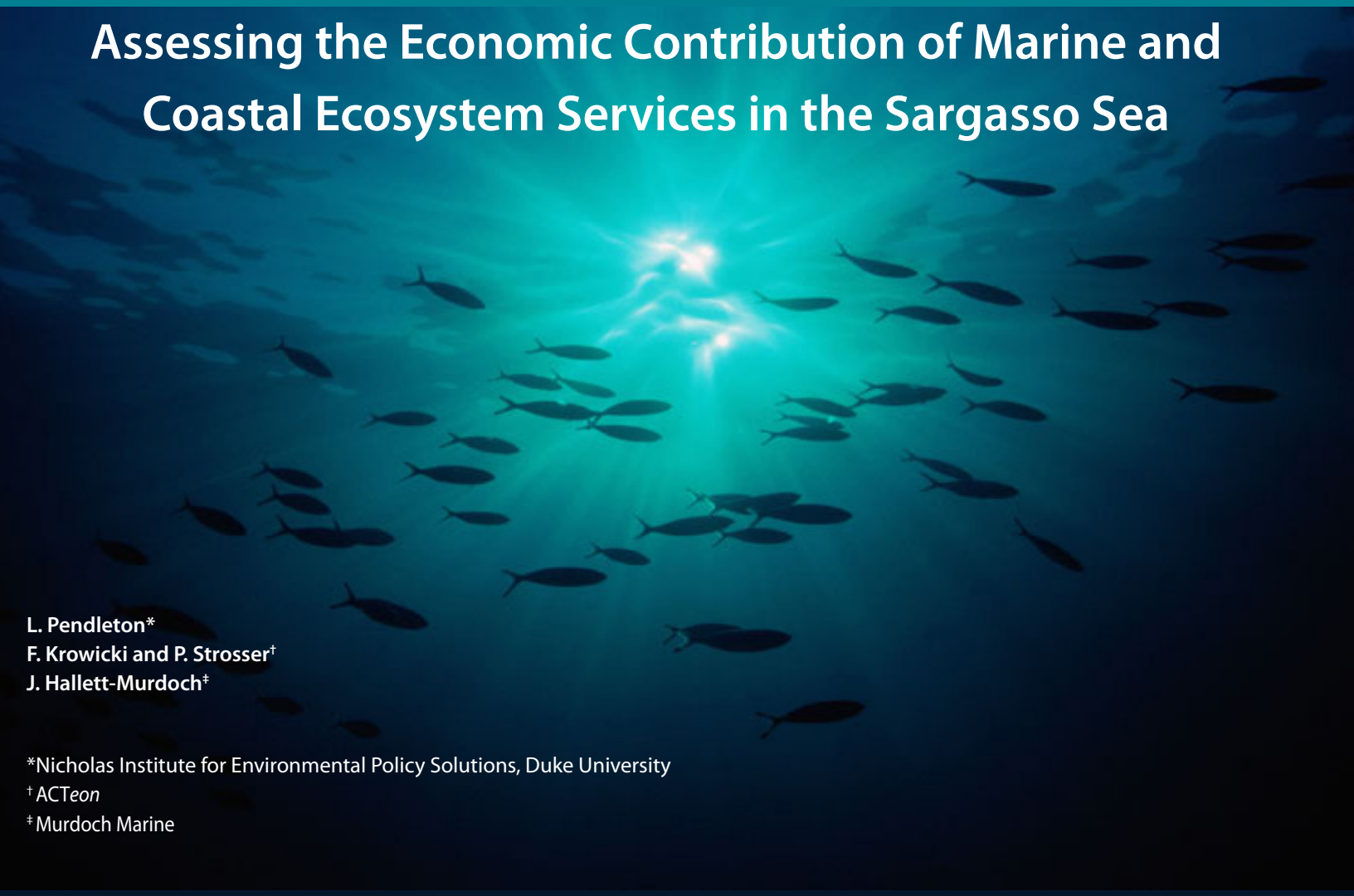
NICHOLAS INSTITUTE REPORT

Assessing the Economic Contribution of Marine and Coastal Ecosystem Services in the Sargasso Sea



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EXECUTIVE SUMMARY

The Sargasso Sea ecosystem generates a variety of goods and services that benefit people. These goods and services, often referred to as *ecosystem services,* provide some outputs that are directly commercially important (e.g., commercial fish stocks, wildlife viewing that supports tourism) and some that are both commercially important and that provide important recreational opportunities (e.g., recreational fishing). The Sargasso Sea ecosystem also provides ecological functions that are essential in the support of human life (e.g., oxygen production and carbon capture and storage). High-seas ecosystems, like that of the Sargasso Sea, abound in genetic diversity and biological compounds that may yield new chemical and medicinal products.

Some ecosystem services in the Sargasso Sea may be harvested directly (e.g., fish or seaweed). In other cases, ecosystem functions provided by the Sargasso Sea may act as only an intermediate element in the production of ecosystem services, for instance when *Sargassum* supports part of the life cycle of organisms that ultimately benefit people far from the region (e.g., eels spawned in the Sargasso Sea are harvested in North America and Europe). The Sargasso Sea ecosystem is part of larger oceanic processes whose ecological and environmental outcomes may affect human well-being globally (e.g., carbon sequestration).

This report provides a variety of measures of the Sargasso Sea's economic value and impact, especially net and gross revenues associated with ecosystem services supported by the sea. Measures of net revenues capture the net benefit of a resource to society. Gross revenues capture important measures of economic activity and impact. Gross revenues support local taxes, income, and jobs. (Note: gross and net revenues are not the same and cannot be added together.)

We present an initial and admittedly incomplete picture of the economic contribution of the Sargasso Sea with a focus on the services provided by the sea's offshore ecosystems. Our findings provide estimates for only a selection of the ecosystem services known to depend on a healthy Sargasso Sea and do not reflect the complete and total net value or economic impact of these services.

A suite of ecosystem services can be tied to the ecological conditions and health of the Sargasso Sea and are directly beneficial to human activities. These services include

- **Provisioning services,** such as commercial fishing.
- **Cultural services,** such as tourism in Bermuda, sport and recreational fishing, education, and turtle, bird, and whale watching; and
- **Regulating services,** such as carbon sequestration and coastal erosion prevention.

In addition, the Sargasso Sea has an economic value because of its existence as a unique ecosystem and home to rare and charismatic species. Moreover, the relatively remote nature of the Sargasso Sea, free from many terrestrial impacts, generates opportunities for research that are not found elsewhere. We include these research values as part of our assessment of educational values.

We find the following:

- The **economic importance of the Sargasso Sea is significant**. Economic expenditures and revenues directly or potentially linked to the Sargasso Sea total anywhere between tens to hundreds of million dollars a year.

- **The greatest economic impacts associated directly with the Sargasso Sea come from commercial fishing of pelagic species** (gross landed value of approximately $100 million/year) **and eel fishing** ($66 million/year)**.**

- Very **large gross expenditures are potentially linked to the Sargasso Sea from whale watching** in other parts of the Atlantic Ocean (estimated at nearly $500 million/year). The proportion of these expenditures that are dependent on the ecological condition of the Sargasso Sea could not be estimated.

- **A healthy Sargasso Sea benefits human activities and people who live within the Sargasso Sea region, especially in Bermuda**. That country receives direct economic benefits from whale watching, commercial and sport fishing.

- The **Sargasso Sea also benefits people of other regions of the world**. In particular, European fishers benefit from eel fishing (receiving approximately 90% of estimated total gross eel-fishing revenues); North American fishers also benefit from this activity. Recent estimates by Sumaila et al. (2014) suggest that fishing vessels from the Americas also benefit from commercial fishing in the Sargasso Sea (more than 66% of the estimated total landed value for the Sargasso Sea). North American businesses and tourists receive most of the benefits of whale watching in other seas (about 95% of the total value estimated). Central and South American communities as well as the Caribbean nations benefit from revenues generated by turtle watching. Estimates of this activity's economic impact exceed $15 million/year at selected locations, but the share of this value attributable to the Sargasso Sea remains unquantified.

The Sargasso Sea is a central element in the North Atlantic marine ecosystem and contributes to the production of ecosystem services that are enjoyed locally and throughout the Atlantic nations. The sea also generates nonuse and regulating services that benefit people globally. **Our findings of the potentially large economic value and economic impact of the services provided by a healthy Sargasso Sea ecosystem call for the active management of this ecosystem.** These findings also show that **protecting the Sargasso Sea is not solely in the interest of the inhabitants of Bermuda. Better management of the Sargasso Sea would benefit people and businesses around the globe**, in particular, in North America (whale watching), Europe (eel fishing), and elsewhere in the Americas (commercial fishing).

Many **components of the economic value and impact of Sargasso Sea ecosystem services remain unquantified**, including

- The role of the Sargasso Sea in supporting **bird life** enjoyed by bird watchers and to **sea life** viewed by scuba divers, snorkelers, and others;

- The economic value of the **contribution of *Sargassum*** to beach creation and shoreline protection, carbon sequestration, oxygen production, and biodiversity protection;

- The **cultural values of organisms that depend on the sea,** such as those of eels to Nordic peoples; and

- The **existence value of the organisms that live in or depend on the Sargasso Sea.** These organisms include rare or threatened species like whales, turtles, sharks, and emblematic species (e.g., anglerfish), all of which may be valued for their mere existence and may increase the existence value of the Sargasso Sea as a unique ecosystem. Other organisms may provide

ecosystem functions or services that are still undiscovered. These values have yet to be quantified.

Strengthening integrated biophysical and socio-economic research is important for improving the long-term protection and management of the Sargasso Sea. The ecosystem functions of the Sargasso Sea and their role in producing and sustaining ecosystem services are still poorly understood, as are human impacts on the ecological health and function of the Sargasso Sea, which affect ecosystem services and thus people. Understanding of the value and economic impact of better management will require better economic and ecological data and a more holistic scientific understanding of the integrated relationship between people and the Sargasso Sea ecosystem. The importance of improved data and understanding is underscored by the potentially large amount of economic activity and value that may be tied to the health of the Sargasso Sea ecosystem and by the potentially large economic benefits of improved management.

CONTENTS

ABBREVIATIONS

EBSA	Ecologically or Biologically Significant Area
EEZ	Exclusive Economic Zone
EIFAAC	European Inland Fisheries and Aquaculture Advisory Commission
ICCAT	International Commission for the Conservation of Atlantic Tuna
ICES	International Council for the Exploration of the Sea
IUCN	International Union for the Conservation of Nature
MA	Millennium Ecosystem Assessment
MPA	Marine Protected Area
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
SAFMC	South Atlantic Fishery Management Council
TEEB	The Economics of Ecosystems and Biodiversity
USD	United States dollars

INTRODUCTION

Objectives of the Report

The Sargasso Sea is both ecologically and economically important (Laffoley et al. 2011). However, quantifying the economic contribution of the Sargasso Sea remains a challenge because this ecosystem lacks official boundaries and because it is remote from most human settlements. Although the Sargasso Sea includes Bermuda and the Bermudian Exclusive Economic Zone (EEZ), much of its waters lies in an area beyond national jurisdictions (ABNJ), known as the high seas. Ocean currents, global biochemical cycles, and wide-ranging ecological processes mean the ecological and human influence of the Sargasso Sea is felt within and well beyond its dynamic boundaries.

High-seas ecosystems generate a variety of goods and services that benefit people. These goods and services, often referred to as *ecosystem services,* provide outputs that are commercially important (e.g., commercial fish stocks, tourism that depends on wildlife viewing) and some that are both commercially important and that also provide important recreational opportunities (e.g., recreational fishing). These ecosystems also support many ecological functions that are essential in the support of human life (e.g., oxygen production and carbon capture and storage). High-seas ecosystems have proved to be places that abound in genetic diversity and biological compounds that may yield new chemical and pharmaceutical products.

This report summarizes the state of knowledge about key, quantifiable ecosystem services that depend, in part or as a whole, on the Sargasso Sea ecosystem—in particular, key ecological connections between the Sargasso Sea and human activities. The report also provides the best available information about the potential economic magnitude or nature of the sea's ecosystem services.[1] In this report, the focus is primarily on the economic activity generated by the offshore ecosystems of the Sargasso Sea (i.e., no coastal ecosystems and corals are included). Finally, findings highlight critical gaps in our understanding of the economic services of the Sargasso Sea that need to be filled to help inform the sea's management.

A Basic Framework for Quantifying Ecosystem Services in the Sargasso Sea

The *high seas,* defined as the water column outside areas of national jurisdiction, cover 64% of the total surface of ocean and seas (Druel 2011). High-seas areas are increasingly used for industrial activities that do not rely directly on ecosystem conditions but that can negatively affect ecosystem health.[1] These activities include maritime transport, communication cables, and offshore oil extraction. In the future, offshore mining might also affect high seas. The high seas sustain living resources that support market-based activities (e.g., fishing and tourism) as well as non-marketed activities (e.g., carbon sequestration, shoreline protection). The economic value of these living resources is not always known, particularly when the resources support activities that lie outside of markets or activities that take place far from the high-seas areas. As a result, it is often difficult to fully assess the economic consequences of increased industrialization, pollution, overfishing, and other high-seas environmental stresses.

This report uses an ecosystem services approach to describe and quantify the economic contribution of ecosystem functions and the living resources that depend on the Sargasso Sea. This approach is well established in both the literature and international initiatives, including the Millennium Ecosystem Assessment (MA 2005) and The Economics of Ecosystems and Biodiversity (TEEB 2010b).

The basic ecosystem services approach treats ecosystems as nature's factories that can produce goods that are directly used by human activities or that can support ecological functions that in turn affect other

[1] Unless otherwise noted, all economic information is adjusted to 2012 U.S. dollars to account for inflation.
[1] *Ecosystem health* is defined as the capacity of ecosystems to function in a way that is sustainable and near optimal levels.

goods and services that people enjoy. *Ecosystem services* are defined as the benefits of nature to households, communities, and economies (Boyd and Banzhaf 2007).

Some ecosystem services in the high seas may be harvested directly (e.g., fish and seaweed). In other cases, high-seas ecosystems may act as an intermediate element in the production of ecosystem services, for instance, when a high-seas ecosystem supports only part of the life cycle of organisms that ultimately are enjoyed elsewhere (e.g., eels spawned in the Sargasso Sea are harvested in North America and Europe). High-seas ecosystems may also be part of larger oceanic processes whose ecological and environmental outcomes affect human well-being globally (e.g., carbon sequestration), including regulating and supporting services that remain poorly understood and difficult to value.

This report summarizes existing information on marine ecosystem services that

- depend primarily on the offshore ecosystem of the Sargasso Sea,
- have a clear ecological connection to the Sargasso Sea,
- correspond to well-defined constituencies and user groups, and
- are likely to be threatened, in an obvious way, by degradation of the health of the Sargasso Sea ecosystem.

The Sargasso Sea supports all of the four principle classes of ecosystem services described by the MA: provisioning services such as food, water, fishing; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services, such as soil formation, photosynthesis, and nutrient cycling (MA 2005).[2] NOTE: The Sargasso Sea provides all these types of services, but because of data limitations, economic information is provided only for selected ecosystem services.

UNDERSTANDING THE HUMAN BENEFITS OF THE SARGASSO SEA: AN ECOSYSTEM SERVICES APPROACH

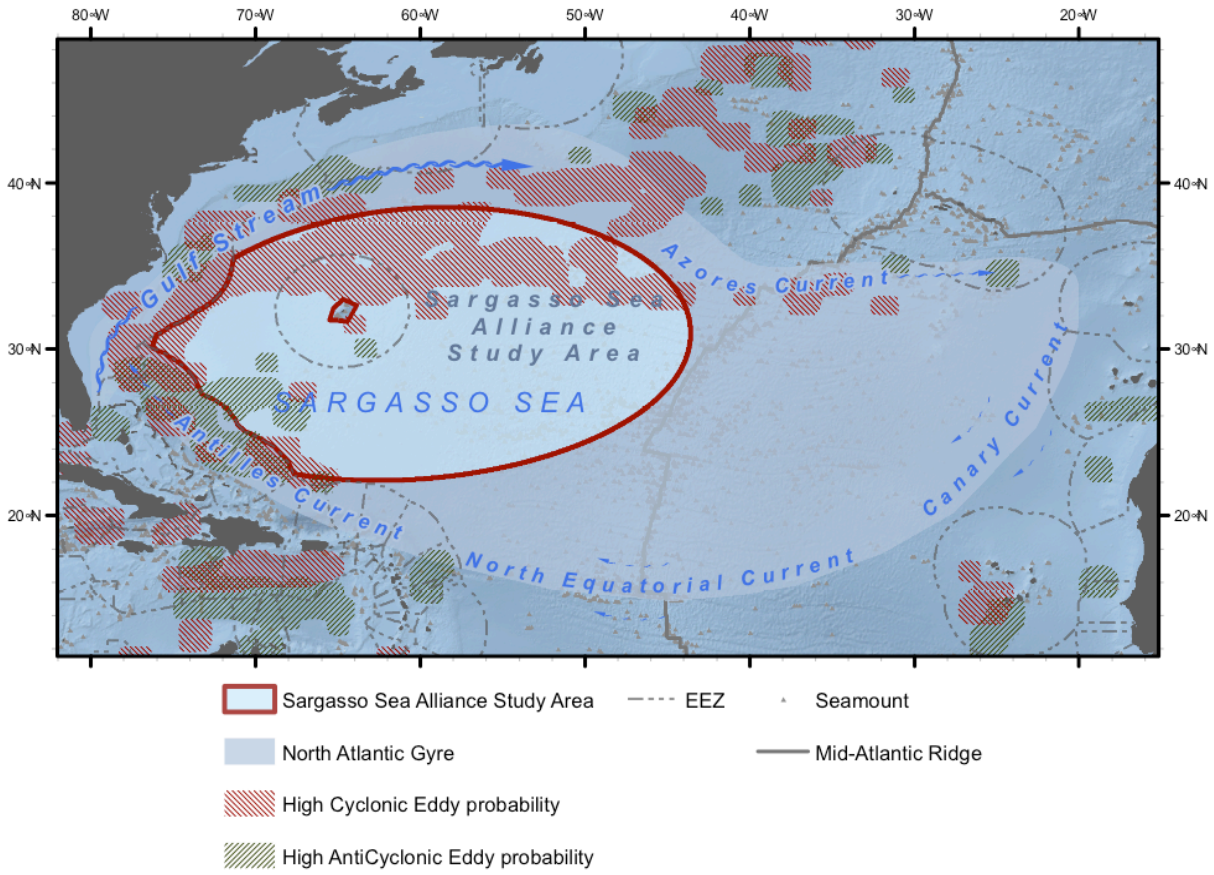
The Sargasso Sea Ecosystem

The Sargasso Sea lies within an oceanic gyre of the western central Atlantic Ocean between approximately 25 degrees and 75 degrees west longitude and between 20 degrees and 40 degrees latitude (Figure 1). Unlike other seas, the Sargasso Sea is defined by currents rather than coastline: the Gulf Stream to the west, the Canary Current to the east, the North Atlantic Drift to the north, and the Antilles Current to the south. The Sargasso Sea Study Area, as defined by the Sargasso Sea Alliance, lies within this large sea. The study area covers 4 million square kilometers (km^2), an area equivalent to the 28 member states of the European Union.[3] Bermuda is the only inhabited island fully within the Sargasso Sea Study Area.

[2] For marine ecosystem services, there are many other classification systems (Costanza et al. 1997; Pimentel et al. 1997; Ewel et al. 1998; Moberg and Folke 1999; Holmlund and Hammer 1999; de Groot et al. 2002; MEA 2003; Hein et al. 2006; Fisher et al. 2009; TEEB 2010a; Haines-Young and Potshin 2010).

[3] See http://www.insee.fr/fr/themes/tableau.asp?reg_id=98&ref_id=CMPTEF01125.

Figure 1. The Sargasso Sea Study Area as Defined by the Sargasso Sea Alliance within a Moving Sea.



Source: Ardron et al. (2011), as reprinted in Laffoley et al. (2011).

Of five similar oceanic gyres (Antoine et al. 1996), the Sargasso Sea is unique in that it supports mats of *Sargassum*, a large, floating marine algae. The Sargasso Sea supports the largest open-ocean *Sargassum*-based ecosystem in the world. *Sargassum* drifts around the Atlantic Ocean, pushed by winds and currents. The *Sargassum* often becomes trapped within the gyre, where it may stay for a long time. As a result, a vast patchwork of mats of *Sargassum* and their resident organisms drift all around the Sargasso Sea as far as the borders of the Caribbean Sea (Gower and King 2011). The patchwork of *Sargassum* mats can cover tens of square kilometers. It is generally believed that these mats of "drift algae" have persisted within the Sargasso Sea for thousands of years (Calder 1995). The *Sargassum* mats host a diverse community of animals and plants, which in turn supports larger migratory species, including tunas, marlin, sharks, and turtles. Because of these characteristics, the Sargasso Sea is often referred to as the "golden floating rainforest."

More than 100 species of invertebrates, more than 280 species of fish, and 23 species of seabird, including many threatened and endangered species, use *Sargassum* as a resource at some point in their life cycle—as a food source, for protection, for nesting or spawning grounds, or as a nursery habitat.[4] The Sargasso Sea is home to 10 endemic species, including the *Sargassum* angler fish (*Histrio histrio*). Four species of sea turtle hatchlings (loggerhead [*Caretta caretta*], green [*Chelonia mydas*], Kemp's Ridley [*Lepidochelys kempi*], and hawksbill [*Eretmochelys imbricata*]) live within the *Sargassum* during their

[4] See Laffoley et al. (2011) for a detailed bibliography of the existing fauna of the Sargasso Sea.

"lost years" (Carr and Meylan 1980).[5] In 2014, the U.S. National Marine Fisheries Service (NMFS) identified *Sargassum* as "critical habitats" for loggerhead turtles (NMFS 2014). American and European eels (*Anguilla rostrata* and *A. anguilla*) also spawn in the Sargasso Sea at the end of their life (Schmidt 1922; Schoth and Tesch 1982; Kleckner and McCleave 1988; McCleave and Miller 1994; Miller 2002; Miller and McCleave 2007). Humpback whales (*Megaptera novaeangliae*) travel through the Sargasso Sea when migrating from breeding grounds in the Caribbean on their way north to feeding grounds in the Arctic (Punt et al. 2006). Many commercially important fisheries species, such as albacore (*Thunnus alalunga*), bluefin (*Thunnus thynnus*), and yellowfin (*Thunnus albacares*) tunas (International Commission for the Conservation of Atlantic Tunas [ICCAT] 2011), make seasonal migrations into and through the Sargasso Sea primarily for feeding during the summer months (Luckhurst 2013). The blue (*Makaira nigricans*) and white (*Tetrapturus albidus*) marlins are also known to spawn in the Sargasso Sea (Luckhurst et al. 2006; South Atlantic Fishery Management Council 2002; White Marlin Biological Review Team 2007).

New Attention to Pressures and Impacts on the Sargasso Sea

The Sargasso Sea is subject to a variety of impacts from human activities. High fishing pressure has led to decreased abundance and heavy pressure on stocks of commercial fish species in the Sargasso Sea (Christensen et al. 2003). Maritime traffic (Laffoley et al. 2011), pollution, and marine debris (Carpenter and Smith 1972; Law et al. 2010) all affect the Sargasso Sea ecosystem. Maritime traffic can affect ecosystem functions and services through potential pollution, the introduction of invasive species, or the noise it creates. Marine litter is especially problematic in the area because the Sargasso Sea is within an ocean gyre in which plastic debris accumulates from around the region. Although unmeasured in the Sargasso Sea, maritime traffic can affect ecosystem functions and ecosystem services through intentional or accidental pollution, through the introduction of invasive species, collisions with marine mammals, through noise, or through vessels sinking. Climate change and changes in ocean chemistry (e.g. ocean acidification) are expected to have serious effects on oceans, including the Sargasso Sea. Environmental changes in the Sargasso Sea have been linked to changes in the recruitment of European eels from the region (Friedland et al. 2007).

The overall importance of *Sargassum* for fish has been recognized by the United States and by ICCAT. Following the 2002 Fishery Management Plan (South Atlantic Fishery Management Council 2002), the United States designated *Sargassum* as essential fish habitat (NMFS 2003). ICCAT has requested that contracting parties assess the ecological status of *Sargassum* as habitat for tuna, billfish, and sharks and has also asked countries to report on activities that may affect the abundance of *Sargassum* (ICCAT 2006, 2011). This was one of the first actions by ICCAT to address fisheries habitat, and it was followed in 2012 by a resolution (ICCAT Resolution 12-12) to "examine the available data and information concerning the Sargasso Sea and its ecological importance to tuna and tuna-like species and ecologically associated species." As a consequence, ICCAT is investigating the suitability of using the Sargasso Sea as a test case for ecosystem management with a view to reviewing the situation in 2015. Finally, on October 18, 2012, the Sargasso Sea was accepted by the 11th Conference of Parties to the Convention on Biological Diversity (Hyderabad, India) as an ecologically and biologically significant area (EBSA) under the criteria adopted by the Convention on Biological Diversity (CBD Decision XI/17, see also table 2 of the CBD Decision Annex).

Who Benefits from the Sargasso Sea?

The literature on the economic value of marine ecosystem services is large and growing, as illustrated by the more than 2,000 ecosystem service value estimates from more than 800 studies available through the Marine Ecosystem Services Partnership online database of ecosystem valuation studies (www.marineecosystemservices.org). Most of the literature to date focuses on coastal ecosystem services

[5] The *lost years* refer to the years during which hatchlings hide and grow in the *Sargassum*, which provides a relatively safe environment.

(e.g., Barbier et al. 2011), but at least a few studies provide value estimates for ecosystem services provided by the deep sea (Armstrong et al. 2010; Jobstvogt et al. 2013). There are only a handful of studies about the economic value of high-seas ecosystem services (Sumaila et al. 2013).

This report provides information from a limited but growing body of assessments of the economic contribution of the Sargasso Sea. Ideally, the measure of economic value would come from estimates of the net economic value (e.g., consumer surplus and producer surplus or profit) resulting from the provision of these services. However, such data are rarely available for the high seas. This report provides net values when available. When these values are absent, the study relies on other measures of economic activity and impact, including the gross revenues associated with ecosystem service activities. Gross revenues do not account for the costs of using an ecosystem service (e.g., conducting the activity). As such, gross revenues (e.g., the landed value for fish harvest) are overestimates of the value to producers of those ecosystem services for which they are associated. Even so, gross revenues capture important measures of economic activity and impact. These revenues support taxes, income, and jobs. It is equally important to note that gross revenues do not convey any information about the value of an ecosystem to the final consumer (i.e., consumer surplus). This report is an initial and admittedly incomplete picture of the economic contribution of the Sargasso Sea, especially its offshore ecosystems. It captures a small portion of the ecosystem services known to depend on a healthy ecosystem and does not reflect the net value of these services.

For a more complete understanding of the contribution of ecosystem services to human well-being and the interpretation of different measures of economic value and impact, the reader is directed to TEEB (2010b) and www.ecosystemvaluation.org.

All data in the report reflect annual economic contributions and are adjusted to 2012 U.S. dollar figures to account for inflation (unless otherwise noted). Many of these estimates are for past years; few were estimated recently, so they are only approximations of current values.

Previous Estimates of the Economic Value and Impact of Ecosystem Services of the Sargasso Sea

Different assessments have already been carried out to (directly or indirectly) estimate the potential economic value and impact of specific services provided by ecosystems around Bermuda, including the larger Sargasso Sea. Beukering et al. (2010) looked at the value of ecosystem services provided by Bermuda's coral reefs with a focus on the valuations of six ecosystem services.[6] Hallett (2011) looked at the contribution of the Sargasso Sea to the economy of Bermuda and its inhabitants. Hallett's report reviews ecological benefits with a focus on that portion of the Sargasso Sea within the Bermudan EEZ (out to 200 nautical miles [nm]) as well as the cultural, historical, and economic importance of the sea to Bermudians. Sumaila et al. (2013) provide economic impact data and some estimates of the rent (a measure of net economic value) for commercial fishing in the Sargasso Sea, the harvest of American and European eels, and the expenditures associated with recreational fishing. Iverson (2012) examined the benefits that could arise following the implementation of a Marine Protected Area (MPA) in the Bermudan EEZ with a focus on benefits related to tourism and research-related activities.

This report summarizes some of these studies and others with a particular focus on isolating those ecosystem services that depend on the ecosystem health of the Sargasso Sea, especially its offshore areas. Additionally, it pays special attention to the international and regional distribution of ecosystem service benefits that depend on the ecological functioning of the Sargasso Sea.

[6] The services are tourism, coastal protection, culture and recreation, amenities, fisheries, and research and education.

Selected Ecosystem Services

This report focuses on a selected set of final ecosystem services that can be tied directly to the ecological conditions of the Sargasso Sea (Table 1). Final services are "components of nature, directly enjoyed, consumed or used to yield human well-being" (Boyd and Banzhaf 2007). For example, fish are a final ecosystem service because they are used directly by humans, whereas the habitat that *Sargassum* provides for fish is an intermediate good that is not directly used or enjoyed by people. The Sargasso Sea provides many essential intermediate services, like spawning areas for certain fish species and habitats and feeding grounds for turtles, and it may provide new genetic resources that could be used in medicines, agriculture, and other final goods. For instance, Venter and colleagues found more than one million previously unknown genes in samples taken from the Sargasso Seas (Venter et al. 2004). Focusing on the final services does not mean the importance of intermediate service should be neglected. In fact, these intermediate services represent an important link among the Sargasso Sea's ecosystem health, its ecological function, and the ultimate economic importance of the Sargasso Sea.

This report focuses on ecosystem services that meet the criteria outlined earlier (e.g., have an ecological connection to the Sargasso Sea ecosystem, correspond to well-defined constituencies and user groups, and are likely to be threatened, in a very obvious way, because of the degradation of Sargasso Sea ecosystem health). It describes the ecology that underpins each ecosystem service, notes the current ecological status of the organisms central to the ecosystem services, and provides estimates of the economic impact or value of ecosystem services.

Table 1. Summary of the Ecosystem Services Provided by the Sargasso Sea.

Category	Final services	Description	Contribution of the Sargasso Sea
Provisioning	Commercial fishing (L, I)	Commercial fish (tunas, swordfish, etc.) are harvested directly in the sea by vessels. Other commercially important fish (e.g., eels) spend part of their life in the Sargasso Sea but are harvested elsewhere (Laffoley et al. 2011). Sea turtles are also harvested in some regions (Troëng and Drews 2004).	Spawning area, adult stage habitat, and area crossed during migration (Laffoley et al. 2011).
	Sargassum harvest (L, I)	*Sargassum* has been harvested for use as fertilizer (South Atlantic Fishery Management Council 2002). Several other uses (biofuel, cosmetics, etc.) are considered (Lenstra et al. 2011) but have not been developed.	The Sargasso Sea is a highly productive area for the production of *Sargassum* (Freestone 2013).
Cultural	Tourism in Bermuda (L)	One of the main economic sectors, tourism depends on a mild climate, clean beaches, and healthy coral reefs (Hallett 2011).	A healthy Sargasso Sea contributes to the attractiveness of Bermuda.
	Sport fishing, recreational fishing (L, I)	Recreational fishing (leisure activity) and sport fishing (competition), targeting species like blue marlin, white marlin, and blackfin tuna, are well developed in Bermuda and along the North American coast (Hallett 2011).	Habitat for adult fish and for fish during other life stages (Laffoley et al. 2011).
	Research and education activities (L)	Because of its access to relatively pristine deep and open oceans, the Sargasso Sea is an important research location, supporting jobs and generating revenue. Research activities include those undertaken by the Bermuda Institute of Ocean Sciences. Bermuda is a port of call for scientific expeditions and hosts the world's longest continuous open ocean time series of oceanographic measurements (Laffoley et al. 2011).	Researchers are drawn to the Sargasso Sea because of its near-pristine ecological condition.
	Turtle, bird, whale watching (L, I)	Wildlife watching (e.g., turtles, whales, and birds) supports business and human well-being along the North and Central American Atlantic coast, the Caribbean, and some West European and African coastal areas (O'Connor 2009; Haney 1986; Laffoley et al. 2011).	These species are present in the Sargasso Sea and/or spend some part of their life cycle in the Sea (Laffoley et al. 2011).
	Existence and cultural values (L, I)	The Sargasso Sea's rich ecosystem contributes to culture, especially in Bermuda (Hallett 2011). The sea is home to a unique ecosystem and to rare and charismatic species valued by some for their existence. *Sargassum* weed hosts 10 endemic species (Laffoley et al. 2011) that may yield existence value. European eels also have a potentially high cultural value (Prosek 2010).	The Sargasso Sea is a unique ecosystem that supports eels, sharks, whales, turtles and angler fish (Laffoley et al. 2011).

Regulating	Carbon sequestration (I)	The Sargasso Sea plays a role in the ocean carbon cycle (Laffoley et al. 2011).	The overall contribution of the Sargasso Sea to carbon sequestration, oxygen production, and nutrient cycling is an active field of research, e.g. Bates et al. (2002), Lomas et al. (2010), Laffoley et al. (2011, 2014).
	Coastal erosion prevention (L,I)	*Sargassum* consolidates sand and helps decrease shoreline and beach erosion (Thomas 2004).	Carried by winds and currents, *Sargassum* contributes directly to beach stabilization (Thomas 2004).

Note: Scale of geography where service is enjoyed: L = local benefits arising in Bermuda, I = international benefits spread in other regions than Bermuda.

ECOSYSTEM SERVICES VALUES AND ECONOMIC IMPACTS IN THE SARGASSO SEA

Fisheries

Fishing vessels from Bermuda harvest fish in the Bermuda EEZ. Vessels from other countries harvest in the larger Sargasso Sea and in the wider Atlantic Ocean, depending on the species harvested.

Among the fish caught in the wider Atlantic, some depend on the Sargasso Sea for at least part of their life (e.g., white and blue marlins).

More than 127 species of fish, including 80 species that reside offshore, are associated with *Sargassum* (Dooley 1972; Fedoryako 1980; Coston-Clements et al. 1991; South Atlantic Fishery Management Council 2002; Casazza and Ross 2008; Sutton et al. 2010). The importance of this habitat to commercial fisheries in the United States was recognized by the National Oceanic and Atmospheric Administration (NOAA) in 2002, when it designated *Sargassum* as an essential fish habitat (NMFS 2003).

The Sargasso Sea Summary Science report (Laffoley et al. 2011) notes that the Sargasso Sea also serves as an important habitat for many forage species (Gibbs and Collette 1959; Stephens 1965; Dooley 1972; Fedoryako 1980; Manooch and Hogarth 1983; Manooch and Mason 1983; Manooch et al. 1984, 1985; Coston-Clements et al. 1991; South Atlantic Fishery Management Council 2002; Casazza and Ross 2008; Rudershausen et al. 2010; Trott et al. 2011, Luckhurst 2013). Some commercially important species of fish (e.g., albacore tuna (*Thunnus alalunga*) and recreationally important species such as blue marlin (*Makaira nigricans)* and white marlin (*Tetrapterus albidus*) spawn in the Sargasso Sea (South Atlantic Fishery Management Council 2002; Luckhurst et al. 2006; White Marlin Biological Review Team 2007). Various species of eels, including European and American eels (*Anguilla* spp.) also spawn in the Sargasso Sea (Schmidt 1922; Schoth and Tesch 1982; Kleckner and McCleave 1988; McCleave and Miller 1994; Miller and McCleave 1994, 2007; Miller 2002).

The Atlantic bluefin tuna (*Thunnus thynnus*) migrates through the Sargasso Sea to northern feeding grounds (Lutcavage et al. 1999; Block et al. 2001, 2005; Wilson and Block 2009) as well as passing through the Sargasso Sea to the eastern Atlantic and the Mediterranean. Yellowfin tuna (*Thunnus albacares*), albacore tuna and swordfish (*Xiphias gladius*) are also known to migrate seasonally through the Sargasso Sea (Luckhurst, 2013). Tagging results indicate that bigeye tuna (*Thunnus obesus*) move from spawning grounds in the eastern tropical Atlantic to the Sargasso Sea and also further west into coastal U.S. waters (ICCAT 2010).

Eel Fishery

What: American eel (*Anguilla rostrata*) and the European eel (*Anguilla anguilla*)

Essential Eel Ecology: The Sargasso Sea supports eel fisheries in North America, Europe, and North Africa. Both the American eel (*A. rostrata*) and the European eel (*A. anguilla*) spawn in the Sargasso Sea and spend their adult life in freshwater on the continents (Schmidt 1922; Kleckner, McCleave, and Wippelhauser 1983; Friedland, Miller, and Knight 2007). For illustrative purposes, this report focuses on the ecological links between the Sargasso Sea and European eels, but a similar life history characterizes North American eels (U.S. Fish & Wildlife Service 2011).

European eels are thought to spawn in the southern part of the Sargasso Sea (Schmidt 1922; Kleckner et al. 1983; Friedland et al. 2007). Very little is known about their spawning migration.[7] It could take between one and three years for the larval eels (known as leptocephali) to reach European coasts (Bonhommeau et al. 2008). The leptocephali transform into "glass eels" on the journey shoreward. The eels reach Western Europe, the Mediterranean, and North African coasts (Miller and Hanel 2011) as elvers and develop into adults in rivers and streams—a stage called "yellow eels." After 6 to 20 years, the mature eels, known as "silver eels," return to their spawning grounds in the Sargasso Sea.[8]

Status: Eel landings have decreased dramatically over the past 40 years. Around 16,000 tons/year of European eels were landed in the 1970s, versus only around 5,000 tons/year in the early 2000s (ICES 2012). Glass eel recruitment in the coastal seas has also significantly decreased in the last decades (Laffoley et al. 2011). Since 2009, European eels have been listed on Appendix II of CITES (Convention of International Trade in Endangered Species of Wild Fauna and Flora, Miller and Hanel 2011), classified as "critically endangered" by the IUCN (Laffoley et al. 2011) and listed on Appendix II of CMS (Convention on Migratory Species – Nov. 2014). A Community Action Plan for the protection and recovery of the eel was adopted by the European Union in 2007 (Laffoley et al. 2011). This plan includes establishment of management plans at the river basin scale to reduce the human-induced mortality of these eels. A petition was sent to the U.S. Fish and Wildlife Service in 2004 to list the American eels under the Endangered Species Act.[9] It was refused at the time, but a new petition was filed in 2010.

Three types of commercial activity depend on eels that spawn in the Sargasso Sea: the wild-caught eel fishery, glass eel fishery, and glass eel farming. Table 2 summarizes data on the gross revenues associated with the harvest of eels that are dependent on the Sargasso Sea. (These gross revenues do not reflect the cost of harvesting, processing, or aquaculture or of subsidies that might exist in these sectors. As such, the gross revenues represent an overestimate of the net benefit of eels to producers. These gross revenues do not reflect the net value of these eels to consumers.)

Building on estimates of the landed catch of eels in Europe for 2009 (estimated at 10,500 metric tons), Sumaila et al. (2013) estimate that the total landed value of eels that depend on the Sargasso Sea is equal to US$125.8 million per year ($123.6 million for the European fleet and $2.2 million for the U.S. fleet), with profits (a measure of net value) estimated at $36 million per year.[10] The authors also estimate that the 2009 landings had a total economic impact of $360 million and an income effect of $60 million a year.[11] This includes benefits to Europe and the United States (not Canada). More recent estimates from ICES (2012), however, put European eel landings at only 3,201 tons for 2011—one-third of the landings

[7] See http://www.fao.org/fishery/species/2203/en.
[8] See http://ec.europa.eu/fisheries/marine_species/wild_species/eel/index_en.htm.
[9] See http://www.dnr.state.md.us/fisheries/fmp/2011/Section_1_American_Eel.pdf.
[10] Sumaila et al. (2013) used landings estimated by the Food and Agriculture Organization of the United Nations. This is based on landings from different years and assumes that the cost of fishing represents 70% of landed value.
[11] The economic impact is defined as "the amount of economic activity generated throughout an economy for every dollar of landed value of fish made." The income effect is "the amount of income generated in an economy for every dollar of landed value of fish" (Sumaila et al. 2013).

reported by Sumaila et al. (2013). It is not clear to what degree this difference reflects a reduction in catch or simply a different estimate of catch. A 2014 report (ICES 2014) finds that eel recruitment continues to decline and is at an all time low. Updating the European eels' landed value by using the same price of US$11/kg used by Sumaila et al. (2013) and the same methodology, this report estimates that the 2012 adjusted landed value of European eels was approximately US$35.9 million—considerably lower than the 2009 estimate by Sumaila et al. (2013).

Eels at a younger stage (glass eels) are harvested and sold to aquaculture industries. In 2012, an estimated 45.4 tons of European glass eels were caught (ICES 2012) mainly in France, Spain, and the United Kingdom (Gollock 2011). Due to high demand and low supply, the price of glass eels between 2008 and 2012 remained very high, ranging from €300 and €492/kg, that is, 2012 US$384–$630 (EIFAC, ICES 2012). This report estimates the total gross revenues in 2012 from European eel glass landings to be between $17.4 million and $28.6 million or $23 million per year on average.

Sumaila et al. (2013) estimated the landed value of adult eels caught in the United States at $2.2 million (2012 US$, annual average catch between 1983 and 1995).

American glass eel landings in the United States are only permitted in Maine and South Carolina (ASFMC American Eel Stock Assessment Peer Review Panel 2012). Prices of American glass eels exceeded $2,000/pound in 2012 (ASFMC American Eel Stock Assessment Peer Review Panel 2012), that is, $4,400/kg.

Less than 500 metric tons of American eels are caught in Canada every year (Engler-Palma et al. 2013). Assuming these landings are silver eels only and assuming landing prices similar to those in the United States (i.e., US$3.4/kg according to Sumaila et al. 2013), this report estimates the landed value of the Canadian silver eel harvest at $1.7 million (2012 US$). Landed value in Canada of American elvers in 1997 was estimated at $2.9 million (2012 US$). Therefore, this report estimates total Canadian landed value at around $4.6 million.

Glass eels are often captured to be used in eel aquaculture, mainly in the Netherlands, Denmark, and Germany.[12] European aquaculture production has been decreasing, from 8,000–9,000 tons in 2003 to 5,000–6,000 tons in 2010/2011 (ICES 2012). The global production of farmed *A. anguilla* peaked at the end of the twentieth century (FAO 2013).

[12] http://www.fao.org/fishery/culturedspecies/Anguilla_anguilla/en#tcNA00EA

Table 2. Summary of Gross Revenues Associated with Eel Harvests Dependent on the Sargasso Sea.

Country	Variable	Landed Weight (metric tons)	Price ($/kg)	Year	Landed Value (US$ 2012, rounded)
Europe	Silver eels	3,201 (ICES 2012)	$11/kg (Sumaila et al. 2013)	2011	35.9
	Glass eels	45.4 (ICES 2012)	€300–492/kg	2012	23.0
	Total revenues				58.9
U.S.	Landed value	—	—	Annual average catch 1983–1995	2.2 (Sumaila et al. 2013)
	Total revenues				2.2
Canada	Silver eels	500 (Engler-Palma et al. 2013)	$3.4/kg (Sumaila et al. 2013)	Average/yr	1.7
	Landed value of elvers	—	—	1997	2.9 (Meister and Flagg 1997)
	Total revenues				4.6

Key points

Gross Revenues from Eel Fishing

Approximately $66 million (2012 US$) in gross revenues are directly attributable to the Sargasso Sea through eels. These gross revenues are the highest in Europe ($59 million) and in North America ($7 million).

The European and Asian aquaculture industries depend on the harvest of European and American eels, but no data are available on the contribution of these eels to aquaculture. Eel harvest and aquaculture in Europe and North America is largely in decline due to the dramatic decline of wild eels. If the decline continues, the ecosystem service value associated with these eels also will decline. Conversely, improvements in eel management could increase the economic value associated with this Sargasso Sea–dependent ecosystem service.

Other Commercial and Recreational Fish Species Fisheries

General Ecology Linking Fish to the Sargasso Sea

What: Scombrids (e.g., bigeye, yellowfin, albacore, bluefin, and blackfin tuna) and billfish (e.g., blue and white marlin, swordfish) are found throughout the Sargasso Sea (Laffoley et al. 2011). Reef fish (groupers, grunts, etc.) also are found in *Sargassum* seaweed and in the Bermudian EEZ (Hallett 2011).

Essential Ecology of Commercial and Recreational Fishes: *Sargassum* mats and the Sargasso Sea ecosystem in general provide important fish habitat for feeding and spawning as well as juvenile habitat. Adult tuna, wahoo, and marlins prey on species that are associated with *Sargassum* mats (Rudershausen et al. 2010; Luckhurst 2013). Flyingfish (Exocoetidae) use *Sargassum* mats as a spawning substrate and this family forms one of the principal prey groups of pelagic predators (Luckhurst 2013). Rudershausen et al. (2010) observed that prey associated with *Sargassum* communities are often taken by dolphinfish and yellowfin tuna.

Status: Laffoley et al. (2011) review the status and ecology of commercially and recreationally important fish species associated with the Sargasso Sea (see Table 3).

Table 3. Examples of Economically Valuable Fish Species Depending on the Sargasso Sea, Their State, and Use of the Sargasso Sea.

Fish species	Use of the Sargasso Sea (Laffoley et al. 2011; Luckhurst 2013)	Where Fished	IUCN Status (Laffoley et al. 2011)
White marlin	Spawning, seasonal foraging ground	North Atlantic	Near threatened
Blue marlin	Spawning, seasonal foraging ground	North Atlantic	Near threatened
Albacore tuna	Migration route, foraging, spawning area	North Atlantic	Near threatened
Atlantic bluefin tuna	Migration route, feeding	West and East Atlantic, Mediterranean (Laffoley et al. 2011)	Endangered
Yellowfin tuna	Migration route, feeding	Atlantic	Near threatened
Bigeye tuna	Migration route, feeding	Atlantic	Vulnerable
Swordfish	Migration route	West Atlantic (Laffoley et al. 2011)	n/a

Source: If not otherwise specified, information is from the ICCAT Statistical Bulletin 2013, http://iccat.int/sbull/SB41-2-2013/Docs/S1/S1-f1.pdf and Sumaila et al. (2013).

Economics of Commercial Fishing within the Sargasso

Sumaila et al. (2013) analyze catch data from the FAO data set to understand the economic impact, value, and distribution of fish landings taken from place in the Sargasso Sea. The authors estimate gross revenues, income effects, and the total economic impact (defined as the total economic activity generated for every dollar of landed value) associated with commercial fishing in the Sargasso Sea (see Table 4). Annual gross revenues derived from commercial fishing directly in the Sargasso Sea exceed $98 million.[13] Of this amount, approximately $42 million represents the net economic value.[14]

[13] This figure corresponds to the landed values less the cost of fishing and the subsidies.

[14] In addition, Luckhurst (2014) analyzed the landings reported by ICCAT for the six main commercial species (five tuna species, swordfish) taken in the Sargasso Sea over a 20-year period (1992–2011), but no economic valuation was attempted.

Table 4. Distribution of the Annual Landed Value, Income Effect, Rent, and Economic Impact from Commercial Fishing in the Sargasso Sea (rounded millions, 2012 US$).

Origin of Vessels	Landed Value	Total cost	Total subsidy	Rent less subsidies	Income effect	Economic impact
Mexico, South/ Central America, Caribbean	58.3	29.5	11.3	17.5	18.9	77.0
Bermuda	0.7	0.078	0.315	0.326	0.943	5.3
United States and Canada	7.4	3.8	0.714	2.9	9.4	22.6
Asia	28.7	3.6	3.0	22.1	25.3	81.7
Europe	3.8	2.4	2.4	–1.0	3.8	14.8
Total	98.9	39.378	17.729	41.826	58.343	201.4

Source: Sumaila et al. (2013).

All of the principal pelagic commercial fish species caught in the Sargasso Sea are highly migratory and, as a consequence, they are also found outside of the area and are harvested throughout the Atlantic. Sumaila et al. (2013) compare landed values of selected species in the Sargasso Sea with the same species caught elsewhere in the Atlantic. The harvesting of selected tuna and billfish in the Atlantic generates more than $1 billion annually. The economic contribution of the Sargasso Sea to these valuable fisheries is unquantified but clearly deserves further attention because critical ecological functions that support these species occur in the Sargasso Sea.

Key points

Gross Revenues from Commercial Fisheries

Around $99 million (2012 US$) of gross revenues are directly attributable to the Sargasso Sea through commercial fisheries (relying on fish species other than eels). Developing countries are the largest beneficiaries. Many of the fisheries' species are threatened; some are vulnerable or endangered.

A substantial proportion of fisheries outside of the Sargasso Sea also depend on the health of the sea. For instance, Sumaila et al. (2013) found that the gross revenues associated with selected Atlantic tuna and billfish exceeds $1 billion (2009 US$). The proportion of these revenues that is dependent on the Sargasso Sea is unquantified and clearly deserves further study.

Economics of Recreational Fishing and Sport Fishing

Bermuda has become known in recent years as a prime location to catch large blue marlin (Luckhurst et al. 2006). Limited information exists on the economic impact or value of recreational and sport fishing linked to the Sargasso Sea but these fishing activities in the Bermuda EEZ are most likely strongly linked to the Sargasso Sea. A study by Hellin (1999) estimated the annual gross revenues of the Bermudan recreational fishery for pelagic species at $311,000. Bermuda has gained a reputation as a destination where anglers can catch exceptionally large (>1,000 pounds) blue marlin (Luckhurst et al. 2006), and anglers, mainly from the United States, visit Bermuda during the summer for international billfish

tournaments (Hallett 2011). Foreign sport fishing vessels often spend several weeks based out of the island for these tournaments, contributing to local economic activity. In 2010, 21 foreign sportfishing vessels visited Bermuda, with an average of four crew members on board in addition to the boat's owner (Bermuda Government Dept. of Environmental Protection, Marine Resources Division). Hallett (2011) estimates that the total expenditure by foreign anglers participating in seasonal tournaments in 2010 was $630,000 (adjusted to 2012 US$).

The Sargasso Sea ecosystem is likely to be economically important for recreational fishing beyond its waters. Recreational fishing and sport fishing events generate revenues in regions such as the Americas as well as in Europe. According to the Billfish Foundation, North Americans traveling to Costa Rica to fish generated $640 million (2012 US$) in 2008—about 2% of Costa Rica's gross domestic product.[15] This amount includes expenditures on travel, restaurants, fishing guides, and transportation. Sport fishing also created $78 million in tax revenues and 63,000 jobs for Costa Rica. How much sport fishing depends on conditions in the Sargasso Sea is not well documented.

The nearby Azores are known as one of the best places in the world to catch marlin. Events organized by the Portuguese Federation of High Sea Sports involve 22 big-game teams, 18 senior boat teams, and 8 boat angling teams. Teams come from 21 countries, including the United States, Egypt, Angola, South Africa, and Mexico. Each team pays between €5,700 and €6,600 for transport, hotel, meals, boat rental, and other costs (Pawson et al. 2007), equivalent to total expenditures of €125,400 to €145,200 for 22 teams in 2007 (on average €135,300, or $220,268 just from the events organized by this federation).

Finally, recreational fishing for scombrids and billfish in the United States and Europe may depend on the ecological health of the Sargasso Sea. In the United States in 2011, more than 2.3 million people participated in recreational fishing (all species combined) in the South Atlantic region, the area most likely under the influence of the Sargasso Sea (NMFS 2012). As an example, during this period, recreational fishing in the South Atlantic region of the United States generated $6.5 billion in terms of expenditures associated with fishing trips and equipment (NMFS 2012). Recreational fishing in the nearby Gulf of Mexico generated $10.5 billion (National Marine Fisheries Services 2012) in associated expenditures on fishing trips and gear. Although the contribution of the Sargasso Sea ecosystem to this recreational fishery is unquantified, the report estimates provide an upper bound (i.e., what is at stake) on U.S. recreational fishing expenditures in areas that could be ecologically linked to the Sargasso Sea. That upper bound was $17 billion in 2011 (2012 US$17.3 billion).

Key points

Gross Revenues from Recreational Fishing

More than $600,000 (2012 US$) in gross revenues are generated in Bermuda through recreational fishing. What proportion of expenditures remains in Bermuda is unknown.

Recreational fishing in the Atlantic is a well-developed activity that generated as much as $17.3 billion of gross revenues in the Atlantic region of United States. The economic contribution of the Sargasso Sea to recreational fishing, especially as a key spawning area for recreationally important fish, has not been quantified and deserves further investigation.

[15] See http://www.billfish.org/research/socioeconomics/.

Wildlife Viewing

Whales

General Ecology Linking Whales to the Sargasso Sea

What: Thirty species of cetaceans have been recorded in the Sargasso Sea (Laffoley et al. 2011). Whale watching relies on a small number of charismatic species.

Essential Ecology of Cetaceans in the Sargasso Sea: The Sargasso Sea is a major migratory route for humpback whales (*Megaptera novaeangliae*), the species most observed by whale watchers. Sperm whales (*Physeter catodon*) live throughout the Sargasso Sea (Antunes 2009; Laffoley et al. 2011).

Status: The population of North Atlantic humpback whales was estimated at approximately 12,000 in 2003. With the population growing at 3.5–6.5% a year (Stevick et al. 2003), the total population may have reached 17,000—a population size similar to pre-exploitation levels (Estes 2006). Sperm whale populations were still only at 32% of their pre-exploitation population of 1,110,000 in 1999 (Whitehead 2002). Sperm whales are classified as vulnerable in the IUCN Red List of Endangered Species (Laffoley et al. 2011).

Economics of Whale Watching

Worldwide, the whale watching industry generates $2.1 billion of total expenditures annually (O'Connor et al. 2009). Utech et al. (2000) estimate expenditures per day per whale watcher in Hawaii at $46.26. The link between the whale-watching industry and the Sargasso Sea is not yet quantified. The ecological health of the Sargasso Sea is likely to be important for whale-watching industries in the Caribbean, New England, Bermuda, and along the Canadian East Coast.[16] There is, for example, an agreement between Bermuda and Stellwagen Bank to protect North Atlantic humpback whales.[17] In 2008, whale watching in these countries served more than 3 million whale watchers annually. It supported more than 600 whale watching businesses with operations in the North Atlantic and Caribbean, representing more than 4,600 jobs, generating nearly $138 million of direct revenues and as much as $374 million in associated tourism spending annually (O'Connor 2009; see Table 5).[18] Cisneros-Montemayor et al. (2010) find that whale watching in most countries is underdeveloped and could be substantially higher, generating more jobs and income.

[16] For example, changes in forage or water quality in the Sargasso Sea could affect whale health. Whaling in Iceland and Norway may also be linked to the Sargasso Sea, but no scientific sources have been found, so figures are not integrated here.
[17] See http://stellwagen.noaa.gov/sister/pdfs/bermuda_ssfs12.pdf.
18 Direct expenditures correspond to the whale-watching ticket price. Indirect expenditures are defined as expenditures by the participant that support the whale-watching trip.

Table 5. Total Expenditures of the Whale Watching Industry, in Places Potentially Linked to the Sargasso Sea.

	Number of Whale Watchers in 2008	Number of Operators in 2008	Estimated Jobs in 2008	Direct Expenditures in ($'000)	Indirect Expenditures in ($'000)	Total Expenditures in ($'000)
Europe	3,950	12	14	380	787	1,200
North America	3,052,785	436	4,426	107,400	361,400	468,800
Bermuda	250	4	4	18,000	16	34
South and Central America	144,238	150	235	12,300	11,800	24,200
Total	3,201,223	602	4,679	138,080	374,003	494,234

Source: Adapted from O'Connor et al. (2009), adjusted to US $2012.

Additionally, whale watching provides economic benefits to tourists that are not reflected in the estimates of whale-watching revenues. For instance, in California, the consumer surplus per person per whale-watching day was estimated at $36.09 in 1999 (2012 US$49.70) by Leeworthy and Wiley (2003).[19] Hoagland and Meeks (2000) estimate the consumer surplus per person per whale-watching day in 1996 in the Stellwagen Bank National Marine Sanctuary, located in Massachusetts Bay, at $25.90 (2012 US$37.90). Combining the number of whale watchers estimated by O'Connor (2009) with these consumer surplus values, this report estimates roughly that the consumer surplus associated with Atlantic whale watching could be $140 million (2012 US$) annually.

Some people may hold existence values for whales. Loomis and Larson (1994) estimate that a 50% increase in whale populations would lead to an increase in the consumer surplus of Californian households of $27.27 (2012 US$42.25). This value includes both use value and existence value.

[19] Consumer surplus is an estimate of willingness to pay beyond what is actually paid and is considered a reflection of economic value to the consumer.

Key points

Gross Revenues from Whale Watching

Whale watching in Bermuda annually generates $34,000 (2012 USD) in gross revenues attributable to the Sargasso Sea.

Whale watching in the Atlantic, which is potentially linked to the Sargasso Sea, generates more than $490 million annually. The dependence of these revenues on the health of the Sargasso Sea is unquantified.

The consumer surplus associated with watching whales that may potentially depend on the Sargasso Sea may be important (on the order of $100 million annually).

Turtles

General Ecology Linking Turtles to the Sargasso Sea

What: Green turtles (*Chelonia mydas*), hawksbill turtles (*Eretmochelys imbricata*), loggerhead turtles (*Caretta caretta*), Kemp's Ridley turtles (*Lepidochelys kempii*), and leatherback turtles (*Dermochelys coriacea*) have all been reported from the Sargasso Sea.

Essential Ecology of Sea Turtles: Several species of sea turtles use the Sargasso Sea as a sheltering habitat from predators as well as a feeding area (Laffoley et al. 2011). *Sargassum* provides nursery habitat for green turtles, hawksbill turtles, loggerhead turtles, and Kemp's Ridley turtles (as cited by Laffoley et al. 2011; Carr and Meylan 1980; Carr 1987; Schwartz 1988; Manzella and Williams 1991). These species are all endangered or critically endangered (Laffoley et al. 2011).

Leatherback turtles migrate from their nesting sites in the Caribbean Sea to the North (New England, Nova Scotia) or to West Africa.[20] The most important nesting area for leatherbacks in the western Atlantic is French Guyana (Eckert et al. 2012). In the United States, the main nesting areas for leatherback turtles include the Atlantic coast of Florida, the U.S. Virgin Islands, and Puerto Rico (Eckert et al. 2012). Kemp's Ridley turtles inhabit coastal waters along Florida but do not nest there (Meylan et al. 1995) and their stock is now thought to be increasing (Bräutigen and Eckert 2006). Richards et al. (2011) estimate the North Atlantic population of female adult loggerhead turtles at around 38,000 and nests in Florida at around 70,000.[21] In 2014, the U.S. National Marine Fisheries Service (NMFS) identified *Sargassum* habitats as "critical" for loggerhead turtles (NMFS 2014).

Florida is one of the largest nesting areas for green turtles in the Caribbean Sea and the western Atlantic Ocean (Meylan et al. 1995).

Status: Loggerhead turtles and green turtles are classified as endangered on the IUCN Red List. Hawksbill turtles, Kemp's Ridley turtles, and leatherback turtles are classified as critically endangered (Laffoley et al. 2011). Hawksbill turtle populations experienced a 63% decline between 1999 and 2004 in Panama—an area that used to be the largest nesting colony in the Western Caribbean region (Bräutigen and Eckert 2006).

[20] Laffoley et al. (2011), refer to James et al. (2005).

[21] Sea turtles often lay several nests per season, depending on the clutch frequency, which in turn depends on each individual and the area, making it difficult to extrapolate the number of individuals on the basis of number of nests.

Economics of Turtles

Like whale watching, turtle watching generates revenues for local businesses and consumer surplus benefits for turtle watchers. Turtles also are eaten or sold for food in some tropical and sub-tropical areas.

A leatherback turtle breeding area in Trinidad and Tobago was estimated to have generated between $60,825 and $97,320 in revenues from turtle-watching tours (Save Our Sea Turtles 2012). Troëng and Drews (2004) examined nine case study sites where turtles generated value in developing countries (see Table 6). At these sites, tourism related to marine turtles (that may be dependent on the Sargasso Sea) generated between $115,000 and $8,576,000 annually, an average of $3 million a year. Gross revenues were estimated by multiplying average total expenditures (food, accommodation, transport) by the number of tourists participating in sea turtle observations. Gross revenues at three sites where marine turtles are one of many attractions vary between $4,000 and $135,000 annually, an average of $50,000 each year.

Table 6. Gross Revenues from Turtle Watching in Locations Potentially Linked to the Sargasso Sea.

Case study	Year	Turtle Species	Estimated Rounded Gross Revenue (2012 $'000)
Major revenue generator			
Tortuguero, Costa Rica	2002	Green turtles	8,576
Projeto TAMAR, Brazil	2001	Loggerhead, hawksbill, Olive Ridley	3,380
Playa Grande, Costa Rica	2002	Leatherback	2,688
Matura, Trinidad and Tobago	2001	Leatherback	716
Grandoca, Costa Rica	2003	Leatherback	115
One of many activities			
Barbados	2003	Green	135
Brazil	2002	Loggerhead	12
Cape Verde	2002	Loggerhead	4
Total			15,626

Source: Adapted from Troëng and Drews (2004).

Sea turtles migrate, so the ecosystem services provided by turtles observed within the Sargasso Sea may also be enjoyed at other sites visited by these turtles. Given that sea turtles are mostly seen when they nest (Richards et al. 2011), understanding the location of nesting areas is essential to identify where the benefits arise from turtles supported by the Sargasso Sea.

Turtle watching takes place along the U.S. East Coast, although no expenditures data are available for this area.

Turtle watching also generates nonmarket values. A survey implemented by Oceana estimates that American scuba divers are willing to pay on average an additional $29.63 (US$32.81 in 2012USD) per dive to see sea turtles.[22] Along North Carolina, willingness to pay per household per year for loggerhead sea turtle protection (including use and nonuse value) was estimated at $10.98 in 1991 (US$18.51 in 2012USD) (Whitehead 1992).[23]

Finally, Troëng and Drews (2004) estimated the revenues from consumptive uses of turtles (e.g. sales of turtles for food or shells) at between $158 and $1.7 million at the sites studied, an average gross revenue of $0.6 million (adjusted to 0.7 million in 2012USD).

Key points

Gross Revenues from Turtle Watching

Gross revenues from turtle watching directly attributable to the Sargasso Sea are unquantified.

Revenues from turtle watching along Atlantic coasts are potentially linked to the Sargasso Sea. More than $15 million annually in direct and indirect expenditures by turtle watchers were found for nine sites in Central America, the Caribbean, and Africa for turtles that may depend on the Sargasso Sea. The fraction of these expenditures that can be tied to the condition of the Sargasso Sea ecosystem has not been quantified.

Research and Education

The Sargasso Sea has long attracted oceanographic and biological researchers. Bermuda's location, close to the United States and close to deep-water ecosystems in the center of the Sargasso Sea, has led to establishment of long-term oceanographic research sites within the Bermuda EEZ. Because of Bermuda's unique characteristics and dependence on a healthy Sargasso Sea ecosystem, this report includes expenditures on marine research and education in its examination of ecosystem services. Although gross revenues and expenditures associated with research and educational activities in the Sargasso Sea are locally important, an estimate of the global value of research is much harder to discern and would involve understanding how such research is used to benefit humankind. A study commissioned by the Pew Environment Group to estimate the potential value of a "blue halo" reserve (marine protected area) in the Bermudian waters of the Sargasso Sea found that current direct spending by researchers working at the Bermuda Institute of Ocean Sciences amounts to approximately $12–$13 million a year (Iverson 2012). Laffoley et al. (2011) estimate that nearly $100 million was spent by the U.S. government and U.S. research institutions over the past 50 years to support time-series and other research projects undertaken in the Sargasso Sea. Several other countries are funding research in the Sargasso Sea, but figures were not available to estimate these contributions. This estimate shows that research is an important activity with benefits that should be investigated in more detail. Additionally, the benefits humans get from a better understanding of ocean functioning should not be neglected.

[22] See http://oceana.org/sites/default/files/reports/SeaTheValue_Final_web1.pdf.
[23] Available online: http://ageconsearch.umn.edu/bitstream/48812/2/18824875.pdf.

Key points

Gross Expenditures from the Research Sector
Some $12 million is spent annually by the Bermuda Institute of Ocean Sciences. Bermuda benefits from the direct expenditures associated with research in the Sargasso Sea; other nations and the world benefit from the final goods and services produced by research discoveries and new knowledge. Total budget allocated to research linked to the Sargasso Sea is expected to be very important and could be significant for the Bermudian economy.

Discussion

The preceding summary of the economic impacts and value of ecosystem services that may be linked to the ecological health of the Sargasso Sea reveals our emerging understanding of the importance of this ecosystem to human well-being. Indeed, this ecosystem provides a suite of services that benefit people and economic activities and are also dependent upon the ecological condition and health of the Sargasso Sea ecosystem. These services include:

- **Provisioning services,** such as commercial fishing;
- **Cultural services**, such as tourism in Bermuda, sport fishing, recreational fishing, education, turtle, bird, and whale watching;
- **Regulating services**, such as carbon sequestration or coastal erosion prevention.

In addition, the Sargasso Sea has an economic value because of its existence as a unique ecosystem and home to rare and charismatic species. The relatively remote nature of the Sargasso Sea, free from many terrestrial impacts, generates opportunities for research that are not found elsewhere.

Quantifying the services provided by the Sargasso Sea is a challenging task. Knowledge about the economic value and impact of these services is mostly limited to the potential gross expenditures and revenues associated with activities that may be linked to the ecological health of the sea. Equally limited is knowledge about the causal relationships between the ecological state of the Sargasso Sea and the services it provides. The economic data presented here are of a heterogeneous nature and include landed values of fish, gross expenditures from practitioners of sea-related activities, gross revenues from tourism, the annual budget of a research organization, and even estimates of consumer surplus, profit, and possible existence values. These estimates cannot be summed because they represent different aspects of economic activity and value. Even so, the available data shed light on critical aspects of the economic contribution of the Sargasso Sea to human well-being:

- The **economic importance of the Sargasso Sea is significant**. Economic expenditures and revenues directly or potentially linked to the Sargasso Sea total anywhere between tens to hundreds of million dollars a year.
- **The greatest economic impacts associated directly with the Sargasso Sea come from commercial fishing of pelagic species** (gross landed value of approximately $100 million/year) **and eel fishing** ($66 million/year)**.**

- Very **large gross expenditures are potentially linked to the Sargasso Sea from whale watching** in other parts of the Atlantic Ocean (estimated at nearly $500 million/year). The proportion of these expenditures that are dependent on the ecological condition of the Sargasso Sea could not be estimated.

- **A healthy Sargasso Sea benefits human activities and people who live within the Sargasso Sea region, especially in Bermuda**. That country receives direct economic benefits from whale watching and from commercial and sport fishing.

- The **Sargasso Sea also benefits people of other regions of the world**. In particular, European fishers benefit from eel fishing (receiving approximately 90% of estimated total gross eel-fishing revenues); North American fishers also benefit from this activity. Based on recent estimates by Sumaila et al. (2014), fishing vessels from the Americas also benefit from commercial fishing in the Sargasso Sea (more than 66% of the estimated total landed value for the Sargasso Sea). North American businesses and tourists receive most of the benefits of whale watching in other seas (about 95% of the total value estimated). Central and South American communities as well as Caribbean nations benefit from revenues generated by turtle watching. Estimates of this activity's economic impact exceed $15 million/year at selected locations, but the share of this value attributable to the Sargasso Sea remains unquantified.

The Sargasso Sea is a central cog in the North Atlantic ecosystem and a key element in the production of ecosystem services throughout the region. The Sargasso Sea produces ecosystem services that are enjoyed locally and throughout the Atlantic nations; it may even generate non-use and regulating services that benefit people globally. Our estimates of the economic value and impact of the services provided by a healthy Sargasso Sea support the call for the active management of this ecosystem. They also show that protecting the Sargasso Sea is in the interest of the inhabitants of Bermuda and of organizations and inhabitants from other continents.

Many components of the economic value and impact of Sargasso Sea ecosystem services are as yet unquantified. These include *inter alia*:

- The role of the Sargasso Sea in supporting **bird life** enjoyed by bird watchers and **sea life** viewed by scuba divers, snorkelers, and others;

- The economic value of the **contribution of *Sargassum*** to the creation of beaches and shoreline protection, carbon sequestration, oxygen production, and biodiversity protection;

- The **cultural values of organisms that depend on the sea,** such as those of eels to Nordic peoples;

- Passive use values, including the existence of charismatic species and rare or threatened species like whales, turtles, sharks, and emblematic species (e.g., the Sargassum anglerfish) as well as potential option values for organisms that are as yet undiscovered.

- The existence value of the organisms that live in or depend on the Sargasso Sea, including rare or threatened species like whales, turtles, sharks, and emblematic species (e.g., anglerfish). All of these organisms may be valued for their mere existence and may add value to the existence value

of the Sargasso Sea as a unique ecosystem.[24] Other organisms may provide ecosystem functions or services that are still undiscovered. These values have yet to be quantified.

Given the potentially large amount of economic activity and value that may be tied to the health of the Sargasso Sea ecosystem and the potential economic benefit of improved management, the scientific community will need to increase its empirical understanding of the economic values of the Sargasso Sea and its ecosystem goods and services. In addition to carrying out research on the missing components of the total economic value of the Sargasso Sea, additional work is required to improve the values estimated in this report. Table 7 highlights possible areas for further research that would help provide more robust estimates of economic values.

[24] For instance, American families were willing to pay $73 per household to help the recovery of the North Pacific right whale (Lew and Wallmo 2011).

Table 7. Potential Candidate Areas for Further Research on Economic Values and Impacts of the Sargasso Sea.

Ecosystem service provided by the Sargasso Sea	Main focus of further research
Eel fishing	Costs of eel and glass eel fishing
	Contribution of eels to Asian and European aquaculture
Commercial fishing	Distribution of revenues and profits from fish depending on the Sargasso Sea, caught in the Atlantic (per species and per country)
Recreational fishing and sport fishing	Expenditures and profits for the species linked to the Sargasso Sea (per species/per country)
	Consumer surplus associated with specific species dependent on the Sargasso Sea
Whale watching	Economic impact, profit, and consumer surplus of the whale watching industry with a focus on Sargasso Sea–dependent whales
Turtle watching	Expenditures, profits, and consumer surplus for turtle watching in North America with a focus on turtles dependent on the Sargasso Sea
Research and education activities	Budget allocated by countries to research projects linked (directly and indirectly) to the Sargasso Sea
	Economic impact of research and education activities in Bermuda
	Use and value of research emanating from the Sargasso Sea
Existence and cultural values for…	Eels, scombrids and billfish, whales, sea turtles

Researchers are only now beginning to realize the potential economic importance of high-seas ecosystems, the economic costs of failing to manage them, and the value of better management. This report merely scratches the surface of the economic importance of the Sargasso Sea.

GLOSSARY

Consumer surplus: The difference between what one pays for a good or service and what one is willing to pay.

Economic impact: Represents a measure of economic activity other than net value and can include gross revenues, jobs, and wages.

Economic value: Represents the net economic improvement in human well-being and is commonly measured by contributions to consumer surplus, producer surplus (e.g., rent), or the combination of the two, which is known as "net social surplus."

Ecosystem services: Benefits of nature to households, communities, and economies (Boyd and Banzhaf 2007).

Ecosystem functions: Can be defined as ecological processes. They allow for ecosystem services provision and contribute indirectly to human well-being. Primary productivity and water cycle are examples of ecosystem functions.

Ecosystem services approach: Can be defined as a framework that includes computing monetary values of ecosystem services to integrate these values in global economic assessments (Armstrong et al. 2010)

Gross revenues: Total amount of money generated by an activity. Gross revenues differ from net revenues. Net revenues are equal to gross revenues less activity costs and subsidies.

Human well-being: Broadly measured by material life conditions (e.g., income, housing) and general quality of life (health status, environmental quality, personal security). See http://www.oecd.org/statistics/OECD-ICW-Framework-Chapter2.pdf.

Producer surplus: The difference between what a producer receives for a good or service and the minimum amount that producer would be willing to accept to produce the same good or service.

Total economic value: "A framework for considering various constituents of value, including direct use value, indirect use value, option value, quasi-option value, and existence value" (TEEB 2010b).

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