Chapter 9. Conclusions on Major Ecosystem Services Other than Provisioning Services

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1. Introduction

The ecosystem services assessed in Part III are large-scale; some of them are planetary in nature and provide human benefits through the normal functioning of the natural systems in the ocean, without human intervention. This makes them intrinsically difficult to value. However, some of these same ecosystem services in turn sustain provisioning services that generate human benefits through the active intervention of humans. This is the case, for example, for the global ecosystem service provided by primary production by marine plants, which by synthesizing organic matter from CO_2 and water, provide the base of nearly all food chains in the ocean (except the chemosynthetic ones), and provide the food for animal consumers that in turn sustain important provisioning ecosystem services from which humans benefit, such as fisheries.

The services in Part III are not the only ones provided by the ocean. Many other ecosystem services are directly or indirectly referred to in Parts IV to VI of this Assessment. The provisioning ecosystem services related to food security are addressed in Part IV, *Assessment of Cross-Cutting Issues: Food Security And Food Safety* (Chapters 10 through 16); those related to coastal protection are referred to in Part VI, *Assessment of Marine Biological Diversity and Habitats*, in *Warm Water Corals* (Chapter 43), *Mangroves* (Chapter 48), and in *Aquaculture* (Chapter 12), *Estuaries and Deltas* (Chapter 44), *Kelp Forests and Seagrass Meadows* (Chapter 47) and *Salt Marshes* (Chapter 49); the maintenance of special habitats are addressed in Chapters on *Open Ocean Deep-sea Biomass* (Chapter 36F); *Cold Water Corals* (Chapter 42) and *Warm Water Corals* (Chapter 43), *Hydrothermal Vents and Cold Seeps* (Chapter 45), *High-Latitude Ice* (46) and *Seamounts and Other Submarine Geological Features Potentially Threatened by Disturbance* (Chapter 51); the sequestration of carbon in coastal sediments, the so-called blue carbon, is addressed in Chapters on *Mangroves* (Chapter 48), *Estuaries and Deltas* (Chapter 44) and *Salt Marshes* (Chapter 49); the cycling of nutrients is covered in *Estuaries and Deltas* (Chapter 44) and *Salt Marshes* (Chapter 49, but also Chapter 6).

Because of the very large scale of the services analysed in Part III, although they are influenced by human activities, they cannot be easily managed, and in certain cases they cannot be managed at all. The uptake of atmospheric CO_2 (Chapter 5) and the role of the ocean in the hydrological cycle (Chapter 4) are two examples of regulatory ecosystem services that cannot be managed or valued easily.

2. Accounting for the human benefits obtained from nature

Ecosystems can exist without humans in them, but humans cannot survive without ecosystems. Throughout history, humanity has made use of nature for food, shelter, protection and engaging in cultural activities. The intensity of humanity's use of nature has changed with the evolution of society and reached high levels with the introduction of modern technologies and industrial systems. Today, at a planetary scale, including the deepest ocean, no natural or pristine systems are found without people or unaffected by the impact of human activities; nor do social systems exist that can thrive without the support of nature. Social and ecological systems are truly interdependent and constantly co-evolving.

This fundamental connection between humans and nature has received different levels of recognition with regard to how we deal with the benefits humans extract from nature in economic terms. Extractive activities, e.g., of minerals, or of living natural resources, such as fibre, timber and fish, raise the issues of irreplaceability and sustainability. The use of nature is multifaceted and, as a norm, a given ecosystem can provide many goods and several services at the same time. For example, a mangrove ecosystem provides wood fibre, fuel, and nursery habitat for numerous species (provisioning services); it detoxifies and sequesters pollutants coming from upstream sources, stores carbon, traps sediment, and thus protects downstream coral reefs, and buffers shores from tsunamis and storms (regulating services); it provides beautiful places to fish or snorkel (cultural services); and it recycles nutrients and fixes carbon (supporting services; Lubchenco and Petes, 2010). When humans convert a natural ecosystem to another use, some ecosystem services may be lost and others services gained. Such a process gives rise to trade-offs between natural services and between these and services not derived from natural capital. For example, when mangroves are converted to shrimp ponds, airports, shopping malls, agricultural lands, or residential areas, new services are obtained: food production, space for commerce, transportation, and housing, but the original natural services are lost (Lubchenco and Petes, 2010).

Therefore, human benefits can be derived from a series of different activities that simultaneously affect the same ecosystem, but that are not necessarily connected with their harvesting or production processes. Sustainability requires that users take only a fraction of the resources, preserving in this way the natural capability of the ecosystem to regenerate the same resources, making them available for use by future generations. The appropriate spatial scale and the time sufficient to recover are part of the sustainability requirement. To extract anchovies (*Engraulis spp.)* or sardines (*Sardinops spp.*) that can regenerate their populations in three to eight years has different implications than to extract orange roughy (*Hoplostethus atlanticus*) from the top of seamounts that needs 100 to 150 years or more to recover.

3. The evolution of management tools

The increase in *"the magnitude of human pressures on the natural system has caused a transition from single-species or single-sector management to multi-sector, ecosystem-based management across multiple geographic and temporal dimensions. (…) Intensification of use of ecosystems increases interactions between sectors and production systems that in turn increase the number of mutual negative impacts (i.e., externalities)"* (Chapter 3).

Because all these processes take place in an integrated socio-ecological system, we have seen an expansion of scope in the decision-making process, incorporating the simultaneous consideration of several uses or industries at the same time and the livelihoods and other social aspects connected with this ensemble of activities. These approaches enable the consideration of tradeoffs among different uses and beneficiaries, enlarging the range of policy options. Only recently have regulatory instruments for better accounting for the indirect and cumulative impacts on natural systems of these multiple uses been incorporated into the management and regulation of human activities. Mobilized by a series of high-level World Conferences addressing these issues, in Stockholm 1972, Rio de Janeiro 1992, Johannesburg 2002, and Rio de Janeiro 2012, the international community has acted to advance and implement this enlarged scope of decision-making across all societies.

Assigning value to the human benefits obtained from nature is more easily done when the goods and services obtained are traded, thereby becoming part of commerce. Prices in different markets are readily available and comparisons are possible. It is not that simple, however, for certain types of benefits, for example, when subsistence livelihoods that do not enter into trade are concerned, or other intangible cultural, recreational, religious or spiritual benefits are involved.

However, the extraction of natural products and other human benefits from wild ecosystems can affect other processes inside the ecosystems that provide valuable permanent services to humanity that are not part of commerce. Examples include the production of organic matter and oxygen through primary production in the ocean, the protection of the coast by mangrove forests, the re-mineralization of decaying organic matter at the coastal fringes, and the absorption of heat and CO_2 by the ocean that has delayed the impacts of global warming. Furthermore, fluctuations in the provision of these natural services can have significant impacts on those natural products that are in commerce.

Climate patterns drive the magnitude and variability of the circulation and heat storage capacity of the surface layers of the ocean, as described in Chapters 4 and 5. The displacement of warm and cold water pools on the surface of the ocean feeds into the dynamics of the atmosphere, generating enormous transient fluctuations in weather patterns, such as the El Niño and La Niña cycles, that cascade down affecting the production of a series of goods and services, not only in the ocean, but most notably also on land. For example, El Niño adversely affects the availability and price of fishmeal and fish oil, also key components of the diet of carnivorous species in aquaculture (see Chapter 12).

4. Scientific understanding of ecosystem services

The fundamental connection between humans and nature has received uneven levels of recognition in how we deal in economic terms with the benefits humans extract from nature.

Humans derive many benefits from all aspects of the natural world. Some of these benefits are provided by nature without human intervention and some require human inputs, often with substantial labour and economic investment. The features and functions of nature which provide these services can be regarded as “natural capital”, and the way in which this natural capital is organized and how it functions in delivering benefits to humans, has led to these types of benefits being described as “ecosystem services”. The Millennium Ecosystem Assessment characterizes ecosystem services as: provisioning services (e.g., food, pharmaceutical compounds, building material); regulating services (e.g., climate regulation, moderation of extreme events, waste treatment, erosion protection, maintaining populations of species); supporting services (e.g., nutrient cycling, primary production); and cultural services (e.g., spiritual experience, recreation, information for cognitive development, aesthetics).

The rent for land or the royalties on mineral extraction are examples of long-established approaches adopted to account for uses of nature. They are based on a one-to-one relationship between one activity or industry and one natural source of the goods or services. The effect of other industries on the same ecosystem is not considered; neither are the impacts on other members of the social system affected by these industries.

To comprehensively account for human benefits and costs, “natural capital” needs to be considered alongside the assets that humans have themselves developed, whether in the form of individual skills (“human capital”), the social structures they have created (“social capital”) or the physical assets that they have developed (“built capital”). Managing the scale of the human efforts in using natural capital is crucial. The ecosystem-services approach allows decision-making to be integrated across land, sea and the atmosphere and enables an understanding of the potential and nature of trade-offs among services given different management actions.

The increasing magnitude of human pressures on the natural system has caused a transition from an emphasis on single-species or single-sector management to multi-sector, ecosystem-based management and hence to the explicit incorporation of human actions in socio-ecological systems management.

A number of variants of the ecosystem-services approach exist. Some emphasize the functional aspects of ecosystems from which people derive benefits. Others put more emphasis on their utilitarian aspects and seek to apply mainstream economic accounting methods, assigning them monetary values obtained in the market or using non-market methodologies. Yet others emphasize human well-being and ethical values. Looking at ecosystem services requires consideration of a wide range of scales, from the completely global (for example, the role of the oceans in distributing heat around the world; Chapter 5) to the very local (for example, the protection offered by coral reefs to low-lying islands; Chapter 42).

Most studies conducted on marine and coastal ecosystem services have been focused locally and, in general, have not taken into account benefits generated further afield. An ecosystem-services approach can help with decision-making under conditions of uncertainty, and can bring to light important synergies and trade-offs between different uses of the ocean. However, attempting to assess the relationship between the operation of ecosystem services and the interests of humans requires a much broader management approach and an understanding that many aspects of the ocean have non-linear behaviour and responses. One difficulty is that to date no generally agreed classification of goods and services derived from natural capital exists that could facilitate the task. Another obstacle is that the range of factors involved at all levels might require the consideration of their interaction at the relevant scale, making their treatment very complex.

Some ecosystem services are more visible and easily understood than others. There is a risk that the less visible an ecosystem service is, the less it will be taken into account in decision-making. There is also a risk that ecosystem services that can be valued in monetary terms will be understood more easily than others, thus distorting decisions. Likewise, the time scales over which some ecosystem services will be affected by decisions will be much longer than others, which an approach with traditionally used discount rates would completely dismiss.

4.1 Information gaps

Describing and mapping the full range of ecosystem services at different scales requires much data on the underlying functions and structure of the way in which ecosystems operate. Although much work has been done, mostly on terrestrial ecosystems, this assessment draws attention in its various chapters to the gaps in the information needed to understand the way in which individual ecosystem services operate in the ocean and along the coasts. In addition to these specific gaps, a more general, overarching gap exists in understanding how all the individual ecosystem services fit together.

4.2 Capacity-building gaps

Many skills have yet to be developed that should integrate an understanding of the operation of ecosystems: knowledge is currently too fragmented between different specialisms.

Even in cases where the appropriate skills exist, some parts of the world lack institutions with the status, resources and commitment to make the necessary inputs into decision-making that will affect a range of ecosystem services from the oceans.

The many institutions that already exist to study the ocean also require new or enhanced abilities and connections, but can be expected to work together. Some international networks already exist to facilitate this. More are needed.

5. The ocean's role in the hydrological cycle

Water is essential for life and the existence of water in a liquid state on the surface of the earth is probably a critical reason why life is found on this planet and not on others. The presence of water on the surface of the earth is the combined result of the cosmic and geological history of the planet during its 4.5 billion years of existence. These processes, at human time-scales of thousands of years, can be considered as quasi-stable.

The ocean dominates the hydrological cycle. The great majority of the water on the surface of the planet, 97 per cent, is stored in the ocean. Only 2.5 per cent of the global balance of water is fresh water, of which approximately 69 per cent is permanent ice or snow and 30 per cent is ground water. The remainder 1 per cent is available in soil, lakes, rivers, swamps, etc. (Trenberth et al., 2007).

Water evaporates from the planet's surface, is transported through the atmosphere and falls as rain or snow. Rain is the largest source of fresh water entering the ocean (~530,000 km^3 yr^{-1}). At the ocean-atmosphere interface, 85 per cent of surface evaporation and 77 per cent of surface rainfall occur (Trenberth et al., 2007; Schanze et al., 2010). The residence time of all water in the atmosphere is only seven days. It is fair to say that *"all atmospheric water is on a short-term loan from the ocean"*.

However, as with many other cycles, the water cycle is a dynamic system in a quasi steady-state condition. This steady-state condition can be altered if the factors controlling the cycle change. The great glaciations, or ice ages, are processes in which, due to interplanetary and planetary changes, huge amounts of water pass from the liquid to the solid state, altering the availability of liquid water on the surface of the earth and dramatically changing the sea level. As a consequence of the change in sea level, the shape of world coastlines and the amount of emerged (or submerged) land is drastically changed.

Changes are occurring today at an unprecedentedly fast but still uncertain rate. A warmer ocean expands and, being contained by rigid basins, the only surface that can move is the free surface in contact with the atmosphere, raising sea level.

In addition, the melting of ice due to a warmer atmosphere and a warmer ocean is increasing the volume of the ocean and in the long run will dominate the amount of total change in sea level.

As the ocean warms, evaporation will increase, and global precipitation patterns will change. The IPCC assess (AR 3, 2001; AR 4, 2007; and AR 5, 2013 and 2014) that the dynamic system of water on earth, driven by global warming, is changing sea level at a mean rate of 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010, increased to 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010 and, due to the changes in climate, will also change the patterns of rain on land.

Warming affects the polar ice caps, and changes in their melting affect the salinity of the ocean. This in turn can affect the ocean circulation, especially the thermohaline vertical circulation, also known as the "conveyor belt" (Chapter 5) and the operation of associated ecosystem services.

Due to the concentration of human population and built infrastructure in the coastal zone, sea level rise will seriously affect the way in which humans operate. The effects of sea-level rise will vary widely between regions and areas, with some of the regions most affected least able to manage a response.

Changes in water run-off will affect both land and sea. Salinity in the different parts of the ocean has changed over time, but is now changing more rapidly. Gradients in salinity are becoming more marked. Because the distribution of marine biota is affected by the salinity of the water that they inhabit, changes in the distribution of salinity are likely to result in changes in distribution of the biota.

Changes in run-off from land are affecting the input of nutrients to the ocean. These changes will also affect marine ecosystems, due to increases in the acidity of the ocean.

The warming of the ocean is not uniform. It is modulated by oscillations such as El Niño. These oscillations cause significant transient changes to the climate and ecosystems, both on land and at sea, and have serious economic effects. The variations in ocean warming will affect the interaction with the atmosphere and affect the intensity and distribution of tropical storms.

5.1 Information gaps

The sheer scale of the changes that are happening to the ocean makes present knowledge inadequate to understand all the implications. There are gaps in understanding sea-level rise, and interior temperature, salinity, nutrient and carbon distributions. Many of these gaps are being addressed as part of the world climate change agenda, but more detail about ocean conditions is needed for regional and local management decisions. The information gaps are particularly serious in some of the areas most seriously affected (e.g., the inter-tropical band).

5.2 Capacity-building gaps

Parts of the water cycle are still subject to uncertainties due to insufficient *in situ* measurements and observations. This is particularly true for surface water fluxes at the regional meso-scale. Because changes in the ocean's role on the hydrological cycle will be pervasive, all parts of the world need to have access to, and the ability to interpret, these changes. People and institutions with the necessary skills exist in many countries, but in many others they lack the status and resources to make the necessary input to decision-making.

6. Sea-Air Interaction

Most of the heat excess due to increases in atmospheric greenhouse gases is absorbed by the ocean. All ocean basins have warmed during recent decades, but the increase in heat content is not uniform; the increase in heat content in the

Atlantic during the last four decades exceeds that of the Pacific and Indian Oceans combined.

'Recent' warming (since the 1950s) is strongly evident in sea surface temperatures at all latitudes in all part of the ocean. Prominent structures that change over time and space, including the El Nino Southern Oscillation (ENSO), decadal variability patterns in the Pacific Ocean, and a hemispheric asymmetry in the Atlantic Ocean, have been highlighted as contributors to the regional differences in surface warming rates, which in turn affect atmospheric circulation.

The effects of these large-scale climate oscillations are often felt around the world, leading to the rearrangement of wind and precipitation patterns, which in turn substantially affect regional weather, sometimes with devastating consequences.

Compared with estimates for the global ocean, coastal waters are warming faster: during the last three decades, approximately 70 per cent of the world's coastline has experienced significant increases in sea surface temperature. Such coastal warming can have many serious consequences for the ecological system, including species relocation.

These changes are also affecting the salinity of the ocean: saline surface waters in the evaporation-dominated mid-latitudes have become more saline, while relatively fresh surface waters in rainfall-dominated tropical and polar regions have become fresher.

Approximately 83 per cent of global CO_2 increase is currently generated from the burning of fossil fuels and industrial activity. Forests and grasslands that usually absorb CO_2 from the atmosphere are being removed, causing even more CO_2 to be absorbed by the ocean. The ocean thus serves as an important sink of atmospheric CO_2, effectively slowing down global climate change. However, this benefit comes with a steep bio-ecological cost. When CO_2 reacts with water, it forms carbonic acid, leading to the ocean becoming more acid – referred to as "ocean acidification". Through various routes, this imposes an additional energy cost to calcifier organisms, such as corals and shell-bearing plankton, although this is by no means the sole impact of ocean acidification (OA).

OA is not a simple phenomenon nor will it have a simple unidirectional effect on organisms. Calcification is an internal process that in the vast majority of cases does not depend directly on seawater carbonate content, since most organism use bicarbonate, which is increasing under acidification scenarios, or CO_2 originating in their internal metabolism. It has been demonstrated in the laboratory and in the field that some calcifiers can compensate and thrive in acidification conditions.

Without significant intervention to reduce CO_2 emissions, by the end of this century, average surface ocean pH is expected to be below 7.8, an unprecedented level in recent geological history. These changes will be recorded first at the ocean's surface, where the highest biodiversity and productivity occur.

The abundance and composition of species may be changed, due to OA, with the potential to affect ecosystem function at all trophic levels. Consequential changes in ocean chemistry could occur as well. Economic studies have shown that potential losses at local and regional scales may be catastrophic for communities and national economies that depend on fisheries.

6.1 *Information Gaps*

Regular monitoring of relevant fluxes across the ocean-atmosphere interface needs to be maintained, including the regular assessment of the accumulation of heat and CO_2 (changes in alkalinity) in the surface layers of the ocean. The state of knowledge regarding OA is only currently moving beyond the nascent stage. Therefore several major information gaps are yet to be filled. Neither all areas of the globe nor all potentially affected animal and plant groups have yet been covered in terms of research. The full range of response and adaptation of organisms, although an active field of research, is very seldom known.

Additional information is required around the effects of mean changes in OA versus changes in variability and extremes; as well as multi-generational effects and adaptive potential of different organisms (Riebesell and Gattuso, 2015; Sunday et al., 2014). The tolerance level by individual organisms to changes in pH must be understood in situ rather than exclusively in laboratory conditions, along with the possible consequential changes in competition by organisms for resources. The effects of potential loss of keystone species within ecosystems are not yet clear, neither are the chemical changes due to pH.

The future agenda of research in OA should include integrating knowledge on multiple stressors, competitive and trophic interactions, and adaptation through evolution and moving from single-species to community assessments (Sunday et al., 2014). Future economic impacts of OA are being studied but much more needs to be done. Monitoring and management strategies for maintaining the marine economy will also be needed. In this regard, it has been suggested that future OA research could focus on species related to ecosystem services in anticipation that these case studies might be most useful for modellers and managers (Sunday et al. 2014).

6.2 *Capacity-Building Gaps*

OA was put in evidence only through long-term observational programmes coordinated by the international research community. To monitor OA on a regular basis, these international efforts need to be continued and institutionally consolidated. OA adaptation is a demanding field of research that requires significant infrastructure (i.e. mesocosm experimental facilities) and highly qualified human resources. These are not readily available in all regions of the world. Further understanding of the scope of adaptation capabilities to OA by plants and animals, the application of mitigation strategies, or the successful management of productive systems cultivating organisms with calcareous exo-skeletons that are regularly exposed to corrosive waters sources, require the existence of these capabilities in place.

7. Primary Production, Cycling of Nutrients, Surface Layer and Plankton

“Marine primary production” is the photosynthesis of plant life in the ocean to produce organic matter, using the energy from sunlight, and carbon dioxide and nutrients dissolved in seawater. Carbon dioxide dissolved in seawater is drawn from the atmosphere. Oxygen is produced as a by-product of photosynthesis both on land and in the ocean. Of the total annual oxygen production from photosynthesis on land and ocean, approximately half originates in marine plants. The plants involved in this process range from the microscopic phytoplankton to giant seaweeds. On land, the other 50 per cent of the world’s oxygen originates in the photosynthesis from all plants and forests. Present-day animals and bacteria rely on present-day oxygen production by plants on land and in the ocean as a critical ecosystem service that keeps atmospheric oxygen from otherwise declining.

Marine primary production, as the primary source of organic matter in the ocean, is the basis of nearly all life in the oceans, playing an important role in the global cycling of carbon. Phytoplankton absorbs about 50 billion tons of carbon a year, and large seaweeds and other marine plants (macrophytes) about 3 billion tons. At a planetary level, this ecological function plays an important role in removing CO_2 – one of the significant greenhouse gases – from the atmosphere. Total annual anthropogenic emissions of CO_2 are estimated at 49.5 billion tons, one-third of which is taken up by the ocean. This ecological service provided by the ocean has so far prevented warming of the planet above 2^{o} C.

Marine primary production also plays a major role in the cycling of nitrogen around the world. A moderate level of uncertainty exists about the extent to which the ocean is currently a net absorber or releaser of nitrogen.

Anthropogenic nutrient loading in coastal waters, ocean warming, ocean acidification, and sea-level rise are driving changes in the phenology (see below) and spatial pattern of phytoplankton and in net primary production as well as in nutrient cycles. These changes are threatening the provision of several ecosystem services at different scales (local, regional).

Changes in macrophyte net primary production and their impacts (losses of habitat and of carbon sinks) are also well documented.

Changes in net primary production by phytoplankton or in the nutrient cycles in the upper levels of the world ocean have been the subject of recent debate. Some analyses suggested a diminishing trend in world primary production (Boyce et al., 2010). However, this result was challenged by Rykaczewski and Dunne (2011) and finally reviewed by the original authors (Boyce, et al., 2014). After recalibration of the datasets, despite an overall decline of chlorophyll concentration over 62 per cent of the global ocean with sufficient observations, they describe a more balanced picture between regional increases and decreases of primary production, without an overall globally pervasive negative trend. The wider consequences of this long-term trend are presently unresolved.

The efficient use of primary production to support animals at higher levels in the food web depends on a good relationship between the timing of bursts of primary production and breeding periods of zooplankton and planktivorous fish. The phenology of species, i.e., the timing of events in the life cycle of species, plays a significant role here. Changes in the phenology of plankton species and planktivorous fish due to ocean warming is starting to produce significant mismatches and could produce many more, affecting the local level of production in the ocean.

Warming of the upper ocean and associated increases in vertical stratification may lead to a major decrease in the proportion of primary production going to zooplankton and planktivorous fish, and an increase in the proportion of phytoplankton being broken down by microbes without first entering the higher levels of the food web. Such a trend would reduce the carrying capacity of the oceans for fisheries and the capacity of the oceans to mitigate the impacts of anthropogenic climate change.

Coastal eutrophication (see Chapter 20) is likely to lead to an increase in the numbers and area of dead zones and toxic phytoplankton blooms. Both can have serious effects on the supply to humans of food from the sea.

Nanoparticles (microscopic fragments of plastic and other anthropogenic substances) pose a potential serious threat to plankton and the vast numbers of marine biota which depend on them.

Increases in nitrogen inputs to the ocean and in sea temperatures may have serious impacts on the type (species, size) and amount of marine primary production, although much debate still occurs about the scale of this phenomenon. Different responses are likely to be found in different regions. This may be particularly significant in the Southern Ocean, where a major drop in primary production has been forecast.

7.1 Information gaps

Completing a worldwide observing system for the biology and water quality of the ocean that could provide cost-effectively improved information to future assessments under the Regular Process is seen as an important gap. Routine and sustained measurements across all parts of the ocean are needed on planktonic species diversity, chlorophyll *a*, dissolved nitrogen and dissolved biologically active phosphorus. Due to their ability to enter into marine food chains, with a potential impact on both marine organism and human health, plastic microparticles need to be systematically monitored.

Without this additional information, it will not be possible to understand or predict the changes that will occur due to the accumulated and combined effect of several drivers. Some information can be derived from satellite remote sensing, but *in situ* observations at the surface and especially at sub-surface levels are irreplaceable, given the fact that the ocean is essentially opaque to electromagnetic radiation, the medium *par excellence* of remote sensing.

7.2 Capacity-building gaps

The gathering of such information requires a worldwide network for data collection. Both a Global Ocean Observing System (GOOS) and a Global Biodiversity Observation Network (GEO BON) are currently being developed to collect biological and ecologically relevant information that, if completed, would fill in some of the information gaps described above. The capacities to participate in these systems need to be extended worldwide. It is also important to develop the skills to explain to decision-makers and the general public the importance of plankton and its significance for the ecosystem services provided by the ocean.

8. Ocean-sourced carbonate production

Many marine organisms secrete calcium carbonate to produce a hard skeleton. These vary in size from the microscopic plankton, through corals, to large mollusc shells. Carbonate production by corals is particularly important, because the reefs that they form are fundamental to the existence of many islands and some entire States.

Sand beaches are also often formed by the fragmented shells of marine biota. Beaches are dynamic structures, under constant change from the effects of the oceans; hence a constant supply of new sand of this kind is needed to sustain them.

Sea-level rise will particularly affect beaches, causing them to move inland. In the case of small islands, this may diminish the already limited inhabitable area. Such changes may also be affected by the availability of new supplies of sand. Such changes could be very serious for States or parts of States comprised of atolls.

The impact of climate change on the rate of biogenic production of carbonate sediment is also little understood, but it seems likely to have negative consequences. Ocean warming has already led to the death (bleaching) of some coral reefs or parts of them.

The acidification of the ocean may lead to significant changes in the biogenic production of calcium carbonate, with implications for the future of coral reefs and shell beaches.

8.1 Knowledge gaps

Long-term data are lacking on the formation and fate of reef islands and shell beaches. Information is particularly lacking on the links between the physical structures and the environmental circumstances that may affect changes in these structures.

8.2 Capacity-building gaps

A gap often exists in the capacities of people living on atolls and in countries depending heavily on tourism from shell beaches to understand the drivers that shape the development of these structures. Without such capacities it is impossible to bring the factors affecting the future of these structures into the making of decisions which can fundamentally affect them.

9. Aesthetic, cultural, religious and spiritual ecosystem services derived from the marine environment

The development of human culture over the centuries has been influenced by the ocean, through transport of cultural aspects across the seas, the acquisition of cultural objects from the sea, the development of culture to manage human activities at sea, and the interaction of cultural activities with the sea.

The ocean has been and continues to be the source of prized materials for cultural use, for example: pearls, mother-of-pearl, coral, and tortoise-shell. Some marine foodstuffs are also ingredients in culturally significant dishes. The high value given to many of these culturally significant objects can lead to their over-exploitation and the long-term damage of the ecosystems that supply them. The sea is an important element in many sites of cultural significance. Forty-six marine and coastal sites are included in the UNESCO World Heritage List.

Even where sites do not reach this high threshold of cultural significance, great aesthetic and economic importance may be attached to preserving the seascape and coastal views. This concern should also be extended to the tangible cultural heritage of past human interaction with the sea and of past human activities in periods of low sea levels. This can be particularly significant in making decisions about the location of new offshore installations.

The intangible cultural heritage of human interaction with the sea is also important. Ten per cent of the items on the UNESCO List of Intangible Cultural Heritage in Need of Urgent Safeguarding involve the ocean. Important cultural areas are derived from the need of humans to operate on the ocean, leading to skills such as navigation, hydrography, naval architecture, chronometry and many other techniques.

The need is increasingly being recognised to understand the knowledge systems developed by many indigenous peoples to understand and manage their interactions with the marine environment.

9.1 Knowledge gaps

In the current fast-changing world, it is important to record much traditional knowledge before it is lost.

9.2 Capacity-building gaps

For cultural goods derived from the sea, a gap exists in many parts of the world for the skills needed to identify and implement potential opportunities to turn local marine objects to good account. Means to support traditional cultural practices so that they endure for future generations need to be provided, and anthropological skills to record and interpret them are also important.

10. The ecosystem services concept and the United Nations and other systems of environmental-economic accounting

As can be seen from the foregoing, there is a general need to bring together information about ecosystem services, in a way which allows judgments to be made about trade-offs. In 1992, the United Nations Conference on Environment and Development (UNCED) called for the implementation of integrated environmental-economic accounting in countries, to complement national accounts by accounting for environmental losses and gains. As a consequence, the United Nations Statistics Division (in charge of maintaining the framework as well as the world standards for the System of National Accounts) led the development of the System of Environmental-Economic Accounting (SEEA) under the auspices of the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA). The SEEA Central Framework was adopted as an international standard by the United Nations Statistical Commission at its 43rd Session in 2012 and the SEEA Experimental Ecosystem Accounting was endorsed by the same commission at its 44th session in 2013 (http://unstats.un.org/unsd/envaccounting/seea.asp). Both the SEEA Central Framework and SEEA Experimental Ecosystem Accounting use the accounting concepts, structures and principles of the System of National Accounts (SNA).

The SSEA provides a way of organizing information in both “physical terms” and “monetary terms” using consistent definitions, concepts and classifications. Physical measures and valuation of ecosystem services and ecosystem assets are discussed in the SEEA Experimental Ecosystem Accounting. Those ecosystem services and ecosystem assets are not typically traded on markets, as explained in Chapter 3, and are difficult to measure because observed prices cannot be used to measure these assets and services as in standard economic accounting (Statistics Division of the United Nations, 2012). Although concepts and methods are still experimental, many United Nations Member States have engaged in ambitious programmes to apply these new concepts (Figure 1).

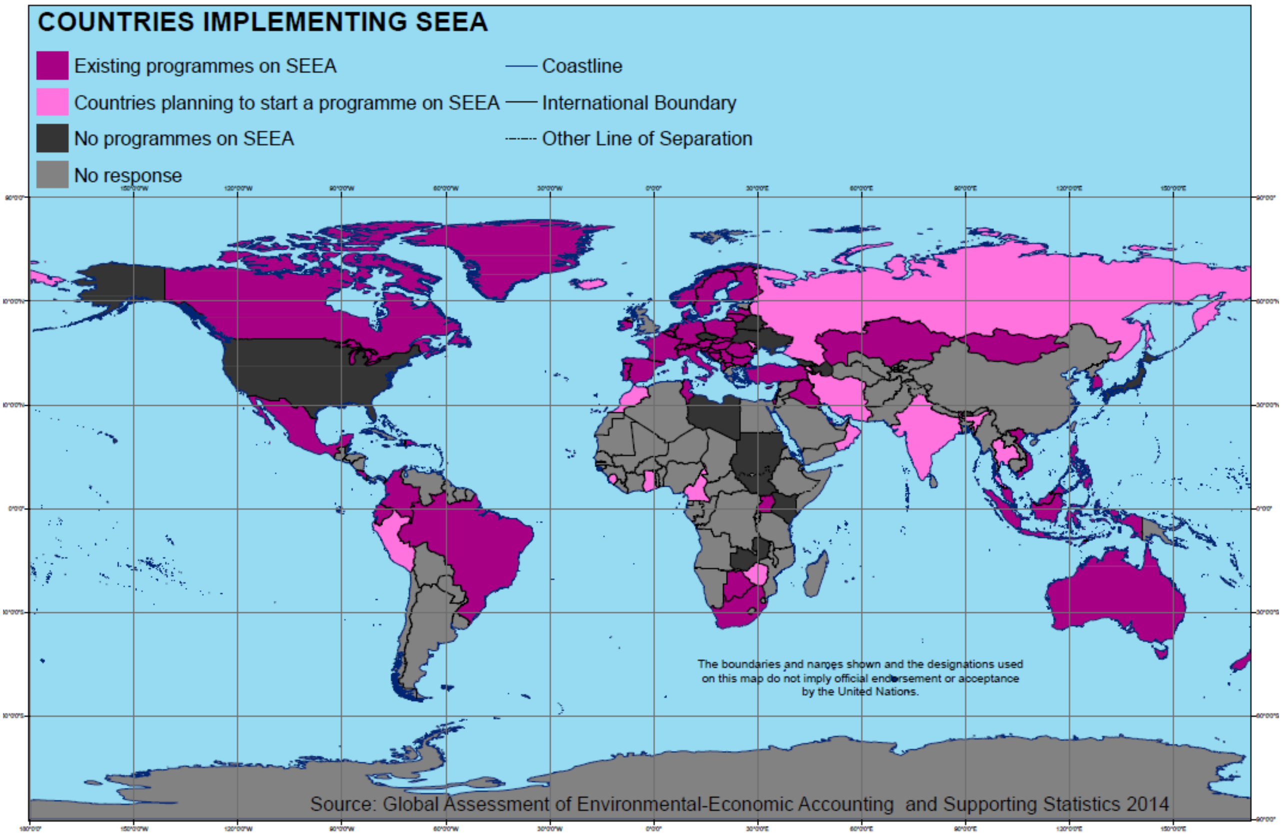

Figure 1. Countries of the world implementing natural capital accounting programmes. The map is provided by the United Nations Statistics Division.

Simplified ecosystem capital accounts are currently being implemented in Europe by the European Environment Agency, in cooperation with Eurostat, as one of the responses to recurrent policy demands in Europe for accounting for ecosystems and biodiversity (The Economics of Ecosystems and Biodiversity:TEEB). The European Union has developed the MAES programme, for Mapping and Assessment of Ecological Services in the 27 countries of the European Union (http://www.eea.europa.eu/publications/an-experimental-framework-for-ecosystem).

The United Kingdom Government has recently completed a national ecosystem assessment (UK National Ecosystem Assessment, 2011) and, building on this report, has made a commitment to include the value of natural capital and ecosystems fully into the United Kingdom environmental accounts by 2020.

11. Conclusions

Long-established approaches adopted to account for uses of nature, like rent or royalties, are based on a one-to-one relationship between one activity or industry and one natural source of the goods or services. The effect of other industries on the same natural source is not considered; neither are the impacts on other members of the social system affected by these industries.

Traditionally these invisible benefits and costs are mostly hidden in the “natural system”, and usually are not accounted for at all in economic terms. The emergence and evolution of the concept of ecosystem services is an explicit attempt to better capture and reflect these hidden or unaccounted benefits and costs, expanding the scope of policy options already available in integrated management approaches through the consideration of the trade-offs among different uses and beneficiaries.

The ecosystem services approach has proven to be very useful in the management of multi-sector processes and is informing today many management and regulatory processes around the world, especially on land. However, the methodologies and different approaches to assess and measure ecosystem services, or to assign them value, as presented in Chapter 3, are far from benefiting from a common set of standards and a consensual framework for their application. Furthermore, as stated in Chapter 3, *“On land, negative impacts can be partially managed or contained in space. However, in the ocean, due to its fluid nature, impacts may broadcast far from their site of origin and are more difficult to contain and manage. For example, there is only one Ocean when considering its role in climate change through the ecosystem service of “gas regulation”.*

In Chapters 4 to 8, the ecosystems services analyzed are provided on different spatial and temporal scales. Most of those ecosystems are described only on large to very large scales, many of them, indeed, at the planetary scale. In contrast, much of the work on valuing ecosystem services in the ocean has focused on smaller systems, for example, on assessing and valuing the services provided by marine parks, marine reserves and marine protected areas, in order to enable local judgments (including such elements as making local planning decisions or establishing fees to charge to visitors). Despite a significant amount of work on ecosystem-services valuation for the ocean and coasts, as reported in Chapter 3, evidence of its broader application in decision-making at the larger scales is still very limited.

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