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EXTENDING THE INDICATOR-BASED ECOSYSTEM REPORT CARD TO THE WHOLE ECOSYTEM; A PRELIMINARY EXAMPLE BASED ON THE SARGASSO SEA

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SUMMARY

To facilitate the implementation of Ecosystem-Based Fisheries Management (EBFM) the Sub-Committee on Ecosystems has developed an indicator-based ecosystem report card. A main objective of this new tool is to improve dialogue between scientists and managers and increase the awareness of the state of the different ecosystem components managed by ICCAT. The Sargasso Sea is a major component of the ICCAT convention area and provides a variety of ecosystem services to ICCAT and other Regional Fisheries Management Organisations (RFMOs) in the Atlantic region. Ecosystem services include a variety of products such as fish for food, but also processes that regulate and maintain our environment and cultural experiences. The ecosystem report card was developed using a Driver-Pressure-State-Impact-Response (DPSIR) approach. We show how this approach can be extended to develop a common understanding of how human activities affect the Atlantic ecosystem. We do this by proposing indicators that can be used to assess the state of the Sargasso Sea, to monitor the impact of human activity on the Atlantic ecosystem, and then discuss ways how these can be validated and management based on them can be implemented.

KEYWORDS

DPSIR , Ecosystem, EBFM, Fishing, Report Card, Sargasso Sea,

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Introduction

The continued and rising worldwide demand for ecosystem goods and services places the marine environment under threat and it is unlikely that many of those resources will continue to be available in the future unless we take action now. There is a need therefore to anticipate the consequences of alternative decisions on ecosystems, and to allow stakeholders to better understand the connections between the pressures that socio-economic factors create.

The Driver-Pressure-State-Impact-Response (DPSIR) framework is a flexible approach that has been used to assist managers and stakeholders in the many steps of the decision-making process required to protect the integrity of ecosystems. The approach has been widely used in the last two decades and has received the endorsement of several international institutions, for example The Organisation for Economic Co-operation and Development (OECD), the European Union (EU), the U.S. Environmental Protection Agency (EPA), and the European Environment Agency (EEA). At least 27 research projects focusing on marine and coastal habitats have used frameworks based on DPSIR (Patrício et al., 2016). These projects have mainly provided conceptual models and a challenge remains to provide indicators and quantitative models that allow management actions to be agreed, implemented, monitored and adapted as necessary.

A variant of the DPSIR framework, the Driver-Pressure-State-Ecosystem services-Response (DPSER) framework, has been used by the Standing Committe on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tuna (ICCAT) as the rationale for developing an indicator-based ecosystem report card (Juan-Jordá, et al., 2018). The report card was limited to targeted and by-caught species in tuna fisheries and so only considered a limited number of drivers, pressures and states. For example the drivers were limited to human population growth and climate change, while pressures were limited to fishing, temperature rise and ocean acidification. The indicators developed were based on catches reported to ICCAT, and there was no social nor economic analysis. Stakeholder input is in the form of feedback from the rapporteurs of the Species Groups on the ecosystem report card and from ICCAT commissioners on how the report card fits into the Ecosytem based Fisheries Management (EBFM) plan presented to managers in 2018 at the meeting of the Standing Working Group on Dialogue between Fisheries Scientists and Managers (SWGFMS).

The reason for moving towards EBFM is because fisheries are dependent on the productivity of the ecosystem, and in turn fisheries have an effect on, and are affected by the ecosystem. It, therefore, follows that prudent and responsible fisheries management should take account of the profound interactions between fisheries and their supporting ecosystem. A variety of interpretations of the ecosystem-based approach have been developed. For example, the FAO Fisheries Atlas, in its section on 'Basic Principles of Ecosystem Management' (Garcia, 2003), states:

> *'The overarching principles of ecosystem-based management of fisheries.....aim to ensure that, despite variability, uncertainty and likely natural changes in the ecosystem, the capacity of the aquatic ecosystems to produce food, revenues, employment and, more generally, other essential services and livelihood, is maintained indefinitely for the benefit of the present and future generations.....to cater both for human as well as ecosystem well-being. This implies conservation of ecosystem structures, processes and interactions through sustainable use. This implies consideration of a range of frequently conflicting objectives and the needed consensus may not be achievable without equitable distribution of benefits.'*

Ecosystem-based management is therefore concerned with ensuring that fishery management does not adversely affect the integrity of the ecosystem and its productivity, so that harvesting of target stocks, and resultant economic and social benefits, is sustainable in the long-term. Ecosystems also provide a range of goods and services that include products such as fish for food, but also processes that regulate and maintain our environment and cultural experiences.

In addition to ICCAT, which is responsible for the management of tuna and tuna-like species in its convention area covering the Atlantic Ocean and adjacent seas, there are many other Regional Fisheries Management Organisations (RFMOs, **Figure 1**) such as the Northwest Atlantic Fisheries Organization (NAFO) and bodies with responsibility for providing advice on and for the management of the Atlantic ecosystem, e.g. the Sargasso Sea Commission (SSC), the International Whaling Commission (IWC), the International Council for the Exploration of the Sea (ICES), the European Inland Fisheries and Aquaculture Advisory Commission (EIFAAC), the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), International Maritime Organisation (IMO), and the International Convention for the Prevention of Pollution from Ships (MARPOL)

For example, the Sargasso Sea ecosystem (**Figure 2**) as well as supporting important commercial activities such as fisheries, generates a variety of ecosystem goods and services that benefit many people such as recreational opportunities that support tourism (Pendleton et al. 2014). The Sargasso Sea ecosystem is also part of larger oceanic processes (Roe et al. 2016) whose environmental outcomes can affect human well-being globally (e.g., carbon capture and sequestration, Pendleton et al. 2014), and is also likely to play an intermediate role in the production of services that support part of the life cycle of organisms that are ultimately harvested outside the region (e.g., eels spawned in the Sargasso Sea are harvested in North America and Europe).

Pendleton et al. (2014), Sumaila et al. (2013), and Laffoley et al. (2011) provide varying estimates of the values of pelagic fisheries, eel fisheries in Canada, Europe and the USA that depend upon eels that spawn in the Sargasso Sea, recreational fishing, reef-associated tourism, and whale and turtle watching. Sumaila et al. (2013) also provide estimates of the indirect-use values for the Sargasso Sea associated with the open ocean, coral reefs, coastal systems and coastal wetlands. The accuracy of many of these estimates is questionable, but all values are large and emphasise the economic importance of the Sargasso Sea and the need to conserve and restore the ecosystem.

Figure 3 shows maritime traffic and **Figure 4** fishing activity in the Sargasso Sea. The economic importance of the Sargasso Sea is therefore significant with expenditures and revenues directly, or potentially totalling up to hundreds of millions of dollars a year with the most important component being commercial fishing of pelagic species and the harvesting of anguillid eels. Large expenditures in the tourism sector of coastal economies may be generated through whale watching, e.g. humpback whales migrate past Bermuda every Spring heading northward (Luckhurst, pers. obs.). A healthy Sargasso Sea supports many essential ecosystem services such as: i) Provisioning services, e.g. commercial fishing; ii) Supporting services, e.g. primary production, nutrient cycling; iii) Cultural services, e.g. tourism, sport fishing, education and iv) Regulating services, e.g. carbon sequestration, coastal erosion prevention.

EBFM emphasises habitat and ecosystem function in the context of fluctuations, and so to advance EBFM requires models that can incorporate spatial structure and environmental processes and to move from suites of single-species fishery indicators and management plans based upon them to integrated ecosystem-based fishery management plans (EBFMP, Pikitch, 2004). In an EBFMP, the impact of a management action would be assessed with respect to the ecosystem as well as individual species. It is entirely possible that a fishery could be considered not to be overfished in a single-species context but overfished within the ecosystem, for example when overfishing of large predators causes food web shifts (Gislason et al., 2003).

This paper explores whether the approach, based on the DPSIR framework, used to develop the ecosystem report card could also be applied to the Sargasso Sea and RFMOs in the Atlantic to help generate a common understanding of how human activities affect ecosystems and to conceptualise desired outcomes leading to the development of measurable management objectives. To do this, we build on the studies that have been presented by the Sargasso Sea Commission (SSC) in the past and the work that has been started by the Sub-Committee on Ecosystems (SC-ECO) to develop indicators to help assess the state of the fisheries in the Atlantic.

An ultimate aim is to develop indicators that could help assess the state of the Atlantic ecosystem and be used to guide adaptive management where design, management, and monitoring is done in an integrated way to systematically test assumptions in order to adapt and learn (Walters, 1986). To do this, will require management to retain a focus on statistical power and controls, the use of computer models to build synthesis and an embodied ecological consensus and the communication of alternatives to the political arena for negotiation of a selection (Tompkins and Adger, 2004).

The DPSIR Framework

The first goal of this study is to create a common understanding, using the DPSIR framework, of how human activities affect the Sargasso Sea, and hence the Atlantic ecosystem. We do this by developing a conceptual model then proposing indicators that can be included in tools such as the Ecosystem Report Card. We then discuss how these indicators can be validated, and used to assess the state of the Sargasso Sea and to monitor the impact of management.

A conceptual model of the system should include the following components:

1) Scientific – fisheries biology, oceanography, climate change

2) Political – legislation, policies

3) Regulatory – organisations e.g. ICCAT, NAFO, ICES, IWC, OSPAR, IMO, MARPOL

4) Social – social and economic factors affecting the system.

5) Institutional settings – government and other policy-making bodies

To move beyond concepts, DPSIR requires the use of ecosystem models (Hyder et. al., 2015) and many elements within the DPSIR framework can be addressed using current models. These include attribution of environmental change to underlying drivers, integration of models and observations to develop more efficient monitoring programmes, assessment of indicator performance for different management goals, and the costs and benefit of alternative management actions.

Requirements of a DPSIR framework

In order to provide a sound scientific basis for evaluating a pelagic ecosystem like the Sargasso Sea, a framework needs to be developed to coordinate and integrate long-term observations of physical, biogeochemical, and biological states (i.e. essential ocean variables EOVs; see Miloslavich, P, Bax N.J et al. 2018), in order to help develop Ocean Monitoring Indicators (OMIs) such as those available from the Copernicus Marine environment monitoring service. EOVs should address fundamental characteristics of the biological components of marine ecosystems that can be combined into indicators that: i) represent the complexity of real-world natural systems, ii) track temporal and spatial changes in the state of the environment, iii) evaluate management performance, iv) deliver information and products to scientific and policy audiences and v) assess progress towards international goals and targets.

In this context, the main steps required to build a DPSIR framework are to:

1) ***Define the system*** - Develop a mechanism to pursue conservation measures for the Sargasso Sea ecosystem through existing regional and international organisations for the benefit of present and future generations (Hamilton Declaration, 2014).
2) ***List key concepts related to system:*** e.g. fisheries catches, conservation, fisheries management, regional and international organizations, existing statutes for Areas Beyond National Jurisdiction (ABNJ.).
3) ***Determine concepts*** that are causing the problem (uphill) or result from the problem (downhill).
4) ***Use uphill and downhill links*** to fill in all five sections of the DPSIR framework with relevant, linked concepts.

Examples of **uphill links** are a) Fishing activity; b) By-catch; c) IUU fishing; d) Pollution; e) Climate change and effects on ocean chemistry; f) Shipping; g) Terrestrial activities e.g. plastics. While examples of d**ownhill links** are a) Fish stock depletion; b) By-catch mortality affecting ecosystem structure; c) IUU – undocumented catch; d) Pollution – effects on trophic web; e) Climate change – Distribution pattern changes, seasonality of migrations; f) Shipping - Hydrocarbon discharges, noise pollution for marine mammals; g) Other human activities such as the continuing commercial interest in harvesting *Sargassum*, the impact of submarine cables, and seabed mining (see Laffoley et al., 2011).

Table 1 summarises the DPSIR framework for the Sargasso Sea, and **Table 2** identifies potential indicators which could be used to monitor the state of the Sargasso Sea Ecosystem Component of the Atlantic Ocean. These tables are preliminary and were developed by the authors based on those of Juan-Jorda et al. (2018) and Henriques et al. (2008). It is recognised that producing the DPSIR tables can be a subjective process, therefore the intention is to review these tables at the SC-ECO meeting and update.

Key questions are:

- What datasets could be used to quantify the current state of the ecosystem with respect to appropriate limit and target reference points, to monitor increases in pressure and to describe responses to management?
- How can the economic benefits, and the potential losses, of the Sargasso Sea be quantified? For example. by estimating the ecosystem services, i.e. the benefits that humans freely gain from a properly-functioning Sargasso Sea ecosystem?

The Sargasso Sea

The ecological significance of the Sargasso Sea, has been described in a series of papers previously presented to the Ecosystem Subcommittee of ICCAT working toward the goal of implementing EBFM (Ecosystem-Based Fisheries Management). These papers examine various aspects of the ecology, migration and trophic structure of the Sargasso Sea pelagic ecosystem. Luckhurst (2014) described elements of the ecology and movement patterns of a total of 16 different fish species whose distributions include the Sargasso Sea. These species were divided into four groups that broadly correspond with ICCAT species groupings: Group 1 – Principal tuna species, Group 2 – Swordfish and billfishes, Group 3 – Small tunas and Group 4 – Pelagic sharks. Information was presented on ecology and habitat use as well as movement and migration patterns derived from conventional and PSAT tagging. The importance of *Sargassum* as essential fish habitat is linked to the feeding habits of tunas and other pelagic predators. Flyingfishes (Exocoetidae) are an important prey species in the diet of tunas and billfishes and some species are dependent on *Sargassum* mats as spawning habitat.

The feeding ecology and diet of a total of 15 different fish predators, corresponding to the principal ICCAT species groups listed above, were used to produce a preliminary pelagic trophic web of the Sargasso Sea (Luckhurst 2015). Values from stable isotope analysis of nitrogen in tissue samples as well as stomach contents analysis were used to estimate the trophic position (TP) for each species. All of the species had TP values equal to or greater than 4.0 with the exception of skipjack tuna (3.8). Large swordfish were the top-ranked predator (TP = 5.1). Large ommastrephid squid had a TP of 4.7 ranking them at a similar trophic level to other large fish predators. Squids are shown to be an important element of this food web in the role of both predator and prey.

An analysis of the catch data in the ICCAT database (CATDIS) for the principal tuna species (yellowfin tuna, albacore tuna, bigeye tuna, bluefin tuna and skipjack tuna) as well as swordfish was conducted for a 20 year period (1992-2011) (Luckhurst 2015). These data were compiled from a total of eleven ICCAT 5x5 degree reporting squares for longliners within the Sargasso Sea; all of these squares are exclusively in international waters (ABNJ) with the exception of Bermuda's EEZ. The analysis indicated that the Sargasso Sea was not a significant fishing area for any of the six species listed above as average annual catch levels for the reference period were under 3% of the respective species stock totals for all of these species.

The spawning area of three species managed by ICCAT – albacore tuna, swordfish, white marlin – in the southern Sargasso Sea was described and the significance of the position of the Subtropical Convergence Zone (STCZ) in relation to the spawning area was highlighted (Luckhurst 2016). Albacore tuna are shown to spawn in March and April in proximity to the STCZ. Swordfish spawning occurs from December to June within the subtropical area (13°–35° N.), but appears to be more intense in the southern Sargasso Sea. White marlin spawn in essentially the same area as albacore from April to June. The overlap of the spawning areas between these three species during similar time periods and in proximity to the STCZ indicates the importance of this oceanographic feature. An analysis of the ICCAT (CATDIS) catches for these three species for the southern Sargasso Sea (20°-30º N.) indicates that these catches are not generally a significant contributor to the Sargasso Sea as a whole.

Two mid-trophic level predators, dolphinfish *Coryphaena hippurus* and wahoo, *Acanthocybium solandri* (both species included in the ICCAT Small Tunas category) are taken principally as by-catch species by longline fisheries in the western Atlantic including the Sargasso Sea (Luckhurst 2017). However, they also support important commercial and recreational line fisheries in the western Atlantic. There is a linkage between oceanography and the seasonality of fisheries landings of these two species. Landings data from Bermuda, in the central Sargasso Sea, are provided as an example. PSAT tagging data from dolphinfish provides evidence of possible migration routes and lengthy residence times in the Sargasso Sea. Both of these two species play an important role in the trophic ecology of this pelagic ecosystem and there is a need to incorporate these and other species into any ecosystem-based fisheries management (EBFM) system for tuna and tuna-like species in the Sargasso Sea.

Squid play an important role in the pelagic trophic web of the northwest Atlantic (including the Sargasso Sea) with two species being commercially exploited: Northern shortfin squid *llex illecebrosus* (Ommastrephidae) which is an oceanic species and the longfin squid *Doryteuthis (Loligo) pealeii* (Loliginidae) which is a neritic species (Luckhurst 2017). The populations of both of these species are strongly influenced by the Gulf Stream, a powerful western boundary current system. Most squid species have life spans of a year or less and, as a consequence, their populations often display irregular annual fluctuations in abundance as opposed to cyclical patterns. Squids are considered to be sensitive to environmental factors and these factors may strongly influence recruitment and early growth. As squids function as both predator and prey, they play an important role in the trophic web of pelagic ecosystems. Studies of stomach contents demonstrate that Ommastrephidae are major contributors to the diets of large pelagic fishes in the central north Atlantic and all five tuna species (Thunnidae) plus swordfish (*Xiphius gladius*) managed by ICCAT have squid as an integral prey group in their diets. As squids are essentially “annual” species and are highly responsive to changes in their environment, it may be possible to use squids as a “sentinel” group with respect to climate change. Given their role in pelagic ecosystems, there is a need to incorporate data on squid into any EBFM model of the north Atlantic.

Sargassum mats appear occasionally on beaches in many Caribbean areas, the coast of Brazil and even the coast of West Africa. The source of the Sargassum is not the Sargasso Sea but the north equatorial recirculation region (NERR) south of the Sargasso Sea between the north equatorial current and the equator. The causes of these mass blooms and strandings are uncertain but may include nutrient availability from the Amazon and Orinoco Rivers, warmer surface temperatures and changes in circulation associated with climate change (Johnson et al 2012, Smetacek and Zingone 2013)). The impact of these mass strandings on local economies is severe, affecting tourism, recreation and fishing as the mats are difficult to dispose of, are unsightly and smell as they decompose.

Discussion

Elicitation

A major barrier in the way of implementing EBFM is the lack of consensus between fisheries policy-makers, managers, stock assessment scientists, conservationists, and ecologists on the degree to which different management strategies are required to implement EBFM (Trochta, et al., 2018). This accords with Leach, et al., (2013) who noted that variability in the natural world and our ability to measure it are not the only sources of uncertainty to affect decisions in managing fisheries; the perceptions and values of scientists, managers, fishers and other stakeholders are also important.

To help identity potential conflicting beliefs and to help build consensus on management an elicitation exercise could be conducted, using a questionnaire based on the DPSIR table. This would be used to elicit ratings of uncertainty on a range of variables from stakeholders on the impact on the ecosystem for the factors (i.e. processes, assumptions and hypotheses) identified. Respondents would be asked to provide scores for the variables in each of three dimensions: i.e.

- Importance of the variable;
- Uncertainty of knowledge concerning the variable; and
- The degree to which that variable is represented in current management.

These dimensions will help describe those aspects of uncertainty that are relevant, e.g. *Does it make a difference? Is the problem tractable? To what extent has it already been tackled? s*ee Leach et al. (2013) for an example based on the management bluefin tuna.

Models

Following an elicitation exercise the next step is the development of indicators that allow management actions to be agreed, implemented, monitored and adapted as necessary. Although there are many potential indicators, a key question is - Can they reliably predict the state of or changes in the system? Although there are many frameworks, there are few tests of their robustness. To move forward therefore requires, management to retain a focus on statistical power and controls, this can be achieved by using computer models to build consensus and by creating a dialogue between managers, stakeholder and scientists (Tompkins and Adger, 2004).

From Single Species towards Ecosystems Based Management

EBFM emphasises habitat and ecosystem function in the context of fluctuations, and so to advance EBFM requires models that can incorporate spatial structure and environmental processes and to move from suites of single-species fishery indicators and management plans based upon them to integrated ecosystem-based fishery management plans (EBFMP, Pikitch, 2004). In an EBFMP, the impact of a management action would be assessed with respect to the ecosystem as well as individual species. For example it is entirely possible that a fishery could be considered not to be overfished in a single-species context but overfished within the ecosystem, for example when overfishing of large predators causes food web shifts (Gislason, et al., 2004).

Reference points are used to prevent overfishing, for example the reference points used in the report card were based on Maximum Sustainable Yield (MSY) and are intended to prevent target overfishing (Kell et al., 2015). Overfishing can take a number of forms, however, for example as well as target, there is growth, recruitment or economic overfishing (Rosenberg and Restrepo, 1996). In Europe, the Marine Fisheries Strategy Directive (MFSD) has placed a legal requirement on Member States to not only consider the fishing pressure and the likely response in the system state to that pressure but also the impact of fishing on population demography, genetics and GES (European Commission 2010, descriptor 3). It is therefore important to develop indicators that help integrate these into management such as those related to growth and recruitment overfishing. For example the Small Tunas Species Group has used a variety of where indicators where catch-at-size data are compared to reference points based on life history parameters. These include the asymtotic length (L_∞), the length at which 50% of individual are mature (L_{50}) and L_{opt}, the size at which a cohort reaches its maximum biomass.

To be robust, indicators must allow the impacts of human activity to be detected against the background of natural variation, for example are changes seen due to environment or fishing pressure? Blanchard et al. (2005)

showed that size-based community metrics are potentially useful indicators because of their theoretical foundation and practical utility and can be used to explore temporal and spatial patterns in size-based community metrics. For example the types of metrics used in the small tuna working group could be extended to the main target and by-caught species. Link (2005) also proposed a set of ecosystem indicators that could be translated into warning thresholds and limit reference points for EBFM.

Conclusions

To facilitate the implementation of EBFM, the Sub-Committee on Ecosystems has developed an indicator-based ecosystem report card. The main objectives of this tool were to improve the dialogue between scientists and managers and to increase the awareness of the state of the different ecosystem components managed by ICCAT. To develop the ecosystem report card a DPSIR framework was used. A value of such approach is that it can be extended to develop a common understanding of how human activities affects the entire Atlantic ecosystem, not just within ICCAT but between RFMOs, other management bodies, fisheries policy-makers, stock assessment scientists, conservationists, and ecologists on the degree to which different management strategies meet agreed objectives

The Sargasso Sea case study showed that the report card was a useful tool that could be extended to other management bodies and include a range of ecosystem components; essential if ICCAT is to move towards EBFM.

Currently indicators used in the report card are limited to those based on MSY which is essentially a target and is affected by a range of factors including exploitation pattern of the fisheries, the environment and species interactions (Cury et al., 2014). Estimation of MSY also requires assumptions to be made about processes such as natural mortality and the stock recruitment relationship that are difficult to estimate in stock assessments (Carruthers et al., 2017). Indicators should be robust to such uncertainty and be extended to include growth and recruitment overfishing, and changes in spatial as well as temporal patterns, for example by using catch-at-size data and reference points based on life history invariants.

A step forward could be to conduct an elicitation exercise to build consensus about the next steps i.e. to develop indicators that allow management actions to be agreed, implemented, monitored and adapted as necessary. Although there are many potential indicators and alternative EFMB frameworks, few tests have been conducted of their robustness. To move forward requires management to focus on statistical power and controls. This can be assisted by using computer models to build consensus and by creating a dialogue between managers, stakeholders and scientists.

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Tables

Table 1: Examples of a Driver-Pressure-State-Impact-Response (DPSIR) analysis for the Sargasso Sea.

Drivers	**Pressures**	**State**	**Impacts**	**Responses**
Fishing				
Food	Catch - target species	Fisheries landings - target species	Overfishing of target species -	Economic loss
Food	By-catch	Fisheries by-catch - non-target spp.	Excessive by-catch -ecosystem dynamics	Fisheries management
Financial gain	Endangered species	Landings - Angullid eels in freshwater	Endangered species	By-catch mitigation
Employment	Lost fishing gear			Conservation programs
Food security	IUU fishing			
Shipping				
International commerce	Noise pollution -cetaceans	Maritime traffic increase	Oil tanker spills - ecosystem impacts	IMO ship regulations
	Hydrocarbon pollution	Ship size increase	Fisheries declines	Air pollution abatement
	Air pollution	Increase spread of invasive spp.		Increase fuel efficiency
	Ballast water - invasive spp.			
Climate change				
Economic growth	Greenhouse gases - incl.	Ocean acidification	Calcium metabolism effects e.g. corals	Attempt to limit negative effects
	CO2, methane, N2O	Ocean temperature increase	Temperature effects -migration, spawning	Renewable energy sources
		Sea level rise	Trophic web changes - keystone species	Green economies
Plastic				
Economic growth	Ubiquitous use of plastics	Volume of plastics increased with	Microplastics ingestion - plankton, fish	Recycle, re-use plastic
	for packaging, food	economic growth	Macroplastics ingestion - turtles, whales	Develop degradeable plastic
Sargassum				
Essential habitat	Commercial harvesting	New production area near equator	Excessive quantities affect fisheries, tourism	Mitigation strategies - beaches
	Ocean chemistry - growth rate changes?			
Mining				
Economic growth	Seabed mining - impacts on benthos dynamics	State of seabed largely unknown due to limited mapping	habitat destruction Removal of minerals - unknown effects	Technological advances to mitigate mining impacts
Undersea Cables				
Undersea Cables	Market demand to increase	Laying cables expensive, disrupts	Long term impact of cables unknown	Cable-laying to minimize impact
Economic growth	communication capacity	benthic habitat		

Table 2: Potential indicators for use within the DPSIR framework.

Driver	**Indicator**	**Data Source**
Fishing		
	Fisheries landings - target species	ICCAT - CATDIS
	Fisheries - non-target species	ICCAT - Task 1
	By-catch species	ICCAT - Task 2
	Landings - Angullid eels in freshwater	International Council for the Exploration of the Sea (ICES) - publications
		NAFO (2017) - Northwest Atlantic Fisheries Organization Report
		EU Common Fisheries Policy - Eurostat databases
		FAO Fisheries Databases
		NOAA - National Marine Fisheries Service (NMFS) Databases
		Canadian Department of Fisheries and Oceans (DFO) - catch database
Shipping		
	Number of ships by size category and type	International Maritime Organization (IMO) databases
	Number of ships by cargo category - oil, containers	International Convention for the Prevention of Pollution from Ships (MARPOL)
	Number and type of fishing vessels - trawlers, longliners	NAFO fishing vessel regulations
	Principal ship tracks across Atlantic	Canadian DFO - Fishing vessel register
		NMFS Fishing Vessel Database
		GESAMP (2015). Pollution in the open ocean.
Climate change		
	Ocean acidification - global	International Panel on Climate Change (IPCC) - Final Report 2014
	Ocean acidification - Sargasso Sea	Bermuda Institute of Ocean Sciences (BIOS) - Hydrostation 'S' database
	Ocean warming - global	BIOS - Bermuda Atlantic Time-Series Study (BATS) database
	Ocean warming - Sargasso Sea	International Council for the Exploration of the Sea (ICES) - publications
	Sea level rise	Woods Hole Oceanographic Institution (WHOI) - publications
	Gulf Stream changes	NOAA Technical Reports
		Copernicus Project - Marine Environment Monitoring Service
		Climatic Data - NAO (North Atlantic Oscillation),
		STCZ (Subtropical Convergence Zone)
Plastic		
	Lost and abandoned fishing gear	Lusher et al. 2017. Microplastics in Fisheries and Aquaculture. FAO Technical Report 615
	Lost aquaculture gear	Joint IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Group of Experts
	Microplastics - trophic web	on the Scientific Aspects of Marine Environmental Protection. http://www.gesamp.org/
	Terrestrial waste	GESAMP (2016) - Microplastics in the marine environment
Sargassum		
	Essential fish habitat	Huffard et al. (2014) -Pelagic *Sargassum* community change over a 40-year period: Mar. Biol.
	Beach stranding - economic impact (tourism, fishing)	Wang and Hu (2017) -Predicting *Sargassum* blooms in the Caribbean Sea from MODIS observations. Geophysical Research letters 44.
	Commercial harvest	*Sargassum* reporting (tropical western Atlantic) - www.usm.edu/gcrl/sargassum
		Franks,Johnson,Ko (2016) -Pelagic *Sargassum* in the tropical north Atlantic. Gulf and Caribbean Research Vol 27, SC6-11.
		South Atlantic Fisheries Management Council (SAFMC) - *Sargassum* Fishery Management Plan. http://safmc.net/sargassum/
Mining		
	Destruction of seabed habitats	International Seabed Authority (ISA) regulations - https://www.isa.org.jm/
	Large sediment plumes in deepsea habitats	Miller at al (2018). An Overview of Seabed Mining - current state of development, environmental impacts, knowledge gaps.
	Chemical, light, noise pollution in deepsea	Sharma,R. (2015). Environmental issues of deepsea mining. Procedia Earth and Planetary Science 11 (2015) 204 – 211
Undersea cables		
	Potential disruption of seabed habitats	De Juvigny et al (2015) - Submarine telecommunication cables in the Sargasso Sea.
	Probably minimal impact but few studies conducted.	
	Few cables across Sargasso Sea.	

Figures

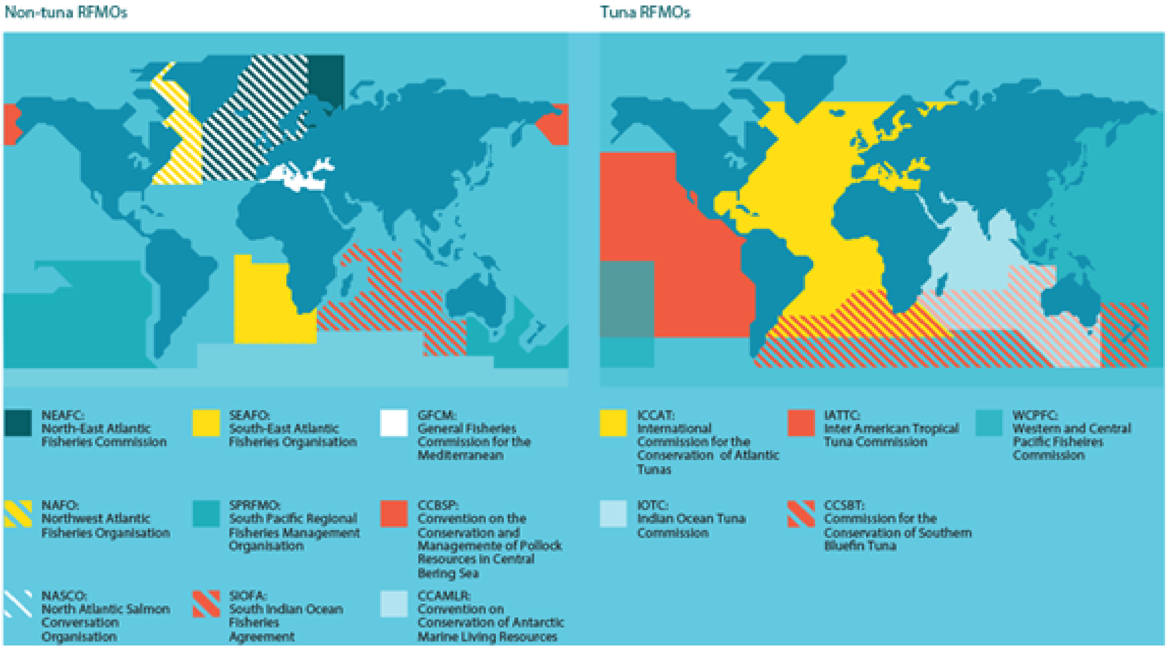

Figure 1. Regional Fisheries Management Organisations – Non-tuna (left panel) and tuna (right panel)

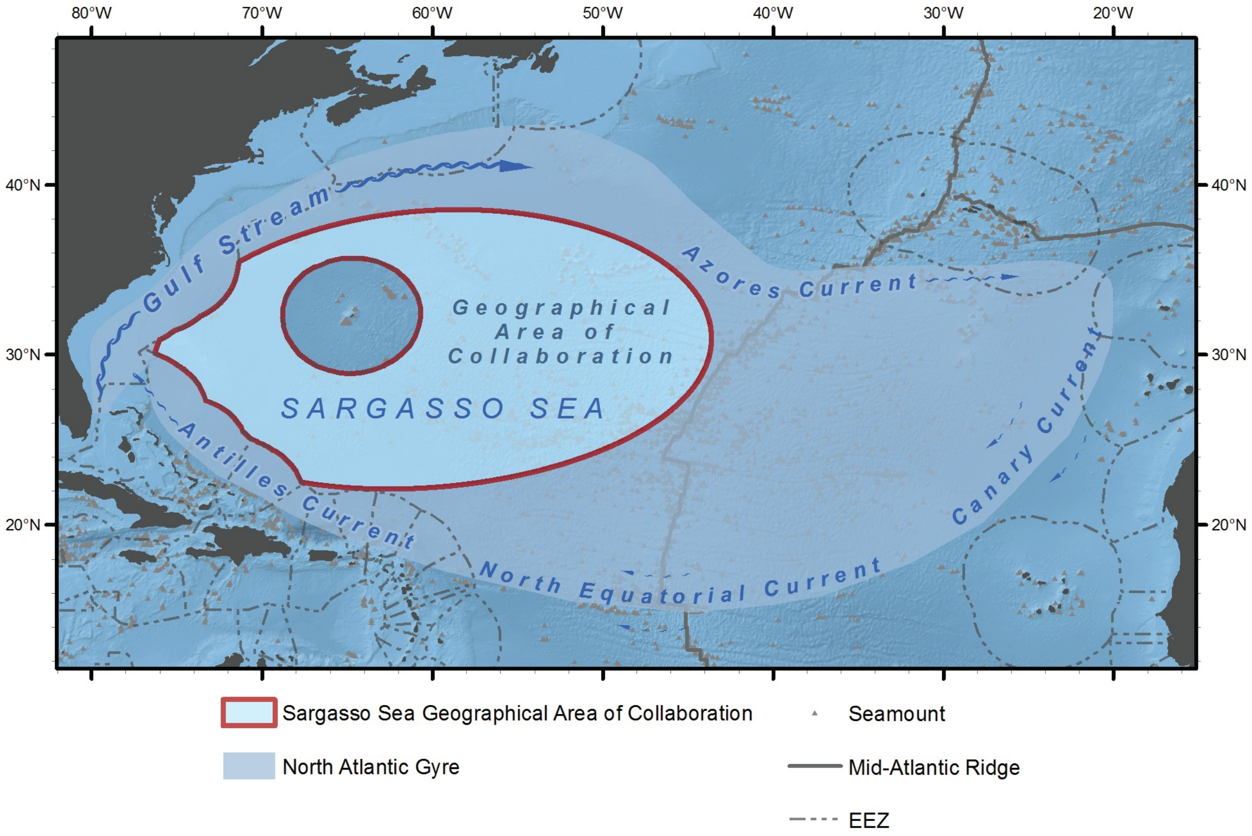

Figure 2 - Sargasso Sea Area of collaboration defined by the Sargasso Sea Commission with boundary, currents and Bermuda's EEZ indicated (from Hamilton Declaration, 2014).

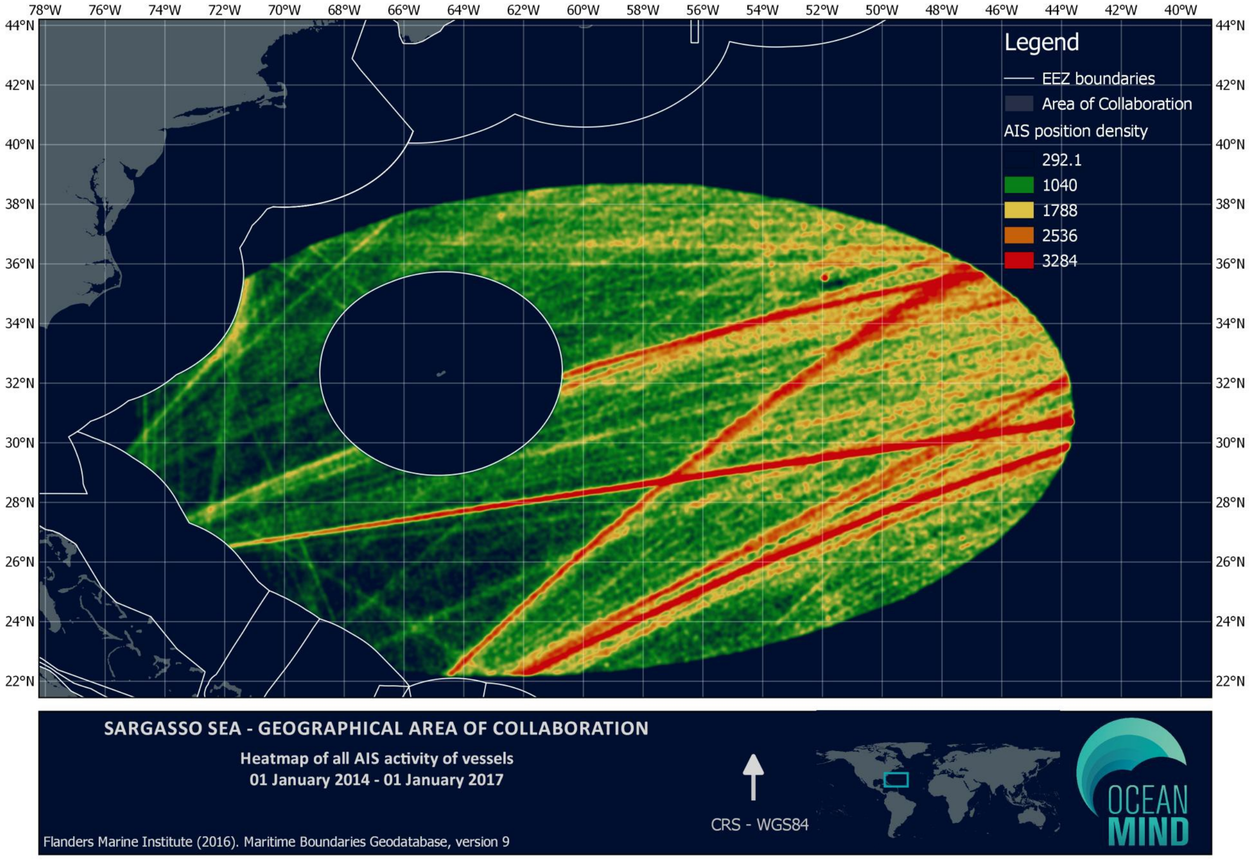

Figure 3. Three year maritime traffic (2014-2016) in the Sargasso Sea, red lines are major shipping lanes.

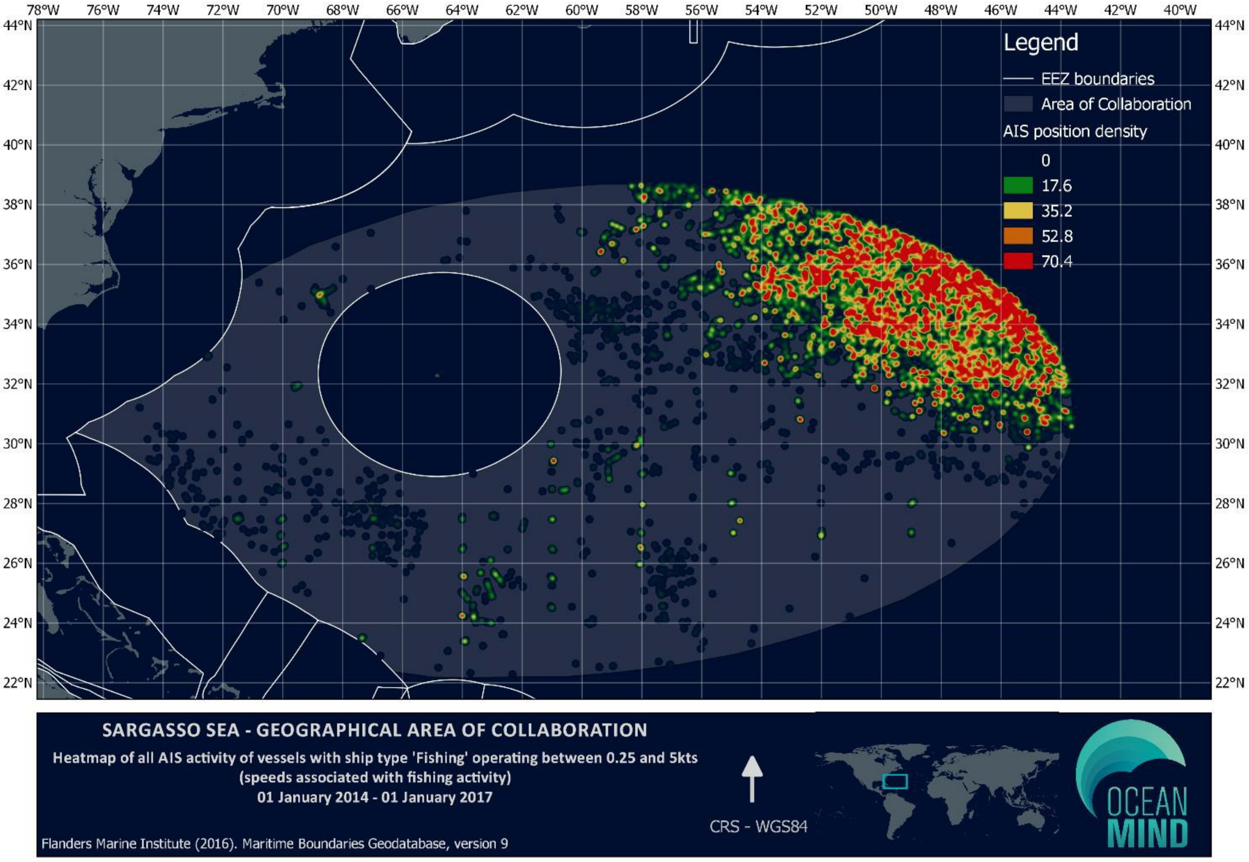

Figure 4. Three year (2014-2016) composite of fishing vessel activity in the Sargasso Sea.