The High Seas and Us

Understanding the Value of High-Seas Ecosystems

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Contents

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Executive Summary

The industrialisation and overuse of the high seas jeopardises the natural wealth of their ecosystems and the services they provide to people. Fishing and shipping continue to inflict harm on high-seas ecosystems. Mining for minerals and new sources of fossil fuels will likely increase the industrial use of the high seas and will further damage their ecosystems. At the same time, the governance of the high seas is fragmented, with different international institutions focusing on specific industrial activities, places, or even different parts of the ecosystems. For instance, weak fisheries governance in the high seas has led to ad hoc regulation that varies from place to place. The result has been widespread overfishing.

There is growing evidence that the ecosystem services provided by the high seas are of high social and economic value. The evidence also is clear that poor management of human activities on the high seas has eroded the natural wealth and productivity of high-seas ecosystems with negative economic and social consequences for all of us.

We examine 15 important ecosystem services provided by the high seas. These fall into the categories of provisioning services (seafood; raw materials; genetic resources; medicinal resources; ornamental resources), regulating services (air purification; climate regulation; waste treatment; biological control) habitat services (lifecycle maintenance; gene pool protection) and cultural services (recreation and leisure; aesthetic information; information for culture, art, design and for cognitive development). The quantity and quality of ecosystem services depend directly on both the living (e.g. animals, algae, microorganisms) and non-living (e.g. the shape and structure of the seabed) components of the marine ecosystems of the high seas.

To understand the potential value of high-seas ecosystem services, we describe and quantify, when possible, the provision and general nature of values provided by these 15 types of ecosystem services. We put these values in the context of the costs of improved governance and management of human activities in the high seas with a particular focus on improved marine protection.

Few ecosystem services in the high seas can be accurately valued given currently available information. We lack scientific information about the provision and use of most high-seas ecosystem services and their quantity and nature, and even lack knowledge regarding how and where, precisely, they are produced. The high seas support economically important species that may swim, migrate or drift well beyond the physical boundaries of the high seas. This makes it difficult to disentangle the contribution of high-seas ecosystems to the services that are produced in the high seas but are enjoyed elsewhere – sometimes thousands of kilometres away. Many high-seas ecosystem services are not enjoyed directly in all contexts. Instead, in some contexts, many play an intermediate role in the creation of ecosystem services elsewhere (e.g. high-seas ecosystems support prey that are consumed by commercially important fish species which are harvested elsewhere). Clearly, there is the need for more and better science on the provision and value of high-seas ecosystem services.

We provide estimates of the economic value of two important high-seas ecosystem services: carbon storage and fisheries. Carbon is stored by high-seas ecosystems as part of naturally occurring processes in which marine organisms convert sunlight and carbon dioxide into energy and biological production. We estimate that high-seas ecosystems are responsible for nearly half of the biological productivity of the global ocean. While the science of carbon sequestration in the high seas is still evolving, we estimate that nearly half a billion tonnes of carbon, the equivalent of over 1.5 billion tonnes of carbon dioxide, are captured and stored by high-seas ecosystems annually. Based on current estimates of the economic cost of additional carbon in the atmosphere (i.e. the social cost of carbon), we find that the value of carbon storage by high-seas ecosystems ranges between US$74 billion and US$222 billion annually.

In terms of fish stocks, we find that nearly 10 million tonnes of fish are caught annually on the high seas, and that this catch volume translates into more than US$16 billion in gross landed value per year. Furthermore, we estimate that the majority of global ocean fish harvests are of species captured both in exclusive economic zones (EEZs) and in the high seas (54 million tonnes or 68% of global fish harvests). We consequently conclude that overfishing on the high seas is likely to negatively impact fish catches within the EEZs of coastal States and vice versa.

There is overwhelming, albeit incomplete, evidence that the economic value of high-seas ecosystems and their associated services are of great importance to humankind. High-seas ecosystems, however, are degraded and threatened by future impacts as industrial uses of the high seas expand. Improved governance, ecosystem-based management and natural resource accounting can help to slow and even reverse the decline in the value of high-seas ecosystems caused by poor management and overuse. Better management and governance, however, are hampered by a lack of scientific, economic and social data that provide a clear understanding of how human activities affect high-seas ecosystems and how ecosystem changes, in turn, affect human economic wellbeing.

The crew of the Coast Guard *Cutter Rush* escorts the suspected high seas drift net fishing vessel *Da Cheng* in the North Pacific Ocean on 14 August 2012. © U.S. Coast Guard

Why Value the High Seas?

The global ocean represents the single largest ecosystem on Earth comprising 1.3 billion km^3 of water. It comprises more than 90% of the habitable space for life on the planet (Angel, 1993) and yet it is the most poorly understood of all the Earth's ecosystems. For example, an estimated 91% of marine species are still to be discovered (Mora *et al.*, 2011).

The enormity of the global ocean and the central role it plays in supporting life on Earth came sharply into focus more than 40 years ago when the Apollo missions produced the first images of the 'Blue Earth' from space. People have lived near the ocean for millennia and maritime people have recognised that the ocean is important for humankind. The ocean yields non-living resources including oil and gas, minerals, sand and gravel, and even drinking water in places where sources of fresh water prove scarce. Ocean currents, tides and waves are now being harnessed to produce energy. The ocean has long served as the principle medium for trade and migration. It was, of course, the value of living ocean resources that first drew people to the sea. Ocean fisheries and aquaculture provide food for billions of people and livelihoods for millions. Seaweed is gathered around the world for food and fertiliser. Mangroves provide shoreline protection and firewood. The benefits we derive from these healthy, functioning ecosystems are known as ecosystem services.

Increasingly, industrial uses of the ocean and over-use of living resources threaten the ecological health of the ocean ecosystems and the benefits they produce. There is irrefutable evidence that both the physical and biological parts of the ocean play key roles in atmospheric and thermal regulation, the water and nutrient cycles, and thus in the maintenance of conditions for life on Earth. These 'regulating services' are poorly understood and rarely factor into decisions about how to manage human activities that affect ocean health.

Most people experience the ocean from shore, rarely seeing or understanding what lives below the surface and beyond the breaking waves. As a result, the ocean-ecosystem goods and services that most people know are those from coastal waters, including fisheries, tourism and coastal protection from habitats such as mangrove forests and coral reefs. These coastal ecosystems are important and they are also under severe pressure from human activities. Most of the ocean, however, and thus most ocean ecosystems (by volume and size), exist beyond the continental shelf. Much of this area is officially considered the 'high seas' (i.e. the area beyond the exclusive economic zones [EEZs] of all nations). The high seas comprise more than 60% of the ocean by surface area and more than 70% by volume (Figure 1).

From the surface, the high seas' ecosystems appear to vary little over large distances. The remoteness and

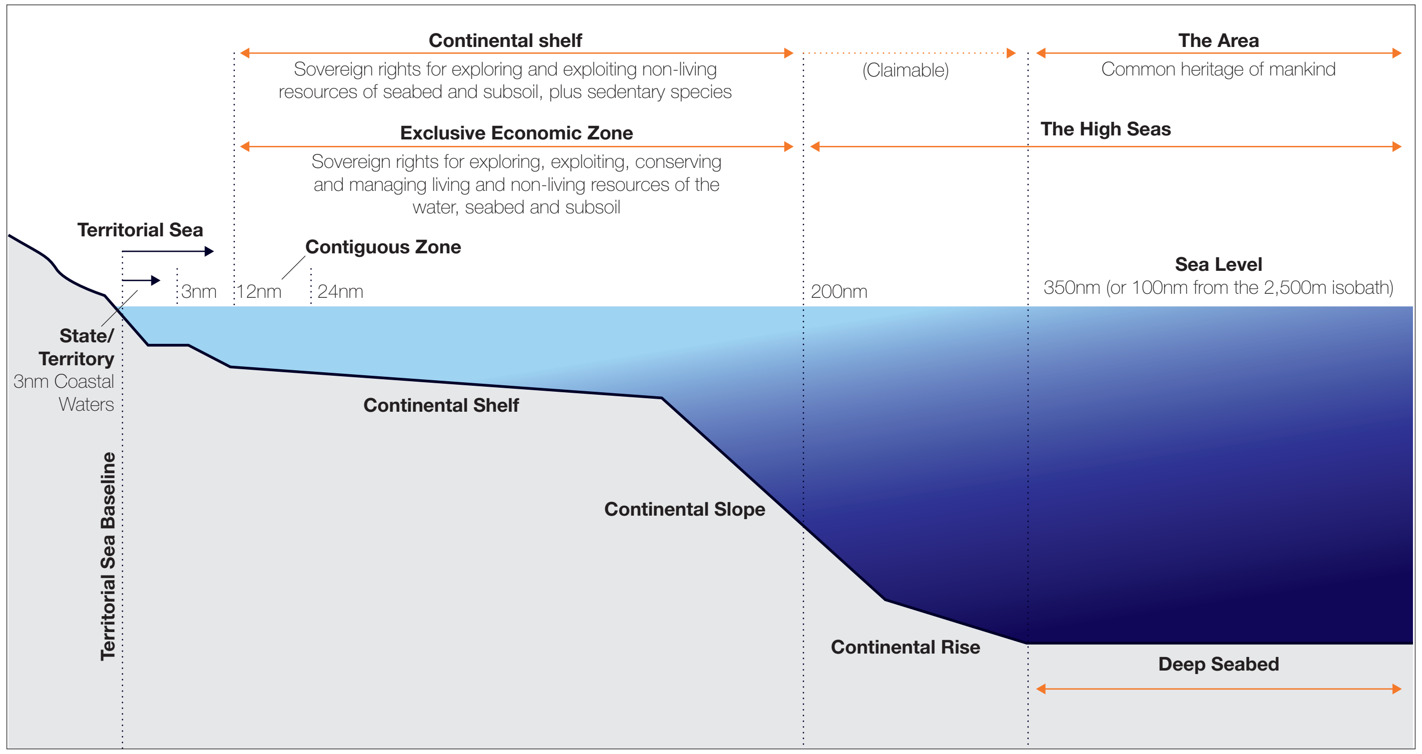


Figure 1. Diagram of maritime zones (based on figure from the Global Carbon Capture and Storage Institute[1])

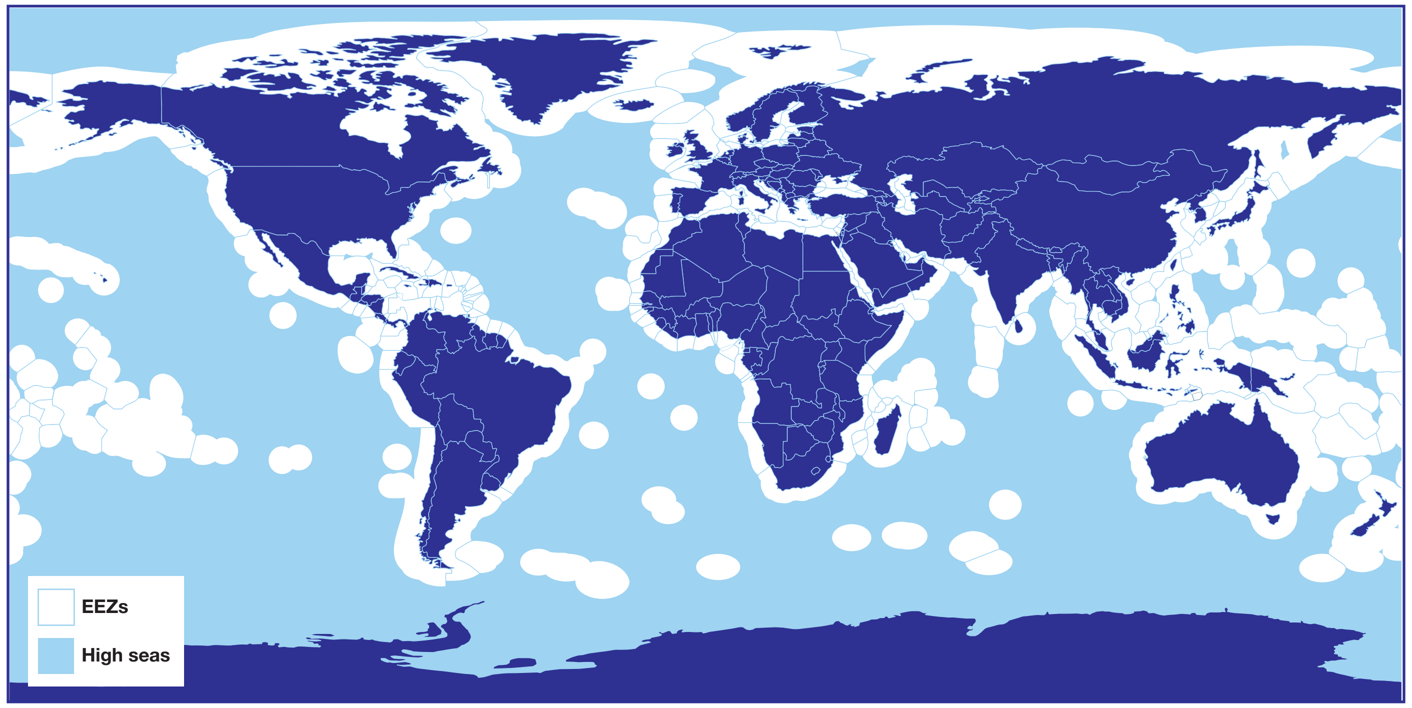


Figure 2. Global map showing the extent of EEZs and the high seas (Sumaila *et al*. In prep.)

vastness of the high seas, combined with a general ignorance of natural life there, has left the high seas and their deep waters unappreciated and poorly governed. Nevertheless, a growing body of research demonstrates that the high seas provide critical ecosystem services to humankind. Yet, despite this importance, there have been no credible attempts to characterise and quantify the economic contribution of high-seas ecosystems. Without such quantification, it is difficult to know how to protect the value of high-seas ecosystems or how to weigh the trade-offs between further industrialisation of the deep sea and the loss of ecosystem value. More specifically, in the absence of such quantification and valuation, the design processes for high-seas governance will lack information on a potentially wide range of economic benefits, which could be compared with the real financial and political costs of improving the management the high seas. Consequently, it is important to start building the evidence base necessary to inform the design of improved high-seas governance.

Is International Governance of the High Seas Protecting their Value?

For millennia, the high seas were ungoverned. Even today, States enjoy great freedom of navigation, overflight, the laying of submarine cables and pipelines, the construction of artificial islands or installations, fishing, and the conduct of scientific research in the high seas. These freedoms, collectively, embody a principle of 'Freedom of the Seas' or '*Mare Liberum*', a concept initially outlined by Hugo Grotius in the 17th Century. Some of these freedoms are now qualified and, for all practical purposes, are under some form of regulation. The seabed and the resources beneath it, for example, are now explicitly governed for the purposes of exploitation of mineral resources. Under the United Nations Convention on the Law of the Sea, this 'Area' is regulated by the UN International Seabed Authority (ISA) as the "common heritage of mankind".

Other human activities are governed, regulated and/or managed by a variety of international bodies. Regional Fisheries Management Organisations (RFMOs) provide a forum for States to cooperate on all matters related to management of fisheries within a geographic area (reporting of catches, scientific data, setting catch limits and fishing rules). The UN Food and Agricultural Organization (FAO) gathers fisheries statistics globally, acts as a forum for all RFMOs, and also plays a role in international efforts to resolve systemic difficulties in fisheries management.

The International Maritime Organization (IMO)[2] is charged with promoting the safety and security of, as well as the prevention of pollution (including greenhouse gas emissions) from, shipping. The IMO also administers important conventions including the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL).

Regional Seas Conventions, such as the Oslo-Paris Convention (OSPAR) in the northeast Atlantic, encourage international cooperation in the protection of the marine environment. OSPAR and similar bodies, tend to work with industrial sectors that are exploiting or having an impact on marine ecosystems.

At the global level, there are international conventions that govern or direct human activities on the high seas. The Convention on Biological Diversity (CBD) is one such convention that was developed to conserve biological diversity, and to ensure its sustainable use and the fair and equitable sharing of benefits arising from the discovery of genetic resources. The Convention also applies to the ocean and has contributed to the setting of global targets for their protection (e.g. the CBD's Aichi Biodiversity Target 11 to protect 10% of coastal and marine ecosystems through protected areas and other effective area-based conservation measures).

Given the complicated and growing international framework for governance and management of activities in the high seas, one might believe that human activities on the high seas are managed sustainably and that ocean ecosystems are healthy. Trends in global fish catches and other evidence of degradation of marine ecosystems, however, suggest that this is not the case. The latest report by FAO on the state of the world's fisheries finds that overexploitation of global fish stocks has increased and is more critical for stocks found on the high seas (FAO, 2012). An analysis of 48 fish stocks managed by RFMOs found that 32 are thought to be overfished or depleted (67%; Cullis-Suzuki & Pauly, 2010). A recent example of the seriousness of the situation is that of the Pacific jack mackerel fishery. While international negotiations were taking place to establish a new RFMO (the South Pacific Regional Fisheries Management Organisation [SPRFMO]), stocks of this species fell from an estimated 30 million to 3 million tonnes (SPRFMO, 2011). Catches declined from a peak of 5 million tonnes per year in the 1990s to 2 million tonnes in the mid-2000s, and by 2010 had fallen to 0.7 million tonnes (FAO, 2012).

Where good governance on the high seas does exist, it has focused on sectors for which improved regulation was likely to a) yield substantial economic benefits to that sector (e.g. shipping or mineral exploitation) or b) result in a reduction in the collateral economic and environmental damages caused by these sectors (e.g. shipping accidents involving catastrophic release of oil or chemicals and subsequent claims for compensation). Overall, better environmental management of the high seas has been hampered by a chronic under-valuation of the economic benefits that will arise from healthier high-seas ecosystems. This under-valuation stems from two factors: (1) together, the high-seas ecosystems are almost inconceivably large and remote, making monitoring, control and surveillance of activities difficult and potentially expensive; and (2) we lack concrete understanding of the economic value that people derive from high-seas ecosystems.

High-Seas Ecosystem Services

Ecosystem services (sometimes called ecosystem goods and services) are the direct and indirect contributions that ecosystems make to human wellbeing (Böhnke-Henrichs *et al.*, 2013; de Groot *et al.*, 2010)[3]. Ecosystem services are nature's products and services – the outputs of healthy, functioning ecosystems and their associated living organisms. Along with essential physical factors and processes, these ecosystems comprise the Earth's natural capital. Research over the last three decades has begun to reveal just how much benefit people derive from healthy ecosystems.

It is now widely acknowledged that formal consideration of Earth's natural capital is increasingly important for the design of sound policies. A number of related and complementary approaches can facilitate such a consideration of natural capital in policy-making, including natural capital accounting, ecosystem-based approaches, and ecosystem service assessments. The information produced by these approaches is useful for decision-making across many levels in society, including government, corporations, and individual citizens. In the context of ecosystem service assessments, in order to best inform policy decisions, such assessments require sound knowledge of the natural and social science that describe how ecosystems work and how services are produced. Ecosystem service assessments also require reliable estimates of the market and non-market value of these services, and an understanding of how human activities (and the pressures exerted by these activities) affect the provision and value of ecosystem services (for better or worse).

The high seas generate a wide variety of services, many of which are dependent on the state of the ecosystem, that have the potential to provide a range of benefits to people. The benefits provided by these ecosystem services can be valued by information gleaned directly from markets or through methods that help determine how these goods and services affect human wellbeing in other ways (Philcox, 2007). While more than 900 studies are known which estimate values for marine ecosystem services[4], there are few that provide good estimates of the value of high-seas ecosystem services (e.g. Sumaila *et al.*, 2011).
For the ocean in general, and the high seas and deep

sea in particular, we have a poor understanding of how ecosystems work, how they produce ecosystem services, and even how people use and value these services (TEEB, 2012). To further complicate matters, both the industrial uses and ecosystem service benefits of the ocean are changing rapidly. Ships are getting bigger and faster and plying new routes. Deep-sea mining may open a new era of high-seas industrialisation. Ecotourism to high seas areas is in its infancy and bioprospecting promises to uncover new marine genetic resources. Consequently, there is a need to initiate, and then continue to develop, the analysis of high-seas ecosystems and the services they provide to humanity.

Fifteen Important Types of Ecosystem Services Supported by the High Seas

The relationship between ecosystem condition, the production of ecosystem services, and the benefits people receive from these services is complicated (Figure 3). There are many kinds of ecosystem services that arise from high-seas areas. Some ecosystem services are exclusive – for instance, the value one places on a tuna in the net is exclusive of the value one places on a wild, free swimming tuna that may, in turn, provide other benefits to society.

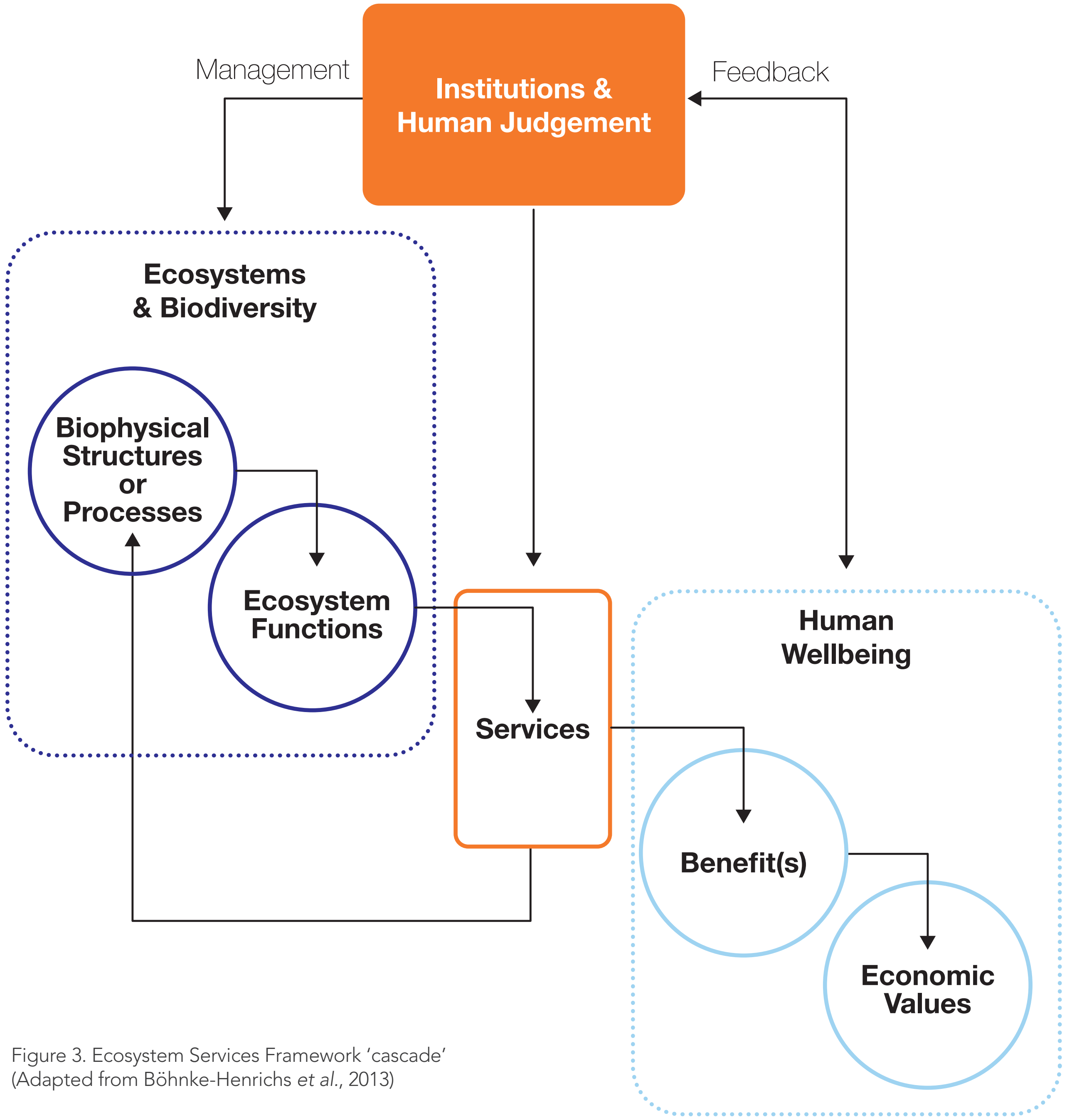


Figure 3. Ecosystem Services Framework 'cascade' (Adapted from Böhnke-Henrichs *et al.*, 2013)

To keep track of the many high-seas ecosystem services, we identified and defined 15 types of marine ecosystem services (Table 1). This list builds on the framework of categories of marine ecosystem services most recently refined by Böhnke-Henrichs *et al.* (2013)[5]. Our list differs from previous lists in that we (1) do not include marine ecosystem services that are exclusively coastal and (2) reword the original definitions so they focus on the high seas.

The well-defined shortlist of high-seas ecosystem services also helps us keep track of how changes in governance, policy or management may affect ecosystems, ecosystem services, and ultimately people. The 15 categories provide a basis for analysing and interpreting existing scientific literature on high-seas ecosystems, and for estimating values associated with the benefits provided by these services. Following Böhnke-Henrichs *et al.* (2013) and TEEB (de Groot *et al.*, 2010), we organised these high-seas ecosystem services into broad categories: provisioning; regulating; habitat; cultural.

Ecosystem Service (ES) Category	Definition
Provisioning services	
1. Sea Food (see Case Study on High-Seas Fisheries)	All available marine fauna and flora extracted from the high seas for the specific purpose of human consumption as food
2. Raw Materials	The extraction of any biologically mediated material from the high seas, excluding material covered by ES 5
3. Genetic Resources	Any material that is extracted from the high seas for use in non-marine, non-medicinal contexts, excluding the research value associated with ES 15
4. Medicinal Resources	Any material that is extracted from the high seas for its ability to provide medicinal benefits, excluding the research value associated ES 15
5. Ornamental Resources	Any material extracted from the high seas for use in decoration, etc.
Regulating Services	**Definition**
6. Air Purification	The removal from the air of natural and anthropogenic pollutants by the high seas
7. Climate Regulation (see Case Study on Carbon Sequestration)	The contribution of the biotic elements of the high seas to the maintenance of a favourable climate via its production and sequestration of climate-influencing substances
8. Waste Treatment	The bioremediation by the high seas of anthropogenic pollutants
9. Biological Control	The contribution of the high seas to the maintenance of natural, healthy population dynamics that support ecosystem resilience by maintaining food webs
Habitat Services	**Definition**
10. Lifecycle Maintenance	The contribution of the high seas to migratory species' populations through the provision of essential habitat for reproduction and juvenile maturation
11. Gene Pool Protection	The contribution of the high seas to the maintenance of viable gene pools through natural selection/evolutionary processes
Cultural Services	**Definition**
12. Recreation and Leisure	The provision of opportunities for recreation and leisure that depend on the state of the high seas
13. Aesthetic Information	The contribution that the high seas make to the existence of a surface or subsurface landscape. This includes informal Spiritual Experiences but excludes that which is covered by ES 12, 14, and 15
14. Inspiration for Culture, Art and Design	The contribution that the high seas make to the existence of environmental features that inspire elements of culture, art, and/or design. This excludes that which is covered by ES 5, 12, 13, and 15
15. Information for Cognitive Development	The contribution of the high seas to education, research, and learning. This includes contributions of the high seas to the research into ES 3, ES 4

Table 1. Summary of high-seas ecosystem services

Economically Valuing High-Seas Ecosystem Services

In this section, we provide an overview of the basic economic nature of the 15 high-seas ecosystem services defined above. To date, few attempts have been made to estimate the economic value of high-seas ecosystem services. This is for a variety of reasons but they may be summarised as:

- A lack of scientific information on the routes and pathways through which an ecosystem service is delivered and the overall level of provision of the ecosystem service;
- data are available on the overall benefits derived from an ecosystem service but are insufficiently detailed to be disaggregated into high seas and EEZ/coastal portions;
- the high-seas ecosystems may play a role in the production of an ecosystem service that is enjoyed elsewhere (e.g. high-seas ecosystems support fisheries or ecotourism within EEZs) and therefore has not been accounted for;
- as well as providing a benefit, the ecosystem service or activity in question may also harm the environment and therefore may have a negative impact on the provision of other ecosystem services. An example of this is carbon capture by the high seas, which also results in ocean acidification, which damages marine life.

In the context of this study, we only have sufficient data to conduct a preliminary valuation of two key high-seas ecosystem services: fisheries and biological carbon sequestration. We develop these valuations in more detail at the end of this section.

Provisioning Services

The high seas yield ecosystem services that are directly harvested from the sea. **Seafood harvest** may be the best known of the high-seas provisioning services. Annually, nearly 10 million tonnes of fish are caught in the high seas with a landed value of approximately US$16 billion. This figure represents the gross returns from fishing and does not account for the cost of fishing. Neither does it account for additional value added through processing and marketing prior to purchase and consumption or other uses. **Living and ecosystem-dependent raw materials** are also directly harvested from high-seas areas. Between 1970 and the present day, hundreds of novel chemical compounds, from a wide variety of marine species, have been identified and utilised in a range of sectors. Currently, it is impossible to know how many of these compounds are found in the high seas. In the past, types of *Sargassum*, a seaweed, were harvested for use in food and cosmetics. *Sargassum* could potentially be harvested from high-seas areas. High-seas ecosystems support a myriad of organisms that contain untold **genetic resources**. Patents reveal a rapidly increasing interest in the application of marine genes in non-medicinal contexts. Recent research also indicates that marine organisms are twice as likely as terrestrial species to have at least one gene patented. The groups of marine organisms (e.g. bacteria, seaweed, fish, etc.) from which patented genetic sequences originate are noticeably different from those in which marine medicinal compounds are found. There are a number of examples of the discovery of medicinal resources from marine ecosystems, including the first HIV treatment, anti-cancer treatments, and anti-herpes treatments. The high seas are also likely to yield similar medicinal discoveries. Because of the time lag between discovery and product development, decisions made with respect to investments in the development of marine-derived medicinal resources will be reflected in the products released 10 to 20 years in the future. Finally, the high seas may yield **ornamental resources**. The precious-coral industry actively extracts corals from the high seas, especially in the Pacific. There are also shark-based ornamental resources and trophy fish that are supported by the high-seas ecosystems. For all ornamentals, it is hard to disentangle the extent to which harvesting occurs in the high seas rather than in territorial waters.

Regulating Services

High-seas ecosystems also serve to **regulate** how natural processes work. The role of the oceans in the regulation of the global carbon cycle is well known. In the case study at the end of this section, we explore the value that life in the high seas provides by **capturing and storing carbon** (also known as carbon sequestration) that would otherwise enter the atmosphere and contribute to global warming. Ecosystems in the high seas are responsible for nearly half the oceans' photosynthetic primary production and thus a significant portion of biologically mediated carbon capture and storage. High-seas ecosystems may also play a role in air purification, for example, absorbing mercury released into the atmosphere as a result of industrial activities such as burning coal. Biological processes and organisms in the high seas also have the capacity to treat certain types of waste, although the ecological processes that may provide **waste treatment** are poorly understood. Finally, the resilience of healthy high-seas ecosystems provides a biological control mechanism that helps moderate the potential booms and busts in high-seas marine organisms that may result as negative consequences of human activities (e.g. introduction of invasive species, overfishing or climate change effects).

Habitat Services

The high seas are the ecological hub of marine ecosystems worldwide. As a result, high-seas ecosystems provide habitat that is essential to the health of millions of species – a service referred to as **lifecycle maintenance**. Examples include the habitat that the Sargasso Sea provides for breeding eels and as a nursery for marine turtles. As scientific knowledge on ecological connectivity improves, it is likely that knowledge regarding the provision of this service will also improve. High-seas ecosystems also contribute to the overall resilience of marine species by supporting the **gene pool** upon which marine organisms depend if they are to adapt to changing ocean conditions. The ecological basis of the habitat services provided by the high seas is extremely poorly known, but rapidly developing.

European Eel (*Anguilla anguilla*), which spawns in the Sargasso Sea. © Wil Meinderts / FLPA

Cultural Services

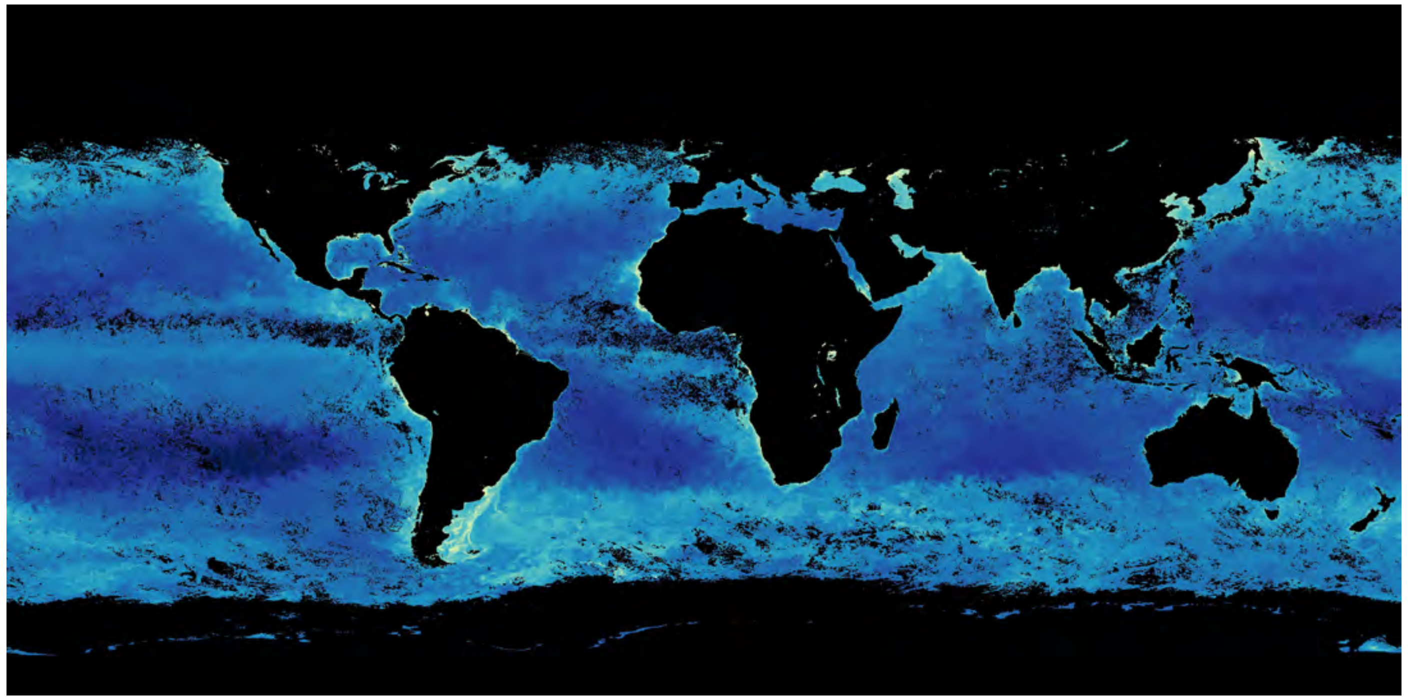
Cultural services are the benefits people obtain from ecosystems through recreation and aesthetic experiences, as well as spiritual enrichment, mental development, and reflection (MEA, 2005). **Tourism, leisure and recreation** are the best-known cultural services associated with ocean ecosystems. Globally, tourism is a growing industry, and this includes marine nature tourism. While the vast majority of recreational opportunities and activities relate to coastal and near-shore environments, there are a few key examples of high-seas-based recreation including boat-based Antarctic eco-tourism, transoceanic cruise-ship tourism, and even deep-sea tourism to hydrothermal vent fields or wrecks such as *RMS Titanic*. It is worth noting that many cultural ecosystem services that are enjoyed closer to shore depend on high-seas ecosystems, e.g. whale watching. The remoteness and inaccessibility of most high-seas areas means the direct aesthetic information provided by them is limited, although high-seas ecosystems likely support **aesthetic** services that are enjoyed closer to shore. Bermuda's Golden Rainforest, the vast mats of *Sargassum* in the Sargasso Sea, and images of hydrothermal vent communities have already inspired art and photography in the high and deep seas[6]. Because the high seas remain relatively unexplored, new discoveries there promise a continuous stream of new information for mental development.

Case Studies of Ecosystem Services Provided by the High Seas

Carbon Capture and Storage by Marine Life

The ocean has been responsible for the capture and storage of more than half of the carbon dioxide produced by the burning of fossil fuels and a third of the total produced by humankind. The ability of the ocean to capture and store carbon reduces the rates of increase of atmospheric carbon dioxide and can slow changes in global temperature and other consequences associated with climate change. Carbon capture and storage occurs through both physical processes, which do not involve living organisms, and biological processes in which living organisms play the dominant role. Physical processes include carbon dioxide dissolving in the ocean and then being transported to places where seawater sinks into the deep sea and away from the atmosphere for hundreds to thousands of years. Biological processes include the 'fixation' of carbon by photosynthesis in the surface layers of the ocean (<200m depth) by a diverse group of microorganisms called phytoplankton. This is the same process by which plants on land use the sun's energy (thus 'photo-') to convert carbon dioxide into living tissue (thus 'synthesis'). Phytoplankton grow by fixing carbon and other nutrients, then they die and sink or are consumed by zooplankton and other organisms that eventually die and become particulate organic carbon (POC), a portion of which sinks into the deep ocean where it is lost from the atmosphere (captured and stored) over long timescales[7]. Phytoplankton may also produce or be converted to dissolved organic carbon, a fraction of which is also transported into the deep ocean by sinking water.

The ability of ocean life to fix carbon, measured as primary production, and then transfer this carbon into the deep ocean depends on many factors. Chief among these are processes associated with the grazing of phytoplankton by animals and its degradation by bacteria. A very large proportion of fixed carbon is converted back into carbon dioxide through respiration and is lost again to the atmosphere. The mechanism by which carbon dioxide is captured over a longer term by marine life is known as the 'biological carbon pump'. Additionally, there is a carbonate pump by which marine organisms (mainly phytoplankton) produce particles of calcium carbonate, which also sink into the deep ocean.



Map showing where phytoplankton live in the ocean. These plants are an important part of the ocean's food chain because many animals (such as small fish and whales) feed on them. Scientists use satellites to measure how much phytoplankton are growing by observing the colour of the light reflected from the shallow depths of the water. © Aqua/MODIS NASA

A first step in estimating the amount of carbon captured by living organisms and stored by high-seas ecosystems is to estimate the net primary production at the ocean's surface and then apportion this between the high seas and EEZs. We used satellite imagery to measure the productivity of phytoplankton (Behrenfeld & Falkowski, 1997; Dunne *et al.* 2007), taking the average primary production of the oceans over 10 years.

Out of about 47 billion tonnes of carbon fixed by phytoplankton, we estimate that the high seas are responsible for 49% (i.e. about 23 billion tonnes). While coastal waters are known for their high productivity, the high seas have a very large surface area and thus account for a huge amount of biological productivity in total. The amount of carbon captured and stored at depth can be estimated from measurements of fixed carbon (net primary production) and how it is consumed or decomposed by animals and microorganisms as it sinks. Using an estimate of the amount of carbon stored in particulate form below 1,000m (i.e. 0.276 billion tonnes per year) and adding carbon exported through other biological mechanisms (i.e. including nitrification, the carbonate pump, and dissolved organic carbon), and accounting for a portion of the continental slope <1,000m deep that lies outside of the EEZs, **we estimate a total figure for biological carbon capture and storage in the high seas of 0.448 billion tonnes of carbon annually**.

Our estimates of carbon capture and storage in the high seas are preliminary and are necessarily subject to a great deal of uncertainty. This largely arises from uncertainties regarding the rate at which organic carbon is consumed as it sinks and also the role of animals in actively moving the carbon from the surface into deep water (e.g. by eating POC at the surface and migrating into deeper water). Evidence is accumulating that the depth zone between 200m and 1,000m, the so called 'twilight zone'[8], may be particularly important in understanding how efficiently primary production is sequestered into the deep sea.

To account for uncertainty in the accuracy of our estimates of carbon capture and storage, we take the figure of 1,644 billion tonnes of carbon dioxide per year (+/- 50%) as a basis for estimating the economic value of keeping carbon dioxide out of the atmosphere by the life in the high seas[9]. Estimating the value of this ecosystem service is also not a simple matter as the carbon prices can be estimated in a variety of ways. A simple approach is to base the price on carbon trading or market values. Unfortunately, carbon prices are currently highly distorted with low prices that do not reflect the social costs of carbon emissions. A second approach is to estimate the replacement costs (i.e. the price to avoid the emission of a tonne of carbon through technological means). The third approach uses integrated assessment models to estimate the social damage costs through time that are associated with the release of one tonne of carbon dioxide – a value known as the social cost of carbon (SCC).

Here, we used the SCC by adopting the figures used by the US Federal Government Interagency Working Group (IAWG). This group consists of members of the US Departments of Agriculture, Commerce, Transportation and Energy together with the Environmental Protection Agency, among others, and was set up to provide a consistent value for the social benefits of climate change abatement (IAWG, 2010).

The figures used by the IAWG come from the average of three different models, which use different climate scenarios assessed using different discount rates. The IAWG selected four prices for carbon from the distributions from these models for use in their regulatory analysis. Three of the prices were based on the average SCC across models and socioeconomic-emissions scenarios at the 2.5%, 3% and 5% discount rates, respectively. The fourth price was chosen to represent the higher-than-expected economic impacts from climate change, further out in the tails of the SCC distribution[10].

For our calculations, we use the latter price of SCC for 2010, which was US$90 per tonne of carbon. To account for uncertainty in these figures we compute values with a range of +/- 50% for this price.

Given the above, the total social benefit of carbon capture and storage by the high seas amounts to US$148 billion a year in constant 2010 dollars (with a range of US$74 to US$222 billion for mid-estimates).

It is important to remember that excess carbon dioxide coming from human activities also has the potential to change the physical properties of seawater (through ocean acidification and increases in sea temperature), thus altering the biological sequestration of carbon dioxide in the ocean. Our estimates do not account for these additional changes.

Fisheries in the High Seas

Seafood harvest is perhaps the most familiar service provided by marine ecosystems, including the high seas. The high-seas fishing industry is also a dominant source of ecological pressure in high-seas ecosystems with impacts that may affect the supply of other ecosystem services (e.g. carbon capture and storage). Poorly managed fisheries affect the economic value of the service as well as other aspects of social welfare, including the support of sustainable livelihoods, food security, and distributional equity. While it is unlikely that artisanal fishing communities would venture into the high seas, it is worth noting that the overfishing in the high seas may negatively impact stocks fished closer to shore because, as reported below, a large proportion of global fish catch is from species that live both in EEZs and the high seas. This means that many fish caught in the high seas could possibly have been caught in coastal waters if it were not for the high-seas fishing fleet. Even if not caught in the high seas, overfishing in the high seas could have a negative impact on the productivity of coastal fisheries.

Ocean fisheries take place in both coastal waters (i.e. those within the EEZ of maritime countries) and the high seas. Here, we analyse the economic impacts of high-

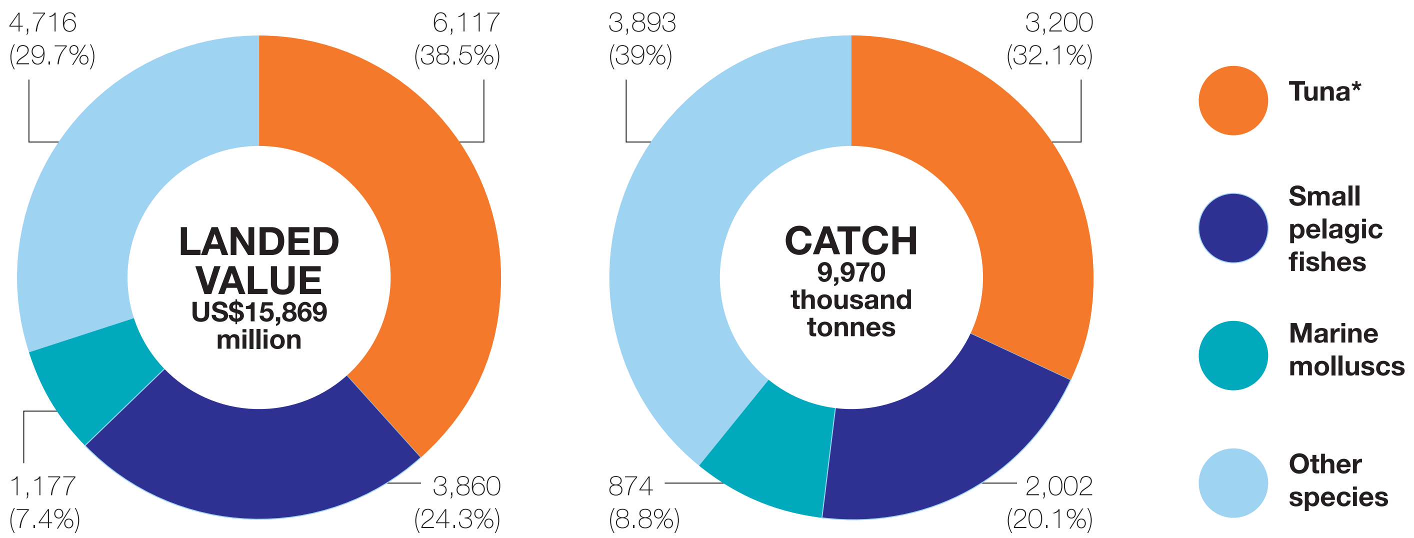


Figure 4. Top species/taxon groups (2000–2010) by average high-seas landed value and average high-seas catch.
Average annual landed values and catches were taken from the Sea Around Us catch and price database.
Grouped tuna species include yellowfin, bigeye, skipjack and albacore.

seas fisheries with a focus on the degree of 'sharing' and interaction between fish stocks in these two politically demarcated areas of the global ocean.

Forty-two percent of the global commercially important fish species we analysed are caught in both the high and coastal seas. Less than 1% are caught exclusively on the high seas. The highly migratory and 'straddling' stocks that occur in both the high seas and in EEZs account for 67% of the total global catch and 72% of the total landed value associated with global commercial fisheries.

We found that a total annual average of about 10 million tonnes of fish from highly migratory and straddling stocks were caught in the high seas, constituting just over 12% of the global annual average marine fisheries catch of 80 million tonnes. The landed value of this catch is estimated at about US$16 billion annually, which makes up about 15% of total global marine landed value of about US$109 billion (Swartz *et al.* 2012). Tuna species account for the largest share of value and the second largest share of total catch (Figure 4).

Focusing on the large pelagic species for which we have good data, we find that the 10 leading high-seas fishing nations together land 63% of the high-seas catch and capture 70% of the landed values, respectively (Table 2). In other words, 10 countries reap the largest commercial share of this common heritage of humankind.

'High seas only' fishing plays a relatively small role in the economic value of global fisheries, but a potentially large ecological role in the ocean – supporting the large global fishery that exists within EEZs and some small-scale and subsistence fishing too, all the while playing a key role in the global ocean ecosystem. This paradox suggests that it might make economic, social, and ecological sense for the high seas to be completely closed to fishing. In fact, a recent paper (White and Costello, 2014) predicts that closing the high seas completely to fishing would result in higher net economic benefits, relative to the current situation. By protecting the natural capital of fish stocks in the high seas, coastal nations would continue to benefit from the fisheries that depend on the high seas, but which can be caught in EEZs. Such a policy action would almost surely result in a more equitable sharing of the fisheries service benefits that come from maintaining the ecological health of high-seas fisheries. If closing the high seas to commercial fishing results in more fish in the sea, it could also yield a conservation benefit by contributing to a more sustainable and resilient ocean – not only to overfishing but to other threats such as climate change and ocean acidification. It is also possible that fishing within EEZs could increase as a result of a high seas closure. While this may diminish the conservation value of such a closure, it would still address some of the equity concerns associated with a lack of access to the high seas by many maritime countries.

Countries and companies that fish within the high seas may argue that closing the high seas will lead to massive risks to food security through reduction in catches, employment, revenues and profits. Our analysis indicates that the potential negative impacts of such a closure are not so obvious and many of the impacts could well be positive. Clearly, this important question needs further investigation.

Fishing country	Average high seas landed value (million USD)	% of global (country) landed value	Average high seas catch (000 t)	% of global (country) catch
Japan	2,711	27	880	21
South Korea	1,158	41	649	39
Taiwan	948	60	624	66
Spain	672	30	297	33
USA	656	8	222	5
Chile	610	19	939	23
China	603	6	608	7
Indonesia	394	9	372	11
Philippines	369	16	346	17
France	331	20	98	17
Total for top ten	**8,452**	-	**5,035**	-

Table 2. Top high-seas fishing nations by average annual landed value (2000–2010).

Note that small pelagic fishes were not included in ranking countries because of the low taxonomic resolution of the catch data present in country-specific data. Average annual landed values and catches (2000–2010) were taken from the Sea Around Us Project catch and price database.

Ecosystem Health and the Value of High-Seas Ecosystem Services

The production and value of ecosystem services within the high seas is the result of many complex interactions between the living and non-living parts of marine ecosystems (e.g. ecological characteristics such as bathymetry, turbidity, seabed habitat characteristics, benthic organisms, etc.). Table 3 provides a list of ecological characteristics that are essential to the sustainability and productivity of high-seas ecosystems. This list was largely, but not exclusively, drawn from the list of categories of ecological characteristics identified in the European Marine Strategy Framework Directive as the parts of ecosystems most closely associated with maintaining function and health (EU Commission, 2008)[11].

Changes in the ecological characteristics of the high seas will alter overall ecosystem functioning, ecosystem health, the provision of ecosystem services, and by extension potentially the value of the benefits derived from the provision of ecosystem services to some degree as well. Here, we consider the linkages between ecological characteristics and the key ecosystem services provided by the high seas. Although there are many knowledge gaps and uncertainties regarding the linkages between ecological components and ecosystem services, it is still possible to elaborate to a certain extent on these linkages in the context of the high seas. It is important to note that although many ecosystem services are connected to these broad categories of ecological characteristics, there will be differences in the specific detail of how each ecosystem service is connected to each relevant ecological characteristic.

Ecological Characteristic
Topography and Bathymetry
Turbidity
Spatial/Temporal Distribution of Nutrients
Predominant Seabed Habitat Types & Characteristics
Predominant Water Column Habitat Types & Characteristics
Living Organisms of the Seabed
Living Organisms of the Water Column
Chemical Additives
Sediment Contamination
Ocean Circulation

Table 3. Ecological characteristics driving ecosystem services provision (adapted from European Commission, 2008)

Provisioning Services

Given the nature of provisioning services, their supply will strongly depend on the abundance and numbers of species of living organisms within high-seas ecosystems and the structure of the communities and food webs they form. For example, if the abundance of phytoplankton declines, organisms higher in the food chain also will decline and many of these, like fish for seafood and whales, may be important to people (Chassot *et al.*, 2010). Furthermore, the access to ecosystem services such as genetic, medical or ornamental resources will depend on the actual presence of the living organisms that provide these resources (Kenchington *et al.*, 2003). Of course, if species are driven to local extinction within a specific marine ecosystem, as a consequence, for example, of overfishing (Tylianakis *et al.*, 2010), then the resources they provide would immediately become unavailable at that location. The delivery of provisioning services depends on healthy ecosystems and on ecological functions and community structures that maintain stable food webs that assure the abundance of economically important species.

Regulating Services

Natural environments are constantly subject to natural variations in climate and other factors that modify environmental conditions. In the context of marine systems, it has been widely recognised that the diversity of life, reflected in the ecological characteristics of living organisms of the seabed and water column, plays a fundamental role in the maintenance of regulating services. This is because a diversity of living organisms helps to control essential processes such as sedimentation, nutrient and gas cycling, and the formation of habitat (Barnes & Hughes, 1982; Tilman *et al.*, 2006; Worm *et al.*, 2006; Loreau & de Mazancourt, 2013). Human pressures that disrupt these processes will, in turn, affect the supply of regulating services. For example, phytoplankton contribute to the biological carbon pump that ultimately fixes carbon in the living tissue of organisms and their waste products (e.g. Sayre, 2010). Events and activities that alter the composition of phytoplankton communities are likely to affect the climate regulation service provided by marine ecosystems. Similarly, bacteria, phytoplankton and zooplankton have fundamental roles related to nutrient cycling and the removal of polluting particles from the environment (Balch & Fabry, 2008; Barnes & Hughes, 1982). Whenever the structure of these living communities is altered, the provision of regulating services such as air purification and waste treatment is also likely to be altered.

One indication that the service of biological control already has been altered may be found in the bloom of a particular species (e.g. jellyfish or algae). For example, it is thought that overfishing (as has been seen in the South China Sea and the Black Sea) is capable, in some circumstances, of altering ecosystem structures to the point where biological controls cannot re-establish healthy food webs (Shiganova, 1998; Daskalov, 2002; Daskalov *et al.*, 2007; Jiang *et al.*, 2008).

Habitat Services

The two habitat services likely to be important in the high seas: 'lifecycle maintenance' and 'gene pool protection', are themselves highly dependent on essential ecological processes and are affected by the state of a wide range of ecological characteristics. As a result, changes in any of the critical ecological characteristics can alter the ability of a habitat to support life. Such disruptions include changes in reproductive patterns and the development of juvenile migratory species. For example, cold water corals from the deep sea form important habitats for many species (Ramirez-Llodra *et al.*, 2010). Human activities, such as trawling, that damage deep-sea coral populations will have direct effects on many marine species (e.g. Althaus *et al.*, 2009). Loss of organisms may affect productivity. The local extinction of species reduces species diversity and thus may compromise the integrity of the food webs and other ecological functions. The development of animals higher in the food chain depends on the productivity of lower levels (Chassot *et al.*, 2010). As a result, declines in the productivity of a habitat used by migratory animals for breeding or for protection of juveniles may force these species to travel longer distances to find suitable alternative locations (Robinson *et al.*, 2009). This directly affects the ability of the ecosystem to provide the lifecycle maintenance service. The physical, chemical and biological conditions of a region also determine the conditions under which evolutionary processes will take place. In other words, the key ecological characteristics outlined above play an important role in the evolution of the organisms within an ecosystem. If environmental conditions change too rapidly (Pianka, 2011), it may disrupt the evolutionary process.

Cultural Services

In addition to fundamental physiological requirements, humans have other personal and collective needs and points of connection with the environment (e.g. self-development, recreation, cultural identity). Studies have shown that natural environments are a source of inspiration for humans (Frumkin, 2001; Chiesura & Groot, 2003; Stedman, 2003). Marine ecosystems provide a variety of non-material services that are of great importance to the cultural and personal development of human societies. The way in which people perceive and use each of these services will not only depend on the state of the ecosystem providing it, but also on the nature of the human activity involved. Ecosystem services such as recreation and aesthetic information can suffer greatly in ecosystems that are highly degraded. Other types of cultural services, such as information for cognitive development[12], and inspiration for culture art and design[13], may or may not be negatively affected by environmental degradation even if the ecological state of the components underpinning these services changes. For example, although the subject of marine photography may change with changing environmental conditions, it is not necessarily the case that changing environmental conditions will result in a greater or fewer number of marine photographs taken in a given time period, and changes in ecosystem state may or may not affect the financial value of marine photographs. These features of cultural ecosystem services make it difficult to identify the ecological characteristics on which their provision depends, especially in the context of the high seas (the marine system furthest removed from daily society). Furthermore, the relevant linkages between cultural ecosystem services in the high seas and ecological components are likely to be case-specific, and so cannot be generalised at a global scale. It is worth noting, however, that it may be the case that human impacts that occur partially or wholly in the high seas may have indirect impacts on the flow of cultural ecosystem services in EEZs. For example, pollutants deposited on the high seas may affect charismatic species there that also play a role in coastal ecotourism. If these pollutants affect the species' health or survival they could negatively affect recreation in coastal waters. For example, persistent organic pollutants may harm killer whales that spend time in the high seas, but are viewed closer to shore (Ross, 2006).

Bloom of phytoplankton in the Black Sea on June 4, 2008, along the southern coast near the Turkish cities of Sinop and Samsun caused by over-fertilization from agricultural runoff and wastewater. NASA image c/o MODIS Rapid Response Team

Service Category	Relevant Services	Ecosystem Characteristic	Key Focus
Provisioning	• Seafood • (Biogenic) Raw Materials • Genetic Resources • Medicinal Resources • Ornamental Resources	Turbidity Spatial/Temporal Distribution of Nutrients Predominant Seabed Habitat Types and Characteristics Predominant Water Column Habitat Types and Characteristics Living organisms of the seabed Living organisms of the water column Ocean Circulation	• Community structures that assure the abundance of species of interest • Trophic relations that maintain healthy food webs
Regulating	• Air Purification • Climate Regulation • Waste Treatment • Biological Control	Topography and Bathymetry Turbidity Spatial/Temporal Distribution of Nutrients Living organisms of the seabed Living organisms of the water column Ocean Circulation	• Biodiversity determines the control of essential processes
Habitat	• Lifecycle Maintenance • Gene Pool Protection	Topography and Bathymetry Turbidity Spatial/Temporal Distribution of Nutrients Predominant Seabed Habitat Types and Characteristics Predominant Water Column Habitat Types and Characteristics Living organisms of the seabed Living organisms of the water column Chemical Additives Sediment Contamination Ocean Circulation	• Closely related to essential ecological processes; availability depends on factors that affect regulating and provisioning services
Cultural	• Recreation and Leisure • Aesthetic Information • Inspiration for Culture, Art and Design • Information for Cognitive Development	Topography and Bathymetry Turbidity Spatial/Temporal Distribution of Nutrients Predominant Seabed Habitat Types and Characteristics Predominant Water Column Habitat Types and Characteristics Living organisms of the seabed Living organisms of the water column Ocean Circulation	

Table 4. Ecosystem state – high-seas ecosystem service dependencies

Governance, Ecosystem Health and the Services that Benefit Humankind

Human activities drive changes in ecosystem health, measured by their impact on key ecological characteristics that underpin the production and sustainability of ecosystem services in the high seas. Pollution, the transmission of invasive species, and direct habitat destruction (in the case of seafloor extraction) are detrimental to ecological health and ecosystem service values of the high seas. The effects of climate change, especially increasing ocean temperatures, decreasing oxygen, and acidification all have the potential to alter the health of ecosystems and the value of ecosystem services.

Many human activities that occur in the high seas have both positive and negative economic consequences. Some financially profitable activities in the high seas are arguably independent of ecosystem health (e.g. shipping and mining of deep-seabed mineral resources). Nevertheless, such activities may directly and indirectly damage marine life and ecosystems in the high seas. Other types of activities depend directly on ecosystem health, yet the poor management of these activities results in damage to the very same ecosystems. For instance, by reducing the productivity and resilience of fish stocks, overfishing has a direct impact on the ability of the high seas to produce seafood. Other impacts of fishing such as bycatch and the destruction of ecosystems and physical disturbance (e.g. generation of sediment plumes by bottom trawls) can reduce stocks of other types of seafood, and affect lifecycle maintenance, biological control, genetic and medicinal resources, and even climate regulation.

Some institutions manage human activities directly (e.g. RFMOs, the IMO). Other institutions focus on the condition of ecological, environmental and human states. As described elsewhere in this report, the governance of the high seas is highly fragmented and this fragmentation needs to be taken into account when predicting the potential outcome of better high-seas governance. Indeed, reduced fragmentation may be a proposed reform.

The highly complex and integrated systems that characterise high-seas ecosystems complicate any analysis of the value of improved governance. For instance, overfishing in the Sargasso Sea affects food webs that in turn affect fish that are prey species for whales that support ecosystem services enjoyed in the United States. Similarly, the noise and pollution caused by the high-seas fishing fleet may have direct negative impacts on the fish species these ships target, as well as other organisms. Additionally, a myriad of factors beyond the control of high-seas governance institutions interact with governable human activities. These ungovernable factors include climate change, pollution, loss of near-shore habitats, nutrients and sediments from large rivers, and population growth – the ultimate pressure. The complex nature of high-seas ecosystems and the interconnectedness of high-seas and near-shore areas mean that both the pressures to be controlled and the beneficiaries of better governance are often far flung. Understanding the impact of high-seas governance actions on the welfare of people can be daunting given our current poor state of knowledge about high-seas ecosystems and their services.

The Benefits and Costs of Better High-Seas Governance

Better governance in the high seas can help to reduce the negative environmental impacts of human activities there. By doing so, improved governance can increase the value of high-seas ecosystems. At the same time, improvements in governance come at a cost. These costs include the direct costs of enforcing new laws, the political and administrative costs of changing governance regimes, and the real financial costs that are imposed on the businesses and people involved in activities that may be more regulated under new governance regimes. The net benefit of improved governance, simply put, is the difference in value with and without governance reform, minus the costs of increased governance.

UN General Assembly 56th plenary meeting of the 64th session considers oceans and the law of the sea © Ryan Brown/UN Photo

The benefit

To identify and begin to estimate the potential benefits that flow from the provision of ecosystem services as a consequence of better governance, we must understand how governance affects human activities, how changes in these activities influence ecological health, and how these changes affect the production and sustainability of the services generated by high-seas ecosystems. Better governance could improve high-seas ecosystem health by limiting the environmental and ecosystem damages associated with human activities that affect the high seas.

One way to understand, and ultimately quantify, the benefits of improved governance is by using a framework that is similar to the Drive-Pressure-State-Impact-Response (DPSIR) model. In this framework, governance reform changes damaging behaviours (e.g. overfishing or shipping) that result in changes in key ecological components that affect ecosystem and environmental health (state) and ultimately ecosystem service delivery and value (impact).

A scientific understanding of the linkages between people, ecosystem condition, ecosystem service production and the resulting benefits and values allows for a broad assessment of the likely effects of human activities on ecosystem services. This same basic approach is useful in understanding the potential ecosystem service benefits of better governance of these human activities. Understanding the exact effect of a particular governance change on ecosystem service value requires good data on all of these linkages as well as more precise knowledge of the nature of the connection between individual parts of the model, especially the links between ecosystem components and specific ecosystem services.

The costs

Better governance often results in changes that have a real economic cost to society. The costs of improved high-seas governance will include those costs associated with the creation of governance institutions, their administration, and the implementation of new policies and management measures. A key question, then, is whether the benefits of improved high-seas governance outweigh the costs.

New governance may build upon existing legislative institutions or frameworks. For example, new governance to better address the environmental damage caused by mining could be achieved through a new Secretariat established within the ISA (e.g. Barbier *et al.*, 2014). New governance may also require new institutions or the reconfiguration of existing institutions. There could be substantial costs associated with the establishment and day-to-day financing of these new institutional arrangements. Of course, reorganisation could also result in cost savings. These costs and savings should be assessed.

If new regulations are required, the regulatory authority is likely to incur ongoing monitoring and enforcement costs as well as the potential ongoing costs of continuing dialogue with affected industries and agents in civil society. These ongoing engagements will be necessary if the regulatory body intends to pursue a course of management that will adapt to changes in (1) evidence on effectiveness (vis-à-vis impacts on marine ecosystems); (2) industry/civil society implementation costs; and (3) changes within industrial sectors (e.g. the development of new technologies or changes in demand and supply conditions).

The industries to be regulated will also incur costs. Costs incurred before any regulation is implemented may include the costs associated with participation in consultations, the transaction costs associated with understanding the new legal requirements, and the costs of incorporating new regulations into business plans and operations. Costs also will be incurred as industries take steps to create procedures that will ensure compliance. Lobbying costs might also be included as another form of cost to society.

The ongoing costs to industry will depend on the specific policy measures or reforms that are prescribed as part of reformed governance. Broadly speaking, new regulations may result in a loss of profits for the regulated industry. These are known as opportunity costs. For instance, if part or all of the high seas are closed to fishing, the profits to commercial fishers operating in the high seas may be completely lost. The losses to regulated industries, of course, may be offset by gains elsewhere; for instance, fish catch and profits may increase in EEZs.

The commentary in this section suggests that both the regulation itself and its governance must be very clearly specified in order to conduct an assessment of (1) the total costs of governance reform and new regulations; (2) the distribution of costs; and (3) the level of certainty we can assign to any cost estimates. There is little information available about the costs associated with governance reforms or even the cost of existing high-seas governance. It is thus difficult to assess the costs of changes to high-seas governance in advance. It is worth noting that the IMO and ISA budgets were £61,151,200 (2010–2011) and US$13,014,710 (2011-2012), respectively (IMO, 2013; ISA, 2013). While the costs per unit area of the high seas may seem small, these budgets indicate that the costs of governing specific aspects of the high seas can be substantial.

Conclusions

The high seas supports at least 15 major categories of ecosystem services that are known to be important to human wellbeing. These ecosystem services generate benefits that have demonstrable economic value. While few of the benefits stemming from these ecosystem services can be valued using current data, available data do show that in the case of just two of these ecosystem services (climate regulation and seafood) the benefits resulting from the flow of ecosystem services amounts to tens to hundreds of billions of dollars of value to society annually.

High-seas marine ecosystem services are thought to generate far less value than could be possible because of uncontrolled and poorly managed human activities that damage the ecosystems upon which these ecosystem services depend. Better high-seas management could stem the decline in the value of high-seas ecosystem services, improve the resilience of high-seas ecosystems, and even increase the overall value of these ecosystems and the services they produce.

Unfortunately, a careful cost-benefit analysis is impossible given the current state of knowledge about high-seas ecosystems, the benefits people derive from these ecosystems, and the ways in which human activities affect these benefits. A lack of science, though, should not prevent obvious reforms in high-seas governance that will directly benefit high-seas ecosystems and the values they generate. Nevertheless, as high-seas governance progresses, better science and data will be essential to carefully design governance regimes that will best serve the ecological and economic needs of society. Towards that end, the implications derived from this research are:

1. **Increase funding and capacity for marine scientific research aimed specifically at reaching a better qualitative and quantitative understanding of high-seas ecosystem service production and value.**

2. **Support better international coordination and more funding for natural and social science research aimed at a more complete understanding of the role of high-seas ecosystems in the global ocean carbon cycle.**

3. **Support primary research into the ecological and economic consequences of human activities in the high seas. This research should also include the costs of current governance and management of the high seas and the potential future costs of proposed reforms.**

4. **Support the application of systems of natural capital accounting for high seas areas, integrate these with emerging national accounts of marine natural capital, and promote the use of these accounts in decision-making that affects the long-term sustainability and productivity of high-seas ecosystems.**

5. **Conduct a thorough socioeconomic cost-benefit analysis of proposed reforms to governance and management of high-seas fisheries. High-seas fisheries have high value but are currently degraded and performing below their economic potential. The ecological health of high-seas fish stocks also has a direct impact on fisheries within the EEZs of coastal states. New paradigms for ocean management, such as partial or total closure of the high seas, should be investigated as part of this process. Such analysis should encompass ecosystem and fisheries sustainability, the costs of monitoring and enforcement, and the distribution of costs and benefits.**

6. **Build scientific capacity and data sharing relevant for ecosystem services in developing countries, including marine science, economics, governance and law related to the sustainable management of the oceans. Developing countries depend crucially on marine ecosystem services and high-seas marine ecosystem health.**

Endnotes

1. http://www.globalccsinstitute.com/publications/preliminary-feasibility-study-co2-carrier-ship-based-ccs/online/43946
2. http://www.imo.org/Pages/home.aspx
3. Definition is based on that used by the UNEP programme *The Economics of Ecosystems and Biodiversity* (TEEB). See: http://www.teebweb.org/resources/glossary-of-terms/ (last accessed 20 January, 2014).
4. See: http://www.marineecosystemservices.org
5. These 15 categories focus solely on the marine ecosystem services that are generated within the boundaries of the high seas and would likely benefit from better management there. We consider spill-over effects from the high seas into territorial waters (e.g. fisheries) but do not include other commonly named services (such as 'disaster mitigation') within this typology of high-seas ecosystem services since it is difficult to conceive of a high-seas management intervention that might affect the provision of such ecosystem services.
6. See the art and science collaborative of Cindy van Dover and colleagues at http://oceanography.ml.duke.edu/discovery/
7. The Independent Panel on Climate Change define the sequestration depth as a minimum of 1,000m, where carbon is stored in the ocean for hundreds of years or more.
8. The 'twilight zone' refers to the fact that some sunlight is present but it is insufficient for photosynthesis.
9. Note the figure in carbon dioxide-equivalents is calculated as 3.67 x 0.448 Gt C yr^{-1}.
10. See the May 2013 Technical Update, available at: www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf
11. In the context of assessing ecosystem services changes, it is necessary that the characteristics considered be linked with ecosystem state because ecosystem services are defined as being ecosystem-state dependent.
12. The focus of research, study, and learning may change with changing environmental state, but the overall provision of opportunities to learn is not limited by changing environmental state.
13. Although it may seem straightforward to assume that artistic inspiration is greater in the context of the most pristine scenes and environments, there is historical precedent for artists being inspired by different forms of damage and destruction. For an example see: *The Carcass of Beef* by Rembrandt, 1657.

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This work arose from the many relevant and timely questions which the Global Ocean Commissioners had with respect to the value of the high seas. We hope that this body of work helps to answers those questions and give the commissioners the information they need to elicit changes in ocean governance and management in order that the value of the high seas is not further diminished but is maintained and enhanced.

Plastic bag floating in the open ocean. Caye Caulker, Belize © Patrick Kelley / Marine Photobank

Global Ocean Commission

The High Seas and Us: Understanding the Value of High-Seas Ecosystems

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