

Part II

The Context of the Assessment

Chapter 1. Introduction – Planet, Oceans and Life

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1. Why the ocean matters

Consider how dependent upon the ocean we are. The ocean is vast – it covers seven-tenths of the planet. On average, it is about 4,000 metres deep. It contains 1.3 billion cubic kilometres of water (97 per cent of all water on Earth). But there are now about seven billion people on Earth. So we each have just one-fifth of a cubic kilometre of ocean to provide us with all the services that we get from the ocean. That small, one-fifth of a cubic kilometre share produces half of the oxygen each of us breathes, 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 across the globe the exports and imports that we produce and consume. It contains the oil and gas deposits and minerals on and beneath the seafloor that we increasingly need to use. The submarine cables across the ocean floor carry 90 per cent of the electronic traffic on which our communications rely. Our energy supply will increasingly rely on wind, wave and tide power from the ocean. Large numbers of us take our holidays by the sea. That one-fifth of a cubic kilometre will also suffer from the share of the sewage, garbage, spilled oil and industrial waste which we produce and which is put into the ocean every day. Demands on the ocean continue to rise: by the year 2050 it is estimated that there will be 10 billion people on Earth. So our share (or our children's share) of the ocean will have shrunk to one-eighth of a cubic kilometre. That reduced share will still have to provide each of us with sufficient amounts of oxygen, food and water, while still receiving the pollution and waste for which we are all responsible.

The ocean is also home to a rich diversity of plants and animals of all sizes – from the largest animals on the planet (the blue whales) to plankton that can only be seen with powerful microscopes. We use some of these directly, and many more contribute indirectly to our benefits from the ocean. Even those which have no connection whatever with us humans are part of the biodiversity whose value we have belatedly recognized. However, the relationships are reciprocal. We intentionally exploit many components of this biodiverse richness. Carelessly (for example, through inputs of waste) or unknowingly (for example, through ocean acidification from increased emissions of carbon dioxide), we are altering the circumstances in which these plants and animals live. All this is affecting their ability to thrive and, sometimes, even to survive. These impacts of humanity on the oceans

are part of our legacy and our future. They will shape the future of the ocean and its biodiversity as an integral physical-biological system, and the ability of the ocean to provide the services which we use now and will increasingly need to use in the future. The ocean is vital to each of us and to human well-being overall.

Looking in more detail at the services that the ocean provides, we can break them down into three main categories. First, there are the economic activities in providing goods and services which are often marketed (fisheries, shipping, communications, tourism and recreation, and so on). Secondly, there are the other tangible ecosystem services which are not part of a market, but which are vital to human life. For example, marine plants (mainly tiny floating diatoms) produce about 50 per cent of atmospheric oxygen. Mangroves, salt marshes and sea grasses are also natural carbon sinks. Coastal habitats, including coral reefs, protect homes, communities and businesses from storm surges and wave attack. Thirdly, there are the intangible ecosystem services. We know that the ocean means far more to us than just merely the functional or practical services that it provides. Humans value the ocean in many other ways: for aesthetic, cultural or religious reasons, and for just being there in all its diversity – giving us a “sense of place” (Halpern et al., 2012). Not surprisingly, given the resources that the ocean provides, human settlements have grown up very much near the shore: 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 (Small et al 2004).

All these marine ecosystem services have substantial economic value. While there is much debate about valuation methods (and whether some ecosystem services can be valued) and about exact figures, attempts to estimate the value of marine ecosystem services have found such values to be on the order of trillions of US dollars annually (Costanza, et al., 1997). Nearly three-quarters of this value resides in coastal zones (Martínez, et al., 2007). The point is not so much the monetary figure that can be estimated for non-marketed ecosystem services, but rather the fact that people do not need to pay anything for them – these services are nature’s gift to humanity. But we take these services for granted at our peril, because the cost of replacing them, if it were possible to do so, would be immense and in many cases, incalculable.

There are therefore very many good reasons why we each need to take very good care of our-fifth of a cubic kilometre share of the ocean!

2. Structure of this Assessment

It is this significance of the ocean as a whole, and the relatively fragmented way in which it is studied and in which human activities impacting upon it are managed, that led in 2002 the World Summit on Sustainable Development to recommend (WSSD 2002), and the United Nations General Assembly to agree (UNGA 2002), that there should be a regular process for the global reporting and assessment of the marine environment, including socioeconomic aspects. Under the arrangements

developed for this purpose, this Assessment is the first global integrated assessment of the marine environment (see further in Chapter 2).

Three possible focuses exist for structuring this Assessment: the ecosystem services (market and non-marketed, tangible and intangible) that the marine environment provides; the habitats that exist within the marine environment, and the pressures that human activities exert on the marine environment. All three have advantages and disadvantages.

Using ecosystem services as the basis for structuring the Assessment would follow the approach of the Millennium Ecosystem Assessment (2005). This has the advantage of broad acceptance in environmental reporting. It would cover provisioning services (food, construction materials, renewable energy, coastal protection), while highlighting regulating services and quality-of-life services that are not captured using a pressures or habitats approach to structuring the Assessment. It would have the disadvantage that some important human activities using the ocean (for example, shipping, ports and minerals extraction) would be covered only incidentally.

Using marine habitats as the basis for structuring the Assessment would have the advantage that habitats are the property that inherently integrates many ecosystem features, including species at higher and lower trophic levels, water quality, oceanographic conditions and many types of anthropogenic pressures (AoA, 2009). The cumulative aspect of multiple pressures affecting the same habitat, that is often lost in sector-based environmental reporting (Halpern et al., 2008), is captured by using habitats as reporting units. It would have the disadvantage that consideration of human activities would be fragmented between the many different types of habitats.

Using pressures as the basis for structuring the Assessment would have the advantage that the associated human activities are commonly linked with data collection and reporting structures for regulatory compliance purposes. For instance, permits that are issued for offshore oil and gas development require specific monitoring and reporting obligations to be met by operators. It would have the disadvantage that many important ecosystem services would only be covered in relation to the impacts of the human activities.

Given that all three approaches have their own particular advantages and disadvantages, the United Nations General Assembly endorsed a structure for this Assessment that combined all three approaches, thereby structuring the World Ocean Assessment into seven main Parts, as follows.

Part I. Summary

The Summary is intended to bring out the way in which the assessment has been carried out, the overall assessment of the scale of human impact on the oceans and the overall value of the oceans to humans, and the main threats to the marine environment and human economic and social well-being. As guides for future action it also describes the gaps in capacity-building and in knowledge.

Part II. The context of the Assessment

This chapter is intended as a broad, introductory survey of the role played by the ocean in the life of the planet, the way in which they function, and humans' relationships to them. 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)

Part III looks at the non-marketed ecosystem services provided to the planet by the ocean. It considers, first, the scientific understanding of such ecosystem services and then looks at the earth's hydrological cycle, air/sea interactions, primary production and ocean-based carbonate production. Finally it looks at aesthetic, cultural, religious and spiritual ecosystem services (including some cultural objects which are traded). Where relevant, it draws heavily on the work of Intergovernmental Panel on Climate Change (IPCC) – the aim is to use the work of the IPCC, not to duplicate or challenge it.

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

The aim of Part IV is to look at all aspects of the vital function of the ocean in providing food for humans. It draws substantially on information collected by the Food and Agriculture Organization of the United Nations (FAO). The economic significance of employment in fisheries and aquaculture and the relationship these 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 human activities that can impact on the oceans (other than those relating to food) are covered in Part V of the assessment. Each chapter describes the location and scale of activity, the economic benefits, employment and social role, environmental consequences, links to other activities and capacity-building gaps.

Part VI. Assessment of marine biological diversity and habitats

The aim of Part VI is: (a) to give an overview of marine biological diversity and what is known about it; (b) to review the status and trends of, and threats to, marine ecosystems, species and habitats that have been scientifically identified as threatened, declining or otherwise in need of special attention or protection; (c) to review the significant environmental, economic and/or social aspects in relation to the conservation of marine species and habitats; and (d) to find gaps in capacity to identify marine species and habitats that are viewed 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

Part VII finally looks at the overall impact of humans on the ocean, and the overall benefit of the ocean for humans.

3. The physical structure of the ocean

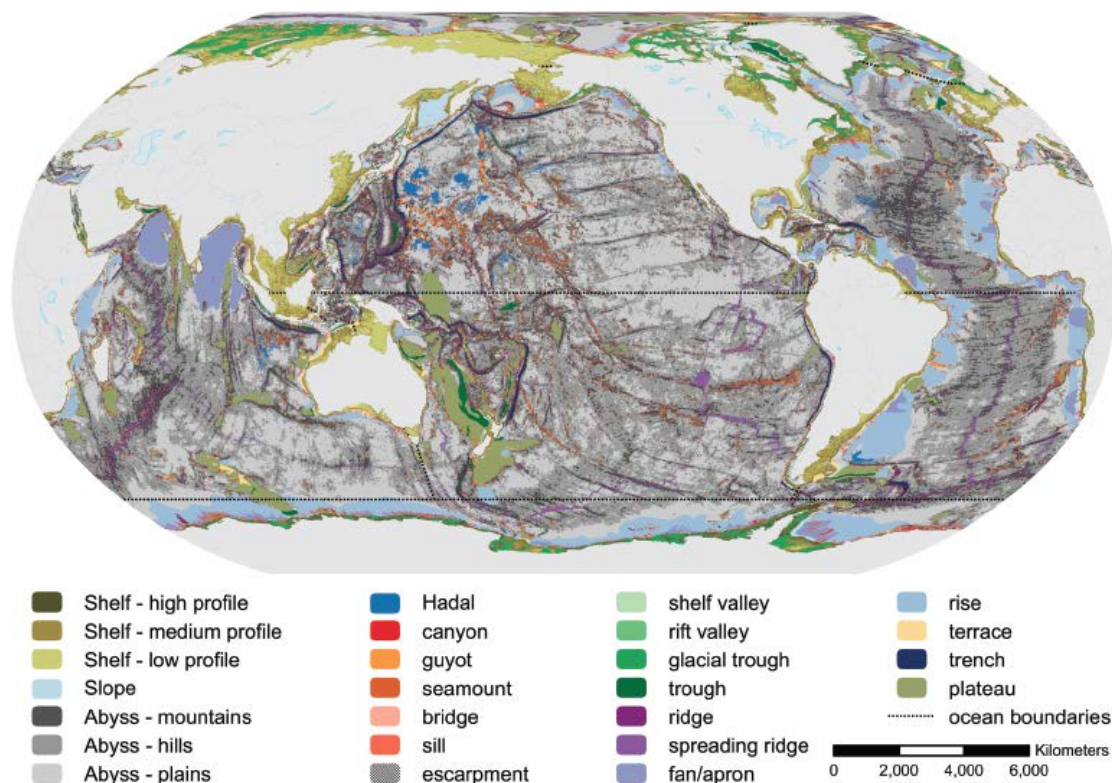
Looking at a globe of the earth one thing that can be easily seen is that, although different names appear in different places for different ocean areas, these areas are all linked together: there is really only one world ocean. The seafloor beneath the ocean has long remained a mystery, but in recent decades our understanding of the ocean floor has improved. The publication of the first comprehensive, global map of seafloor physiography by Bruce Heezen and Marie Tharp in 1977 provided a pseudo-three-dimensional image of the ocean that has influenced a long line of scholars. That image has been refined in recent years by new bathymetric maps (Smith and Sandwell, 1997) which are used to illustrate globes, web sites and the maps on many in-flight TV screens when flying over the ocean.

A new digital, global seafloor geomorphic features map has been built (especially to assist the World Ocean Assessment) using a combination of manual and ArcGIS methods based on the analysis and interpretation of the latest global bathymetry grid (Harris et al., 2014; Figure 1). The new map includes global spatial data layers for 29 categories of geomorphic features, defined by the International Hydrographic Organization and other authoritative sources.

The new map shows the way in which the ocean consists of four main basins (the Arctic Ocean, the Atlantic Ocean, the Indian Ocean and the Pacific Ocean) between the tectonic plates that form the continents. The tectonic plates have differing forms at their edges, giving broad or narrow continental shelves and varying profiles of the continental rises and continental slopes leading from the abyssal plain to the continental shelf. 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) has created submarine canyons, glacial troughs, sills, fans and escarpments. Around the ocean basins there are marginal seas, partially separated by islands, archipelagos or peninsulas, or bounded by submarine ridges. These marginal seas have sometimes been formed in many ways: for example, some result from the interaction between tectonic plates (for example the Mediterranean), others from the sinking of former dry land as a result of isostatic changes from the removal of the weight of the ice cover in the ice ages (for example, the North Sea).

The water of the ocean circulates within these geological structures. This water is not uniform: there are very important physical and chemical variations within the

sea water. Salinity varies according to the relativity between inputs of freshwater and evaporation. Sea areas such as the Baltic Sea and the Black Sea, with large amounts of freshwater coming from rivers and relatively low evaporation have low salinity – 8 parts per thousand and 16 parts per thousand, respectively, as compared with the global average of 35 parts per thousand (HELCOM 2010, Black Sea Commission 2008). The Red Sea, in contrast, with low riverine input and high insolation, and therefore high evaporation, has a mean surface salinity as high as 42.5 parts per thousand (Heilman et al 2009). Seawater can also be stratified into separate layers, with different salinities and different temperatures. Such stratification can lead to variations in both the oxygen content and nutrient content, with critical consequences in both cases for the biota dependent on them. A further variation is in the penetration of light. Sunlight is essential for photosynthesis of inorganic carbon (mainly CO₂) into the organic carbon of plants and mixotrophic species¹. Even clear water reduces the level of light that can penetrate by about 90 per cent for every 75 metres of depth. Below 200 metres depth, there is not enough light for photosynthesis (Widder 2014). The upper 200 metres of the ocean are therefore where most photosynthesis takes place (the euphotic zone). Variations in light level in the water column and on the sea bed are caused by seasonal fluctuation in sunlight, cloud cover, tidal variations in water depth and (most significantly, where it occurs) turbidity in the water, caused, for example, by resuspension of sediment by tides or storms or by coastal erosion. Where turbidity occurs, it can reduce the penetration of light by up to 95 per cent, and thus reduce the level of photosynthesis which can take place (Anthony 2004).



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

¹ That is, plankton species that both photosynthesize and consume other biota.

Figure 1. Geomorphic features map of the world's oceans (after Harris et al., 2014). Dotted black lines mark boundaries between major ocean regions. Basins are not shown.

The new map provides the basis for global estimates of physiographic statistics (area, number, mean size, etc.): for example, it can be estimated that the global ocean covers 362 million square kilometres and the ocean floor contains: 9,951 seamounts covering 8.1 million square kilometres; 9,477 submarine canyons covering 4.4 million square kilometres; and the mid-ocean spreading ridges cover 6.7 million square kilometres with an additional 710,000 square kilometres of rift valleys where hydrothermal vent communities occur (Harris et al., 2014).

There is an important distinction to be made between the terminology used in scientific description of the ocean and the legal terminology used to describe States' rights and obligations in the ocean. Some important terms that will be used throughout this Assessment include the "continental shelf", "open ocean" and "deep sea".

Unless stated otherwise, "continental shelf" in this Assessment refers to the geomorphic continental shelf (as shown in Figure 1) and not to the continental shelf as defined by the United Nations Convention on the Law of the Sea. The geomorphic continental shelf is usually defined in terms of the submarine extension of a continent or island as far as the point where there is a marked discontinuity in the slope and the continental slope begins its fall down to the continental rise or the abyssal plain (Hobbs 2003). In total, continental shelves cover an area of 32 million square kilometres (out of a total ocean area of 362 million square kilometres).

The term "open ocean" in this Assessment refers to the water column of deep-water areas that are beyond (that is, seawards of) the geomorphic continental shelf. It is the pelagic zone that lies in deep water (generally >200 m water depth).

The term "deep sea" in this Assessment refers to the sea floor of deep-water areas that are beyond (that is, seawards of) the geomorphic continental shelf. It is the benthic zone that lies in deep water (generally >200 m water depth).

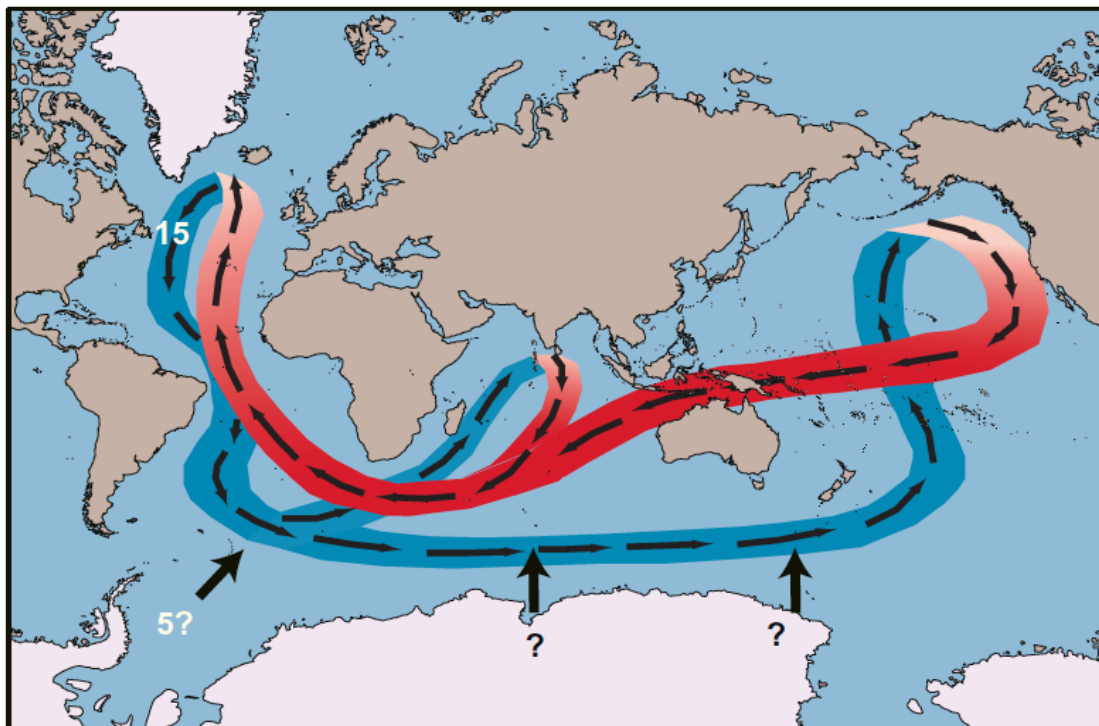
4. Seawater and the ocean/climate interaction

The Earth's ocean and atmosphere are parts of a single, interactive system that controls the global climate. The ocean plays a major role in this control, particularly in the dispersal of heat from the equator towards the poles through ocean currents. The heat transfer through the ocean is possible because of the larger heat-capacity of water compared with that of air: there is more heat stored in the upper 3 metres of the global ocean than in the entire atmosphere of the Earth. Put another way, the oceans hold more than 1,000 times more heat than the atmosphere. Heat transported by the major ocean currents dramatically affects regional climate: for example, Europe would be much colder than it is without the warmth brought by the Gulf Stream current. The great ocean boundary currents transport heat from the equator to the polar seas (and cold from the polar seas towards the equator), along

the margins of the continents. Examples include: the Kuroshio Current in the northwest Pacific, the Humboldt (Peru) Current in the southeast Pacific, the Benguela Current in the southeast Atlantic and the Agulhas Current in the western Indian Ocean. The mightiest ocean current of all is the Circumpolar Current which flows from west to east encircling the continent of Antarctica and transporting more than 100 Sverdrups (100 million cubic meters per second) of ocean water (Rintoul and Sokolov, 2001). As well as the boundary currents, there are five major gyres of rotating currents: two in the Atlantic and two in the Pacific (in each case one north and one south of the equator) and one in the Indian Ocean.

The winds in the atmosphere are the main drivers of these ocean surface currents. The interface between the ocean and the atmosphere and the effect of the winds also allows for the ocean to absorb oxygen and, more importantly, carbon dioxide from the air. Annually, the ocean absorbs 2,300 gigatonnes of carbon dioxide (IPCC, 2005; see Chapter 5).

In addition to this vast surface ocean current system, there is the ocean thermohaline circulation (ocean conveyor) system (Figure 3). Instead of being driven by winds and the temperature difference between the equator and the poles (as are the surface ocean currents), this current system is driven by differences in water density. The most dense ocean water is cold and salty which sinks beneath warm and fresh seawater that stays near the surface. Cold-salty water is produced in sea ice “factories” of the polar seas: when seawater freezes, the salt is rejected (the ice is mostly fresh water), which makes the remaining liquid seawater saltier. This cold saltier water sinks into the deepest ocean basins, bringing oxygen into the deep ocean and thus enabling aerobic life to exist.



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Figure 2. The global ocean “conveyor” thermohaline circulation (Broecker, 1991). Bottom water is formed in the polar seas via sea-ice formation in winter, which rejects cold, salty (dense) water. This sinks to the ocean floor and flows into the Indian and North Pacific Oceans before returning to complete the loop in the North Atlantic. Numbers indicate estimated volumes of bottom water production in “Sverdrups” (1 Sverdrup = 1 million m³/s), which may be reduced by global warming because less sea ice will be formed during winter. Blue indicates cold currents and red indicates warm currents. The black question marks indicate sites long the Antarctic margin where bottom water may be formed but of unknown volumes. The question mark after the “5” indicates that this value is certain.

Wind-driven mixing affects only the surface of the ocean, mainly the upper 200 metres or so, and rarely deeper than about 1,000 metres. Without the ocean’s thermohaline circulation system, the bottom waters of the ocean would soon be depleted of oxygen, and aerobic life there would cease to exist.

Superimposed on all these processes, there is the twice-daily ebb and flow of the tide. This is, of course, most significant in coastal seas. The tidal range varies according to local geography: the largest mean tidal ranges (around 11.7 metres) are found in the Bay of Fundy, on the Atlantic coast of Canada, but ranges only slightly less are also found in the Bristol Channel in the United Kingdom, on the northern coast of France, and on the coasts of Alaska, Argentina and Chile (NOAA 2014).

Global warming is likely to affect many aspects of ocean processes. Changes in sea-surface temperature, sea level and other primary impacts will lead, among other things, to increases in the frequency of major tropical storms (cyclones, hurricanes and typhoons) bigger ocean swell waves and reduced polar ice formation. Each of these consequences has its own consequences, and so on (Harley et al., 2006; Occhipinti-Ambrogi, 2007). For example, reduced sea ice production in the polar seas will mean less bottom water is produced (Broecker, 1997) and hence less oxygen delivered to the deep ocean (Shaffer et al., 2009).

5. The ocean and life

The complex system of the atmosphere and ocean currents is also crucial to the distribution of life in the ocean, since it regulates, among other factors, (as said above) temperature, salinity, oxygen content, absorption of carbon dioxide and the penetration of light and (in addition to these) the distribution of nutrients.

The distribution of nutrients throughout the ocean is the result of the interaction of a number of different processes. Nutrients are introduced to the ocean from the land through riverine discharges, through inputs direct from pipelines and through airborne inputs (see Chapter 20). Within the ocean, these external inputs of nutrients suffer various fates and are cycled. Nutrients that are adsorbed onto the surface of particles are likely to fall into sediments, from where they may either be remobilised by water movement or settle permanently. Nutrients that are taken up by plants and mixotrophic biota for photosynthesis will also eventually sink towards the seabed as the plants or biota die; *en route* or when they reach the seabed, they

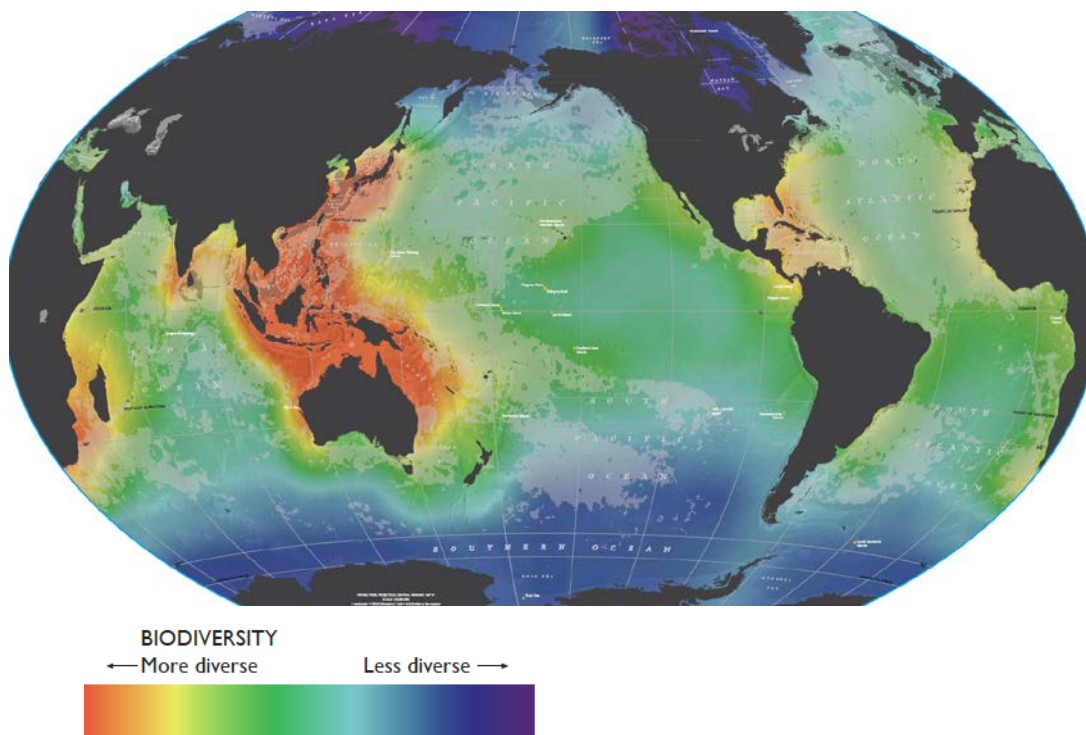
will be broken up by bacteria and the nutrients released. As a result of these processes, the water in lower levels of the ocean is richer in nutrients.

Upwelling of these nutrient-rich waters is caused by the interaction of currents and wind stress. In simple terms, along coasts (especially west-facing coasts with narrow continental shelves), coastal, longshore wind stress results in rapid upwelling; further out to sea, wind-stress produces a slower, but still significant, upwelling (Rykaczewski et al., 2008). Upwelled, nutrient-rich water is brought up to the euphotic zone (see previous section), where most photosynthesis takes place (see Chapter 6). The reality is far more complex, and upwelling is influenced by numerous other factors such as stratification of the water column and the influence of coastal and seafloor geomorphology, such as shelf-incising submarine canyons (Sobarzo et al., 2001). Other important factors are river plumes and whether the upwelling delivers the nutrient that is the local limiting factor for primary productivity (for example, nitrogen or iron; Kudela et al., 2008). Ocean upwelling zones commonly control primary productivity hotspots and their associated, highly productive fisheries, such as the anchoveta fishery off the coast of Peru. The Peruvian upwelling varies from year to year, resulting in significant fluctuations in productivity and fisheries yields. The major factor producing these variations is the El Niño Southern Oscillation, which is the best studied of the recurring variations in large-scale circulation, and its disruptive effects on coastal weather and fisheries are well-known (Barber and Chavez, 1983).

The major ocean currents connect geographic regions and also exert control on ocean life in other ways. Currents form natural boundaries that help define distinct habitats. Such boundaries may isolate different genetic strains of the same species as well as different species. Many marine animals (for example, salmon and squid) have migration patterns that rely upon transport in major ocean current systems, and other species rely on currents to distribute their larvae to new habitats. Populations of ocean species naturally fluctuate from year to year, and ocean currents often play a significant role. The survival of plankton, for example, is affected by where the currents carry them. Food supply varies as changing circulation and upwelling patterns lead to higher or lower nutrient concentrations.

The heterogeneity of the oceans, its water masses, currents, ecological processes, geological history and seafloor morphology, have resulted in great variations in the spatial distribution of life. In short, biodiversity is not uniformly distributed across the oceans: there are local and regional biodiversity “hotspots” (see Chapters 33 and 35). Figure 3 shows a way in which the diversity of species is consequently distributed around the world. Various classification systems have been devised to systematize this variety, including the European Nature Information System (EUNIS) (Davies and Moss, 1999; Connor et al., 2004) and the Global Open Ocean and Deep Sea-habitats (GOODS) classification and its refinements (Agnostini 2008; Rice et al 2011)).

Part VI (Assessment of marine biodiversity and habitats) describes in more detail the diversity that is found across the ocean, and the way in which it is being affected by human activities.



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Figure 3. Distribution of biodiversity in the oceans. Biodiversity data: Tittensor et al., 2010. Human impact data: Halpern et al., 2008, Map: Census of Marine Life, 2010; Ausubel et al., 2010; National Geographic Society, 2010).

6. Human uses of the ocean

Humans depend upon the ocean in many ways and our ocean-based industries have had impacts on ocean ecosystems from local to global spatial scales. In the large majority of ocean ecosystems, humans play a major role in determining crucial features of the way in which the ecosystems are developing.

The impacts of climate change and acidification are pervasive through most ocean ecosystems. These, and related impacts, are discussed in Part III (Assessment of major ecosystem services from the marine environment (other than provisioning services)), together with the non-marketed ecosystem services that we enjoy from the ocean and the ways in which these may be affected by the pervasive impacts of human activities.

For wide swathes of the Earth's population, fish and other sea-derived food is a provisioning ecosystem of the highest importance. Part IV (Assessment of the cross-cutting issues: food security and food safety) examines the extent to which humans rely on the ocean for their food, the ways in which capturing, growing and marketing that food is impacting on ecosystems and the social and economic position of those engaged in these activities and the health risks to everyone who enjoys this food.

The wide range of other human activities is examined in Part V (Assessment of human activities and the marine environment): these activities include the growing importance of worldwide transport in the world economy; the major role of the

seabed in providing oil and gas and other minerals; the non-consumptive uses of the ocean to provide renewable energy; the potential for non-consumptive use of marine genetic resources; the uses of seawater to supplement freshwater resources; and the vital role of the ocean in tourism and recreation. In addition, it is necessary to consider the way in which human activities that produce waste can affect the marine environment as the wastes are discharged, emitted or dumped into the marine environment, and the effects of reclaiming land from the sea and seeking to change the natural processes of erosion and sedimentation. Finally, we need to consider the marine scientific research that is the foundation of all our attempts to understand the ocean and to manage the human activities that affect it.

7. Conclusion

Our planet is seven-tenths ocean. From space, the blue of the ocean is the predominant colour. This Assessment is an attempt to produce a 360° review of where the ocean stands, what the range of natural variability underlies its future development and what are the pressures (and their drivers) that are likely to influence that development. As the description of the task set out in Chapter 2 (Mandate, information sources and method of work) shows, the Assessment does not attempt to make recommendations or analyse the success (or otherwise) of current policies. Its task is to provide a factual basis for the relevant authorities in reaching their decisions. The aim is that a comprehensive, consistent Assessment will provide a better basis for those decisions.

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