DUKE ENVIRONMENTAL AND ENERGY ECONOMICS WORKING PAPER SERIES
organized by the
NICHOLAS INSTITUTE FOR ENVIRONMENTAL POLICY SOLUTIONS
and the
DUKE UNIVERSITY ENERGY INITIATIVE

Assessing the Value of Marine and Coastal Ecosystem Services in the Sargasso Sea

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Working Paper EE 14-05
July 2014

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Contents

Glossary

Consumer Surplus:

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

Economic Value: Represents the net economic improvement in human well being and is commonly measured by contribution 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 people obtain from ecosystems (MEA, 2005).

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 consists in computing monetary values of ecosystem services in order to integrate these values in global economic assessments (Armstrong *et al.*, 2010)

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

Human well-being is broadly defined through several key components like material life conditions (e.g. income, housing…) and through a more general quality of life (health status, environmental quality, personal security…)[1].

Total economic value is "the entire value of flow of a good or a service or the entire value of a stock at a given point of time" (UNEP, 2011).

Abbreviation

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

[1] http://www.oecd.org/statistics/OECD-ICW-Framework-Chapter2.pdf

IUCN	International Union for the Conservation of Nature
MEA	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
U.S.	United States
USD	United States Dollars

Introduction

Objectives

The Sargasso Sea is both ecologically and economically important (Laffoley et al., 2011). However, quantifying the exact economic contribution of areas of the high seas, like the Sargasso Sea, remains a challenge because of the absence of fluid and official boundaries for these ecosystems and the fact that they are remote from most human settlements. While 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. Despite its remote location, ocean currents, global biochemical cycles, and wide-ranging ecological processes mean the ecological and human influence of the Sargasso Sea are felt both within and well-beyond its dynamic boundaries.

This report summarizes our current knowledge of key ecosystem services that depend, in part or as a whole, on the Sargasso Sea ecosystem. We present the current state of knowledge on the key ecological connections between the Sargasso Sea and human activities, and provide the best available information on the potential economic magnitude or nature of these ecosystem services[2]. Like many high seas ecosystems, current knowledge on the economic importance of the Sargasso Sea is limited. We know enough to know they are important and worth safeguarding, however there is much we do not know in detail, but need to know about the economic contribution of the Sargasso Sea. As a result, the report highlights critical knowledge gaps that need to be filled to help better inform management regimes in 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

[2] We adjust all economic information to year 2012 US dollars to account for inflation.

do not directly rely on ecosystem conditions, but that can negatively affect ecosystem health[3]. These activities include maritime transport, communication cables or offshore oil extraction. In the future, off-shore mining might also affect high seas. The high seas also support living resources that in turn 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, in particular when they support non-market-based activities or activities that take place far from these high seas areas. As a result, it is often difficult to fully assess the economic consequences of increased industrialization, pollution, overfishing and other environmental stresses that occur on the high seas.

We use an ecosystem services approach to describe and quantify the economic contribution of ecosystem functions and the living resources that depend upon the Sargasso Sea. The ecosystem services approach is now well established in both the literature and a number of international initiatives including the Millennium Ecosystem service Assessment (MEA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB, 2010).

The basic ecosystem services approach treats ecosystems as nature's factory that can produce goods that are directly used by human activities or can support ecological functions that in turn affect goods and services people enjoy (Figure 1). We define marine ecosystem services as the **benefits people obtain from marine ecosystems (MEA, 2005)**. Like the MEA, we focus on final ecosystem services, but also note the many intermediate ecosystem services are produced by high seas ecosystems. Further, we do not attempt to quantify those aspects of ecosystem value that are still unknown or yet to be realized.

Some ecosystem services in the high seas may be harvested directly (e.g. fish or seaweed). In other cases, high seas ecosystems may act as only an intermediate step in the production of ecosystem services, for instance when a high seas ecosystem supports only part of the life history of organisms that ultimately are enjoyed far from the site (e.g. eels spawn in the Sargasso Sea and are harvested in North America and Europe). High seas ecosystems may even be part of larger oceanic processes whose ecological and environmental outcomes affect human wellbeing globally (e.g., carbon sequestration), known as, regulating and supporting services, that remain poorly understood and difficult to value.

In this brief report, we summarize existing information on ecosystem services:

- for which there is at least some evidence of an ecological connection to the Sargasso Sea Ecosystem,
- that 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 the Sargasso Sea ecosystem health.

We follow the basic ecosystem services categories outlined by the MEA[4]:

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;

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[3] We define ecosystem health as the ability of ecosystems to function, and hence to provide ecosystem services, in a way that is sustainable and near optimal levels.

[4] but note that there are many other classification systems for marine ecosystem services (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).

Supporting ecosystem services such as soil formation, photosynthesis and nutrient cycling (MEA, 2005).

The Sargasso Sea provides all these types of services. However based on the data we were able to identify, we provide economic information for provisioning and cultural services only.

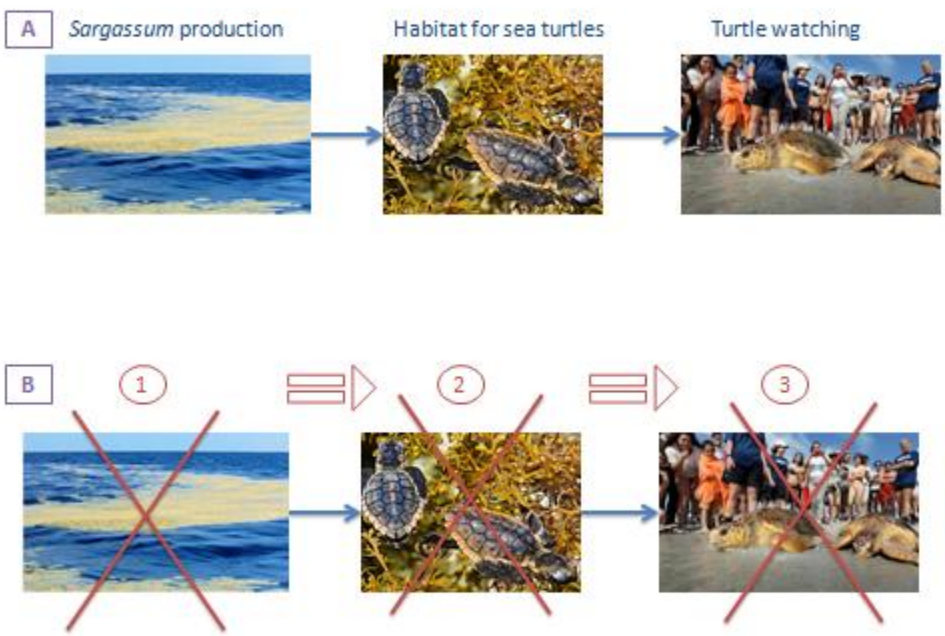


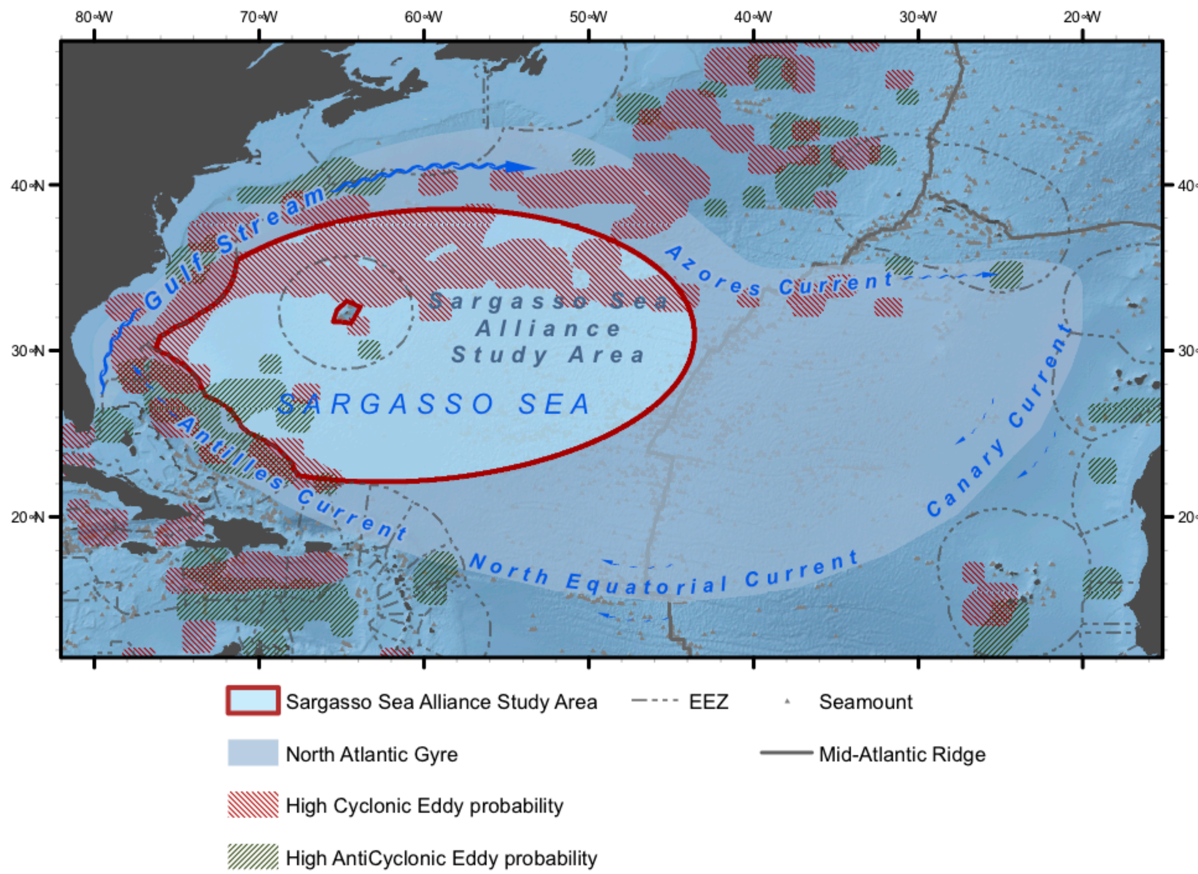
Figure 1 Illustration on the dependence between ecosystem functions (e.g. *Sargassum* production), local outcomes (e.g. habitat for turtles) and ecosystem services (e.g. turtle watching).

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 2). 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 defined by the Sargasso Sea Alliance lies within this large sea. The study area covers 4 million km^2, an area equivalent to the 28 Member States of the European Union[5]. Bermuda is the only inhabited island fully within the Sargasso Sea Study Area.

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



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

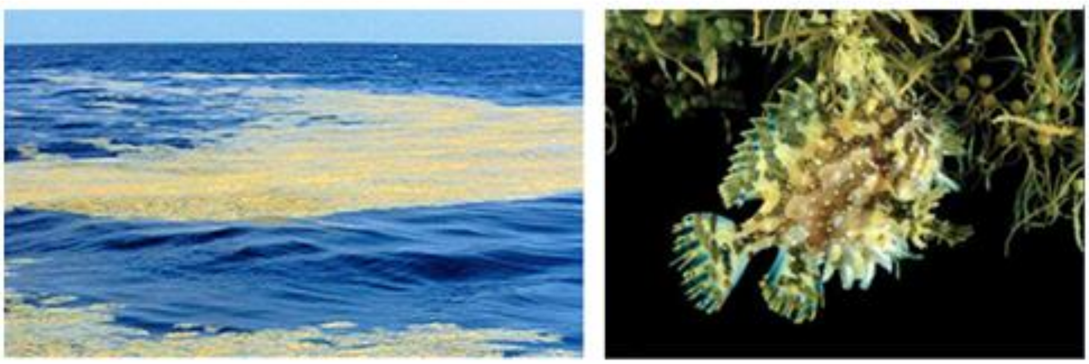
Figure 2 The Sargasso Sea Study Area as defined by the Sargasso Sea Alliance within a moving sea.

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 there for a very long time. As a result, a vast patchwork of mats of *Sargassum* weed and their resident organisms drift all around the Sargasso Sea and 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 (Figure 3) hosts 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".

Over 100 species of invertebrates, more than 280 species of fish, and 23 species of seabird[6], including many threatened and endangered species, utilize *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. The Sargasso Sea is home to ten 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

[6] See Laffoley et al., 2011, for a detailed bibliography of the existing fauna of the Sargasso Sea.

"lost years"[7] (Carr and Meylan, 1980). American and European eels (*Anguilla rostrata* and *A. anguilla)* also spawn in the 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*) tuna (International Commission for the Conversation of Atlantic Tunas (ICCAT, 2011), travel north 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).



Sources: coastalecology.org and Laffoley et., al (2011).

Figure 3 The golden floating rainforest and a *Sargassum* Angler fish, an endemic predator.

New attention to pressures and impacts on the Sargasso Sea

The Sargasso Sea also is subject to a variety of impacts from human activities . High fishing pressures globally have led to decreased abundance and heavy pressure on populations of commercial fish species in the Sargasso Sea (Christensen, 2003). Maritime traffic is also very developed in the Sargasso Sea (Laffoley et al., 2013). Like oceans worldwide, the Sargasso Sea is also subject to pollution and marine debris (Carpenter and Smith, 1972; Law et al., 2010). Maritime traffic can affect ecosystem functions and ecosystem services through potential pollution, the introduction of invasive species, or through the noise it creates. Marine litter is especially problematic in the area since the Sargasso Sea is within an ocean gyre in which plastic debris from around the region accumulates. Although unquantified in the Sargasso Sea, maritime traffic can affect ecosystem functions[8] and ecosystem services through intentional or accidental pollution, the introduction of invasive species, collisions with marine mammals, through[2] noise or through vessels sinking. Climate change also is expected to have serious impacts on oceans - through ocean acidification and changes in sea temperatures. Environmental changes in the Sea have already been linked to changes in the recruitment of European eels from the region (Friedland et al., 2007).

The combined ecological and economic importance of the Sargasso Sea, combined with the recognition of the increasing threats it faces, have led to increased political attention to its management (or lack of

[7] The lost years refer to the years where hatchlings hide and grow in the *Sargassum* providing a safer environment.
[8] 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.

management). The Sargasso Sea Alliance was created in 2010 through an initiative led by the Government of Bermuda. The mandate of the Alliance includes raising awareness on the importance of the Sargasso Sea and promoting better management of the area (Laffoley et al., 2011). The biodiversity associated with *Sargassum* ecosystems in the Sargasso Sea has been considered so important and unique, that the the United States South Atlantic Fisheries Management Council has considered *Sargassum* mats a critical fish habitat that deserves high protection (ICCAT, 2006; National Oceanographic and Atmospheric Administration (NOAA) and National Marine Fisheries Service (NMFS), 2003) and International Commission for the Conservation of Atlantic Tuna (ICCAT) has set a 2015 deadline to consider similar action (ICCAT Resolution 12-12). For the first time in ICCAT's history, ICCAT has resolved to use the Sargasso Sea as a case study on how to manage a whole ecosystem instead of a single species. Finally, on October 18, 2012, the Sargasso Sea was accepted by the 11th Conference of Parties to the Convention on Biological Diversity (Hyperabad, India) to be an ecologically and biologically significant area (EBSA) under the criteria adopted by Convention on Biological Diversity (CBD Decision XI/17, see also table 2 of the CDB Annex).

Who benefits from the Sargasso Sea? Valuing ecosystem services provided today.

The literature on the economic value of marine ecosystem services is large and growing, as illustrated by the more than 2000 ecosystem service values from more than 800 studies available under the Marine Ecosystem Services Partnership on-line database of ecosystem valuation studies. Most of the literature to date focuses on coastal ecosystem services (e.g. Barbier, 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 small handful of studies about the economic value of high seas ecosystem services (Sumaila et al, 2014).

In this study, we provide information from a limited, but growing body of assessments of the economic contribution of the Sargasso Sea. Ideally, one will look for measures of the net economic value (e.g. the consumer surplus and profit) that results from the provision of these services. However, such data are rarely available for the high seas. In the absence of net value, we rely on other measures of economic value and impact, including the gross revenues associated with ecosystem service activities. Gross revenues do not account for the costs of conducting the activity. As such, gross revenues (e.g. the landed value for fish harvest), are over-estimates of the economic value of those ecosystem services for which they are associated. While gross revenues are overestimates of the "value" of a given ecosystem service, it is equally important to note that our summary only captures a small portion of the ecosystem services known to depend upon a healthy Sargasso Sea.

All data in the report reflect annual economic contributions but are adjusted to 2012 U.S. dollar values to account for inflation. We caution the reader that few of these values were estimated in the last several years and so they are only approximations of current values.

Previous estimates of the economic value and impact of services value of the Sargasso Sea

Different assessments have already been carried out to (directly or indirectly) estimate the potential economic value and impact of services provided by ecosystems around Bermuda, including the Sargasso Sea writ large. Van 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[9]. Hallett (2011) looked at the contribution of the Sargasso Sea to the economy of Bermuda and its inhabitants. Hallett's 2011 report reviews the ecological benefits to Bermuda of the Sargasso Sea with a focus on that portion of the

[9] Tourism, coastal protection, cultural and recreation, amenity, fishery, research and education.

Sargasso Sea within the Bermudian EEZ (out to 200 nm) as well as the cultural, historical and economic importance of the sea to Bermudians. Sumaila et al. (2014) provide economic impact data and some estimates of the rent (a measure of net economic value) for commercial fishing taking place in the Sargasso Sea, the harvest of American and European Eels, and expenditures associated with recreational fishing. A 2012 study by the Iverson (2012) examined the benefits that could arise following the implementation of a Marine Protected Area (MPA) in the Bermudian EEZ with a focus on benefits related to tourism and to research-related activities.

In the present report, we summarize these studies and other studies with a particular focus on isolating those ecosystem services that depend on the ecosystem health of the Sargasso Sea. Additionally, we pay 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

We have identified a set of final ecosystem services that can be tied directly to the ecological conditions of the Sargasso Sea (Table 1). **Final services** are defined as the ones that **contribute directly to human well-being.** For example, fish are a final ecosystem service since they are utilized directly by humans, while the habitat that the *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, habitats and feeding grounds for turtles and many other species and may provide new genetic resources that could be used in medicines, agriculture, and other final goods. Venter et al. found more than one million previously unknown genes in samples taken from the Sargasso Seas (Venter, 2004). Using this definition, *Sargassum* that is harvested for sale is a final good since it is directly used in human activities – even if it is used as an intermediate good (e.g. fertilizer) once sold. Focusing on the final services does not mean the importance of intermediate service should be neglected. In fact, these intermediate services represent the link between the Sargasso Sea's ecosystem health, its ecological function, and the ultimate economic importance of the Sargasso Sea. Table 1 Summary of the ecosystem services provided by the Sargasso Sea

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

Category	Final services	Description	Contribution of the SS
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 captured in some regions (Troëng and Drews, 2004).	Spawning area, adult stage habitat, or area crossed during migration (Laffoley et al., 2011).
	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).
	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	The Sargasso Sea is the unique open-ocean *Sargassum*-based ecosystem (Freestone,

		these uses exists currently.	2013).
Cultural	Tourism in Bermuda (L)	Tourism is one of the main economic sectors in Bermuda. It relies heavily on its mild climate, clean beaches and healthy coral reefs (Hallett, 2011).	A healthy Sargasso Sea contributes to the attractiveness of Bermuda with for example healthy coral reefs contributing to snorkeling (Beukering et al., 2010).
	Research, education and protection activities (L)	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 long-running time series of ocean measurements as well as its unique biological and environmental conditions.
	Turtle, bird and whale watching (L, I)	Wildlife watching (e.g. turtles, whales and birds) supports industries and human wellbeing 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 can be seen 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 Sargasso Sea is home to a unique ecosystem and to rare and charismatic species that some may value for their existence. European eels also have a potentially high cultural value (J. 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, 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 gas emissions which has global benefit.	The overall contribution of the Sargasso Sea to carbon sequestration, oxygen production, and nutrient cycling is an active research area (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).

In the following sections we focus on a select group of ecosystem services that meet the criteria outlined earlier (e.g. some evidence of an ecological connection to the Sargasso Sea ecosystem; corresponds to well-defined constituencies and user groups; and that are likely to be threatened, in a very obvious way, because of the degradation of the Sargasso Sea ecosystem health). For each selected ecosystem service, we provide a short description of the ecology that underpins this service, the current ecological status of the organisms central to the ecosystem services, and estimates of the economic impact or value of ecosystem services are presented.

Towards the assessment of ecosystem services values in the Sargasso Sea

The Sargasso Sea ecosystem and fisheries

Vessels from Bermuda harvest fish in the EEZ, in the larger Sargasso Sea and in the wider Atlantic Ocean (see Figure 4 below). 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 the figure below), some depend for some of their life stages on the Sargasso Sea (represented in blue, e.g. white and blue marlins), some others are not relying on the Sargasso Sea at all (represented in purple below, e.g. seatrout, Atlantic croaker and spot)

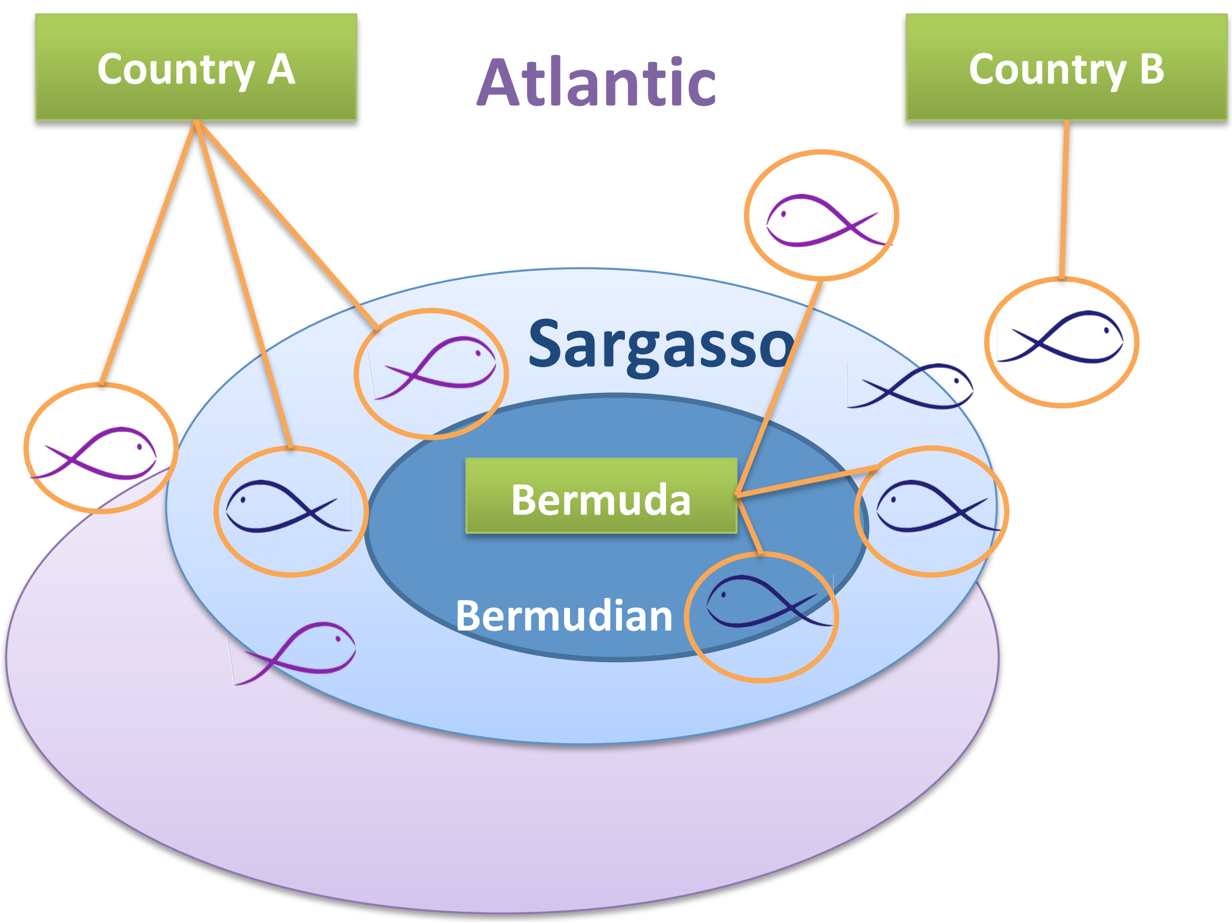


Figure 4 Fishing activities and their relations to the Sargasso Sea

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 U.S. was recognized by the 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 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; Manooch et al., 1985; Coston-Clements et al., 1991; SFMC, 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 the white and blue marlins (SFMC, 2002; Luckhurst et al., 2006; White Marlin Biological Review Team, 2007). Various species of eels, including European and American eels, spawn at depth in the Sargasso Sea (Schmidt, 1922; Schoth and Tesch, 1982; Kleckner and McCleave, 1988; McCleave and Miller, 1994; Miller and McCleave, 1994; Miller, 2002; Miller and McCleave, 2007).

The Atlantic bluefin tuna (*Thunnus thynnus*) migrate through the Sargasso Sea to northern feeding grounds (Lutcavage, et al., 1999, Block, et al., 2001; Block et al., 2005; Wilson and Block 2009) as do the yellowfin (*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).

The eel fishery

General ecology linking eels to the Sargasso Sea

What?

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

Essential Eel Ecology: The Sargasso Sea supports eel fisheries in North America and Europe and North Africa. Both the American eel (*Anguilla rostrata*) and the European eel (*Anguilla 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, we focus on the ecological links between the Sargasso Sea and European Eels, but a similar life history characterizes North American eels.

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). Once the eels reach Western Europe, the Mediterranean, and North African coasts (Miller and Hanel, 2011) they develop into adults in rivers and streams - a stage called “yellow eels”. After 6 to 20 years[11], the mature eels, known as “silver eels” return to their spawning grounds in the Sargasso Sea.

[10] http://www.fao.org/fishery/species/2203/en
[11] http://ec.europa.eu/fisheries/marine_species/wild_species/eel/index_en.htm

Status: Eel landings have decreased rapidly over the last 40 years. European eels are critically endangered (Laffoley et al., 2011). Around 16,000 tons of European eels were landed in the 1970s seventies, 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 in 2013 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 the 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 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 river basin scale in order to reduce the eels' human-induced mortality. Regarding American 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[13]. It was refused at the time but a new petition was filed in 2010.

The economics of eel fishing

Three types of commercial fishery depend upon 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 upon the Sargasso Sea. These gross revenues do not reflect the cost of harvesting, processing, or of aquaculture, nor subsidies that might exist in these sectors. As such, the gross revenues represent an overestimate of the net economic value of the current contribution of the Sargasso Sea to the eel fisheries of Europe and North America.

Building on European landed value for 2009 (estimated at 10,500 tons), Sumaila et al. (2014) estimate that the total landed value of eels that depend upon the Sargasso Sea is equal to U.S. $125.8 million per year ($123.6 million for the European fleet and $2.2 million for the fleet), with profits (a measure of net value) being estimated at U.S. $36 million per year (based on landing data from different years). The authors also estimate that the 2009 landings had a total economic impact at $360 million and an income effect of $60 million a year. This includes benefits to Europe and the U.S. (not Canada). More recent estimates from ICES (2012), however, put European eel landings at 3,201 tons for the year 2011 – one third of the landings reported by Sumaila et al. (2014). Updating the European eels landing value by using the same price of USD 11/kg used by Sumaila et al. (2014)[14] and the same methodology, we estimate that the **2012 adjusted landed value** of European eels was approximately **USD 35.9 million**, thus considerably lower than the 2009 value estimated by Sumaila et al. (2014).

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 a high demand and a low supply, the price of glass eels between 2008 and 2012 remained very high, ranging from 300 and 492€/kg, i.e. USD 2012 384 – 629.8 (EIFAC, ICES, 2012). Therefore, estimates of total revenues in 2012 from European eel glass landings range between $17,433,600 and 28,592,920 or **$23 million per year on average**.

[12]http://www.ices.dk/news-and-events/news-archive/news/Pages/Latest-ICES-advice-on-European-Eel---stocks-remain-critical.aspx
[13] http://www.dnr.state.md.us/fisheries/fmp/2011/Section_1_American_Eel.pdf
[14] Decrease in stock might have increased eel price since, so the landed value might have been even higher.

Glass eels are often captured to be used in eel aquaculture with most aquaculture occurring in the Netherlands, Denmark and Germany[15]. European aquaculture production has been decreasing in the past years from, 8000 – 9000 tonnes in 2003 to 5000 – 6000 tonnes in 2010/2011 (ICES, 2012). The global production of farmed *Anguilla anguilla* peaked at the end of the twentieth century and has since declined (FAO, 2013)

Sumaila et al. (2014) estimated the landed value of adult eels caught in the U.S. at **USD 2.2 million** (annual average catch between 1983 and 1995) (2012).

American glass eel landings in the U.S. are only permitted in the States of Maine and South Carolina (ASFMC American Eel Stock Assessment Peer Review Panel, 2012). Prices of American glass eels exceeded $2000/pound in 2012 (ASFMC American Eel Stock Assessment Peer Review Panel, 2012).

Less than 500 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 similar to those in the U.S. (i.e. USD 3.4/kg according to Sumaila et al., 2014), we estimate the landed value of the Canadian silver eel harvest at $ 1.7 million (USD 2012). Landed value in Canada of American elvers in 1997 was estimated at $2.9 million (USD 2012). Therefore, we estimate total Canadian landed value around **$4.6 million**.

[15] 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	Price	Year	Source	(USD 2012) rounded Value ($'000)
Europe	Silver Eels (tons)	3201	$11 /kg (Sumaila et al., 2014)	2011	ICES (2012)	35,900
	Glass eels (tons)	45.4	€300- 492 /kg	2012	ICES (2012)	23,000
	Total revenues					58,900
U.S.	Landed value	-	-	Annual average catch 1983 - 1995	Sumaila et al. (2014)	2,200
	Total revenues					2,200
Canada	Silver Eels (tons)	500	$3.4 /kg (Sumaila et al., 2014)	Average/year	Engler Palma et al. (2013)	1,700
	Landed value of elvers	-	-	1997	Fisheries and Ocean Canada*	2,900
	Total revenues					4,600
TOTAL						65,700

Key points

Gross revenues from eel fishing

Around $66 million (USD, 2012) 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).

Some important revenues from European and American eels aquaculture in Asia are expected but no data have been found. Eel harvest and eel 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 substantially improve the economic value associated with this Sargasso Sea-endent ecosystem service.

Other commercial and recreational fish species fisheries

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. Reef-based fish (groupers, grunts etc..), are native in *Sargassum* seaweed and in the Bermudian EEZ (Hallett, 2011).

Essential Ecology of Commercial and Recreational Fishes: *Sargassum* mats and the Sargasso Sea in general provide important fish habitat for feeding, 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 guts.

Status: Laffoley et al. (2011) review the current 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 SS, their state and use of the SS

Fish species	Life stage in the Sargasso Sea (Laffoley et al., 2011)	Where fished[16]	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

The Economics of commercial fishing within the Sargasso Sea (tending finalization of report by Sumaila et al., 2014)

[16] 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., (2014).

Sumaila et al. (2014) analyze catch data from the FAO dataset 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[17] associated with commercial fishing taking place in the Sargasso Sea[18] (see Table 4). Gross revenues derived from commercial fishing directly in the Sargasso Sea exceed $98 million annually of which approximately $42 million represent the net economic value.

Table 4: Distribution of the annual landed value, income effect and economic impact from commercial fishing in the Sargasso Sea.
Source: Sumaila et al., 2014[19]

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

Fish species caught in the Sargasso Sea also occur outside of the area and are harvested throughout the Atlantic. Sumaila et al. (2014) 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 U.S. $1 billion annually (2009). The exact dependence of these stocks on the ecological health of Sargasso Sea is unknown and so the economic contribution of the Sargasso Sea to these valuable fisheries is currently unquantifiable, but clearly deserves further attention.

[17] defined as the total economic activity generated for every dollar of landed value

[18] These figures include the Bermudian EEZ and are based on landings in 2006. Prices are annual average prices from 1950 to today. Landed values are expressed in 2005 USD.

[19] 2012 Adjusted rounded values

Key points

Gross revenues from commercial fisheries

Around **$99 million (USD, 2012) 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 (USD 2009). What proportion of these revenues is dependent upon the Sargasso Sea is unknown.

The economics of recreational and sportfishing

Limited information exists on the economic impact or value of recreational and sportfishing linked to the Sargasso Sea. Bermudian sport and recreational fishing activities are most likely to be linked to the Sargasso Sea. A study of recreational fishing by Hellin (1999) estimated the annual Bermudian recreational fishery of pelagic species at $311,000. Bermuda has gained a reputation as a destination to catch exceptionally large (>1000 lbs) marlin (Luckhurst, 2003), and anglers largely from the U.S. are attracted to Bermuda during the summer for several international billfish tournaments (Hallett, 2011). Foreign sportfishing vessels often spend several weeks on the island for these tournaments, enhancing the local economy. In 2010, 21 foreign 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). Sportfishing brings economic benefits to Bermuda. Hallett (2011) estimates that the total expenditure by foreign anglers participating in seasonal tournaments in 2010 was $630,000 (in 2012 USD), though this estimate is likely conservative given that lodging and food cost approximately twice as much in Bermuda[20]. Therefore, it is likely that sportfishing for billfish brought an estimated **$1.3 million** in gross revenues to Bermuda's economy in 2010.

As with commercially important scombrids and billfish, the Sargasso Sea is likely to be important for recreational fishing outside of the sea. Recreational fishing and sportfishing events generate revenues in regions such as North, Central and South America as well as Europe. According to the Billfish Foundation (Billfish Foundation[21]), North Americans traveling to Costa Rica to fish generated $640 million (2012 USD) in 2008 – about 2% of Costa Rica's GDP. This includes expenditures in travel, restaurants, fishing guides, and transportation. Sportfishing also created $78 million in tax revenues and 63 000 jobs for Costa Rica. How much of this sportfishing depends upon conditions in the Sargasso Sea is unknown.

The Azores are known for being one of the best places worldwide to catch marlins. 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 U.S., Egypt, Angola, South Africa, Mexico). Each team pays between €5,700 – 6,600 for transport, hotel meals, boat rental and other local costs (Pawson et al., 2007), equivalent to total expenditures ranging from €125,400 to €145,200 for 22

[20] http://www.bermuda-online.org/costoflivingguide.htm
[21] http://www.billfish.org/research/socioeconomics/

teams in 2007 (on average €135,300, i.e around $ 220,268 just from the events organized by this Federation).

Finally, recreational fishing for scombrids and billfish in the U.S. and Europe may depend on the ecological health of the Sargasso Sea. In the U.S., more than 2.3 million people participated in recreational fishing activities (all fish species combined) in the U.S. 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. 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[22] in associated expenditures on fishing trips and gear. 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 upon the ecological health of the Sargasso Sea ecosystem[23].

Key points

Gross revenues from Recreational fishing

Around $**1.3 million (USD, 2012) in gross revenues** are generated in Bermuda through recreational fishing. What part actually remains in Bermuda is unknown, as well as the evolution of these revenues through time.

Recreational fishing in the Atlantic is a well developed activity generated as much as **$17 billion** of gross revenues in the Atlantic regions of United States and Western Europe and the waters of the Azores. An unknown fraction of these revenues is potentially dependent on ecological conditions in the Sargasso Sea, but the data are insufficient to determine what fraction can be associated with Sargasso Sea-dependent fish stocks.

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 few of these 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 occur throughout the Sargasso Sea (Antunes, 2009). Whales spend a substantial amount of time in the Sargasso Sea during migration and feed here.

[22] National Marine Fisheries, 2012.

[23] In 2011, species that were the most caught by recreational fishermen in the U.S., were seatrout, Atlantic croaker and spot, species that are not found in the Sargasso Sea (NMFS, 2012).

Status: The population of North Atlantic humpback whales was estimated at nearly 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).

The Economics of Whale watching

Worldwide, the whale watching industry generates $2.1 billion of total expenditures annually (O'Connor, 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[24] in the Caribbean, New England, Bermuda, and along the Canadian East Coast[25]. In 2008, whale watching in these countries served more than 3 million whale watchers annually. It supported more than 600 whale watching businesses with whale watching 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 billion in terms of associated tourism spending annually (O'Connor (2009) – see Table 5 below)[26].

Table 5 Total expenditures of the whale watching industry, in places potentially linked to the Sargasso Sea.
<u>Source</u>: *Adapted from O'Connor et al. 2009, adjusted to USD 2012*

	Number of whale watchers in 2008*	Number of operators in 2008*	Estimated jobs in 2008*	Direct expenditures in (2012)USD ($'000)	Indirect expenditures in (2012) USD ($'000)	Total Expenditures in USD (2012) ($'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

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

[24] For example changes in forage or water quality in the Sargasso Sea could affect whale health.
[25] 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.
[26] Direct expenditures correspond to the whale watching ticket price. Indirect expenditures are defined as expenditures by the participant which supports the whale watching trip.

Additionally, whale watching provides economic benefits to tourists that are not directly accounted for in the whale watching industry economics. For instance, in California, the consumer surplus[27] per person per whale watching day was estimated at $36.09 in 1999 (USD 2012 49.7) by Leeworthy and Wiley (2003). 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 $25.9 (USD 2012 37.9). Combining the number of whale watchers estimated by O'Connor (2009) with these consumer surplus values, the consumer surplus associated with Atlantic whale watching can be estimated at (USD 2012) $140 million annually. We also note that some people may hold existence values for whales. Loomis and Larson (1994) estimate the increase of the consumer surplus of Californian households at $27.27 for a 50% increase in whale population. This value entails both existence use value and existence value.

Key points

Gross revenues from whale watching

$34,000 (USD 2012) 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*), and Kemp's Ridley turtles (*Lepidochelys kempii*) and leatherback turtles (*Dermochelys coriacea*).

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). All of these sea turtles are endangered or critically endangered (Laffoley et al., 2011).

[27] 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.

Leatherback turtles migrate from their nesting sites in the Caribbean Sea to the North (New England, Nova Scotia[28]) or to Western Africa. The most important nesting area for Leatherbacks in the western Atlantic is French Guiana. Estimates of the number of nests have varied 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 U.S., 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 Ridley turtles inhabit coastal waters along Florida but do not nest there (Meylan et al., 1995). Their stock is now thought to be increasing (Braütigen 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 subdivided in at least 5 subpopulations (Richards et al., 2011). More information on the use of the Sargasso Sea to these populations has not been found. Florida is one of the largest nesting areas for Green Turtles in the Caribbean Sea and the western Atlantic Ocean (Meylan et al., 1995). Information on the importance of the Sargasso Sea for these turtle populations (e.g. how many turtles of these turtles spend time in the the Sargasso Sea) has not been found.

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, Braütigen & Eckert, 2006).

The Economics of turtles

Like whale watching, turtle watching generates revenues for local businesses and consumer surplus benefits for turtle watchers. Turtles also are sold for food in some places.

For instance, the leatherback turtle breeding area in **Trinidad and Tobago** generated between **$60,825 and 97,320** in revenues from turtle watching tours (Save Our Sea Turtles, 2012). Troëng and Drews (2004) look at 9 case study sites in developing countries (See Table 6). Gross revenues from sites where non-consumptive use of marine turtles, such as tourism, is a major revenue generator and on sites where turtles may go through the Sargasso Sea, range from $115,000 to $8,576,000 annually at the sites with an average of $3 million per year. Gross revenues were estimated by multiplying 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.

[28] Laffoley et al., 2011, refer to James, Myers and Ottensmeyer, 2005.

Table 6: Gross revenues from turtle watching in different locations potentially linked to the SS.
Source: Adapted from Troëng and Drews (2004)

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

Sea turtles migrate and so the ecosystem services provided by turtles observed within the Sargasso Sea may also be enjoyed at other sites visited by these sea 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 provide aggregated information on wildlife viewing. In 2011, 10.1 million people in the U.S. watched animals other than birds, land mammals, fish and marine mammals, this category includes turtles among other species (U.S. Department of the Interior, 2011).

Turtle watching also generates non-market values. A survey implemented by Oceana estimates that American scuba divers are willing to pay on average $29.63 per dive to see sea turtles[29]. Along North

[29] http://oceana.org/sites/default/files/reports/SeaTheValue_Final_web1.pdf

Carolina, willingness to pay per household per year for loggerhead sea turtle protection (includes use and non-use value) was estimated at $10.98 in 1991 (Whitehead, 1992)[30].

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 studies with average gross revenue of $0.6 million i.e. 2012 USD 0.7 million[31].

Key points

Gross revenues

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 where 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

The Sargasso Sea has long attracted oceanographic and biological researchers. Bermuda's location, close to the United States and close to deep water in the center of the Sargasso Sea, has led to the establishment of long term oceanographic research sites within the Bermuda EEZ. In 2007, van Beukering et al. (2010) estimated that research expenditures for coral reef-based studies totaled $2.3 million ($2.6 million USD 2012). 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 Bermudian waters of the Sargasso Sea found that current direct spending by researchers of the Bermuda Institute of Ocean Sciences amounts to approximately $12-13 million per year (Iverson, 2012). Laffoley et al (2011) estimate nearly $100M is spent by U.S. Government bodies and research institutes over the last 50 years to support time series and other research projects undertaken in the Sargasso Sea. While this estimate does not identifying the distribution of benefits across countries from this spending, it does show that research is an important activity whose benefits should be further investigated. Furthermore 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 that can contribute to our understanding of changing oceanic conditions and processes.

[30] available online: http://ageconsearch.umn.edu/bitstream/48812/2/18824875.pdf
[31] Assuming data are from 2002.

Key points

Gross expenditures

Around **$12 million** are annually spent by BIOS located in Bermuda. Bermuda 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.

Conclusion

The preceding summary of the economic impacts and value of ecosystem services originating in the Sargasso Sea reveals the emerging understanding of the importance of this ecosystem to human wellbeing. Indeed, the ecosystem of the Sargasso Sea provides a series of services that can be tied to the ecological conditions and health of the Sargasso Sea and that are directly beneficial to human activities. These include:

- **Provisioning services** such as: commercial fishing, sport fishing, recreational fishing and *Sargassum* harvest;
- **Cultural services** such as: tourism in Bermuda, research, education 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.

Valuing the services provided by the Sargasso Sea is a challenging task, as current knowledge about these values, and on the causal relationships between the ecological state of the Sargasso Sea and the services provided, is scarce. Furthermore, available economic values are of a heterogeneous nature, ranging from landed values of fish to expenditures from practitioners of a sea-related activity, gross revenues from tourism or the annual budgets of a (research or protection) organization. Still, the knowledge available delivers some understanding on the importance of the relationships between the Sargasso Sea and human activities.

- The **economic importance of the Sargasso Sea is significant**! Economic values directly or potentially linked to the Sargasso Sea for the individual services assessed are in the order of **several ten to hundred million dollars per year** as indicated in the figure below.
- The **highest economic values directly linked to the Sargasso Sea** are for **shoreline protection** provided by coral reefs ($279 million/year).
- **The highest economic impacts associated directly with the Sargasso Sea come from commercial fishing** taking place in the Sargasso Sea (landed value of around $100 million

/year[32]) and **eel fishing** ($66 million/year). For the latter, the study stresses the absence of information on eel fishing values for Central & South America, Africa and Asia (eel aquaculture): thus, the real value is likely to be higher as the estimate provided here.

- The main **economic values <u>potentially linked</u> to the Sargasso Sea** are for whale watching practiced in other parts of the Atlantic (estimated at nearly $500 million/year), a share of this value only being attributed to the Sargasso Sea. However, there is no evidence today that can help assessing the order of magnitude of this share.

- A healthy Sargasso Sea benefits **human activities and inhabitants who live within the Sargasso Sea region/Bermuda.** Direct economic impacts to the area originate from **shoreline protection** provided by coral reefs to Bermuda (see value above) and also from **whale watching organized in Bermuda** and **recreational/cultural activities** linked to the coral reefs in Bermuda.

- The Sea also 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 Northern America (around 10% of the total gross revenues estimated)[33]. **Commercial fishing** taking place in the Sargasso Sea benefits in particular **Central and Southern America** (around 60% of the total value estimated). And the benefits of **whale watching** in other seas accrues **mainly to Northern America** (around 95% of the total value estimated) and Central & Southern America (a bit less than 5% of the total value estimated). Estimates for the economic impact of turtle watching exist only for Central & South America (around $15 Million/year), with only a share of this value being attributed to the Sargasso Sea.

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, throughout the Atlantic nations, and may even generate non-use and regulating services that benefit people globally. The estimates of the economic values and impact of the services provided by a healthy Sargasso Sea ecosystem **advocate for 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: clearly, as it benefits to human activities and inhabitants from all other continents, in particular Northern America (whale watching), Europe (eel fishing) and Central and South America (commercial fishing), it is also **in the interest of organizations and inhabitants from these continents**.

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

- The value of the **contribution of the Sea to bird life** that are enjoyed by birdwatchers directly in the area and elsewhere, and sealife that may be viewed by scuba divers and snorkelers.

- We also do not have any quantitative understanding of the **contribution of *Sargassum*** in the creation of beaches and shoreline protection, carbon sequestration, oxygen production, or biodiversity protection[34].

[32] Note this is a gross revenue whereas the one for shoreline protection entails its economic value.
[33] As indicated above, 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.
[34] In our opinion, generic estimates of the value of a hectare of ocean are unreliable proxies for these values.

- As the commercial harvest and mariculture of marine plants continues to increase globally 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.

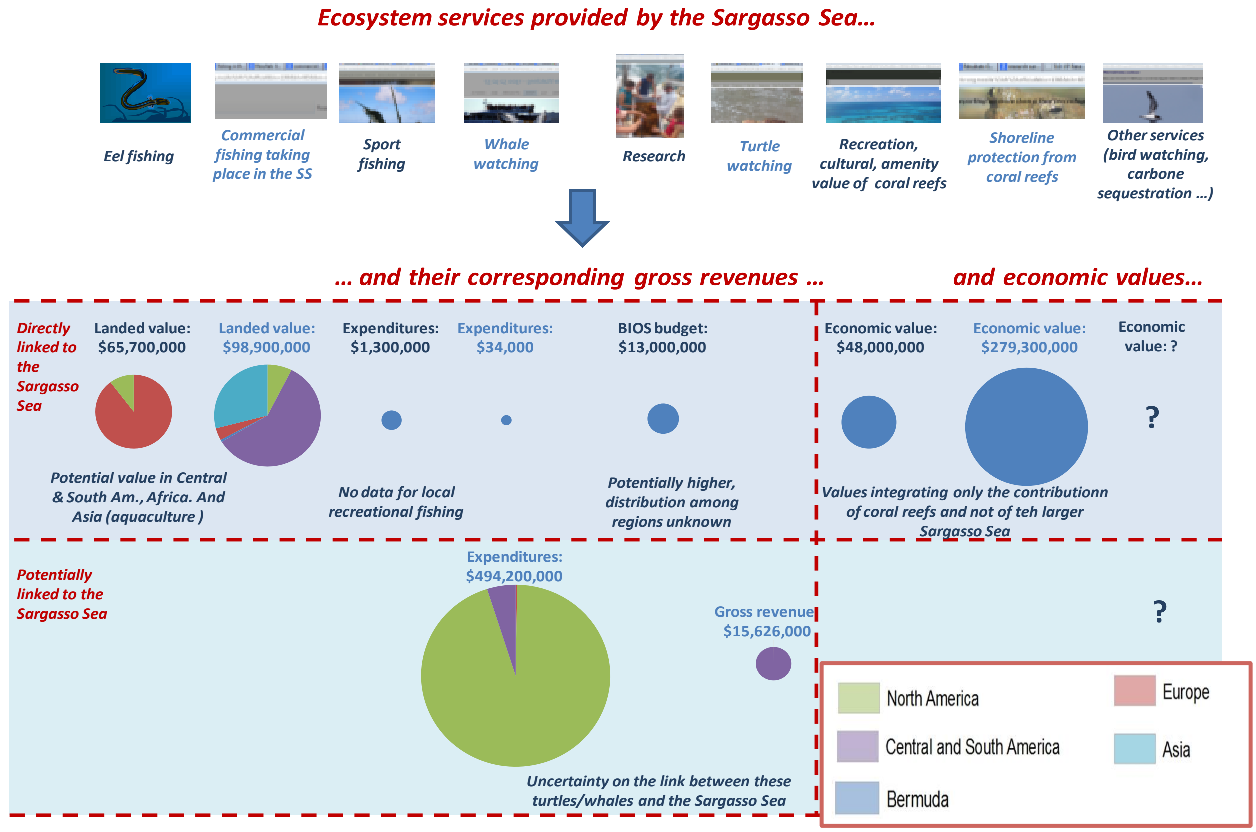
- **Other cultural values** are associated with the Sargasso Sea and have not been estimated so far. Eels are likely to have an important cultural value, contributing to traditional Christmas dishes in Sweden or traditional food locally in Canada for example.

- 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[35], turtles, sharks, and emblematic species that have fascinated 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. Other organisms may provide ecosystem functions or services that are still undiscovered. These values have yet to be quantified.

Finally, there is still insufficient science to allow us to fully understand how the suite of human impacts affects the ecological health and function of the Sargasso Sea and how this in turn affects people. The Sargasso Sea represents a complex and integrated ecosystem in which the many cumulative impacts of humans must be managed. To fully understand this system and the value of better management will require better data and a more holistic scientific understanding of the integrated relationship between people and the Sargasso Sea ecosystem.

[35] 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).

Figure 7. Which revenues and economic values for ecosystem services provided by the Sargasso Sea? A summary of the main valuation results



Note: The size of the pies are roughly proportional to the total value of annual impacts/benefits estimated for individual ecosystem services.
Main areas of uncertainties in regional estimates/share of the different regions are specified in italic for individual services.

Further efforts are thus required for enhancing the knowledge base on the economic values of the Sargasso Sea as a whole or of individual services its ecosystem delivers. In addition to carrying out research on the missing components of the total economic value of the Sargasso Sea mentioned above, additional work is also required on the values estimated in the present report. Figure 8 below highlights possible areas for further research that would help providing more robust estimates of economic values. In addition, it is important that efforts are made to translate the proxies of economic values provided in studies (such as total expenditures or landed values) unto economic values that can be compared and added to each others. This would help understanding the distribution of the economic value of the Sargasso Sea ecosystem services among services and also among countries and continents.

Figure 8. Potential candidate areas for further research on economic values

Ecosystem service provided by the Sargasso Sea	Main focus of further research
Eel fishing	Costs of eel and glass eel fishing
	Asian ranching industry profit
Commercial fishing	Distribution of revenues from fish depending on the SS, caught in the Atlantic (per species and per country)
Recreational fishing and sport fishing	Expenditures for the species linked to the SS (per species/per country)
	Consumer surplus from having the possibility to fish specific species
Whale watching	Economic impact of the whale watching industry
Turtle watching	Expenditures for turtle watching in North America
	Consumer surplus
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
Existence and cultural values for…	Eels, scombrids and billfish, whales, sea turtles

Finally, despite its potential ecological and economic importance, the exact ecological functioning of the Sargasso Sea and its role in the production of ecosystem services throughout the Atlantic region remain poorly understood. The link between whales, turtles, commercial fish in the Atlantic and the Sargasso Sea remains poorly analyzed. In order to get economic values of the services provided by the Sargasso Sea that can help making decisions, the changes in economic values following changes in the Sargasso Sea ecological conditions need to be understood. Cumulative impacts as well as the strong connectedness between all elements in the Sargasso Sea ecosystem need to be accounted for. This is far from our current understanding. Strengthening integrated biophysical and socio-economic research is a pre-requisite to improving the long-term protection and management of the Sargasso Sea.

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Photo credits

Figure 1:

Sargassum picture. Source: coastalenergy.com

Turtles eating Sargassum: Ardron et al., 2011 unpublished, Source: Laffoley et al., 2011

Turtle watching: http://www.13wmaz.com/news/photo-gallery.aspx?storyid=172735

Figure 3:

Sargassum picture. Source: coastalenergy.com

The Sea Anglerfish: David Shale, source: Laffoley et al., 2011

Figure 7:

Eel fishing:

Commercial fishing: http://en.wikipedia.org/wiki/Fishing_trawler

Sportfishing: http://www.hendersonparkinn.com/destin-florida-beach-vacations-news/fishing-things-to-do-in-destin/

Whale watching: http://www.manlywhalewatching.com/photos.html

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Recreation and cultural value of coral reefs: http://tripwow.tripadvisor.com/tripwow/ta-06c3-9b6c-586a

Shoreline protection from coral reefs: http://www.endangeredspeciesinternational.org/coralreefs5.html

Other services: Brian Patteson, http://seabirding.com/legacy/bermuda_petrel_pterodroma_cahow.htm

Appendix

Eco-system 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. (2014)	-	58,900	6,800	n.d.	n.d.	n.d.	65,700	Values de creasing quickly. No data for Africa and South ar Central America where fishing might arise. Revenues from eel ranching potentially very high in Asia.
Commercial fishing taking place in the SS	Landed value	Sumaila et al. (2014)	700	3,800	7,400	58,300	28,700	-	98,900	Work in progress. Values integrating Spanish mackerel, overestimate of catc for South America.
Sportfishing	Expenditures	Hallett (2011)	1,300	-	-	-	-	-	1,300	Recreational fishing by local fishermen not included.
Whale watching	Total expenditures	O'Connor (2009)	34	-	-	-	-	-	34	Data from 2008.
Research	BIOS annual budget	Pew Environment Group (2010)	13,000	n.d.	n.d.	n.d.	n.d.	n.d.	13,000	Data only from one research institution. Research budgets fı other countries institutions (especially the US) likely to be ı high and contributing to Bermudian economy.
Revenues possibly related to the Sargasso Sea										
Whale watching	Total expenditures	O'Connor (2009)	-	1,200	468,800	24,200	-	-	494,200	Weak knowledge on the dependence of these whales oı the Sargasso Sea

Turtle watching	Gross revenue	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 US where turtl watching might arise and depe on the Sargasso Sea
Recreation, cultural and amenity value of Bermudian coral reefs	Economic value	Van Beukering et al. (2010)	48,000	-	-	-	-	-	48,000	Value only for the contributior Bermudian coral reefs. Contribution from the Sargassu and the wider Sargasso Sea are can be higher.
Shoreline protection value of Bermudian coral reefs	Economic value	Van Beukering et al. (2010)	279,300	-	-	-	-	-	279,300	Value only for the contributior Bermudian coral reefs. Contribution from the Sargassu and the wider Sargasso Sea are can be higher.