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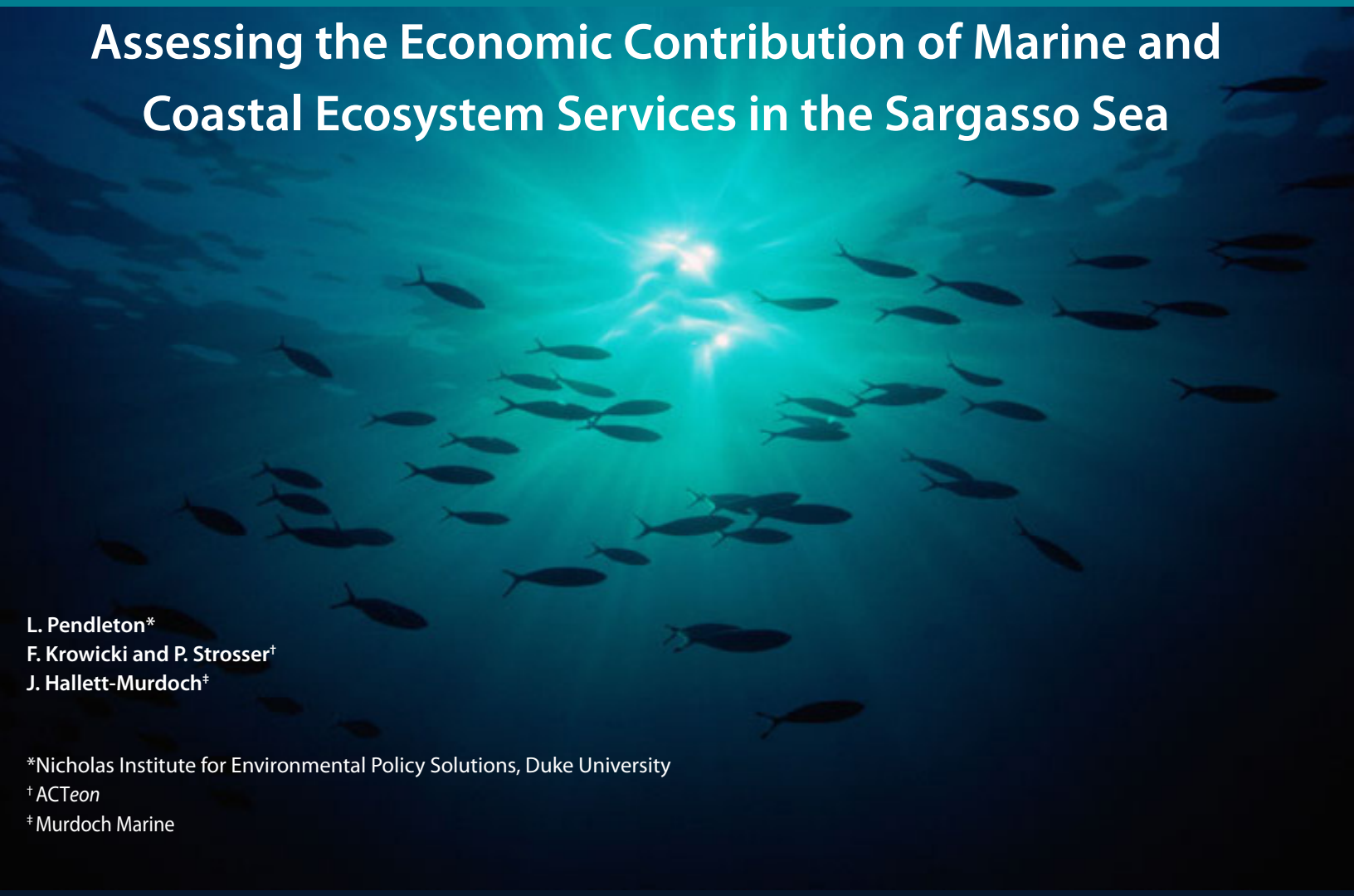
Assessing the Economic Contribution of Marine and Coastal Ecosystem Services in the Sargasso Sea



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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 only part of the life cycle of organisms that ultimately benefit people far from the region (e.g., eels spawn in the Sargasso Sea and 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 to society 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.)

This report is an initial and admittedly incomplete picture of the economic contribution of the Sargasso Sea. It captures just a small portion of the ecosystem services known to depend on a healthy Sargasso Sea and does not reflect the complete and total net value 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 and *Sargassum* harvest;
- **Cultural services,** such as tourism in Bermuda, sport fishing, recreational fishing, education, research and protection activities, and turtle, bird, and whale watching; and
- **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. Moreover, the pristine nature of the Sargasso Sea generates opportunities for research that are not found elsewhere. We include these research values as part of our assessment of educational values.

Key findings of this research include 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** (gross landed value of some $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). Only a portion of these expenditures can be attributed to the Sargasso Sea. These expenditures could not be quantified because there is no research or data to measure the importance of the Sargasso Sea to whales that live in that sea during part of their lives.

- 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 sport fishing. Its coral reefs, which are supported by the outer edges of the Sargasso Sea ecosystem, provide shoreline protection** and **recreational/cultural opportunities**.

- 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. **Central and Southern America fishing fleets** benefit from **commercial fishing** in the Sargasso Sea (receiving approximately 60% of the estimated total landed value). 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 benefit from revenues generated by turtle watching. Estimates of this activity's economic impact exist only for Central and South America (around $15 million/year), and only a share of this value is attributed to the Sargasso Sea.

Overall, the Sargasso Sea is a central element in the North Atlantic marine ecosystem and in the production of ecosystem services that are enjoyed locally and throughout the Atlantic nations. It may even generate nonuse and regulating services that benefit people globally. The large estimates of the Sargasso Sea's economic value and of the impact of the services provided by a healthy Sargasso Sea ecosystem **call for the active management of this ecosystem**. They also underscore the understanding 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 Central and South America (commercial fishing).

Many **components of the economic value and impact of Sargasso Sea ecosystem services remain unknown**. These components include:

- C**ontributions to bird life** enjoyed by bird watchers and to sea life viewed by scuba divers, snorkelers, and others;

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

- U**se values that could come from a sustainably managed *Sargassum* harvest**;

- **Cultural values** such as those of eels to Nordic and upper-latitude peoples;

- Existence values of charismatic species, including rare or threatened species like whales, turtles, sharks, and emblematic species (e.g., anglerfish) as well as organisms that are as yet undiscovered.

Strengthening integrated biophysical and socio-economic research is a pre-requisite to 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. To understand 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 both the data and the 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.

Table ES-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, marlins etc.) are harvested directly in the sea by vessels from many nations. Other commercially important fish (e.g., eels) spend a 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, or area crossed during migration (Laffoley et al. 2011).
	Sargassum harvest (L, I)	*Sargassum* can be harvested to be used as fertilizer (South Atlantic Fishery Management Council 2002). Several other uses (biofuel, cosmetics, etc.) are considered (Lenstra et al. 2011), but no development of these uses exists currently.	The Sargasso Sea is a highly productive area for the production of *Sargassum* (Freestone 2013).
Cultural	Tourism in Bermuda (L)	Tourism is one of the main economic sectors in Bermuda. It depends on a mild climate, clean beaches, and healthy coral reefs (Hallett 2011).	A healthy Sargasso Sea contributes to the attractiveness of Bermuda. Coral reefs are important for snorkeling tourism (Beukering et al. 2010).
	Sport fishing, recreational fishing (L, I)	Recreational fishing and sport fishing, targeting species like marlin and tuna, is 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 near-pristine deep and open oceans, the Sargasso Sea has been an important research location, supporting jobs and revenue generation in Bermuda. Research activities include the Bermuda Institute of Ocean Sciences. Bermuda is also a port of call for scientific expeditions and hosts the world's longest continuous open ocean time series (Laffoley et al. 2011).	Researchers are drawn to the Sargasso Sea because of its pristine ecological condition.
	Turtle, bird, and 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 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 that some may value 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 is a site of high primary productivity that leads to carbon sequestration, much of which is recycled by bacteria that may play a key role in ocean carbon sequestration (Laffoley et al. 2011). Carbon sequestration reduces green house concentrations in the atmosphere, which has global benefit.	The overall contribution of the Sargasso Sea to carbon sequestration, oxygen production, and nutrient cycling is under study (Bates et al. 2002; Lomas et al. 2010).
	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).

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

CONTENTS

ABBREVIATIONS

EBSA	Ecologically and 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 the Sargasso Sea lies in an area beyond national jurisdiction, 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 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 medicinal 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] Finally, it highlights critical knowledge gaps that need to be filled to help inform management of the Sargasso Sea.

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.[2] 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 can support ecological functions that in turn affect the goods and services people enjoy. *Ecosystem services* are defined as the benefits of nature to households, communities, and economies (Boyd and Banzhaf 2007).

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

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 only 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

- for which there is at least some evidence of an ecological connection to the Sargasso Sea,
- that correspond to well-defined constituencies and user groups, and
- that 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 ecosystem services, such as soil formation, photosynthesis and nutrient cycling (MA 2005).[3] The Sargasso Sea provides all these types of services, but because of data limitations, we provide economic information only for provisioning and cultural services.

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

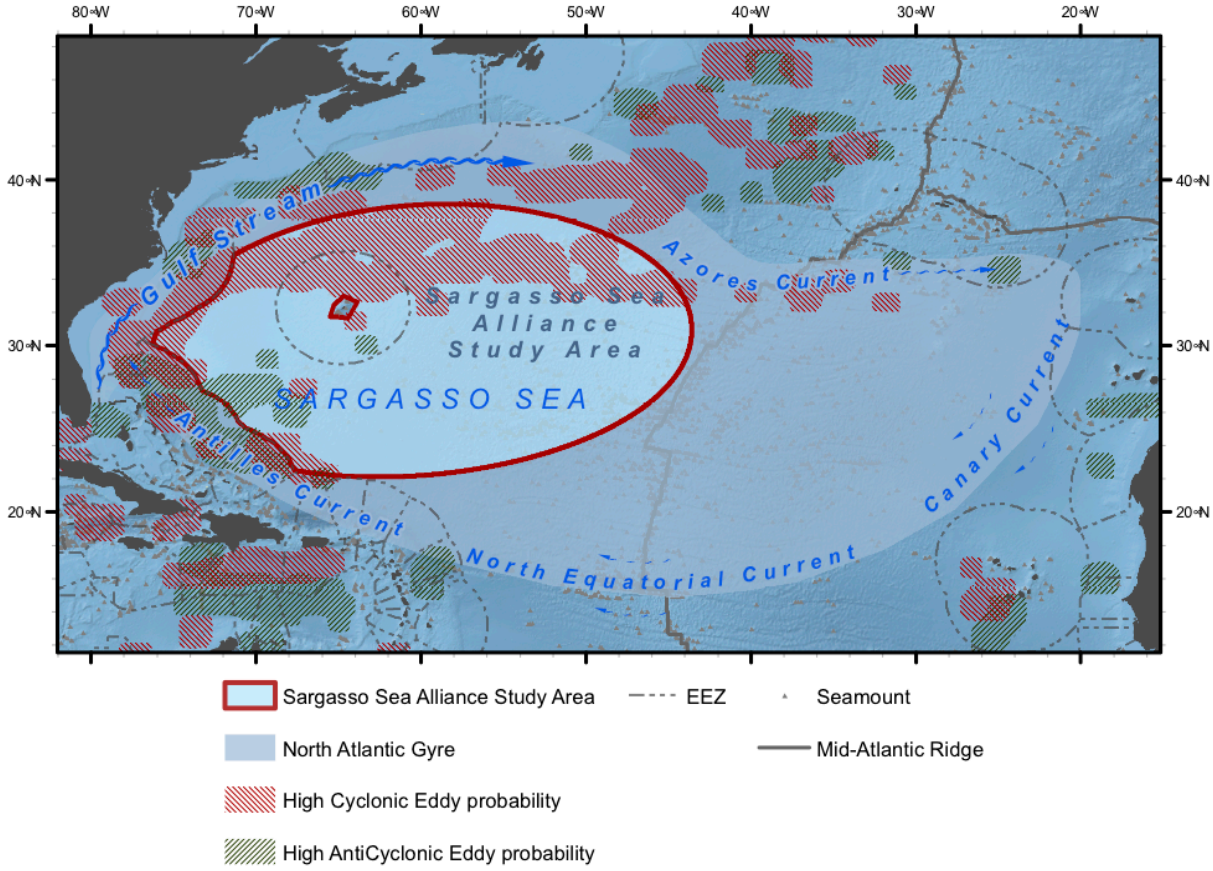
The Sargasso Sea Ecosystem

The Sargasso Sea lies within an oceanic gyre of the western central Atlantic Ocean between 30 degrees and 75 degrees west longitude and between 20 degrees and 40 degrees latitude (Figure 1). Unlike other seas, the Sargasso 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.[4] Bermuda is the only inhabited island fully within the Sargasso Sea Study Area.

[3] 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).

[4] 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 form of marine plant. 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* is trapped within the gyre, where it stays 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. Due to 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.[5] 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 "lost years" (Carr and Meylan 1980).[6] 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

[5] See Laffoley et al. (2011) for a detailed bibliography of the existing fauna of the Sargasso Sea.
[6] The *lost years* refer to the years during which hatchlings hide and grow in the *Sargassum*, which provides a relatively safe environment.

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 albacores*) tunas (International Commission for the Conversation of Atlantic Tunas [ICCAT] 2011), travel through the Sargasso Sea during the spring and summer to feeding grounds further north. The blue (*Makaira nigricans*) and white (*Tetrapturus albidus*) marlins are also thought to spawn in the Sargasso Sea (South Atlantic Fishery Management Council 2002; Luckhurst et al. 2006; 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.[7] Climate change is expected to have serious affects on oceans, including the Sargasso Sea, through ocean acidification and changes in sea temperatures. 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 is 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 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 (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 study 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

[7] Ecosystem functions can be defined as intermediate services. They are ecological functions contributing indirectly to human welfare. Primary productivity and nutrient cycling are examples of ecosystem functions.

provision of these services. However, such data are rarely available for the high seas. This study 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 local 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. 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). We caution the reader that 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.[8] 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 Bermudans. Sumaila et al. (2013) provide economic impact data and some estimates of the rent (a measure of net economic value) for commercial fishing that takes place 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.

The present report summarizes these studies and others with a particular focus on isolating those ecosystem services that depend on the ecosystem health of the Sargasso Sea. Additionally, this study pays special attention to the international and regional distribution of ecosystem service benefits that depend on the ecological functioning of the Sargasso Sea.

Selected Ecosystem Services

This report focuses on a 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 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). Using this definition, *Sargassum* that is harvested for sale is a final ecosystem good because it is directly used in human activities—even though it is also used as an intermediate good (fertilizer) once

[8] Tourism, coastal protection, cultural and recreation, amenities, fisheries, and research and education.

sold. 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 between the Sargasso Sea's ecosystem health, its ecological function, and the ultimate economic importance of the Sargasso Sea.

Table 2. 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, marlins etc.) are harvested directly in the sea by vessels from many nations. Other commercially important fish (e.g. eels) spend a 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, or area crossed during migration (Laffoley et al. 2011).
	Sargassum harvest (L, I)	*Sargassum* can be harvested to be used as fertilizer (South Atlantic Fishery Management Council 2002). Several other uses (biofuel, cosmetics, etc.) are considered (Lenstra et al. 2011), but no development of these uses exists currently.	The Sargasso Sea is a highly productive area for the production of *Sargassum* (Freestone 2013).
Cultural	Tourism in Bermuda (L)	Tourism is one of the main economic sectors in Bermuda. It depends on a mild climate, clean beaches and healthy coral reefs (Hallett 2011).	A healthy Sargasso Sea contributes to the attractiveness of Bermuda. Coral reefs are important for snorkeling tourism (Beukering et al. 2010).
	Sport fishing, recreational fishing (L,I)	Recreational fishing and sport fishing, targeting species like marlin and tuna, is 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 near-pristine deep and open oceans, the Sargasso Sea has been an important research location, supporting jobs and revenue generation in Bermuda. Research activities include the Bermuda Institute of Ocean Sciences. Bermuda is also a port of call for scientific expeditions and hosts the world's longest continuous open ocean time series (Laffoley et al. 2011).	Researchers are drawn to the Sargasso Sea because of its pristine ecological condition.
	Turtle, bird and 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 et al. 2009; Haney, 1986; Laffoley et al. 2011).	These species are present in the Sargasso Sea and/or spend some part of their life there (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 Sargasso Sea is home to a unique ecosystem and rare and charismatic species that some may value. *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 is a site of high primary productivity that leads to carbon sequestration, much of which is recycled by bacteria that may play a key role in ocean carbon sequestration (Laffoley et al. 2011). Carbon sequestration reduces green house concentrations in the atmosphere, which has global benefit.	The overall contribution of the Sargasso Sea to carbon sequestration, oxygen production, and nutrient cycling is under study (Bates et al. 2002; Lomas et al. 2010).
	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.

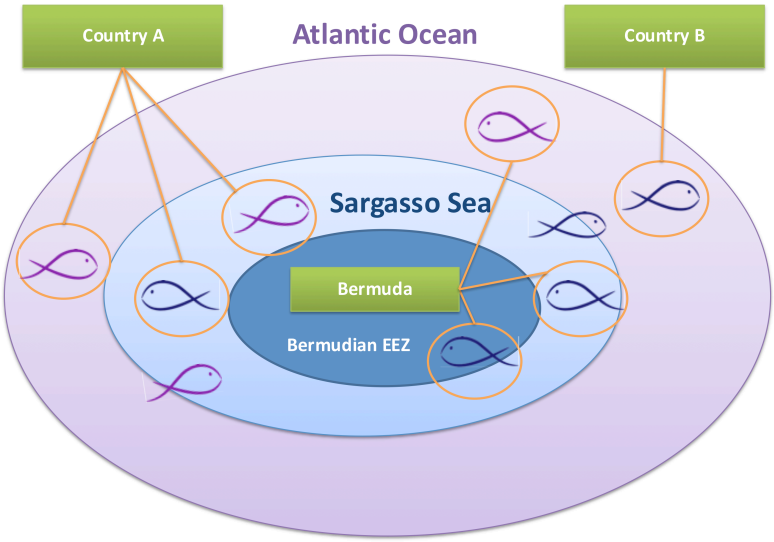
This report focuses on ecosystem services that meet the criteria outlined earlier (e.g., evidence an ecological connection to the Sargasso Sea ecosystem; correspond to well-defined constituencies and user groups; and that are likely to be threatened, in a very obvious way, because of the degradation of Sargasso Sea ecosystem health). The report 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.

ECOSYSTEM SERVICES VALUES AND ECONOMIC IMPACTS IN THE SARGASSO SEA

Fishing vessels from Bermuda harvest fish in the Bermuda EEZ, in the larger Sargasso Sea, and in the wider Atlantic Ocean (see Figure 2). Vessels from other countries harvest in these three regions depending on the species harvested.

Among the fish caught in the wider Atlantic (purple area in Figure 4), some depend on the Sargasso Sea for at least part of their life (represented in blue, e.g., white and blue marlins), whereas others do not rely on the Sargasso Sea at all (represented in purple below, e.g. seatrout, Atlantic croaker, and spot).[9]

Figure 2. Fishing Activities and Their Relations to the Sargasso Sea.



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* 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). A number of commercially important species of fish spawn directly in the *Sargassum,* including white and blue marlin (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, 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).

[9] For marlins, see Laffoley et al. (2011). For seatrout, see http://www.asmfc.org/species/spotted-seatrout.

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 do the yellowfin tuna(*Thunnus albacares*), the albacore tuna (*Thunnus alalunga*), and the Atlantic swordfish (*Xiphias gladius*). Several other tuna species, including the bigeye tuna (*Thunnus obesus*), also move from spawning grounds in the eastern tropical Atlantic to the Sargasso Sea and further west into coastal U.S. waters (ICCAT 2010).

Fisheries

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.[10] It could take between one and three years for the juveniles (known as leptocephali) to reach European coasts (Bonhommeau et al. 2008). The leptocephali become "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.[11]

Status: Eel landings have decreased dramatically over the 40 years. European eels are critically endangered (Laffoley et al. 2011). Around 16,000 tons of European eels were landed in the 1970s, versus only around 5,000 tons 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). However, the International Council for the Exploration of the Sea (ICES) reports a recent slight improvement in glass eel recruitment in the North Sea and in Western Europe.[12] Since 2009, European eels have been listed on Appendix II of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (Miller and Hanel 2011) and classified as "critically endangered" by the IUCN (Laffoley et al. 2011). A Community Action Plan for the protection and recovery of the eel has been adopted by the European Union in 2007 (Laffoley et al. 2011). This plan includes the establishment of management plans at the river basin scale to reduce the eels' human-induced mortality. A petition was sent to the U.S. Fish and Wildlife Service in 2004 to list the American eels under the Endangered Species Act.[13] It was refused at the time, but a new petition was filed in 2010.

Three types of commercial fishery depend on eels that spawn in the Sargasso Sea: the wild-caught eel fishery, glass eel fishery, and glass eel farming. Table 2 provides 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 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 value 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

[10] See http://www.fao.org/fishery/species/2203/en.
[11] See http://ec.europa.eu/fisheries/marine_species/wild_species/eel/index_en.htm.
[12] See http://www.ices.dk/news-and-events/news-archive/news/Pages/Latest-ICES-advice-on-European-Eel---stocks-remain-critical.aspx.
[13] See http://www.dnr.state.md.us/fisheries/fmp/2011/Section_1_American_Eel.pdf.

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) being estimated at $36 million per year.[14] 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.[15] This includes benefits to Europe and the United States (not Canada). More recent estimates from ICES (2012), however, put European eel landings at 3,201 tons for 2011—one third of the landings reported by Sumaila et al. (2013). Updating the European eels' landing value by using the same price of US$11/kg used by Sumaila et al. (2013)[16] and the same methodology, we estimate that the 2012 adjusted landed value of European eels was approximately US$35.9 million, thus 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$384–629.8 (EIFAC, ICES 2012). Therefore, estimates of total gross revenues in 2012 from European eel glass landings range between $17,433,600 and $28,592,920 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 similar landing prices to those in the United States (i.e., US$3.4/kg according to Sumaila et al. 2013), we estimate 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, we estimate total Canadian landed value around $4.6 million.

Glass eels are often captured to be used in eel aquaculture, with most aquaculture occurring in the Netherlands, Denmark, and Germany.[17] European aquaculture production has been decreasing in the past years 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 and has since declined (FAO 2013).

[14] 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 assuming the cost of fishing represents 70% of landed value.
[15] 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).
[16] Decrease in stock might have increased eel price since then, so the landed value might have been even higher.
[17] 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 ($/kg)	Year	(US$ 2012) rounded Landed Value ($'000)
Europe	Silver eels	3,201 (ICES 2012)	$11/kg (Sumaila et al. 2013)	2011	35,900
	Glass eels	45.4 (ICES 2012)	€300–492/kg	2012	23,000
	Total revenues				58,900
U.S.	Landed value	—	—	Annual average catch 1983–1995	2,200 (Sumaila et al. 2013)
	Total revenues				2,200
Canada	Silver eels	500 (Engler-Palma et al. 2013)	$3.4/kg (Sumaila et al. 2013)	Average/yr	1,700
	Landed value of elvers	—	—	1997	2,900 (Meister and Flagg 1997)
	Total revenues				4,600

Key points

Gross Revenues from Eel Fishing

Around $66 million (2012 US$) of 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.

General Ecology Linking Fish to the Sargasso Sea

What: Scombrids (big eye, yellowfin, albacore, bluefin, skipjack, blackfin) and billfish (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 marlin are dependent on prey that feed within *Sargassum* mats (Rudershausen et al. 2010). Other pelagic species that inhabit these regions are dependent on *Sargassum*. Rudershausen et al. (2010) observe that prey associated with *Sargassum* communities are preferred by dolphinfish and yellowfin tuna, which sometimes even have algae in their digestive tracts.

Status: Laffoley et al. (2011) review the status and ecology of commercially and recreationally important fish species associated with the Sargasso Sea, highlighting the endangered status of some species, such as tunas and billfish (see Table 3).

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

Fish species	Life stage in the Sargasso Sea (Laffoley et al. 2011)	Where fished	IUCN Status (Laffoley et al. 2011)
White marlin	Foraging ground for all life stages	North Atlantic	Near threatened
Blue marlin	Foraging ground for all life stages	North Atlantic	Near threatened
Albacore tuna	Migration route, possible spawning area	North Atlantic	Near threatened
Atlantic bluefin tuna	Migration route, possible spawning area	West and East Atlantic (Laffoley et al. 2011)	Endangered
Yellowfin tuna	Migration route	Atlantic	Near threatened
Bigeye tuna	Migration route, possible temporary residence	Atlantic	Vulnerable

Source: If not specified otherwise, information come 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 taking 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 taking place in the Sargasso Sea (see Table 4).[18] Annual gross revenues derived from commercial fishing directly in the Sargasso Sea exceed $98 million of which approximately $42 million represent the net economic value.[19]

[18] These figures include the Bermudian EEZ and are based on landings in 2006. Prices are based on a database gathering and "filling in" annual average prices for all fish taxa and countries from 1950 to today. Landed values are expressed in 2005 US$.

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

Table 4. Distribution of the Annual Landed Value, Income Effect, Rent, and Economic Impact from Commercial Fishing in the Sargasso Sea.

Regions from where fleets are coming and where fish is landed	Landed Value ($'000)	Total cost ($'000/t)	Total subsidy ($'000)	Rent ($'000)	Rent less subsidies ($'000)	Income effect ($'000)	Economic impact ($'000)
South and Central America	58,300	29,500	11,300	28,800	17,500	18,900	77,000
Bermuda	700	78	315	641	326	943	5,300
North America	7,400	3,800	714	3,600	2,900	9,400	22,600
Asia	28,700	3,600	3,000	25,100	22,100	25,300	81,700
Europe	3,800	2,400	2,400	1,400	–1,000	3,800	14,800
Total	98,900	39,378	17,729	59,500	41,826	58,343	201,400

Source: Sumaila et al. (2013), 2012 adjusted round values.

Fish species caught in the Sargasso Sea also live 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 $1 billion annually (2009 US$). The dependence of these stocks on the ecological health of the Sargasso Sea is unknown, so the economic contribution of the Sargasso Sea to these valuable fisheries is currently unquantifiable but clearly deserves further attention.

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 these species are near threatened, some are vulnerable or endangered.

A substantial proportion of fisheries outside of the Sargasso Sea may also depend on the health of the Sea. For instance, Sumaila et al. (2013) find that the gross revenues associated with selected Atlantic tuna and billfish exceeds $1 billion (2009 US$). What proportion of these revenues is dependent on the Sargasso Sea is unknown.

Economics of Recreational Fishing and Sport Fishing

Limited information exists on the economic impact or value of recreational and sport fishing linked to the Sargasso Sea. Sport and recreational fishing activities in the Bermuda EEZ are most likely to be linked to the Sargasso Sea. A study of recreational fishing 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) marlin (Luckhurst 2006, and anglers largely from the United States visit Bermuda during the summer for international billfish tournaments (Hallett 2011). Foreign sport fishing vessels often spend several weeks on the island for these tournaments, contributing to local economic activity. In 2010, 21 foreign vessels visited Bermuda, with an average of four crewmembers 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 $630,000 (2012 US$).

The Sargasso Sea ecosystem is likely to be economically important for recreational fishing outside of the sea. Recreational fishing and sport fishing events generate revenues in regions such as North, Central, and South America as well as 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.[20] This includes expenditures in 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 unknown.

The nearby Azores are known for being 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 ranging from €125,400 to €145,200 for 22 teams in 2007 (on average €135,300, around $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, more than 2.3 million people participated in recreational fishing activities (all species combined) in the South Atlantic region in 2011, 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 U.S. generated $6.5 billion in terms of expenditures associated with fishing trips and equipment (NMFS 2012). Recreational fishing in the nearby Gulf of Mexico, an area also thought to be influenced by conditions of the Sargasso Sea, generated $10.5 billion (National Marine Fisheries Services 2012) in associated expenditures on fishing trips and gear. Although scientific evidence does not exist to show how these fisheries depend on the health of the Sargasso Sea, the report's estimates provide an upper bound (i.e., what is at stake) of U.S. recreational fishing expenditures in areas that could be ecologically linked to the Sargasso Sea of $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 regions of United States. The data and science do not exist to determine what proportion of these revenues is potentially dependent on ecological conditions in the Sargasso Sea.

Similarly significant recreational fishing expenditures are also made in the Northeast and Mid-Atlantic regions as well as Western Europe. Only a fraction of this activity is likely dependent on the ecological health of the Sargasso Sea ecosystem.[21]

[20] See http://www.billfish.org/research/socioeconomics/.
[21] In 2011, species that were the most caught by recreational fishermen in the United States were seatrout, Atlantic croaker, and spot, species that are not found in the Sargasso Sea (NMFS 2012).

Wildlife Viewing

Whales

General Ecology Linking Whales to the Sargasso Sea

What: Thirty species of cetaceans are known to spend some portion of their lives 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 whales, including humpback whales (*Megaptera novaeangliae*), the species most observed by whale watchers. Sperm whales (*Physeter catodon*) also are known to live throughout the Sargasso Sea (Antunes 2009). Whales spend a substantial amount of time in the Sargasso Sea during migration and feed here.

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 might be at least 17,000 today, 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 list. Humpback whales are not classified (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. However, the link between the whale watching industry and the Sargasso Sea is unknown. 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.[22] There is, for example, an agreement between Bermuda and Stellwagen Bank to protect North Atlantic humpback whales.[23] 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, supporting more than 4,600 jobs, generating nearly $138 million of direct revenues, and generating as much as $374 million in terms of associated tourism spending annually (O'Connor 2009; see Table 5).[24] Cisneros-Montemayor et al. (2010) find that whale watching in most countries is underdeveloped and could be substantially higher, generating more jobs and income.

[22] 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.
[23] See http://stellwagen.noaa.gov/sister/pdfs/bermuda_ssfs12.pdf.
[24] Direct expenditures correspond to the whale watching ticket price. Indirect expenditures are defined as expenditures by the participant which supports 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 (2012) US$ ($'000)	Indirect expenditures in (2012) US$ ($'000)	Total Expenditures in (2012) US$ ($'000)
Total Europe	3,950	12	14	380	787	1,200
Total 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.

*For the few data from 2006 and 2007, we assume the number of whale watchers is constant between 2006 and 2008.

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).[25] Hoagland and Meeks (2000) estimate the consumer surplus per person per whale watching day in the Stellwagen Bank National Marine Sanctuary in 1996, located at the mouth of the 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, we estimate roughly that the consumer surplus associated with Atlantic whale watching could be $140 million (2012 US$) annually. We also note that 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.

[25] 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

$34,000 (2012 USD) of gross revenues generated by whale watching, are annually attributable to the Sargasso Sea. These expenditures arise in Bermuda.

Direct and indirect expenditures for whale watching in the Atlantic potentially linked to the Sargasso Sea represent more than $490 million annually. The dependence of these revenues on the health of the Sargasso Sea is unknown.

Whale watching consumer surplus, directly attributable to the Sargasso Sea is very small (on the order of $13,000 (2012 USD) annually for whale watchers originating in Bermuda.

Whale watching consumer surplus potentially linked to 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 imbricate*), loggerhead turtles (*Caretta caretta*), Kemp's Ridley turtles (*Lepidochelys kempii*), and leatherback turtles (*Dermochelys coriacea*) are found in the Sargasso Sea.

Essential Ecology of Sea Turtles: Several species of sea turtles use the Sargasso Sea as a hiding and 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 sea turtles 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.[26] The most important nesting area for leatherbacks in the western Atlantic is French Guiana. Estimates of the number of nests vary from 5,029 to 63,294 between 1967 and 2005 (Eckert et al. 2012). The population of leatherback turtles in the North Atlantic was estimated between 34,000 and 94,000 (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's islands (Eckert et al. 2012). Kemp's Ridley turtles inhabit coastal waters along Florida but do not nest there (Meylan et al. 1995). 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. The North Atlantic loggerhead population is assumed to be divided into at least five subpopulations (Richards et al. 2011). Florida is one of the largest nesting areas for green turtles in the Caribbean Sea and the western Atlantic Ocean (Meylan et al. 1995). In 2014, the U.S. National Marine Fisheries Service (NMFS) identified *Sargassum* habitats as "critical habitats" for loggerhead turtles (NMFS 2014).

Status: Loggerhead turtles and green turtles are classified as endangered on the IUCN 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 to 2004 in Panama—an area that used to be the largest nesting colony in the Western Caribbean region (Large Caribbean region, Bräutigen and Eckert 2006).

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

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 places.

For instance, 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) examine nine turtle case study sites in developing countries (see Table 6). Tourism related to marine turtles (that may be dependent on the Sargasso Sea) generated between $115,000 and $8,576,000 annually with 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 observation. Gross revenues at three sites where marine turtles are one of many attractions vary between $4,000 and $135,000 annually with 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 South and Central America			15,622
Total Africa			4

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. The 2011 National Survey of Fishing, Hunting, and Wildlife-associated Recreation provides aggregated information on wildlife viewing. In 2011, 10.1 million people in the United States watched

animals other than birds, land mammals, fish, and marine mammals; this category includes turtles (U.S. Department of the Interior et al. 2011).

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.[27] Along North Carolina, willingness to pay per household per year for loggerhead sea turtle protection (includes use and nonuse value) was estimated at $10.98 in 1991 (US$18.51 in 2012USD) (Whitehead 1992).[28]

Finally, Troëng and Drews (2004) estimated revenues from consumptive use (e.g. sales of turtles for food or shells) between $158 and $1.7 million at the sites studied with average gross revenue of $0.6 million i.e. 2012 USD 0.7 million.[29]

Key points

Gross Revenues from Turtle Watching

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

Revenues from turtle watching along Atlantic coasts are potentially linked to the Sargasso Sea. More than $15 million annually in direct and indirect expenditures were found for nine sites in Central America, the Caribbean and Africa for turtles that may depend on the Sargasso Sea. It is unknown what fraction of these expenditures can be tied to the condition of the Sargasso Sea ecosystem.

Research and Education

The Sargasso Sea has long attracted oceanographic and biological researchers. Bermuda's location, close to the United States and close to nearly pristine deepwater ecosystems in the center of the Sargasso Sea, has led to the 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 the analysis. 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. Beukering et al. (2010) estimated that research expenditures in 2007 for coral reef–based studies totaled $2.3 million (2012 US$2.6 million). A more recent study commissioned by the Pew Environment Group to estimate the potential value of a Blue Halo Reserve (marine protected area) in the Bermudan 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 research institutions over the past 50 years to support time series and other research projects undertaken in the Sargasso Sea. Although this estimate does not identify the distribution of benefits across countries from this spending, it does show that research is an important activity with benefits that should be investigated further. Additionally, the benefits humans get from a better understanding of ocean functioning and contribution to climate change mitigation, for example, should not be neglected. This is especially the case for the Sargasso Sea long time series, which can contribute to our understanding of changing oceanic conditions and processes.

[27] See http://oceana.org/sites/default/files/reports/SeaTheValue_Final_web1.pdf.
[28] Available online: http://ageconsearch.umn.edu/bitstream/48812/2/18824875.pdf.
[29] Assuming data are from 2002.

Key points

Gross Expenditures from the Research Sector
Around $12 million are annually spent by BIOS located in Bermuda. The country enjoys many of the direct expenditures associated with research in the Sargasso Sea, while 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 the emerging understanding of the importance of this ecosystem to human well-being. Indeed, this ecosystem provides a suite of services that can be tied to the ecological conditions and health of the Sargasso Sea and are directly beneficial to human activities. These include:

- **Provisioning services,** such as commercial fishing;
- **Cultural services,** such as tourism in Bermuda, sport fishing, recreational fishing, education, research and protection activities; 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 pristine nature of the Sargasso Sea 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 a sea-related activity, gross revenues from tourism or the annual budgets of a research or protection organization, and even estimates of consumer surplus, profit, and possible existence values. These different estimates cannot be summed because they represent different aspects of economic activity and value. Even so, the available data shed initial 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 for the ecosystem services assessed are in the order of many tens to hundreds of million dollars per year (Figure 3).
- The highest economic values directly linked to the Sargasso Sea are for shoreline protection provided by coral reefs ($279 million/year).
- The largest economic impacts associated directly with the Sargasso Sea come from commercial fishing (landed value of around $100 million/year) and eel fishing ($66 million/year).[30]
- The largest expenditures *potentially* linked to the Sargasso Sea are for whale watching practiced in other parts of the Atlantic Ocean (estimated at nearly $500 million/year), with only a portion

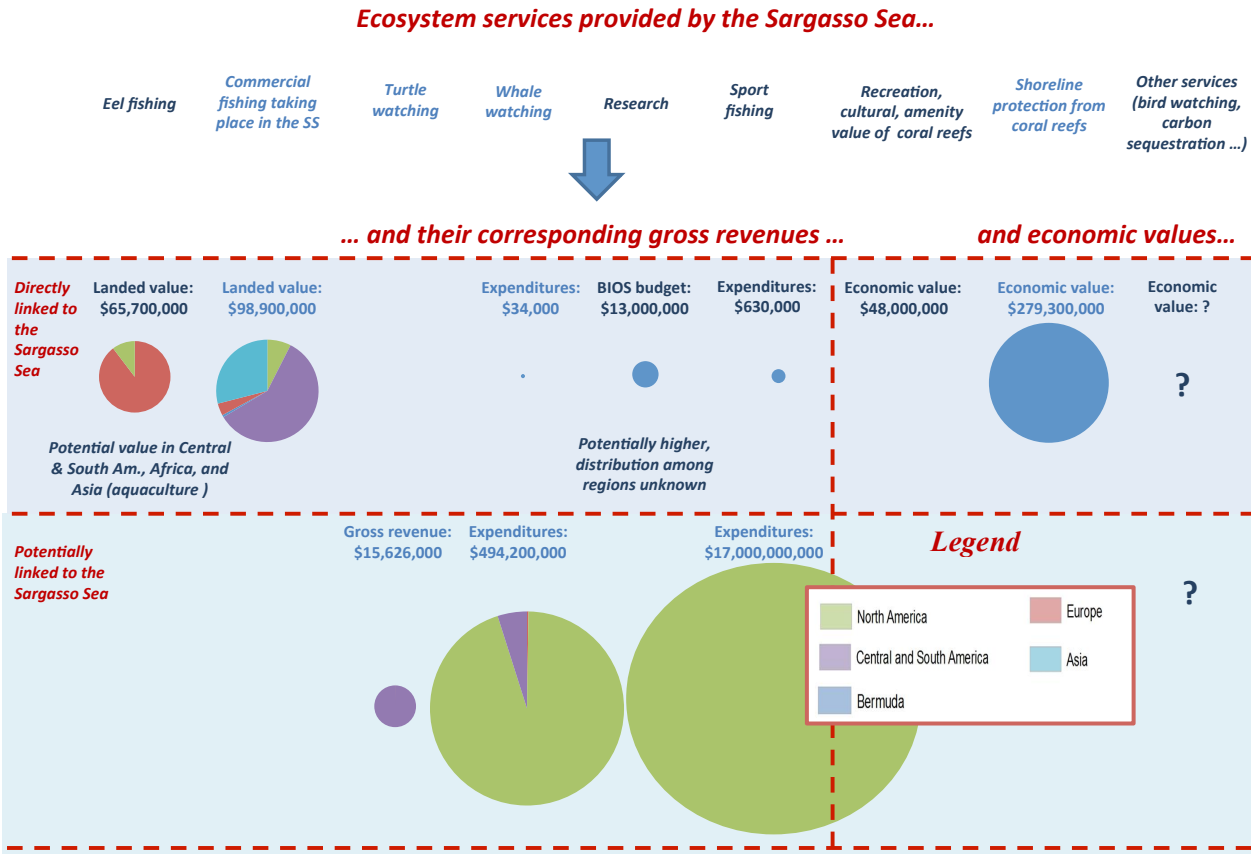
[30] This is a gross revenue, whereas the one for shoreline protection entails its economic value.

of this attributed to the Sargasso Sea. However, there is no existing evidence that can help assess the order of magnitude of this share.

- A healthy Sargasso Sea benefits human activities and people who live within the region, especially Bermuda. Direct economic impacts to the area originate from shoreline protection provided by coral reefs to Bermuda, whale watching organized in Bermuda, and recreational/cultural activities linked to the coral reefs in Bermuda.

- The Sargasso Sea benefits human activities and inhabitants of other regions and continents in the world. In particular, eel fishing benefits mainly accrue to Europe (around 90% of the total gross revenues estimated), and less so to North America (around 10% of the total gross revenues estimated).[31] Commercial fishing in the Sargasso Sea especially benefits Central and South America fishing fleets (around 60% of the total landed value estimated). The benefits of whale watching in other seas accrue mainly to North America (around 95% of the total value estimated) and Central and South America (a bit less than 5% of the total value estimated). Estimates for the economic impact of turtle watching exist only for Central and South America (around $15 million/year), with only a portion of this value being attributed to the Sargasso Sea.

Figure 3. Revenues and Economic Values for Ecosystem Services Provided by the Sargasso Sea: A Summary of the Main Results.



[31] As indicated, however, values for other continents (Central and South America, Asia, and Africa) could not be estimated. Evidence suggests that these values are positive and might be far from marginal.

Overall, 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, and may even generate non-use and regulating services that benefit people globally. The estimates of the economic value and impact of the services provided by a healthy Sargasso Sea call for the active management of this ecosystem. They also underscore that protecting the Sargasso Sea is far from being in the sole interest of the inhabitants of the Bermuda. Because such management would benefit human activities and inhabitants around the globe, in particular North America (whale watching), Europe (eel fishing), and Central and South America (commercial fishing), it is clearly also in the interest of organizations and inhabitants from other continents.

There are many components of the economic value and impact of Sargasso Sea ecosystem services that are as yet unknown. These include *inter alias:*

- The value of the contribution of the Sargasso Sea to bird life that is enjoyed by bird watchers directly in the area and elsewhere, and sea life that may be viewed by divers, snorkelers, and others.

- There is no quantitative understanding of the contribution of *Sargassum* in the creation of beaches and shoreline protection, carbon sequestration, oxygen production, or biodiversity protection.[32]

- As the commercial harvest and mariculture of marine plants continues to increase globally and as research and development reveal new uses of processed macroalgaes, the potential use value that could come from a sustainably managed *Sargassum* harvest in the Sargasso Sea could increase.

- Other cultural values are associated with the Sargasso Sea and have not been estimated so far. For instance, eels are likely to have an important cultural value, contributing to traditional Christmas dishes in Sweden or traditional food locally in Canada.

- The Sargasso Sea is home at some point to a number of charismatic species that may have existence value. These include rare or threatened species like whales, turtles, sharks, and emblematic species that have fascinated humans for a long time (e.g., anglerfish) all of which may be valued for their mere existence and add value to the existence value of the Sargasso Sea as a unique ecosystem.[33] Other organisms may provide ecosystem functions or services that are still undiscovered. These values have yet to be quantified.

CONCLUSION

The Sargasso Sea ecosystem provides at least three key types of services that can be quantified in monetary terms. These include provisioning services, such as commercial fishing, genetic resources, and medicinals; cultural services, such as tourism in Bermuda, research, sport fishing, recreational fishing, education and protection activities, and turtle, bird, and whale watching; and regulating services, such as carbon sequestration, habitat provision, or coastal erosion prevention. Additionally, the Sargasso Sea is home to rare and charismatic species like anglerfish and whales that may be valued for their mere existence.

Some activities that turn these ecosystem services into economic activity occur directly in the Sargasso Sea. For instance, commercial fishing and even some wildlife viewing takes place on the high-seas

[32] In the authors' opinion, generic estimates of the value of a hectare of ocean are unreliable proxies for these values.
[33] For instance, American families were willing to pay $73 per household to help the recovering of the North Pacific right whale (Lew and Wallmo 2011).

portion of the Sargasso Sea. Many other activities take place closer to shore but depend on the health of high-seas ecosystems. For instance, tunas, billfish, and eels spend critical life stages in the high seas but are caught closer to shore by commercial and recreational fishermen. Similarly, whales, turtles, and sharks travel through and depend on high-seas ecosystems like the Sargasso Sea but are most commonly seen by tourists in coastal waters often far from the Sargasso Sea. For instance, the Sargasso Sea ecosystem plays a critical role in the lives of whales, which in turn support an Atlantic whale watching industry that generates more than $500 million/year in revenues and an additional $100 million in benefits to whale watchers beyond what they pay for their excursions. The turtle watching industry in Central America benefits similarly from the Sargasso Sea. Troëng and Drews (2004) estimate that turtle watching at just nine sites in Central America generates more than $15 million in gross revenues annually. Sumaila et al. (2013) find that commercial fishing outside of the Sargasso Sea may depend on the health of the Sargasso Sea ecosystem. The authors estimate that the gross revenues associated with selected Atlantic tuna and billfish species groups known to depend on the Sargasso Sea, exceeds $1 billion (2009 US$). Although science cannot yet reveal how much the Sargasso Sea contributes to these activities, there is no mistaking the important ecological role that this high-seas ecosystem plays in supporting these values.

Although the bounty of the high seas belong in principle to all of society, the benefits of the high seas often accrue to a selected few. This is true in the case of the Sargasso Sea. For instance, the harvest of eels that breed only in the Sargasso Sea generates benefits that mainly accrue to Europe (around 90% of the total gross revenues estimated), and less so to North America (around 10% of the total gross revenues estimated).[34] Commercial fishing taking place in the Sargasso Sea benefits in particular Central and South American nations (around 60% of the total value estimated). The benefits of tourism based on viewing whales accrues mainly to North America (around 95% of the total value estimated), even though these whales may spend a large part of their life in the high seas.

Strengthening integrated biophysical and socioeconomic research is a prerequisite to 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 known. There is insufficient science to allow us to understand how the suite of human impacts that affects the ecological health and function of the Sargasso Sea affects ecosystem services and thus people. Understanding 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.

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 must increase our 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 the present report. Table 7 highlights possible areas for further research that would help provide more robust estimates of economic values.

[34] As indicated, however, values for other continents (Central and South America, Asia, and Africa) could not be estimated. Evidence suggests that these values are positive and might be far from marginal.

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 SS (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 value of better management, and the economic costs of failing to manage them. This report merely scratches the surface of the economic importance of the Sargasso Sea.

APPENDIX: ECONOMIC VALUES OF ECOSYSTEM SERVICES PROVIDED BY THE SARGASSO SEA AND THE LIMITS OF AVAILABLE DATA

Ecosys-tem services	Type of data	Source	Adjusted value (2012) ($'000)							
			Bermuda	Europe	North America	Central and South America	Asia	Africa	Total	Limits/sources of uncertainty
Revenues directly related to the Sargasso Sea										
Eel fishing	Landed value of eels and glass eels	ICES (2012), Engler-Palma et al. (2013), Sumaila et al. (2013)	—	58,900	6,800	n.d.	n.d.	n.d.	65,700	Values decreasing quickly. No data for Africa and South and Central America where fishing might arise. Revenues from eel ranching potentially very high in Asia.
Commer-cial fishing taking place in the SS	Landed value	Sumaila et al. (2013)	700	3,800	7,400	58,300	28,700	-	98,900	Work in progress. Values integrating Spanish mackerel, overestimate of catches for South America.
Sport fishing	Expen-ditures	Hallett (2011)	1,300	-	-	-	-	-	1,300	Recreational fishing by local fishermen not included.
Whale watching	Total expen-ditures	O'Connor (2009)	34	-	-	-	-	-	34	Data from 2008.

Ecosys-tem services	Type of data	Source	Adjusted value (2012) ($'000)							
			Bermuda	Europe	North America	Central and South America	Asia	Africa	Total	Limits/sources of uncertainty
Research	BIOS annual budget	Iverson (2012)	13,000	n.d.	n.d.	n.d.	n.d.	n.d.	13,000	Data only from one research institution. Research budgets from other countries institutions (especially the U.S.) likely to be very high and contributing to Bermudan economy.
Revenues possibly related to the Sargasso Sea										
Whale watching	Total expen-ditures	O'Connor et al. (2009)	—	1,200	468,800	24,200	—	—	494,200	Weak knowledge on the dependence of these whales on the Sargasso Sea
Turtle watching	Gross reve-nue	Troëng and Drews (2004)	—	n.d.	n.d.	15,622	—	4	15,626	Weak knowledge on the link between these turtles and the Sargasso Sea. Lack of data for Europe and the U.S. where turtle watching might arise and depend on the Sargasso Sea

Ecosys-tem services	Type of data	Source	Adjusted value (2012) ($'000)							
			Bermuda	Europe	North America	Central and South America	Asia	Africa	Total	Limits/sources of uncertainty
Rec-reation, cultural and amenity value of Bermud-an coral reefs	Econo mic value	Beukering et al. (2010)	48,000	—	—	—	—	—	48,000	Value only for the contribution of Bermudan coral reefs. Contribution from the *Sargassum* and the wider Sargasso Sea area can be higher.
Shoreline protect-ion value of Bermud-an coral reefs	Econo mic value	Beukering et al. (2010)	279,300	—	—	—	—	—	279,300	Value only for the contribution of Bermudian coral reefs. Contribution from the *Sargassum* and the wider Sargasso Sea area can be higher.

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 are the 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 are the total amount of money generated by an activity. Gross revenues differ rom net revenues. Net revenues are equal to gross revenues less activity costs and subsidies.

Human well-being is 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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