been particularly well documented, although their nature depends on the type, intensity and duration of the pollution or nutrient input. Persistent pressures of that type have been documented to alter greatly the species composition and biomass of the benthos directly and indirectly, through processes such as the formation of dead zones and hypoxic zones as a result of eutrophication problems and seawater circulation

[45] See chaps. 28 and 37-39.
[46] See chaps. 11 and 37-39.

changes driven by climate change. Even in the open ocean, evidence is increasing for chemical contamination of deep-pelagic animals. Although the pathways for such contaminations are not well known, high concentrations of heavy metals and persistent organic pollutants have been reported.[47]

Impacts of disturbance from noise

Anthropogenic noise in the ocean increased in the last half of the past century. Commercial shipping is the main source, and the noise that it produces is often in frequency bands used by many marine mammals for communication. Many other types of marine biotas have also been shown to be affected by anthropogenic noise. Other significant sources of noise are seismic exploration for the offshore hydrocarbon industry and sonar. The impact of noise can be both to disrupt communication among animals and to displace them from their preferred breeding, nursery or feeding grounds, with consequent potential effects on their breeding success and survival.[48]

Impacts of recreational fishing

Recreational fishing is a popular activity in many industrialized countries, in which up to 10 per cent of the adult population may participate. The impact of that type of fishing is only sometimes taken into account in fishery management, although the quantities caught can be significant for the management of stocks experiencing overfishing. In several countries, there is a substantial industry supporting the recreational catching of sport fish (including trophy fish, such as marlins, swordfish and sailfish), but catch statistics are generally not available.[49]

Implications for human well-being and biodiversity

Food resources

The overfishing of some fish stocks is reducing the yield realized from those stocks. Such reductions in yield are likely to undermine food security. The role of fisheries in food security is further considered below.[50]

Species structure of highly productive sea areas

Many human activities have been documented to have impacts on marine life living on the seabed (benthic communities). The adverse effects of mobile bottom-contacting fishing gear on coastal and shelf benthic communities have been documented essentially everywhere that such gear has been used. Bottom trawling has caused the destruction of a number of long-lived cold-water coral and sponge communities that are unlikely to recover before at least a century. Many reviews show that, locally, the nature of those impacts and their duration depend on the type of substrate and frequency of trawling. Those effects have been found in all the regional assessments.[51]

With regard to fish and pelagic invertebrate communities, much effort has been devoted to teasing apart the influences of exploitation and of environmental conditions as drivers of change in fish populations and communities, but definitive answers are elusive. Most studies devote attention to explaining variation among coastal fish-community properties in terms of features of the physical and chemical habitats (including temperature, salinity, oxygen and nutrient levels, clarity of, and pollutants in, the water column) and of depth, sediment types, benthic communities, contaminant levels, oxygen levels and disturbance of the sea floor. All of those factors have been shown to influence fish-community composition and structure in at least some coastal areas of each ocean basin.

[47] See chaps. 36A-H.
[48] See chaps. 17, 21 and 37.
[49] See chaps. 28, 40 and 41.
[50] See chap. 11.
[51] See chaps. 36A-H, 42, 51 and 52.

The scale at which a fish-community structure is determined and its variation is documented can be even more local, because some important drivers of change in coastal fish communities are themselves very local in scale, such as coastal infrastructure development. Other obvious patterns are recurrent, such as increasing mortality rates (whether from exploitation or coastal pollution) leading both to fish communities with fewer large fish and to an increase in species with naturally high turnover rates. However, some highly publicized projections of the loss of all commercial fisheries or of all large predatory fish by the middle of the current century have not withstood critical review.[52]

C. Food security and food safety

Seafood products, including finfish, invertebrates and seaweeds, are a major component of food security around the world. They are the major source of protein for a significant fraction of the global population, in particular in countries where hunger is widespread. Even in the most developed countries, the consumption of fish is increasing both per capita and in absolute terms, with implications for both global food security and trade.[53]

Fisheries and aquaculture are a major employer and source of livelihoods in coastal States. Significant economic and social benefits result from those activities, including the provision of a key source of subsistence food and much-needed cash for many of the world's poorest peoples. As a mainstay of many coastal communities, fisheries and aquaculture play an important role in the social fabric of many areas. Small-scale fisheries, particularly those that provide subsistence in many poor communities, are often particularly important. Many such coastal fisheries are under threat because of overexploitation, conflict with larger fishing operations and a loss of productivity in coastal ecosystems caused by a variety of other impacts. Those include habitat loss, pollution and climate change, as well as the loss of access to space as coastal economies and uses of the sea diversify.[54]

Capture fisheries

Globally, capture fisheries are near the ocean's productive capacity, with catches on the order of 80 million metric tons. Only a few means to increase yield are available. Addressing sustainability concerns more effectively (including ending overfishing, eliminating illegal, unreported and unregulated fishing, rebuilding depleted resources and reducing the broader ecosystem impacts of fisheries and the adverse impacts of pollution) is an important aspect of improving fishery yields and, therefore, food security. For example, ending overfishing and rebuilding depleted resources may result in an increase of as much as 20 per cent in potential yield, provided that the transitional costs of rebuilding depleted stocks can be addressed.[55]

In 2012, more than one quarter of fish stocks worldwide were classified by the Food and Agriculture Organization of the United Nations as overfished. Although those stocks will clearly benefit from rebuilding once overfishing has ended, other stocks may still be categorized as fully exploited despite being on the borderline of overfishing. Such stocks could yield more if effective governance mechanisms were in place.

Current estimates of the number of overfished stocks do not take into account the broader effects of fishing on marine ecosystems and their productivity. Those impacts, including by-catch, habitat modification and effects on the food web, significantly affect the ocean's capacity to continue to produce food sustainably and must be carefully

[52] See chaps. 10, 11, 15, 34, 36A-H and 52.
[53] See chap. 10.
[54] See chap. 15.
[55] See chaps. 11, 13, 36A-H and 52.

managed. Fish stock propagation may provide a tool to help to rebuild depleted fishery resources in some instances.[56]

Fishing efforts are subsidized by many mechanisms around the world, and many of those subsidies undermine the net economic benefits to States. Subsidies that encourage overcapacity and overfishing result in losses for States, and those losses are often borne by communities dependent on fishery resources for their livelihood and food security.[57]

Aquaculture

Aquaculture production, including seaweed culture, is increasing more rapidly than any other source of food production in the world. Such growth is expected to continue. Aquaculture, not including the culture of seaweeds, now provides half of the fish products covered in global statistics. Aquaculture and capture fisheries are codependent in some ways, as feed for cultured fish is in part provided by capture fisheries, but they are competitors for space in coastal areas, markets and, potentially, other resources. Significant progress has been made in replacing feed sources from capture fisheries with agricultural production. Aquaculture itself poses some environmental challenges, including potential pollution, competition with wild fishery resources, potential contamination of gene pools, disease problems and loss of habitat. Examples of those challenges, and measures that can mitigate them, have been observed worldwide.[58]

Social issues

In both capture fisheries and aquaculture, gender and other equity issues arise. A significant number of women are employed in both types of activities, either directly or in related activities along the value chain. Women are particularly prominent in product processing, but often their labour is not equitably compensated and working conditions do not meet basic standards. Poor communities are often subject to poorer market access, unsafe working conditions and other inequitable practices.[59]

Food safety

Food safety is a key worldwide challenge for all food production and delivery sectors, including all parts of the seafood industry, from capture or culture to retail marketing. That challenge is of course also faced by subsistence fisheries. In the food chain for fishery products, potential problems need to be assessed, managed and communicated to ensure that they can be addressed. The goal of most food safety systems is to avoid risk and prevent problems at the source. The risks come from contamination from pathogens (particularly from discharges of untreated sewage and animal waste) and toxins (often from algal blooms). The severity of the risk also depends on individual health, consumption levels and susceptibility. There are international guidelines to address those risks but substantial resources are required in order to continue to build the capacity to implement and monitor safety protocols from the water to the consumer.

D. Patterns of biodiversity

A basic, but key, conclusion of the present Assessment is that there are clear patterns of biodiversity, both globally and regionally. A key question is whether there are consistent large-scale patterns of biodiversity, governed by underlying factors that constrain the distribution of the wide range of marine life across the wide variety of habitats. Global-scale studies to explore this question began long ago and have grown substantially in the past decade. The enormous amounts of data collected and compiled by the Census

[56] See chap. 13.
[57] See chap. 15.
[58] See chap. 12.
[59] See chap. 15.

of Marine Life enable exploration and the mapping of patterns across more taxonomic groups than ever before, thus facilitating an understanding of the consistency of patterns of biodiversity.

Perhaps the most common large-scale biodiversity pattern on the planet is the “latitudinal gradient”, typically expressed as a decline in the variety of species from the equator to the poles. Adherence to that pattern varies among marine taxa. Although coastal species generally peak in abundance near the equator and decline towards the poles, seals show the opposite pattern. Furthermore, strong longitudinal gradients (east-west) complicate patterns, with hotspots of biodiversity across multiple species groups in the coral triangle of the Indo-Pacific, in the Caribbean and elsewhere.

Oceanic organisms, such as whales, differ in pattern entirely, with species numbers consistently peaking at mid-latitudes between the equator and the poles. This pattern defies the common equator-pole gradient, suggesting that different factors are at play. Various processes may also control the difference in species richness between the oceanic and coastal environments (for example, in terms of dispersal, mobility or habitat structure), but general patterns appear to be reasonably consistent within each group.

However, across all groups studied, ocean temperature is consistently related to species diversity, making the effects of climate change likely to be felt as a restructuring factor of marine community diversity.

Although the patterns above hold for the species studied, numerous groups and regions have not yet been examined. For example, global-scale patterns of diversity in the deep sea remain largely unknown. Knowledge of diversity and distribution is biased towards large, charismatic species (for example, whales) or economically valuable species (for example, tuna). Our knowledge of patterns in microbial organisms remains particularly limited relative to the considerable biodiversity of those species. Enormous challenges remain even to measure this. Viruses remain another critical part of the oceanic system of which we lack any global-scale biodiversity knowledge.

Patterns of global marine biodiversity, other than species richness, are only just beginning to be explored. For example, investigations suggest that, globally, the higher the latitude at which a reef is located, the greater the evenness in the number of individuals of each species tend to be in that reef. Such a pattern, in turn, affects functional richness, which relates to the diversity of function in reef fish, a potentially important component of ecosystem productivity, resilience and provision of goods and services.[60]

Implications

Location of biodiversity hotspots and their relationship to the location of high levels of ecosystem services

Although marine life is found everywhere in the ocean, biodiversity hotspots exist where the number of species and the concentration of biotas are consistently high relative to adjacent areas. Some are subregional, such as the coral triangle in the Indo-Pacific, the coral reefs in the Caribbean, the cold-water corals in the Mediterranean and the Sargasso Sea. Some are more local and associated with specific physical conditions, such as biodiversity-rich habitat types. Key drivers of biodiversity are complex three-dimensional physical structures that create a diversity of physical habitats (associated with rocky sea floors), dynamic oceanographic conditions causing higher bottom-up productivity, effects of land-based inputs extending far out to sea (such as the inputs from the River Amazon) and special vegetation features creating unique and productive habitats near the shore. Those complex habitats, however, are often highly vulnerable to disturbance.

[60] See chaps. 34, 35 and 36A-H.

The high relative and absolute biodiversity of those hotspots often directly supports the extractive benefits of fishing and other harvests, providing a direct link between biodiversity and the provision of services by the ocean. The areas supporting high relative and absolute levels of biodiversity not only harbour unique species adapted to their special features, but also often serve as centres for essential life-history stages of species with wider distributions. For example, essentially all the biodiversity hotspots that have been identified have also been found to harbour juvenile fish, which are important for fisheries in adjacent areas.

Hotspots for primary productivity are necessarily also hotspots for production of oxygen as a direct result of photosynthesis. Furthermore, underlying the high biodiversity is often a high structural complexity of the habitats that support it. That structure often contributes other services, such as coastal protection and regeneration. In addition, it is the concentrated presence of iconic species in an area which adds to aesthetic services (supporting tourism and recreation) and spiritual and cultural services.[61]

Biodiversity and economic activity

Sometimes, because of the special physical features that contribute to high biodiversity, and sometimes because of the concentration of biodiversity itself, many societies and industries are most active in areas that are also biodiversity hotspots. As on land, humanity has found the greatest social and economic benefits in the places in the ocean that are highly productive and structurally complex. For example, 22 of the 32 largest cities in the world are located on estuaries; mangroves and coral reefs support small-scale (artisanal) fisheries in developing countries. Biodiversity hotspots tend to attract human uses and become socioeconomic hotspots. Hence biodiversity-rich areas have a disproportionately high representation of ports and coastal infrastructure, other intensive coastal land uses, fishing activities and aquaculture. This is one of the major challenges to the sustainable use of marine biodiversity.[62]

Some marine features, such as seamounts, often found in areas beyond national jurisdiction, have high levels of biodiversity, frequently characterized by the presence of many species not found elsewhere. Significant numbers of the species mature late, and therefore reproduce slowly. High levels of fishing have rapidly undermined the biodiversity of many such features, and risk continuing to do so in the absence of careful management.[63]

New forms of economic activity in the open ocean, such as seabed mining, and the expansion of existing forms of activity, such as hydrocarbon extraction, have the potential to have major impacts on its biodiversity, which is to date poorly known. Without careful management of those activities, there is a risk that the biodiversity of areas affected could be destroyed before it is properly understood.[64]

E. Increased use of ocean space

The world is seeing a greatly intensified use of ocean space. Since around the middle of the nineteenth century, there has been a great growth in the range of human activities in the ocean, each demanding its share of ocean space. At the same time, and in consequence, the regulation of activities in the ocean has increased. In a campaign to draw attention to this, the fishermen of the Netherlands coined the slogan “Fishing on a postage stamp”, arguing that, by the time that all the other uses of the exclusive economic zone of the Netherlands (shipping lanes, offshore oil and gas extraction, sand and gravel extraction, dumping of dredged material, offshore wind-power installations, submarine cables and pipelines, etc.) had been allocated their spaces, not much space

[61] See chaps. 8, 34, 36A-H and 52.
[62] See chaps. 26, 34 and 36A-H.
[63] See chaps. 36F and 51.
[64] See chaps. 21-23 and 36F.

was left for their traditional fishing activities. Whether or not their activities were actually restricted, their slogan drew attention to a challenge faced all around the world as increasing demands are made for space for ocean-based activities.

Not all the uses of ocean space within national jurisdictions have the same implications. Some uses effectively exclude most other concurrent uses, for example where fishing rights for benthic species (such as oysters) in areas of national jurisdiction have been allocated to individual proprietors, where tourism would be hampered by other developments or where "no-take" marine protected areas have been created. Others may have a global distribution, but may have a lesser impact, such as shipping lanes and submarine cables. Yet others have, at least so far, only localized impacts, usually determined by the availability of some local resource. Those are likely to be intensive, limiting other uses in the areas where they occur, for example aquaculture, offshore oil and gas extraction, sand and gravel extraction and offshore wind-power installations.

Those differing implications of the developments in human uses of the ocean are important for policy decisions on how, and at what level (national, regional, global), activities should be best managed.[65]

Increased coastal population and urbanization (including tourism)

A large proportion of humans live in the coastal zone: 38 per cent of the world's population live within 100 km of the shore, 44 per cent within 150 km, 50 per cent within 200 km, and 67 per cent within 400 km. This proportion is steadily increasing. Consequently, there are growing demands for land in the coastal zone. Land reclamation has therefore been taking place on a large scale in many countries, particularly by reclaiming salt marshes, intertidal flats and mangroves. At the same time, where coastal land is threatened by erosion, large stretches of natural coastline have been replaced by "armoured", artificial coastal structures. Those can significantly affect coastal currents and the ability of marine biotas to use the coast as part of their habitat. Tourist developments have also significantly increased the lengths of artificial coastline. Changes in river management, such as the construction of dams, and the building of coastal infrastructures, such as ports, can significantly change the sedimentation pattern along coasts. Such changes can increase coastal erosion and promote other coastal changes, sometimes with the effect that coastal land is lost for its current use, producing demands for replacement space.[66]

Aquaculture and marine ranching

Increases in aquaculture, which is growing rapidly, and in marine ranching, which has substantial growth potential, require extensive ocean space as well as clean waters and, often, the dedicated use of an unpolluted seabed. Those requirements can result in conflicts with other uses, including, in some cases, the aesthetic or cultural values of sea areas. Similar demands for ocean space are also made by industries concerned with the production of cultural goods, such as pearls. Problems will result if management of such expansion is not integrated with that of other sectors.

Shipping routes and ports

World shipping has been growing consistently for the past three decades. Between 1980 and 2013, the annual tonnage carried in the five main shipping trades increased by 158 per cent. Although the use of ocean space by a ship is not continuous, on the more densely trafficked routes, shipping lanes cannot be used safely for other activities, even where those activities themselves are intermittent. Some of the ranges of the largest populations of seabirds in the northern hemisphere are intersected by major shipping routes, with consequent risk of disturbance to the wildlife and mortality from chronic or catastrophic oil and other spills.

[65] See chaps. 12, 17, 19, 21-24 and 28.
[66] See chaps. 18, 26, 28, 48 and 49.

The fundamental change in general cargo shipping (from loose bulk to containerized) has also produced a total change in the nature of the ports that act as terminals for that traffic, as large areas of flat land are needed for handling containers, both on departure and arrival. That land has, in many cases, been provided by means of land reclamation. As shipping traffic continues to grow, further substantial areas of land will be required. Dredging to create ports and to maintain navigation channels produces large amounts of dredged material that has to be disposed of. Most of that material is dumped at sea, where it smothers any biota on the seabed.[67]

Submarine cables and pipelines

The vital role that submarine cables now play in all forms of communication through the Internet — whether for academic, commercial, governmental or recreational purposes — means that there will continue to be a demand for more capacity, and hence for more submarine cables. Although submarine cables (and any protective corridors around them) cover only very narrow strips of seabed, they introduce a line break across the seabed that prevents other activities from spreading across it. Submarine cables will therefore continue to neutralize increasing segments of the seabed for any purpose that impinges on the seabed. Submarine pipelines are unlikely ever to venture into the open-ocean areas where many submarine cables have to be laid, but they have a growing role for transporting oil and gas through coastal zones and between continents and their adjacent islands. In some ways, therefore, their increased demand for seabed space is likely to be in areas where there are demands from other uses.[68]

Offshore hydrocarbon industries

The growth of the offshore oil and gas industry has increased the demand by that sector for access to ocean space within areas under national jurisdiction (including space for pipelines to bring the hydrocarbon products ashore). More than 620,000 km^2 (almost 9 per cent) of the exclusive economic zone (EEZ) of Australia is subject to oil and gas leases. In the United States, about 550,000 km^2 of the whole EEZ is subject to current oil and gas leases, including 470,000 km^2 in the Gulf of Mexico, representing 66 per cent of the EEZ of the United States in that area. When such significant proportions of the ocean areas under national jurisdiction are thus subject to such prior claims, overlaps in sectoral interests become inevitable.

Offshore mining

Offshore mining is currently confined to shallow-water coastal regions, although growing exploration activity is focused on deep-sea minerals. About 75 per cent of the world’s tin, 11 per cent of gold, and 13 per cent of platinum are extracted from the placer deposits near the surface of the coastal seabed, where they have been concentrated by waves and currents. Diamonds are also an important mining target. Aggregates (sand, coral, gravel and seashells) are also important: the United Kingdom, the world’s largest producer of marine aggregates, currently extracts approximately 20 million tons of marine aggregate per year, meeting around 20 per cent of its demand. Those activities are all concentrated in coastal waters, where other demands for space are high. Deep-water deposits that have generated continuing interest, but are not currently mined, include ferromanganese nodules and crusts, polymetallic sulphides, phosphorites, and methane hydrates. Demands for deep-sea space are likely to develop in the future.[69]

Offshore renewable energy

Offshore renewable energy generation is still in its early stages, although substantial offshore wind farms have been installed in some parts of the world. Most forms of

[67] See chaps. 17 and 18.
[68] See chap. 19.
[69] See chap. 22.

marine-based renewable energy require ocean space, and wind farms already cover significant areas in the coastal North Sea. Wave and tidal energy will make equal, if not larger, demands. The location of wind, wave and tidal installations can have significant effects on marine biotas. Special care is needed in siting installations that can affect migration routes or feeding, breeding or nursery areas. This is therefore a field in which the requirements of the new energy sources for ocean space could be important competitors with other, longer-established uses or with the need to conserve marine biodiversity.[70]

Fishery management areas

Capture fisheries have a very long history, predating newer ocean uses, such as aquaculture, offshore energy infrastructure, submarine cables, pipelines or tourism. The fishermen exploiting those long-practised fisheries usually have a feeling of "ownership", even though they rarely have had any established legal rights to exclude others from their customary fishing grounds. There is a growing trend, however, as part of fishery management within national jurisdictions, for fishing enterprises or fishing communities (including indigenous fishing communities) to be recognized as having some form of rights to fish to a defined extent in a defined area. Those benefiting from such rights frequently see constraints on fishing from other activities in those defined areas as invasions of what they consider as entitlements. This is the "front line" of conflicts in uses. If it is not directly addressed, some ocean uses will find it difficult to thrive.[71]

Marine protected areas

The Plan of Implementation of the World Summit on Sustainable Development (Johannesburg Plan of Implementation),[72] adopted in 2002, called for the implementation of marine protected areas. Although a marine protected area does not necessarily imply an area in which all human activities are excluded, in many cases it does imply that some, or most, such activities will be at least controlled or regulated. The commitment made by many States to a target for such protected areas of at least 10 per cent of the areas under their jurisdiction[73] will be a factor in future use of ocean space, given that, at present, marine protected areas represent a much smaller part of the ocean area under national jurisdiction.

Implications of demands for ocean space

That long list of types of human activity shows there are simply too many demands for all to be accommodated in a way that will not constrain some aspect of their operation. The allocation of ocean space is a much more complex task than that of land-use planning onshore. In the first place, the ocean is three-dimensional. Some uses can be in the same area but vertically separated, thus ships, for example, can pass over submarine cables without any problem, except in shallow water. Secondly, some uses are transient: ships and fishing vessels in particular pass and repass, and other uses may take place in the intervals between them. Thirdly, there is no general tradition of permanent rights of private ownership, even in areas under national jurisdiction. However, the more intense the shipping or fishing, the more difficult it is for other uses to be accommodated. Developing effective ways of organizing the allocation of ocean space is not an easy task, given the wide range of interests that need to be considered and reconciled.

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[70] See chap. 23.

[71] See chaps. 11 and 15.

[72] *Report of the World Summit on Sustainable Development, Johannesburg, South Africa, 26 August-4 September 2002* (United Nations publication, Sales No. E.03.II.A.1 and corrigendum), chap. I, resolution 2, annex, para. 32 (c).

[73] See United Nations Environment Programme, document UNEP/CBD/COP/10/27, annex, decision X/2, sect. IV, target 11.

F. Increasing inputs of harmful material

Land-based inputs

The agricultural and industrial achievements of the past two centuries in feeding, clothing and housing the world's population have been at the price of seriously degrading important parts of the planet, including much of the marine environment, especially near the coast. Urban growth, unaccompanied in much of the world by adequate disposal of human bodily wastes, has also imposed major pressures on the ocean. Land-based inputs to the ocean have thus contributed much to the degradation of the marine environment. The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities of 1995 highlighted the need for action to deal with sewage (including industrial wastes that are mixed with human bodily wastes) in developing countries. Although much has been done to implement national plans adopted under the Programme, particularly in South America, the lack of sewage systems and wastewater treatment plants is still a major threat to the ocean. This is particularly the case for very large urban settlements.[74]

Several aspects have to be considered in relation to the increasing inputs of harmful material from the land into the ocean.

Heavy metals and other hazardous substances

From the point of view of industrial development, many industrial processes have brought with them serious environmental damage, especially when the concentration of industries have led to intense levels of inputs to the sea of wastes which could not be assimilated. That damage is largely caused by heavy metals (especially lead, mercury, copper and zinc). With the development of organic chemistry, new substances have been created to provide important services in managing electricity (for example, polychlorinated biphenyls) and as pesticides. Chlorine has also been widely used in many industrial processes (such as pulp and paper production), producing hazardous by-products. Many of those chemical products and processes have proved to have a wide range of hazardous side-effects.

There are also problems from imperfectly controlled incineration, which can produce polycyclic aromatic hydrocarbons and, where plastics are involved, dioxins and furans. All those substances have adverse effects on the marine environment. As well as the long-known hazardous substances, there is evidence that some substances (often called endocrine disruptors), which do not reach the levels of toxicity, persistence and bioaccumulation[75] in the accepted definitions of hazardous substances, can disrupt the endocrine systems of humans and animals, with adverse effects on their reproductive success. Action is already being taken on several of those, but more testing is needed to clarify whether action is needed on others.

Over time, steps have been taken to reduce or, where possible, eliminate many of the impacts of heavy metals and hazardous substances. In some parts of the world, the efforts of the past 40 years have been successful, and concentrations in the ocean of many of the most seriously damaging heavy metals and other hazardous substances are now diminishing, for example in the North-East Atlantic, even though problems persist in some local areas. New technologies and processes have also been widely developed that have the ability to avoid those problems, but there are gaps in the capacities to apply those newer processes, often because of the costs involved.

The differential growth in industrial production between countries bordering the North Atlantic, on the one hand, and those bordering the South Atlantic, the Indian Ocean and the Pacific, on the other hand, means that much of that growth is now taking place in parts of the world that had not previously had to deal with industrial discharges on the

[74] See chap. 20.

[75] Bioaccumulation is the process whereby substances are ingested by animals and other organisms, but not broken down or excreted, and thus build up in their bodies.

current scale. In the past, industrial production had been dominated by the countries around the North Atlantic basin and its adjacent seas, as well as Japan. Over the past 25 years, the rapid growth of industries along the rest of the western Pacific rim and around the Indian Ocean has dramatically changed that situation. The world's industrial production and the associated waste discharges are rapidly growing in the South Atlantic, the Indian Ocean and the western Pacific. Even if the best practicable means are used to deal with heavy metals and hazardous substances in the waste streams from those growing industries, the growth in output and consequent discharges will increase the inputs of heavy metals and other hazardous substances into the ocean. It is therefore urgent to apply new less-polluting technologies, where they exist, and means of removing heavy metals and other hazardous substances from discharges, if the level of contamination of the ocean, particularly in coastal areas, is not to increase.

Frameworks have also emerged at the international level for addressing some of the problems caused by heavy metals and hazardous substances. In particular, the Stockholm Convention on Persistent Organic Pollutants[76] and the Minamata Convention on Mercury[77] provide agreed international frameworks for the States party to them to address the issues that they cover. Implementing them, however, will require much capacity-building.[78]

Oil

Although pollution from oil and other hydrocarbons is most obviously linked to offshore production and their maritime transport, substantial inputs of hydrocarbons occur from land-based sources, particularly oil refineries. In some parts of the world, it has proved possible to reduce such pressures on the marine environment substantially.[79]

Agricultural inputs

The agricultural revolution of the last part of the twentieth century, which has largely enabled the world to feed its rapidly growing population, has also brought with it problems for the ocean in the form of enhanced run-off of both agricultural nutrients and pesticides, as well as the airborne and waterborne inputs of nutrients from waste from agricultural stock. In the case of fertilizers, their use is rapidly growing in parts of the world where only limited use had occurred in the past. That growth has the potential to lead to increased nutrient run-off to the ocean if the increased use of fertilizers is not managed well. There are therefore challenges in educating farmers, promoting good husbandry practices that cause less nutrient run-off and monitoring what is happening to agricultural run-off alongside sewage discharges. In the case of pesticides, the issues are analogous to those of industrial development. Newer pesticides are less polluting than older ones, but there are gaps in the capacity to ensure that these less-polluting pesticides are used, in terms of educating farmers, enabling them to afford the newer pesticides, supervising the distribution systems and monitoring what is happening in the ocean.

Eutrophication

Eutrophication resulting from excess inputs of nutrients from both agriculture and sewage causes algal blooms. Those can generate toxins that can make fish and other seafood unfit for human consumption. Algal blooms can also lead to anoxic areas (i.e. dead zones) and hypoxic zones. Such zones have serious consequences from environmental, economic and social aspects. The anoxic and hypoxic zones drive fish away and kill the benthic wildlife. Where those zones are seasonal, any regeneration that happens is usually at a lower trophic level, and the ecosystems are therefore

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[76] United Nations, *Treaty Series*, vol. 2256, No. 40214.
[77] United Nations Environment Programme, document UNEP(DTIE)/Hg/CONF/4, annex II.
[78] See chap. 20.
[79] See chap. 20.

degraded. This seriously affects the maritime economy, both for fishermen and, where tourism depends on the attractiveness of the ecosystem (for example, around coral reefs), for the tourist industry. Social consequences are then easy to see, both through the economic effects on the fishing and tourist industries and in depriving the local human populations of food.[80]

Radioactive substances

In the case of radioactive discharges into the ocean, there have been, in the past, human activities that have given rise to concern, but responses to those concerns, and the actions taken, have largely removed the underlying problems, even though there is a continuing task to monitor what is happening to radioactivity in the ocean. In particular, the ending of atmospheric tests of nuclear weapons and, more recently, the improvements made in the controls on discharges from nuclear reprocessing plants have ended or reduced the main sources of concern. What remains is the risk voiced in the Global Programme of Action that public reaction to concerns about marine radioactivity could result in the rejection of fish as a food source, with consequent harm to countries that have a large fishery sector and damage to the world's ability to use the important food resources provided by the marine environment.[81]

Solid waste disposal

The dumping of waste at sea was the first activity capable of causing marine pollution to be brought under global regulation, in the form of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972[82] (the London Convention), regulating the dumping of wastes and other matter at sea from ships, aircraft and man-made structures. The controls under that agreement have been progressively strengthened, particularly in the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972[83] which introduced the approach of a total ban on dumping, subject to limited exemptions. If the Convention or the Protocol were effectively and consistently implemented, that source of inputs of harmful substances would be satisfactorily controlled. However, there are gaps in knowledge about their implementation. Over half of the States party to the London Convention and the Protocol thereto do not submit reports on dumping under their control. This may mean that there is no such dumping, but it may also mean that the picture presented by the reports that are submitted is incomplete. Some of the world's largest economies have not become party to either agreement, and nothing is known of what is happening with respect to dumping under their control. The reported dumping is very largely of dredged material, most of it from the creation or maintenance of ports. Clear guidance under the London Convention lays down the conditions under which that material may be dumped. To the extent that that guidance is followed, there should be no significant impact on the marine environment, except for the smothering of the seabed, and to the extent that the dump sites are in areas with dynamic tidal activity, even that impact will be limited. There is also some evidence that illegal dumping is taking place, including that of radioactive waste, but complete proof of this has not been obtained.[84]

Marine debris

Marine debris is present in all marine habitats, from densely populated regions to remote points far from human activities, from beaches and shallow waters to the deepest ocean trenches. It has been estimated that the average density of marine debris varies between 13,000 and 18,000 pieces per square kilometre. However, data on plastic accumulation in the North Atlantic and Caribbean from 1986 to 2008 showed

[80] See chap. 20.
[81] See chap. 20.
[82] United Nations, *Treaty Series*, vol. 1046, No. 15749.
[83] International Maritime Organization, document IMO/LC.2/Circ.380.
[84] See chap. 24.

that the highest concentrations (more than 200,000 pieces per square kilometre) occurred in the convergence zones between two or more ocean currents. Computer model simulations, based on data from about 12,000 satellite-tracked floats deployed since the early 1990s as part of the Global Ocean Drifter Program, confirm that debris will be transported by ocean currents and will tend to accumulate in a limited number of subtropical convergence zones or gyres.

Plastics are by far the most prevalent debris item recorded, contributing an estimated 60 to 80 per cent of all marine debris. Plastic debris continues to accumulate in the marine environment. The density of microplastics within the North Pacific Central Gyre has increased by two orders of magnitude in the past four decades. Marine debris commonly stems from shoreline and recreational activities, commercial shipping and fishing, and dumping at sea. The majority of marine debris (approximately 80 per cent) entering the sea is considered to originate from land-based sources.[85]

Nanoparticles are a form of marine debris, the significance of which is emerging only now. They are minuscule particles with dimensions of 1 to 100 nanometres (a nanometre is one millionth of a millimetre). A large proportion of the nanoparticles found in the ocean are of natural origin. It is the anthropogenic nanoparticles that are of concern. Those come from two sources: on the one hand, from the use of nanoparticles created for use in various industrial processes and cosmetics and, on the other hand, from the breakdown of plastics in marine debris, from fragments of artificial fabrics discharged in urban wastewater, and from leaching from land-based waste sites. Recent scientific research has highlighted the potential environmental impacts of plastic nanoparticles: they appear to reduce the primary production and the uptake of food by zooplankton and filter-feeders. Nanoparticles of titanium dioxide, which is widely used in paints and metal coatings and in cosmetics, are of particular concern. When nanoparticles of titanium dioxide are exposed to ultraviolet radiation from the sun, they transform into a disinfectant and have been shown to kill phytoplankton, which are the basis of primary production. The scale of the threats from nanoparticles is unknown, and further research is required.[86]

Shipping

Pollution from ships takes the form of both catastrophic events (shipwrecks, collisions and groundings) and chronic pollution from regular operational discharges. Good progress has been made over the past 40 years in reducing both. There have been large increases in the global tonnage of cargo carried by sea and in the distances over which those cargoes are carried. There have also been steady increases in the number of passengers carried on cruise ships and ferries. In spite of this, the absolute number of ship losses has steadily decreased. Between 2002 and 2013, the number of losses of ships of over 1,000 gross tonnage thus dropped by 45 per cent to 94. This is largely due to efforts under the three main international maritime safety conventions: the International Convention on the Safety of Life at Sea,[87] dealing with ship construction and navigation, the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978,[88] dealing with crew, and the International Convention for the Prevention of Pollution from Ships (MARPOL).

Pollution from oil has been the most significant type of marine pollution from ships. The number of spills exceeding 7 tons has dropped steadily, in spite of the growth in the quantity carried and the length of voyages, from over 100 spills in 1974 to under five in 2012. The total quantity of oil released in those spills has also been reduced by an even greater factor. Progress has also been made in improving response capabilities, though much remains to be done, especially as coastal States have to bear the capital cost of acquiring the necessary equipment. Reductions in oil pollution have resulted from more

[85] See chap. 25.
[86] See chaps. 6 and 25.
[87] United Nations, *Treaty Series*, vol. 1184, No. 18961.
[88] United Nations, *Treaty Series*, vol. 1361, No. 23001.

effective enforcement of the MARPOL requirements, particularly in western Europe. The changes in arrangements for reparation for any damage caused by oil pollution from ships have improved the economic position of those affected.

In spite of all that progress, oil discharges from ships remain an environmental problem, for example, around the southern tip of Africa and in the North-West Atlantic. Off the coast of Argentina, however, a solution to the impact of those discharges on penguin colonies seems to have been found by rerouting coastal shipping. The likely opening of shipping routes through the Arctic between the Atlantic and the Pacific risks introducing that form of pollution into a sea area where response infrastructure is lacking, oil recovery in freezing conditions is difficult and the icy water temperature inhibits the microbial breakdown of the oil.[89]

Pollution from cargoes of hazardous and noxious substances appears to be a much smaller problem, even though there are clearly problems with misdescriptions of the contents of containers. Losses of containers, however, appear to be relatively small: in 2011, the losses were estimated at 650 containers out of about 100 million carried in that year.

Sewage pollution from ships is mainly a problem with cruise ships: with up to 7,000 passengers and crew, they are the equivalent of a small town and can contribute to local eutrophication problems. The local conditions around the ship are significant for the impact of any sewage discharges. The increased requirements under MARPOL on the discharges of ship sewage near the shore are likely to reduce the problems, but the identification of the cases where ships have contributed to eutrophication problems will remain difficult.

The dumping of garbage from ships is a serious element of the problem of marine debris. In 2013, new, more stringent controls under MARPOL came into force. Steps are being taken to improve the enforcement of those requirements. For example, the World Bank has helped several small Caribbean States to set up port waste-reception facilities, which has made it possible for the Wider Caribbean to be declared a special area under annex V of the Convention, under which stricter requirements apply. Other States (for example the Member States of the European Union) have introduced requirements for the delivery of waste ashore before a ship leaves port and have removed economic incentives to avoid doing so. It is, however, too early to judge how far those various developments have succeeded in reducing the problem.[90]

Offshore hydrocarbon industries

Major disasters in the offshore oil and gas industry have a global, historical recurrence of one about every 17 years. The most recent is the Deepwater Horizon blowout of 2010, which spilled 4.4 million barrels (about 600,000 tons) of oil into the Gulf of Mexico. The other main harmful inputs from that sector are drilling cuttings (contaminated with drilling muds) resulting from the drilling of exploration and production wells, “produced water” (the water contaminated with hydrocarbons that comes up from wells, either of natural origin or through having been injected to enhance hydrocarbon recovery), and various chemicals that are used and discharged offshore in the course of exploration and exploitation.

Those materials can be harmful to marine life under certain circumstances. However, it is possible to take precautions to avoid such harm, for example by prohibiting the use of the most harmful drilling muds, by limiting the proportion of oil in the produced water that is discharged or by controlling which chemicals can be used offshore. Such regulation has been successfully introduced in a number of jurisdictions. Nonetheless, given the growth in exploration and offshore production, there is no doubt that those inputs are increasing over time, even though exact figures are not available globally.

[89] See chap. 17.
[90] See chaps. 17 and 25.

Produced water, in particular, increases in quantity with the age of the field being exploited.[91]

Offshore mining

The environmental impacts of near-shore mining are similar to those of dredging operations. They include the destruction of the benthic environment, increased turbidity, changes in hydrodynamic processes, underwater noise and the potential for marine fauna to collide with vessels or become entangled in operating gear.[92]

Implications for human well-being and biodiversity

Human health, food security and food safety

Marine biotas are under many different pressures from hazardous substances on reproductive success. Dead zones and low-oxygen zones resulting from eutrophication and climate change can lead to systematic changes in the species structure at established fishing grounds. Either can reduce the extent to which fish and other species used as seafood will continue to reproduce at their historical rates. When those effects are combined with those of excessive fishing on specific stocks, there are risks that the traditional levels of the provision of food from the sea will not be maintained.

In addition, heavy metals and other hazardous substances represent a direct threat to human health, particularly through the ingestion of contaminated food from the sea. The episode of mercury poisoning at Minamata, in Japan, is probably the most widely known event of that kind, and the reason why the global convention to address such problems is named after the town. There are places around the world where local action has been taken to prevent or discourage the consumption of contaminated fish and other seafood. In other places, monitoring suggests that levels of contamination dangerous for human health are being reached. In yet other places, there are inadequate monitoring systems to check on risks of that kind. Ensuring linkages between adequate systems for controlling the discharge and emissions of hazardous substances and the systems for controlling the quality of fish and other seafood available for human consumption is therefore an important issue. In the case of subsistence fishing, the most effective approach is to ensure that contamination does not occur in the first place.

The lack of proper management of wastewater and human bodily wastes causes problems for human health, both directly through contact with water containing pathogens and through bacteriological contamination of food from the sea, and indirectly by creating the conditions in which algal blooms can produce toxins that infect seafood. Those problems are particularly significant in and near large and growing conurbations without proper sewage treatment systems, such as found in many places in developing countries.[93]

Impacts on marine biodiversity

Part of the standard definition of hazardous substances in the context of marine pollution is that they are bioaccumulative — that is, once they are taken into an organism, they are not broken down or expelled, and continue to accumulate in it. Because of that characteristic, they also are accumulated more in the higher levels of the food web. As creatures at the lower levels are eaten by those at higher levels, the hazardous substances in the former are retained and accumulated by the latter. Some of those substances affect the reproductive success of the biota in which they have accumulated. There are also some effects on immune systems, with the result that individuals and populations become less resistant to outbreaks of disease. The deaths of many seals in the North-East Atlantic in the 1990s from the phocine distemper virus

[91] See chap. 21.
[92] See chap. 23.
[93] See chaps. 4-6, 10-12, 15 and 20.

have thus been linked to impaired immune systems. Likewise, improvements in a fish-health index in the same area in the 2000s have been attributed to reductions in the local concentrations of various hazardous substances.

The combined effects of hazardous substances, marine debris, oil and eutrophication (including the large and growing number of dead zones) resulting from the input of harmful material, waste and excessive amounts of nutrients into the ocean therefore represent a significant pressure on marine biodiversity.[94]

G. Cumulative impacts of human activities on marine biodiversity

When the many pressures described above, from fishing and other types of marine harvesting to demand for ocean space and inputs of harmful materials, are brought together, the result is a complex but dangerous mix of threats to marine biodiversity. To those threats must be added several other significant factors. Those arise from a number of separate sources, including noise from ships and seismic exploration and the introduction of competing non-native species by aquaculture and long-distance shipping (and their further distribution by recreational boats). Taken altogether, those factors represent a massive set of pressures on marine biodiversity.[95]

Implications for marine biodiversity

Such cumulative impacts of human uses are reported in all the regional biodiversity assessments in part VI of the present Assessment. There are indeed well-documented examples of cases where habitats, lower-trophic-level productivity, benthic communities, fish communities and seabird or marine mammal populations have been severely altered by pressures from a specific activity or factors (such as overfishing, pollution, nutrient loading, physical disturbance or the introduction of non-native species). However, many impacts on biodiversity, particularly at larger scales, are the result of the cumulative and interactive effects of multiple pressures from multiple drivers. It has repeatedly proved difficult to disentangle the effects of the individual pressures, which impedes the ability to address the individual causes.[96]

Even in the Arctic Ocean, where human settlements are relatively few and small, the potentially synergistic effects of multiple stressors come together. Furthermore, those stressors operate against a background of pressures from a changing climate and increasing human maritime activity, primarily related to hydrocarbon and mineral development and to the opening of shipping routes. Those changes bring risks of direct mortality, displacement from critical habitats, noise disturbance and increased exposure to hunting, which are superimposed on high levels of contaminants, notably organochlorines and heavy metals, as a result of the presence of those substances in the Arctic food web.[97]

In the open ocean (remote from land-based inputs), shifts in bottom-up forcing (that is, primary productivity) and competitive or top-down forcing (that is, by large predators) will also produce complex and indirect effects on ecosystem services. The stress imposed by low oxygen, low pH (that is, higher acidity) or elevated temperatures can reduce the resilience of individual species and ecosystems through shifts in organism tolerance and community interactions. Where this happens, it retards recovery from disturbances caused by human activities, such as oil spills, trawling and (potentially in the future) seabed mining. Slower growth of carbonate skeletons due to increased ocean acidification, delayed development under hypoxic conditions and increased respiratory demands with declining food availability illustrate how climate change could

[94] See chaps. 4-6, 20, 21, 25, 36A-H and 52.
[95] See chaps. 11, 12, 17-23 and 25-27.
[96] See chaps. 36A-H and 53.
[97] See chap. 36G.

exacerbate anthropogenic impacts and compromise deep-sea ecosystem structures and functions, and ultimately its benefits to human welfare.[98]

Those multiple pressures interact in ways that are poorly understood but that can amplify the effects expected from each pressure separately. The North Atlantic has been, comparatively, the subject of much scientific research. It has many long-term ocean-monitoring programmes and a scientific organization that has functioned for over a century to promote and coordinate scientific and technical cooperation among the countries around the North Atlantic. Even there, however, experts are commonly unable to disentangle consistently the causation of unsustainable uses of, and impacts on, marine biodiversity. This may initially seem to be discouraging. Nevertheless, well-documented examples exist of the benefits that can follow from actions to address past unsustainable practices, even if other perturbations are also occurring in the same area.[99]

Marine mammals, marine reptiles, seabirds, sharks, tuna and billfish

Cumulative effects are comparatively well documented for species groups of the top predators in the ocean, including marine mammals, seabirds and marine reptiles. Many of those species tend to be highly mobile and some migrate across multiple ecosystems and even entire ocean basins, so that they can be exposed to many threats in their annual cycle. Some of those species are the subject of direct harvesting, particularly some pinnipeds (seals and related species) and seabirds, and by-catch in fisheries can be a significant mortality source for many species. However, in addition to having to sustain the impact of those direct deaths, all of those species suffer from varying levels of exposure to pollution from land-based sources and increasing levels of noise in the ocean. Land-nesting seabirds, marine turtles and pinnipeds also face habitat disturbance, such as through the introduction of invasive predators on isolated breeding islands, the disturbance of beaches where eggs are laid or direct human disturbance from tourism, including ecotourism.[100]

Some global measures have been helpful in addressing specific sources of mortality, such as the global moratorium on all large-scale pelagic drift-net fishing called for by the General Assembly in 1991, which was a major step in limiting the by-catch of several marine mammal and seabird species that were especially vulnerable to entanglement. However, for seabirds alone, at least 10 different pressures have been identified that can affect a single population throughout its annual cycle, with efforts to mitigate one pressure sometimes increasing vulnerability to others. Because of the complexity of those issues, conservation and management must therefore be approached with care and alertness to the nature of the interactions among the many human interests, the needs of the animals and their role in marine ecosystems.[101]

Ecosystems and habitats identified for special attention

Just as species can face the effects of multiple pressures over their annual cycle as they migrate (sometimes around an entire ocean basin), habitats can integrate the effects of multiple pressures across the interacting species that use them. Many cases are presented in the chapters on specialized habitats, which are often sites of concentrated human activities. For example, warm-water corals face major threats, such as extractive activities, sewage and other pollution, sedimentation, physical destruction and the effects of anthropogenic climate change, including increased coral bleaching. Such stressors often interact synergistically with one another and with natural stressors, such as storms. Likewise, cold-water corals are often challenged by the synergistic effects of

[98] See chaps. 4-6, 11, 17, 20, 36F, 37-39 and 52.
[99] See chap. 36A.
[100] See chaps. 27, 37-39 and 52.
[101] See chaps. 11 and 38.

low oxygen and increasing acidification, as well as by physical damage from fishing practices.[102]

All coastal habitats, including kelp forests, seagrass beds and mangroves, face multiple interacting threats from land-based sources, species invasions and direct anthropogenic pressures. For example, mangroves may face the aggregate effects of coastal and urban development, sewage and other pollutants, solid waste disposal, damage from extreme events, such as hurricanes, as well as conversion to aquaculture or agriculture and climate change. Each of the chapters on specific habitats presents similar lists of pressures, often present on the same sites. Although protection from direct human uses of areas where habitats occur (such as bans on converting mangroves to aquaculture or port facilities) can often produce immediate benefits, pressures such as land-based runoff, diseases and invasive species require coordinated efforts far beyond the specific habitats for which the protection is intended.[103]

Considering specific types of important marine and coastal habitats, estuaries and deltas are categorized globally as in poor overall condition, based on published assessments of them for 101 regions. In 66 per cent of cases, their condition has worsened in recent years. There are around 4,500 large estuaries and deltas worldwide, of which about 10 per cent benefit from some level of environmental protection. About 0.4 per cent is protected as strict nature reserves or wilderness areas (categories Ia and Ib of the categories of protected areas as defined by the International Union for Conservation of Nature).[104]

Mangroves are being lost at the mean global rate of 1-2 per cent a year, although losses can be as high as 8 per cent a year in some countries. While the primary threat to mangroves is overexploitation of resources and the conversion of mangrove areas to other land uses, climate-change-induced sea-level rise is now identified as a global threat to them, especially in areas of growing human settlements and coastal development.[105]

Kelp and seagrass habitats are declining worldwide for different reasons. The overfishing of dominant predators and climate change have reportedly caused changes in kelp community structures and distribution over time. Kelp forests are more affected by temperature changes owing to the narrow range in which their sexual reproduction can occur. Seagrass meadows are more affected by anthropogenic activities, such as siltation, pollution and reclamation.[106]

Fishing on seamounts has targeted fish aggregations to depths of 1,500 m. Aggregations on spatially limited topographic features are highly vulnerable, and many target species are slow-growing and long-lived, therefore exhibiting little resilience to disturbance. Furthermore, most fisheries use bottom trawls, gear that is highly destructive to benthic communities. Little recolonization is observed years after closure to fishing. Most sites of deep-water bottom fisheries have been overfished in the past, but there are now increased efforts to seek to regulate their use and to protect deep-water benthic habitats.[107]

[102] See chaps. 42-51.
[103] See chaps. 43, 44 and 47-49.
[104] See chap. 44.
[105] See chap. 48.
[106] See chap. 47.
[107] See chaps. 36F and 51.

Tourism and aesthetic, cultural, religious and spiritual marine ecosystem services

The changes in marine biodiversity can have consequential effects on the ecosystem services that humans obtain from the ocean. Particularly important is the link between the health of warm-water corals and tourism. Warm-water corals represent a major component of the attractiveness of many tourist resorts in the Caribbean, the Red Sea, the Indian Ocean and South-East Asia, and that attractiveness will be seriously undermined if tourists can no longer enjoy the corals. The same applies to other resorts (even in cold-water areas) where one of the attractions is scuba-diving to enjoy the marine wildlife. A different linkage is that to recreational fishing, where a significant industry relies on the availability of large sport fish such as marlins, swordfish and sailfish. In that case, there is a lack of information on which estimates of fish stocks and, consequently, judgements on the sustainable scale of the activity can be based.[108]

The disappearance or, more commonly, the reduction in numbers of iconic species can likewise adversely affect traditional practices. For example, native people on the North-East Pacific coast have seen their traditional whale-hunting halted because of the past overharvesting of grey whales carried out by other people. That hunting was an integral part of their cultural heritage and the affected tribes consider the cultural loss to be very serious. Pollution can have similar effects. For example, the Faroese authorities (Denmark) are taking measures to control the traditional food obtained in the islands from pilot whales because of the high levels of pollutants accumulated in their tissues.[109]

H. Distribution of ocean benefits and disbenefits

In assessing the social and economic aspects of the ocean, it is necessary to consider how different parts of the world, different States and different parts of society are gaining benefits (or suffering disbenefits) as a result of the ways in which human activities linked to the oceans are changing.

Changes in the universal ecosystem services from the ocean

The most obvious distributional effects of climate change relate to the rise in sea level. Some small island States are predicted to become submerged completely and some heavily populated deltas and other low-lying areas also risk inundation. Another important distributional effect is the poleward extension of major areas of storms, which is likely to lead to cyclones, hurricanes and typhoons in areas previously not seriously affected by them. Changes in patterns of variability of oscillations (such as the El Niño-Southern Oscillation) will bring climatic changes to many places and affect new areas, with consequent effects on agriculture and agricultural earnings.[110]

The changes in ocean conditions will affect many other ecosystem services indirectly. For example, some models predict that the warming ocean will increase the fish biomass available for harvesting in higher latitudes and decrease it in equatorial zones. This will shift provisioning services to benefit the middle and moderately high latitudes (which are often highly developed) at the expense of low latitudes, where small-scale (subsistence) fishing is often important for food security.[111]

Developments in fish and seafood consumption

The Food and Agriculture Organization of the United Nations (FAO) estimates that total fish consumption, including all aquaculture and inland and marine capture fisheries, has been rising from 9.9 kg per capita in the 1960s to 19.2 kg per capita in 2012 — an average increase of 3.2 per cent a year over half a century. The distribution of

[108] See chaps. 27, 41 and 43.
[109] See chaps. 8 and 20.
[110] See chaps. 4 and 5.
[111] See chaps. 11 and 15.

consumption per capita varies considerably, from Africa and Latin America and the Caribbean (9.7 kg) to Asia (21.6 kg), North America (21.8), Europe (22.0 kg) and Oceania (25.4 kg). Marine capture fisheries represent 51 per cent and marine aquaculture 13 per cent of the total production of fish (154 million tons), of which 85 per cent is used for food.

The annual consumption of fishery products per capita has grown steadily in developing regions (from 5.2 kg in 1961 to 17.0 kg in 2009) and low-income food-deficit countries (from 4.9 kg in 1961 to 10.1 kg in 2009). This is still considerably lower than in more developed regions, even though the gap is narrowing. A sizeable share of fish consumed in developed countries consists of imports and, owing to steady demand and declining domestic fishery production (down 22 per cent in the period 1992-2012), their dependence on imports, in particular from developing countries, is projected to grow.

FAO estimates indicate that small-scale fisheries contribute about half of global fish catches. When considering catches destined for direct human consumption, the share contributed by the subsector increases, as small-scale fisheries generally make broader direct and indirect contributions to food security (through affordable fish) and employment for populations in developing countries. As well as direct consumption, many small-scale fishermen sell or barter their catch. It is doubtful that much of that trade is covered by official statistics. However, studies have shown that selling or trading even a portion of their catch represents as much as one third of the total income of subsistence fishermen in some low-income countries. Thus an increase in imports of fish by more developed countries from less developed countries has the potential to increase inequities in food security and nutrition, unless those considerations are taken into account in global trade arrangements.[112]

Developments in employment and income from fisheries and aquaculture

The global harvest of marine capture fisheries has expanded rapidly since the early 1950s and is currently estimated to be about 80 million tons a year. That harvest is estimated to have a first (gross) value on the order of 113 billion dollars. Although it is difficult to produce accurate employment statistics, estimates using a fairly narrow definition of employment have put the figure of those employed in fisheries and aquaculture at 58.3 million people (4.4 per cent of the estimated total of economically active people), of which 84 per cent are in Asia and 10 per cent in Africa. Women are estimated to account for more than 15 per cent of people employed in the fishery sector. Other estimates, probably taking into account a wider definition of employment, suggest that capture fisheries provide direct and indirect employment for at least 120 million persons worldwide.

Small-scale fisheries employ more than 90 per cent of the world’s capture fishermen and fish workers, about half of whom are women. When all dependants of those taking full- or part-time employment in the full value chain and support industries (boatbuilding, gear construction, etc.) of fisheries and aquaculture are included, one estimate concludes that between 660 and 820 million persons have some economic or livelihood dependence on fish capture and culture and the subsequent direct value chain. No sound information appears to be available on the levels of death and injury of those engaged in capture fishing or aquaculture, but capture fishing is commonly characterized as a dangerous occupation.

Over time, a striking shift has occurred in the operation and location of capture fisheries. In the 1950s, capture fisheries were largely undertaken by developed fishing States. Since then, developing countries have increased their share. As a broad illustration, in the 1950s, the southern hemisphere accounted for no more than 8 per cent of landed values. By the last decade, the southern hemisphere’s share had risen to 20 per cent. In 2012, international trade represented 37 per cent of the total fish

[112] See chaps. 10, 11 and 15.

production in value, with a total export value of 129 billion dollars, of which 70 billion dollars (58 per cent) was exports by developing countries.[113]

Aquaculture is responsible for the bulk of the production of seaweeds. Worldwide, reports show that 24.9 million tons was produced in 2012, valued at about 6 billion dollars. In addition, about 1 million tons of wild seaweed were harvested. Few data were found on international trade in seaweeds, but their culture is concentrated in countries where consumption of seaweeds is high.[114]

Developments in maritime transport

All sectors of maritime transport (cargo trades, passenger and vehicle ferries and cruise ships) are growing in line with the world economy. It is not possible to estimate the earnings from those activities, as the structure of the companies owning many of the ships involved is opaque. It seems likely that many of the major cargo-carrying operators were making a loss in 2012, as a result of overcapacity resulting from the general economic recession. On the other hand, cruise operators reported profits. According to estimates by the United Nations Conference on Trade and Development, owners from five countries (China, Germany, Greece, Japan and the Republic of Korea) together accounted for 53 per cent of the world tonnage in 2013. It seems likely that profits and losses are broadly proportional to ownership. Among the top 35 ship-owning countries and territories, 17 are in Asia, 14 in Europe and 4 in the Americas.

Worldwide, there are just over 1.25 million seafarers, only about 2 per cent of whom are women, mainly in the ferry and cruise-ship sectors. The crews are predominantly from countries members of the Organization for Economic Cooperation and Development and Eastern Europe (49 per cent of the officers and 34 per cent of the ratings) and from Eastern and Southern Asia (43 per cent of the officers and 51 per cent of the ratings). Africa and Latin America are noticeably underrepresented, providing only 8 per cent of the officers and 15 per cent of the ratings. Pay levels of officers differ noticeably according to their origin, with masters and chief officers from Western Europe receiving on average a fifth or a quarter, respectively, more than those from Eastern Europe or Asia, while pay levels for engineer officers are more in line with one another. The recent entry into force of the Maritime Labour Convention, 2006 should be noted in the context of the social conditions of seafarers.

Statistics on the deaths of and injuries to seafarers are unreliable, and the Secretary-General of the International Maritime Organization has called for efforts to improve them. In general, it would appear that the levels of death and injury are worse than for many land-based industries. Over the past three decades, piracy and armed robbery have re-emerged as a serious risk to seafarers. Much attention has been focused on such attacks on ships in waters off Eastern Africa, but reports show that the problem is more widespread. In the past three years, action against attacks off Eastern Africa appears to have had some success, but attacks elsewhere are also of concern, especially in the South China Sea, the location of over half the incidents reported in 2013, and West Africa.[115]

Developments in offshore energy businesses

Global offshore oil production in mid-2014 was about 28 million barrels per day, which was worth about 3.2 billion dollars per day, and the industry directly employs about 200,000 people globally, mostly in the Gulf of Mexico (where about 60 per cent of the industry is located) and the North Sea. In the same year, the industry accounted for about 1.5 per cent of the gross domestic product (GDP) of the United States, 3.5 per cent of the GDP of the United Kingdom, 21 per cent of the GDP of Norway and 35 per cent of the GDP of Nigeria. The large majority of offshore hydrocarbon production is in the hands of international corporations or national companies usually working in

113 See chaps. 11 and 15.
114 See chap. 14.
115 See chap. 17.

partnership with them. This makes the tracking of the distribution of benefits from this sector, other than direct employment in extraction and processing, very difficult.[116]

Developments in offshore mining

There is limited information about the value of the offshore mining industry and the number of people it employs, but it is unlikely to be significant at present in comparison with terrestrial mining. For example, in the United Kingdom, which is the world's largest producer of marine aggregates, the industry directly employs approximately 400 people.[117]

Developments in tourism

Tourism has generally been increasing fairly steadily for the past 40 years (with occasional setbacks or slowing down during global recessions). In 2012, international tourism expenditure exceeded 1 billion dollars for the first time. Total expenditure on tourism, domestic as well as international, is several times that amount. The direct turnover of tourism contributed 2.9 per cent of gross world product in 2013, rising to 8.9 per cent when the multiplier effect on the rest of the economy is taken into account. The Middle East is the region where tourism plays the smallest part in the economy (6.4 per cent of GDP, including the multiplier effect), and the Caribbean is the region where it plays the largest part (13.9 per cent of GDP, including the multiplier effect).

Most reports of tourism revenues do not differentiate revenues from tourism directly related to the sea and the coast from other types of tourism. Even where tourism in the coastal zone can be separated from tourism inland, it may be generated by the attractions of the sea and coast or its maritime history, as it may be based on other attractions not linked to the marine environment. Consequently, the value of ocean-related tourism is a matter of inference. However, coastal tourism is a major component of tourism everywhere. In small island and coastal States, coastal tourism is usually predominant because it can only take place in the coastal zone in those countries. Particularly noteworthy is the way in which international tourism is increasing in Asia and the Pacific, both in absolute terms and as a proportion of world tourism. This implies that pressures from tourism are becoming of significantly more concern in those regions.

Tourism is also a significant component of employment. Globally, it is estimated that, in 2013, tourism provided 3.3 per cent of employment, when looking at the number of people directly employed in the tourism industry, and 8.9 per cent when the multiplier effect is taken into account. In the different regions, the proportion of employment supported by tourism is approximately the same as the share of GDP contributed by tourism, although, again, what proportion is based on the attractions of the sea and coast is not well known.[118]

Use of marine genetic material

The commercial exploitation of marine genetic resources had very modest beginnings in the twentieth century, particularly when measured against some estimates of the potential of the great diversity of species and biomolecules in the sea. Since 2000, the first drugs derived from marine organisms have been put into commerce (although, using the United States Food and Drug Administration approvals as a measure, only seven have so far received that approval). There has also been considerable growth in the use of marine natural products as food supplements and for other non-medical purposes. Economic and social aspects of the use of marine genetic material are therefore only just beginning to develop.[119]

[116] See chap. 21.
[117] See chap. 23.
[118] See chap. 27.
[119] See chap. 29.

Satellite national accounts

Information on the distribution of economic benefits from the ocean is hard to compile from current information sources. The work of the United Nations Statistics Division in developing a System of Environmental-Economic Accounting and an Experimental Ecosystem Accounting System seems likely to help to fill that information gap. In the same way, national satellite accounts dealing with tourism and fisheries should help to fill information gaps in those fields.[120]

I. Integrated management of human activities affecting the ocean

The Regular Process is to provide an assessment of all the aspects of the marine environment relevant to sustainable development: environmental, economic and social. Even though the marine environment covers seven tenths of the planet, it is still only one component of the overall Earth system. As far as environmental aspects are concerned, major drivers of the pressures producing change in the ocean are to be found outside the marine environment. In particular, most of the major drivers of anthropogenic climate change are land-based. Likewise, the main drivers of increased pressures on marine biodiversity and marine environmental quality include the demand for food for terrestrial populations, international trade in products from land-based agriculture and industries and coastal degradation from land-based development and land-based sources.

Thus, as far as social and economic aspects of the marine environment are concerned, many of the most significant drivers are outside the scope of the present Assessment. For example, the levels of cargo shipping are driven mainly by world trade, which is determined by demand and supply for raw materials and finished products. The extent of cruising and other types of tourism is determined by the levels around the world of disposable income and leisure time. The patterns of trade in fish and other seafood and in cultural goods from the ocean are set by the location of supply and demand and the relative purchasing power of local markets as compared with international ones, modified by national and international rules on the exploitation of those resources. A wide range of factors outside the marine environment are thus relevant to policymaking for the marine environment.

The present Assessment of the marine environment cannot therefore reach conclusions on some of the main drivers affecting the marine environment without stepping well outside the marine environment and the competences of those carrying out the Assessment. It is essential to note, however, that the successful management of human activities affecting the marine environment will require the consideration of the full range of factors relating to human activities affecting the ocean.

Even within the scope of what has been requested, it has not proved possible to come to conclusions on one important aspect: a quantitative picture of the extent of many of the non-marketed ecosystem services provided by the ocean. Quantitative information is simply insufficient to enable an assessment of the way in which different regions of the world benefit from those services. Nor do current data-collection programmes appear to make robust regional assessments of ocean ecosystem services likely in the near future, especially for the less developed parts of the planet.[121]

The assessment of what is happening to aesthetic, cultural, religious and spiritual values is also very difficult. In essentially every coastal or island culture, the indigenous peoples have spiritual links to the sea. They often also have links with species or places, or both, that have high iconic values. The spiritual significance of those marine species and places may be part of their self-identification and reflects their beliefs about the origins of their culture. That is particularly true of island cultures, which are often intimately bound to the sea. Expressions of loss of, or threats to, such cultures and

[120] See chaps. 3 and 9.
[121] See chaps. 54 and 55.

identities are readily found, but the marine component is not easily separated. Even populations that are economically fully developed with largely urbanized lifestyles still look to the ocean for spiritual and cultural benefits that have proven hard to value monetarily.[122]

Nevertheless, there is an overall message that the world has reached the end of the period when human impacts on the sea were minor in relation to the overall scale of the ocean. Human activities now have so many and such great impacts on the ocean that the limits of its carrying capacity are being (or, in some cases, have been) reached. It is instructive to look at the ways in which this has happened in one specific sector: fisheries. In the late nineteenth century, the regulation of fisheries was regarded by many as unnecessary: Thomas Huxley, the great defender of Charles Darwin's theory of natural selection and a leading marine biologist, speaking at the London Fisheries Exhibition, in 1883, said: "In relation to our present modes of fishing, a number of the most important sea fisheries ... are inexhaustible. … [The] multitude of those fishes is so inconceivably great that the number that we catch is relatively insignificant; and secondly, … the magnitude of the destructive agencies at work on them is so prodigious, that the destruction effected by the fisherman cannot sensibly increase the death rate".

In less than 50 years, his qualification "in relation to our present modes of fishing" proved to be prophetic. Modes of fishing had changed to such an extent that international efforts were under way to regulate individual fisheries. We now know that those efforts were even then overdue. Furthermore, experience thereafter showed that the successful management of fisheries required a much broader approach. First to be acknowledged was the need for a multispecies approach: it was necessary to regulate the fisheries not only for each target species individually, but also to take into account the species on which the target species preyed and the species that preyed on it.

In the 1990s, it became clear that the effects of fisheries on other biotas made an ecosystem approach to fishery management necessary, taking into account how a fishery might directly kill other species through by-catches, alter habitats and change relationships in the food web. Since then, the increasing use of the ocean has shown how fisheries managers need to work with other sectors to manage their effects on each other and, collectively, on the ocean that they share.

When various conclusions in parts III to VI of the present Assessment are linked together, they clearly show that a similar broadening of the context of management decisions will produce similar benefits in and among other sectors of human activities that affect the ocean. Examples of such interactions of pressures on the environment include:

(a) The lack of adequate sewage treatment in many large coastal conurbations, especially in developing countries, and other excessive inputs of nutrients (especially nitrogen) are producing direct adverse impacts on human health through microbial diseases as well as eutrophication problems. In many cases, they are creating harmful algal blooms, which are not only disrupting ecosystems, but also, as a consequence, damaging fisheries, especially small-scale fisheries and the related livelihoods and, in some cases, poisoning humans through algal toxins;[123]

(b) Plastic marine debris results from the poor management of waste streams on land and at sea. There is a clear impact of such debris in its original form on megafauna (fish caught in "ghost" nets, seabirds with plastic bags around their necks, etc.) and on the aesthetic appearance of coasts (with potential impacts on tourism). Less obviously, impacts on zooplankton and filter-feeding species have also been demonstrated from the nanoparticles into which those plastics break down, with potentially serious effects all the way up the food web. Likewise, nanoparticles from titanium dioxide (the base of

[122] See chap. 8.
[123] See chap. 20.

white pigments found in many waste streams) have been shown to react with the ultraviolet component of sunlight and to kill phytoplankton;[124]

(c) Although much is being done to reduce pollution from ships, there is scope for more attention to the routes that ships choose and the effects of those routes in terms of noise, chronic oil pollution and operational discharges;[125]

(d) The cumulative effects of excessive nutrient inputs from sewage and agriculture and the removal of herbivorous fish by overfishing can lead to excessive algal growth on coral reefs. Where coral reefs are a tourist attraction, such damage can undermine the tourist business;[126]

(e) The ocean is acidifying rapidly and at an unprecedented rate in the Earth's history. The impact of ocean acidification on marine species and food webs will affect major economic interests and could increasingly put food security at risk, particularly in regions especially dependent on seafood protein.[127]

Better integrated management of human activities affecting the ocean can, in many cases, be achieved with existing knowledge. However, application of that knowledge in many countries requires improvements in the skills of those involved. The last section of the present summary deals with the gaps that have been identified in capacity-building. Furthermore, in many cases, better information is required. Significant knowledge gaps that would need to be filled in order to achieve more general improved and integrated management of human activities affecting the ocean are set out in the penultimate section of the summary.

J. Urgency of addressing threats to the ocean

The greatest threat to the ocean comes from a failure to deal quickly with the manifold problems that have been described above. Many parts of the ocean have been seriously degraded. If the problems are not addressed, there is a major risk that they will combine to produce a destructive cycle of degradation in which the ocean can no longer provide many of the benefits that humans currently enjoy from it.

In particular, the cumulative impact of many of the problems described in the present Assessment must be considered. As always, addressing one aspect of a challenge without considering the other factors involved risks undermining what can be achieved. This means that addressing some challenges may require also addressing the problems of fragmented data collection, which makes it difficult to obtain a clear picture of the overall problem, and uncoordinated action in different fields (in either geographic or thematic terms).

On the other hand, the Assessment contains many examples of efforts made to address individual problems that have resulted in improved ecosystems, economic benefits and improved livelihoods, even though other pressures could not be addressed at the same time. Feasible sectoral improvements do not need to be delayed until the benefits of integrated planning and management can be achieved. They can even facilitate action to address other pressures, either by demonstrating the gains from investing in improved management, or through bringing into clearer focus the costs imposed by other pressures.[128]

Some of the specific threats (such as the intensification of typhoons and hurricanes and changes in the stratification of seawater) are inextricably bound with the problems of climate change and acidification and can only be addressed as part of those issues.

[124] See chaps. 6 and 25.
[125] See chap. 17.
[126] See chaps. 27 and 43.
[127] See chaps. 4, 5, 10 and 52.
[128] See, for example, chap. 36A.

However, many other threats derive from problems that are more local and constitute global problems simply because the same type of problem and threat occurs in many places. For most of those problems, techniques have been developed that can successfully address them. Implementing them successfully is then a question of building the capacities in infrastructure resources, organizational arrangements and technical skills.

Problems of that kind that can be addressed include:

(a) Reducing inputs of hazardous substances, waterborne pathogens and nutrients;[129]

(b) Preventing maritime disasters due to the collision, foundering and sinking of ships, and implementing and enforcing international agreements on preventing adverse environmental impacts from ships;[130]

(c) Improving fishery management;[131]

(d) Managing aquaculture;[132]

(e) Controlling tourism developments that will have adverse impacts on the future of the tourism industry in the locality where they occur;[133]

(f) Controlling solid waste disposal that can reach and affect the marine environment;[134]

(g) Improving the control of offshore hydrocarbon industries and offshore mining;[135]

(h) Establishing and maintaining marine protected areas.[136]

VI. Knowledge gaps

Humans have been exploring the three tenths of the planet that is land for millennia. Serious scientific examination of the land and its plants and animals has been in progress for at least 500 years. Although humans have been using the ocean for millennia, it is only in the past 120 years or so that serious exploration of the seven tenths of the planet covered by the sea (other than charting coasts) has been in progress. It is therefore not surprising that our knowledge of the ocean is much more limited than our knowledge of the land. As the chapters of the present Assessment demonstrate, much is known about much of the ocean, but nowhere do we have the detailed knowledge desirable for the effective future management of human use of the ocean. In some parts of the world, we do not even have sufficient knowledge to apply properly the techniques that have been successfully developed elsewhere. We have a basic framework of understanding, but there are many gaps to be filled in.

The information that we need to understand the ocean can be divided into four main categories: (a) the physical structure of the ocean; (b) the composition and movement of the ocean's waters; (c) the biotas of the ocean; and (d) the ways in which humans interact with the ocean. The identification of the gaps in that knowledge is best based on a survey of the gaps revealed in the chapters of the Assessment. In general, we know least about the Arctic Ocean and the Indian Ocean. The parts of the Atlantic Ocean and the Pacific Ocean in the northern hemisphere are better studied than those in the

[129] See chap. 20.
[130] See chap. 17.
[131] See chap. 11.
[132] See chap. 12.
[133] See chap. 27.
[134] See chaps. 24 and 25.
[135] See chaps. 21 and 23.
[136] See chap. 44.

southern hemisphere and, again in general, the North Atlantic and its adjacent seas are probably the most thoroughly studied — and even there major gaps remain.[137]

Physical structure of the ocean

Chapter 1 (Planet, ocean and life) of the Assessment includes a map characterizing the geomorphic features of the ocean. The detail summarized in that map has been greatly enriched over the past quarter century by local and global studies. Although charting the oceans has been in progress for more than seven centuries in coastal waters and for 250 years along the main routes across the open ocean, many features still require more detailed examination. The designation of exclusive economic zones (EEZs) has led many countries to carry out more detailed surveys as a basis for managing their activities in those zones. Ideally, all coastal States would have such detailed surveys as a basis for their EEZ management.

Because of the significance of ocean acidification for carbonate formation, better information on the formation and fate of reef islands and shell beaches is desirable. It is possible to characterize the physical structure of the ocean in areas beyond national jurisdictions, but the reliability and detail of such characterizations varies considerably among different parts of the ocean: improvements in information of that kind are highly desirable to understand the interaction between the physical structure and the biotas, both in terms of conserving biodiversity and in terms of managing living marine resources.[138]

Waters of the ocean

Gaps persist in understanding sea temperature (both at the surface and at depth), sea-level rise, salinity distribution, carbon dioxide absorption, and nutrient distribution and cycling. The atmosphere and the ocean form a single linked system. Much of the information needed to understand the ocean is therefore also needed to understand climate change. Research promoted by the Intergovernmental Panel on Climate Change will look at many of those questions. It will thus be important to ensure that oceanic and atmospheric research is coordinated.

Ocean acidification is a consequence of carbon dioxide absorption, but understanding the implications for the ocean requires more than just a general understanding of how carbon dioxide is being absorbed, as the degree of acidification varies locally. The causes and implications of those variations are important for understanding the impact on the marine biotas.

In order to track primary production (on which the overwhelming majority of the ocean food web relies), routine and sustained measurements are highly desirable across all parts of the ocean of chlorophyll a (as an important marker of primary production), dissolved nitrogen and biologically active dissolved phosphorus (as the latter two are frequent limiting factors of primary production or causes of algal blooms).[139]

Biotas of the ocean

The Census of Marine Life has been an essential tool for ocean research in clarifying the biodiversity of the ocean and the number and distribution of species. Like all censuses, its value will decrease as time passes until it becomes a snapshot of a particular point in time, and less of an up-to-date picture of what is currently happening. It will be important for the Census to be regularly updated and improved. Improvement is particularly desirable for areas around and between Africa and Central and South America, across the Indian Ocean and in the South Pacific.[140]

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[137] See chap. 30.
[138] See chap. 9.
[139] See chap. 9.
[140] See chap. 35.

Plankton are fundamental to life in the ocean. Information on their diversity and abundance is important for many purposes. Such information has been collected for over 70 years in some parts of the ocean (such as the North Atlantic) through continuous plankton recorder surveys. Nine organizations currently collaborate in extending such surveys, but the desirable comprehensive global coverage has not yet been achieved.

As well as information on biodiversity in the ocean and the number and distribution of the many marine species, information is also highly desirable on the health and reproductive success of separate populations. Many species contain separate populations that have limited interconnections. It is therefore important to understand how the local influences specific to each population are affecting them. As the regional surveys in part VI show, much is already known about the population health and reproductive success of many species, but there are also large gaps in knowledge, particularly in the southern hemisphere.[141]

Fish stock assessments are essential to the proper management of fisheries. A good proportion of the fish stocks fished in large-scale fisheries are the object of regular stock assessments. However, many important fish stocks of that kind are still not regularly assessed. More significantly, stocks important for small-scale fisheries are often not assessed, which has adverse effects in ensuring the continued availability of fish for such fisheries. This is an important knowledge gap to fill. Likewise, there are gaps in information about the interactions between large-scale and small-scale fisheries for stocks over which their interests overlap, and between recreational fishing and other fisheries for some species, such as some trophy fish (marlins, sailfish and others) and other smaller species.[142]

The present Assessment sets out the main specific issues for which there are gaps in our knowledge of marine biotas, in particular of all the species and habitats that have been scientifically identified as threatened, declining or otherwise in need of special attention or protection. Those species include, with some indications of important issues identified in part VI: marine mammals, sea turtles, seabirds (particularly migration routes), sharks and other elasmobranchs (especially the lesser-known species and certain tropical areas), tuna and billfish (particularly the non-principally marketed species), cold-water corals (especially where they are found in the Indian Ocean), warm-water corals (particularly at locations in deeper water), estuaries and deltas (particularly integrated assessments of them), high-latitude ice, hydrothermal vents (especially the extent to which they are found in the Indian Ocean), kelp forests and seagrass beds (especially the degree of loss of kelp and the pathology of the diseases affecting them), mangroves (especially the taxonomy of associated species and their interactions with salt marshes), salt marshes (especially the ecosystem services that they provide) and the Sargasso Sea (especially the links with distant ecosystems).[143]

Ways in which humans interact with the ocean

Some of the issues relating to the ocean and to the ocean biotas (for example, ocean acidification and fish stock assessments) are linked to the way in which humans affect some aspects of the ocean (for example, through carbon-dioxide emissions or fisheries). However, there are many more areas in which we do not yet know enough about human activities that affect or interact with the ocean to enable us to manage those activities sustainably.

For shipping, much information is available about where ships go, their cargo and the economics of their operations. However, important gaps remain in our knowledge about how their routes and operations affect the marine environment. Those issues include primarily the noise that they make, chronic discharges of oil and the extent to which non-native invasive species are being transported. Other information gaps relate to the

[141] See chaps. 36A-H.
[142] See chaps. 11 and 27.
[143] See chaps. 42 to 51.

social aspects of shipping: in particular, little is known about the levels of death and injury of seafarers, an issue recently raised by the Secretary-General of the International Maritime Organization.[144]

Land-based inputs to the ocean have serious implications for both human health and the proper functioning of marine ecosystems. In some parts of the world, those have been studied carefully for over 40 years. In others, little systematic information is found. There are two important gaps in current knowledge. The first is how to link different ways of measuring discharges and emissions. Much information is available from local studies about inputs, but those are frequently measured and analysed in different ways, thereby making comparison difficult or impossible. There are sometimes good reasons for using different techniques, but ways of improving the ability to achieve standardized results and to make comparisons are essential to give a full global view. Secondly, different regions of the world have developed different systems for assessing the overall quality of their local waters. Again, good reasons for such differences almost certainly exist, but knowledge of how to compare the different results would be helpful, particularly in assessing priorities among different areas.[145]

Another area where there are important gaps in knowledge is the extent to which people are suffering from diseases that are either the direct result of inputs of waterborne pathogens or toxic substances, or the indirect result of toxins from algal blooms generated by excessive levels of nutrients. As well as gaps in information on the effects of such health hazards, there are also large gaps in knowledge of their economic effects.

The offshore hydrocarbon industries in some parts of the world collect and publish wide-ranging information on how their activities are affecting the local marine environment. In other parts of the world, little or no such information is found. Because the processes are very similar in most areas, filling the gaps in knowledge in what is happening around the world would be helpful.

The existing offshore mining industries are very diverse and, consequently, their impacts on the marine environment do not have much in common. Where they occur in the coastal zone, it is important that those responsible for integrated coastal zone management have good information on what is happening, particularly in relation to discharges of tailings and other disturbances of the marine environment. As offshore mining expands into deeper waters and areas beyond national jurisdiction, it will be important to ensure that information about their impacts on the marine environment is collected and published.[146]

Information on the disposal of solid waste at sea (dumping) is very patchy. Where reports under the London Convention and the Protocol thereto are not submitted, it is not clear whether dumping does not occur or occurs but is not reported. This represents an important gap in knowledge. The absence of information on dumping, if any, in other jurisdictions also impedes the understanding of the impact on the marine environment of that form of waste disposal.[147]

Our knowledge of marine debris has many gaps. Unless we understand better the sources, fates, and impacts of marine debris, we shall not be able to tackle the problems that it raises. Although the monitoring of marine debris is currently carried out in several countries around the world, the protocols used tend to be very different, preventing comparisons and the harmonization of data. Because marine debris is so mobile, the result is a significant gap in knowledge. There is also a gap in information for evaluating the impacts of marine debris on coastal and marine species, habitats, economic well-being, human health and safety, and social values. Because of their ability to enter into marine food chains, with a potential impact on human health, more

[144] See chap. 17.
[145] See chap. 20.
[146] See chap. 23.
[147] See chap. 24.

information on the origin, fate and effects of plastic microparticles and nanoparticles is highly desirable. Likewise, because of their potential effects on phytoplankton, there is a gap in knowledge about titanium dioxide nanoparticles.[148]

Many aspects of integrated coastal zone management still present important knowledge gaps. Those responsible for managing coastal areas need information on, at least, coastal erosion, land reclamation from the sea, changes in sedimentation as a result of coastal works and changes in river regimes (such as damming rivers or increased water abstraction), the ways in which the local ports are working and dredging is taking place and the ways in which tourist activity is developing (and is planned to develop), and the impacts that those developments and plans are likely to have on the local marine ecosystem (and, for that matter, the local terrestrial ecosystems). It will help the development and effectiveness of integrated coastal management if recognized standards are set and followed for all such information, so that systematic best practices can be developed.[149]

The aesthetic, cultural, religious and spiritual ways in which humans relate to the ocean are also linked to some gaps in our knowledge. Over the centuries, many cultures have built up broad traditional knowledge of the ocean. Such knowledge is often under pressure and will be lost if it is not recorded. For example, Polynesian traditional navigational knowledge was disappearing fast and has been recorded only just in time. Cultural practices (such as traditional Chinese and Iranian boatbuilding) are also disappearing and risk being lost for future generations.[150]

Our knowledge of human interaction with the ocean is also very partial in terms of the ways in which we benefit from it. As has been noted above, it is not yet possible to place a value on the non-marketed ecosystem services derived from the ocean. There are many gaps in the information needed for such an exercise. Information on the effects of changes in the ways in which the planetary ecosystem works needs to be collected and evaluated, in order to permit an economic valuation of the choices for action that may have repercussions on non-marketed ecosystem services. The areas where such information seems particularly closely related to management decisions are integrated coastal zone management (including marine spatial management), offshore hydrocarbon exploitation, offshore mining, shipping routes, port development and waste disposal.[151]

Even with market-related ecosystem services and human activities, there are major information gaps. Such gaps include consistent definitions of what the ecosystem services and human activities cover, how to estimate the value of services and activities that are on the margins of the markets and, even more, the capture of the related data. Gaining a good understanding of the true overall economic situation of such activities as fishing, shipping and tourism would help to improve decision-making in those fields.[152]

Closing those gaps in our knowledge would amount to an ambitious programme of research. Research is already taking place on many more issues on which more information is desirable (for example, on how the genetic resources of the ocean can be used and what the practical possibilities are for seabed mining). Collaboration and sharing will be important for making the best uses of scarce research resources.[153]

VII. Capacity-building gaps

The knowledge gaps identified in the present Assessment all point to gaps in the capacities needed to fill them and to apply the resulting knowledge. On the basis of the

[148] See chaps. 6 and 25.
[149] See chaps. 4, 18 and 27.
[150] See chap. 8.
[151] See chap. 55.
[152] See chaps. 3, 9 and 55.
[153] See chap. 30.

information currently available, it is impossible to say what gaps currently exist in arrangements to build such capacities. Conclusions on where the capacity-building gaps exist could only be reached by conducting a survey, country by country, of the capacity-building arrangements that currently exist and of how suitable they are for each country's needs. The preliminary inventory of capacity-building for assessments[154] compiled by the Division for Ocean Affairs and the Law of the Sea as part of the Regular Process provides some initial information on which to base such a survey, but it would take a much more detailed study than has been possible in the first cycle of the Regular Process to match that information with the needs of each country. The present section therefore looks at the capacities that are desirable, rather than the gaps in capacities for building them.

The outline for the First Global Integrated Marine Assessment requires that capacities be identified to assess the status of the marine environment and to benefit from the various human activities that take place in the marine environment.

Certain capacities are desirable for multiple purposes. The most obvious of that kind of capacity is marine research vessels. Such vessels can provide multipurpose platforms capable of supporting geological and biota surveys, habitat mapping and similar tasks. The present Assessment reviews the current distribution of research vessels around the world. Such vessels may be run by Governments, government institutes, universities, independent research institutes or commercial enterprises. Shared use, for example at a regional level, may be feasible.[155]

Turning from those points to the elements identified as knowledge gaps, the following are the main desirable capacity-building activities.

Physical structure of the ocean

Surveys of the physical structure of the ocean require both sea-going survey capacities and the laboratory and technical staff capabilities to analyse and interpret the resulting data. Both are essential to fill knowledge gaps about the physical structure of the ocean within and beyond national jurisdictions.

Waters of the ocean

Understanding the water column requires capacities to sample, analyse and interpret the ocean in terms of temperature, salinity, stratification, chemical composition and acidity. Much of that can be gathered by autonomous floating devices, such as the floats used by the Array for Real-time Geostrophic Oceanography, which are described in the present Assessment.

Understanding primary production and the implications of sea-level rise requires information on sea levels and chlorophyll a. Such information is most effectively gathered from satellite sensors. Much of it is already available through the Internet, but the equipment and skills needed to access and interpret it are needed to be able to investigate local situations.

Ocean biotas

Better understanding of the ocean biotas demands capacities to organize the regular collection of sampling data on their number, distribution, health and reproductive success, to compile such data into databases (at the national or regional level), to analyse and interpret the data (for instance, taxonomic expertise is required to identify species) and to carry out assessments based on that information. Capacity to carry out marine scientific research is also highly desirable to improve the scientific understanding on which such monitoring is based.

[154] See A/66/189, annex V, and A/67/87, annex V.
[155] See chap. 30.

The capacity to manage fisheries effectively requires ships, equipment and skills to monitor and assess fish stocks. Based on those assessments, capacities are then required to develop, apply and enforce appropriate fishery management policies. Such capacities are likely to include fishery protection vessels to monitor what is happening at sea, access to satellite data to monitor the movements of fishing vessels through transponders, institutional structures to regulate markets in fish and other seafood (including their freedom from contaminants and pathogens) and the necessary enforcement mechanisms at all stages from ocean to table.

Ways in which humans interact with the ocean

Many human activities affecting the oceans are carried out by commercial enterprises. Those can be expected to develop the capacities to generate the knowledge and infrastructure that they need to run their businesses and to comply with relevant regulations. For public authorities, however, capacities will be needed to ensure that they can create appropriate regulations to safeguard social and environmental interests and that they can deal effectively with such commercial enterprises (many of which are international companies). This may be particularly difficult when the public authority concerned is relatively local.

In developing ecosystem-based approaches to the management of human activities affecting the ocean (in parallel to those being developed for fisheries), capacities are necessary to gather and process information relating to the activity and to all the facets of the ocean ecosystems with which the activity in question interacts. The precise information required will vary from activity to activity. Examples of capacities likely to be needed in some specific human activities are those required in order to:

(a) Identify when ship-routing measures are needed to protect the marine environment, specify them and implement such measures;

(b) Plan and implement emergency response plans for maritime disasters. Such plans are likely to require significant capital investment in ships, aircraft, machinery and supplies;

(c) Develop and manage ports capable of handling international maritime traffic. Currently, many such port developments are being carried out and managed by commercial enterprises, in which case the proper regulation of those undertakings will be required;

(d) Ensure adequate port waste-reception facilities to enable ships to discharge their waste without being delayed;

(e) Carry out port State inspections of vessels and follow up any shortcomings detected;

(f) Sample, analyse and interpret land-based inputs to the ocean. Those capabilities need to be able to cover liquid and semi-liquid discharges by pipelines directly into the sea, discharges of liquids and suspended solids to rivers and the water quality of rivers at their mouths, and emissions into the air that may reach and affect the sea. In the case of emissions into the air, it is also desirable to be able to distinguish anthropogenic inputs from natural emissions;

(g) Ensure that new, cleaner technologies are applied to chemical and other production processes, so as to reduce the discharges and emissions of heavy metals and other hazardous substances;

(h) Manage solid waste placed in landfills, so as to prevent the leaching of heavy metals or other hazardous substances that can reach and affect the sea, and manage the incineration of waste to minimize emissions of heavy metals and other hazardous substances in the exhaust gases;

(i) Provide the necessary infrastructure and equipment for the proper handling of land-based industrial discharges, emissions and sewage, so as to minimize the content of heavy metals and other hazardous substances, to remove waterborne pathogens where they could pollute bathing waters and contaminate seafood and to prevent excessive nutrient discharges;

(j) Promote the proper handling of agricultural waste and slurry and the proper use of agricultural fertilizers and pesticides;

(k) Deliver the organization, equipment and skills to monitor and control other human activities that impact on the marine environment;

(l) Manage the coastal zone in an integrated way. Where tourism is significant, those capacities need to include the ability to monitor and regulate tourist developments and activities, so as to keep them within acceptable limits in relation to the carrying capacities of the local ecosystems.

A general gap exists in capacities for an integrated assessment of the marine environment. An integrated assessment needs to bring together: (a) environmental, social and economic aspects; (b) all the relevant sectors of human activities; and (c) all the components (fixed and living) of the relevant ecosystems. The idea of an integrated assessment in that sense is relatively recent. It presents a challenging requirement, which requires specialists in many different fields to work together.

In building capacities for integrated assessments, it is necessary to think further about the concept of an integrated marine assessment. The present assessment is the first global integrated assessment of the marine environment. The Group of Experts who are collectively responsible for it are convinced that the further development and refinement of techniques for making integrated assessments are needed.