Preparatory Data Discovery and Analysis to Support Enhanced Management and Governance of the Sargasso Sea:

A Technical Report on the State of the Ecosystem and Human Use Pressures

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A Report Submitted to Sargasso Sea Commission

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The Sargasso Sea Commission works to "encourage and facilitate voluntary collaboration toward the conservation of the Sargasso Sea." The Hamilton Declaration on Collaboration for the Conservation of the Sargasso Sea, established in 2014, provides a framework for voluntary collaboration between ten signatory governments and a Commission of scientific experts operating in their independent capacities for the conservation of the Sargasso Sea.

This work is an underlying report to the Socio-Ecosystem Diagnostic Analysis (SEDA) for the Sargasso Sea—the first analysis of its kind of a high seas ecosystem.

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Further details: The Secretariat of the Sargasso Sea Commission is hosted by the Washington D.C. Office of the International Union for the Conservation of Nature (IUCN), Suite 300, 1630 Connecticut Avenue NW, Washington D.C., 2009, USA.

A full version of this report and of the reports commissioned by the SSC are available for download on the website at www.sargassoseacommission.org

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List of Acronyms

ABMT – Area Based Management Tool
ABNJ – Areas Beyond National Jurisdiction
ADT – Absolute Dynamic Topography
AFAI – Alternative Floating Algae Index
AIS – Automatic Identification System
AMO – Atlantic Multidecadal Oscillation
AOI – Area of Interest
BBNJ – Biodiversity Beyond National Jurisdiction
CBD – Convention on Biological Diversity
CMIP – Coupled Model Intercomparison Project Phase
CR – Critically Endangered
EBSA – Ecologically or Biologically Significant Area
ECS – Extended Continental Shelf
EDA – Ecosystem Diagnostic Analysis
EEZ – Exclusive Economic Zone
EN – Endangered
ETP – Eastern Tropical Pacific
FAO – Food and Agriculture Organization
GAC – Geographical Area of Collaboration
GFW - Global Fishing Watch
IBA – Important Bird Area
ICCAT - International Commission for the Conservation of Atlantic Tunas
IUU – Illegal, Unreported and Unregulated
ISA -
IMMA – Important Marine Mammal Area
IMO – International Maritime Organization
IOTC – Indian Ocean Tuna Commission
ISRA – Important Shark and Ray Area
ITOPF – International Tanker Owners Pollution Federation
IUCN - International Union for Conservation of Nature
IUU - Illegal, Unreported, and Unregulated
ISA – International Seabed Authority
IWC – International Whaling Commission
KBA – Key Biodiversity Area
MCI – Maximum Chlorophyll Index
MFE – Maximum Feature Extent
MHW – Maximum Heatwave
MIH – Maximum Intensity Heatwave
MMSI – Maritime Mobile Service Identities
MSY – Maximum Sustainable Yield
MTLc – Mean Trophic Level of the Catch
NAFO – Northwest Atlantic Fisheries Organization
OBIS – Ocean Biodiversity Information System
PA – Protected Area
PAH – Polycyclic aromatic hydrocarbons
PSR – Preliminary Subregions
RFMO – Regional Fishery Management Organization
RMU – Regional Management Unit
SAU – Sea Around Us project
SS – Sargasso Sea
SSP – Shared Socioeconomic Pathway
SST – Sea Surface Temperature
TAC – Total Allowable Catch
UNCLOS – United Nations Convention on the Law of the Sea
VME – Vulnerable Marine Ecosystem
VU – Vulnerable
WECAFC – Western Central Atlantic Fishery Commission

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Values from the Resources of the Sargasso Sea

Background

The Sargasso Sea (SS) is an area of the western North Atlantic Ocean where mats of *Sargassum* seaweed (primarily *S. natans* and *S. fluitans*) aggregate, forming what many refer to as a "floating rainforest." The SS is located at the heart of the North Atlantic Gyre, which is made up of several circulating currents including the Gulf Stream, the Azores Current, the Canary Current, the North Equatorial Current, and the Antilles Current. Typical of many oceanic gyres in the northern hemisphere, the western currents of this system are more concentrated and easily discernable than those at the eastern extent. Thus, there is a fairly strong boundary on the western side of the SS, with a more moderate one to the north and south, and a relatively weak bounding effect from those currents found in the eastern extent of the study area. The SS is also influenced by a series of rings and eddies, together known as mesoscale eddies, that can persist for months to years at a time and play a central role in temperature regulation, salinity and nutrient concentration, and *Sargassum* mat aggregation (Benitez-Nelson and McGillicuddy 2008). It is through this system of currents and eddies that *Sargassum* is transported from the Caribbean, traveling into the Gulf of Mexico and up the eastern seaboard of the United Stated entrained in the Gulf Stream, then trapped within the North Atlantic Gyre and concentrated by eddies.

The SS provides a rare mosaic of valuable and protective habitat in the deep water of the open ocean. With a high degree of persistence and a widespread footprint, this thick layer of *Sargassum* attracts a diverse and abundant species assemblage, distinguishing it from any other drift algae (Coston-Clements et al. 1991; Casazza and Ross 2008). There are ten species known to be endemic to floating *Sargassum* including the Sargassum crab (*Planes minutus*), Sargassum pipefish (*Syngnathus pelagicus*), and the Sargassum anemone (*Anemonia sargassensis*), to name a few. Additionally, the SS provides valuable habitat to several species of high conservation value. This feature acts as the spawning area for the economically valuable American and European eels (*Anguilla rostrata* and *A. anguilla*, respectively) which spend their adult lives in freshwater but migrate thousands of miles to the SS to spawn (Kleckner et al. 1983; Friedland et al. 2007). Larval development occurs in the SS, after which both species migratealong the Gulf Stream back to freshwater habitats in North America and Europe where they metamorphose into their juvenile forms, referred to as "glass eels." As an economically valuable species, there is growing international concern over the severe decline of glass eel recruitment, with populations of both species suffering from significant population reduction.

Several species of sea turtles, all of which are listed as Endangered or Critically Endangered by the IUCNRed List (IUCN 2022), spend time as hatchlings and juveniles in the protective layer of the SS. Green seaturtles (*Chelonia mydas*), hawksbill turtles (*Eretmochelys imbricata*), loggerhead sea turtles (*Caretta caretta*), and Kemp's ridley sea turtles (*Lepidochelys kempii*) all use the *Sargassum* as a nursery habitat (Carr and Meylan 1980; Carr, 1987), spending their "lost years" feeding and sheltering in this area. For these, as well as many other species, the *Sargassum* mats provide a stable habitat structure with a rich food supply, protection from predators, and thermal regulation that promotes growth and feeding (Mansfield et al. 2014; Mansfield et al. 2021). In fact, the SS acts as a nursery and spawning habitat for many other species including swordfish (*Xiphias gladius*), dolphinfish (*Coryphaenidae* spp.), flying fish (*Exocoetidae* spp.), and blue marlin (*Makaira nigricans*; Dooley 1972; South Atlantic Fishery Management Council 2002; Luckhurst et al. 2006; Casazza and Ross 2008).

In addition to acting as spawning and nursery habitat for a wide array of species, the SS is a stopover and feeding site for many others. A number of pelagic fish species including Atlantic bluefin tuna (*Thunnus thynnus*) and Atlantic swordfish, both of which are economically important, move through this area (Block et al. 2001; Loefer et al. 2007). Sharks and rays also make use of the SS, inhabiting or migrating through the SS seasonally. For example, basking sharks (*Cetorhinus maximus*) regularly move through this area during winter months at depths of 200 – 1000 m (Skomal et al. 2009). Moreover, as many as 30 cetacean species have been observed in and around the SS. Humpback whales (*Megaptera novaeangliae*) routinely pass through this area during annual migrations and sperm whales (*Physeter macrocephalus*) are commonly observed as well, with adults and calves likely feeding at the frontal convergence and around the boundaries of the Gulf Stream (National Marine Fisheries Services 2010).

The SS provides widespread support to biodiversity and ecosystem health and even aids in global carbon sequestration (Laffoley et al. 2011). The socio-economic and cultural significance of this feature is significant, and it is important to enhance understanding of its spatio-temporal behavior to design and implement impactful conservation measures. This report explores data sources, summaries, and synthesis methodologies to address existing gaps in this area, with the central purpose of delineating boundaries that are relevant and useful to conservation and management initiatives.

Project Overview

The descriptive analysis of the SS's spatio-temporal dynamics is part of the SARGADOM project (https://sargadom.com/en/), funded by Le Fond Français pour l'Environnement Mondial (https://www.ffem.fr), which focuses on hybrid governance of the High Seas using two study sites: the Thermal Dome in the Eastern Tropical Pacific Ocean (ETP) and the Sargasso Sea in the North Atlantic. The analyses summarized in this report, which is part of the effort coordinated by the Sargasso Sea Commission (http://www.sargassoseacommission.org/), has three parts (or "Deliverables"): 1) Describe the dynamic feature and its spatio-temporal variability, 2) Review the data and information needs for the Ecosystem Diagnostic Analysis (EDA), and 3) Analyze and synthesize existing research and information. Deliverable 3 includes the collection, examination, and analysis of data pertaining to the current state of the CRTD ecosystem (such as biological usage) as well as pertinent human-use pressures (such as fishing effort) in the study region. A summary of results from Deliverables 1 and 2 of the SARGADOM project are included here. Together, results from Deliverables 1, 2, and 3 provide a more complete profile of the environmental, oceanographic, biological, ecosystem health, and human-use pressures of the SS.

Ultimately, the information provided here will become part of a greater analysis and synthesis effort (referred to here as the EDA) to allow stakeholders (e.g., managers, trainers, policy experts, etc.) to assess possible management and governance improvements for the SS. This effort is guided by a Driver- Pressure-State-Impact-Response (DPSIR) framework developed by project partners, which has helped to inform identification of data resources and drive analysis and synthesis.

Contextual Information

Temporal Coverage

The temporal coverage and resolution of the summarizations and analyses in Deliverable 3 vary depending on data availability. This contrasts with the physical oceanographic information from Deliverable 1, where we included monthly climatologies and overall means from ten years of data across all variables. Despite disparate temporal coverage, results from Deliverable 1 are meant to provide environmental context to the more focused ecosystem state and human use pressure information explored in this Deliverable 3 report.

Study Region

Area of Interest

The study region was established in consultation with the SARGADOM project leads. The area was intentionally broad to capture any contextual oceanographic features or human-use patterns in adjacent areas, such as the Gulf Stream current system and Canary current system. The study area of interest (AOI) extends from 15°N to 45°N and from 25°W to 82°W (Figure 1). A modified Mollweide projection was selected for any area calculations that required an equal-area map projection.

Dataset Summary Extent

In addition to the AOI, we used two other extents to summarize and analyze various data. One extent was the geographical area of collaboration (GAC; Laffoley et al. 2011), which excludes jurisdictional waters of the Bermudan EEZ (Figure 1). The second extent was developed using a sub-region analysis developed for Deliverable 1 of the SARGADOM project and is referred to as the maximum (MFE; Figure 1) There were three principal steps to defining the MFE. First, we identified sub-region classes that most likely represent conditions that either make up the core of the SS or are important peripheral areas, including classes 3, 7, 8, 9, and 10. Second, we extracted these focal classes from the monthly sub-region classification rasters and counted their annual persistence within the study area. Finally, we extracted areas that were categorized as a focal class for 4 or more months of the year from the persistence layer

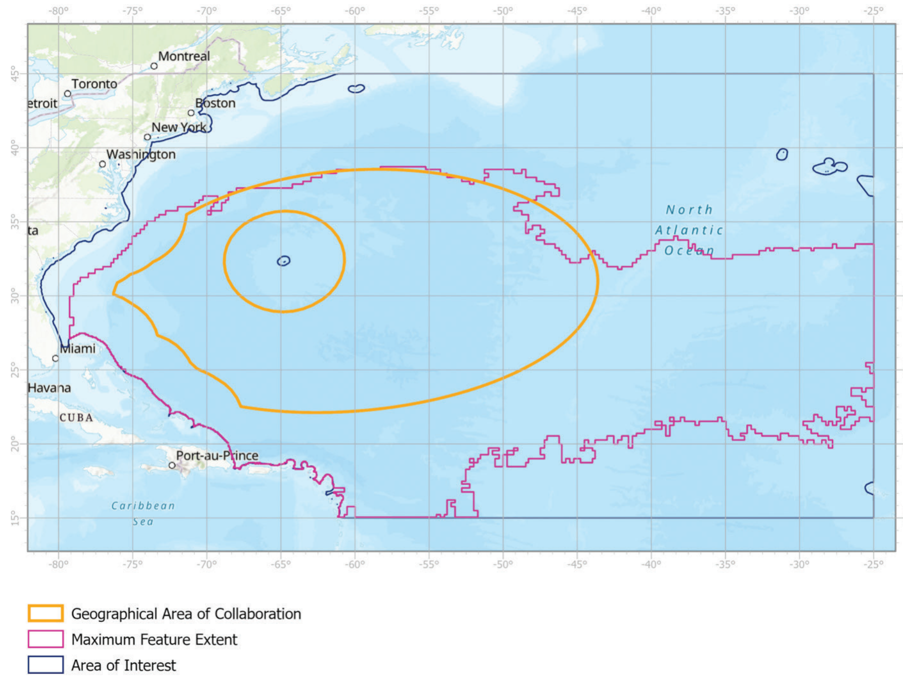


FIGURE 1. Extents used for data extractions and summarizations.

and generated a boundary around these joined areas to determine the maximum area covered by the SS focal sub-regions across the 10-year Deliverable 1 study period.

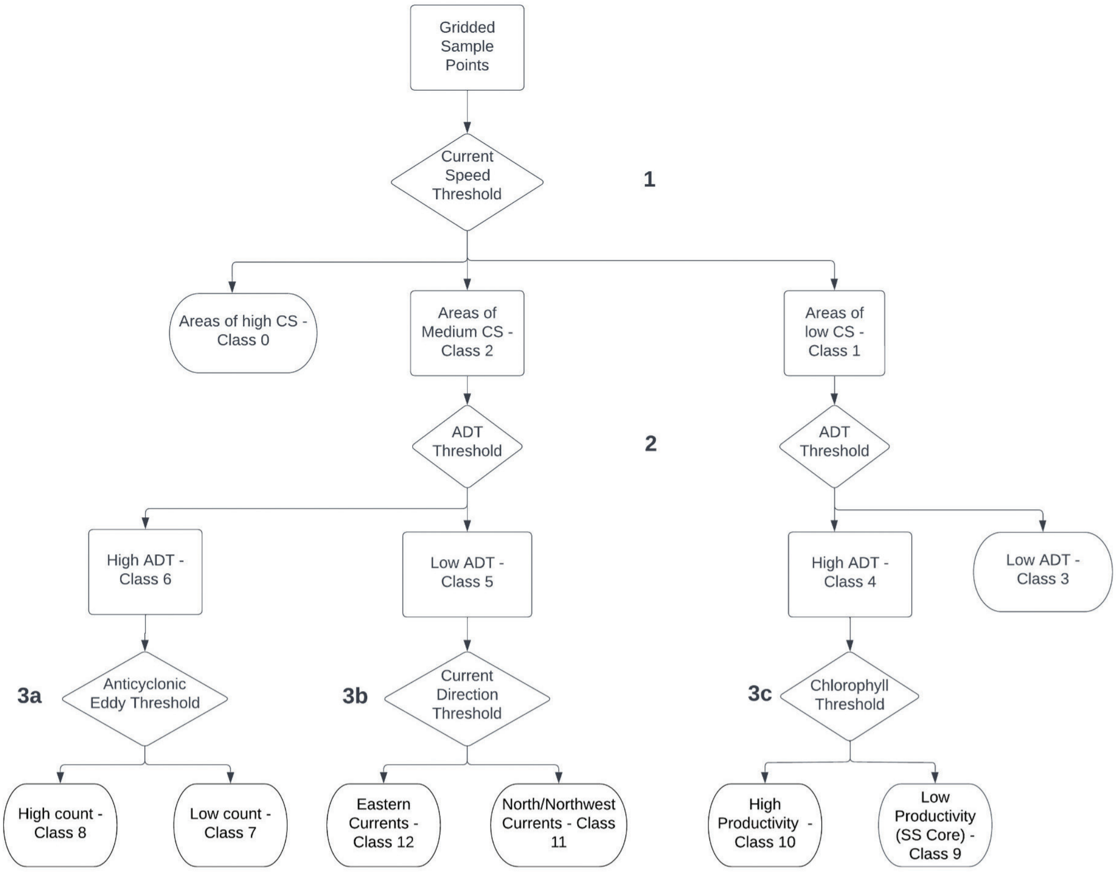
A Summarization of the Feature in Space and Time

Deliverable 1 included a summary of available variables within the AOI, such as surface current speed and direction, eddy density, absolute dynamic topography (ADT), salinity, primary productivity, sea surface temperature (SST), subtropical mode water, sea surface temperature fronts, and Seascape Pelagic Habitat classification. We incorporated several of these variables, including current speed, ADT, surface current direction, anticyclonic eddy density, and primary productivity, into a supervised classification methodology to determine possible sub-regions within the AOI. In this case, sub-regions were meant to represent areas that possess similar biogeographical characteristics and therefore mightprovide useful context for the work performed in Deliverable 3.

As an initial step for our sub-region analysis, we calculated summary statistics for each of the environmental variables listed above using preliminary sub-regions (PSR) (Ardron et al. 2011). We calculated summary statistics using environmental data sampled at a 0.09° regular grid of points, all withassociated values, both overall and per month, for eddy count (anticyclonic), absolute dynamic topography (m), chlorophyll-a concentration (mg/m^2), current speed (m/s), current direction (°) sea surface temperature (°C), and salinity (psu) as well as a PSR identifier. We produced summary statistics for each PSR by grouping points according to their sub-region attribute and calculating values for minimum, mean, standard deviation, maximum and median for each environmental variable. We did this for each month of the year as well as the overall study period. We used summary statistics as a baseline for determining decision rules of the sub-region classification.

Next, we partitioned the gridded points using a supervised decision tree methodology. The supervised decision tree is a method of classifying features that allows for informed decision rules based on valuesof the features themselves, allowing us to implement pre-existing knowledge of the region and its ecology into the classification process. Using summary statistics as a starting point, we evaluated major differences in environmental variable values between areas within the study region. Graphical representation of the full decision tree analysis can be seen in Figure 2.

This analysis ultimately produced 8 distinct classes with varying ecological characteristics (Table 1). While categorized sample points displayed noticeable zonal trends, we determined that the amount of noise observed in this product might prove to be problematic for further data summarizations and management initiatives. We therefore performed two generalizing steps in ArcGIS



Decision Rule	Variable	Number of Resulting Groups	Threshold value(s)
1	Current Speed (m/s)	3	Greater than 0.2; Less than 0.2 and greater than .05; Less than 0.05
2	Absolute Dynamic Topography (m)	4	Greater or less than 0.6
3a	Anticyclonic Eddy (count)	2	Monthly: greater or less than 40; Overall: greater or less than 250
3b	Current Direction (°)	2	Greater than 270 (heading northwest) or between 45 and 135 (heading northeast/southeast)
3c	Chlorophyll-a Concentration (mg/m3)	2	Greater or less than 0.05

FIGURE 2. Supervised decision tree classification process.

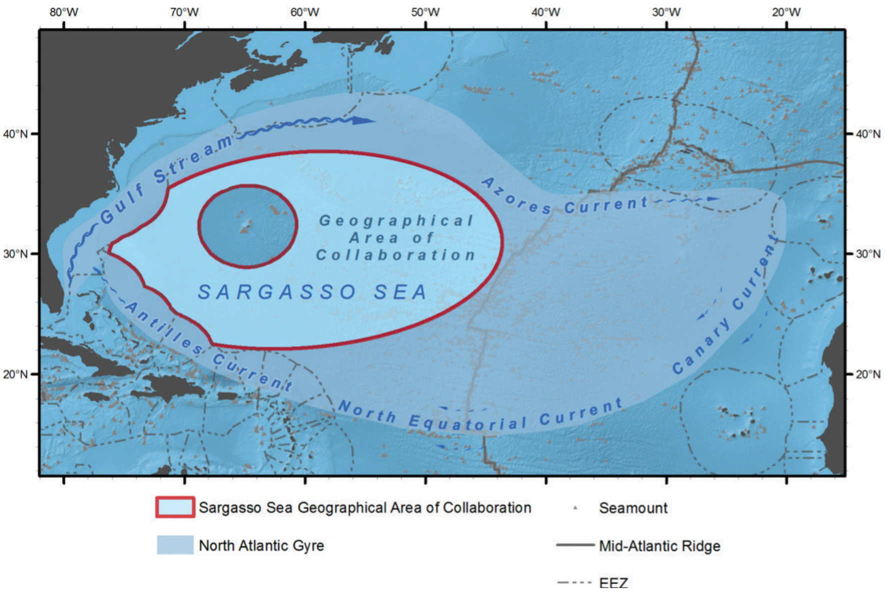
Pro to reduce noise in the final sub-region layer (for a full description of this process see the Feature in Space and Time Report). The final step of the decision tree classification was to evaluate regions of stability based on categorization. This stability metric reflects areas that are categorized as the same class for an extended period which we determined by taking the mode of the 12 monthly categorized rasters. The mode indicates which class is represented most frequently throughout the 12 months of the year. Additionally, we included in our analysis the mode count, which is the number of months the mode occurs throughout the year. Thus, stability within a given area of the study region directly relates to increasing mode count, with 12 being the most stable corresponding to those areas that are categorized as the same class throughout the entire year.

Figure 4 shows the distribution of each class throughout the study area based on categorization of gridded

TABLE 1. Characteristics of each sub-region class.

Class Number	Characteristics	Description
0	High current speed	Gulf Stream zone
3	Low current speed, low ADT	Low energy zone
7	Medium current speed, high ADT, low anticyclonic eddy count	Transition zone
8	Medium current speed, high ADT, high anticycloniceddy count	Antilles Current and margins
9	Low current speed, high ADT, low productivity	Lower productivity core
10	Low current speed, high ADT, high productivity	High Productivity core
11	Medium current speed, low ADT, north/northwest current direction	North Equatorial Current zone
12	Medium current speed, low ADT, eastern currentdirection	Azores Current zone

FIGURE 3. Sargasso Sea Geographical Area of Collaboration



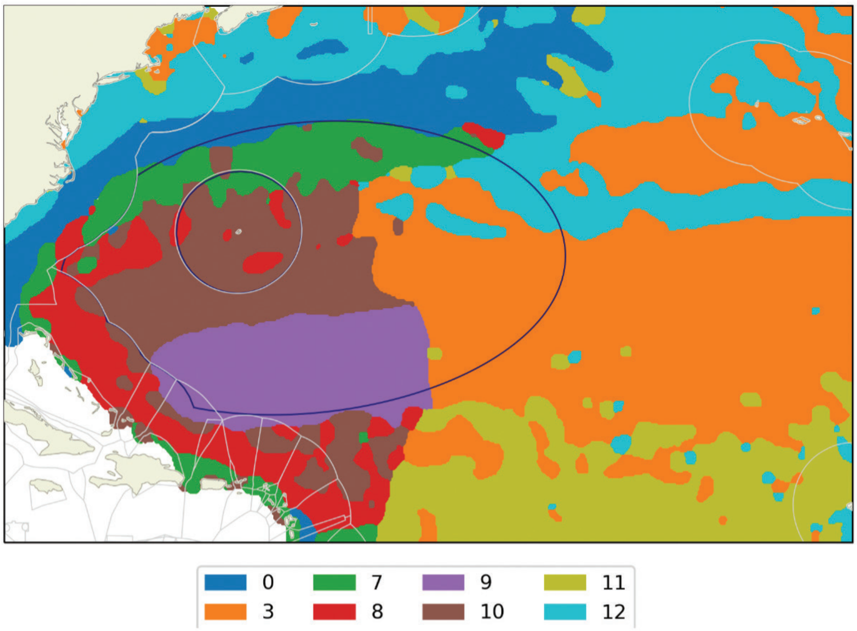


FIGURE 4 Overall sub-region classification

points with corresponding environmental variable values that represent summarizations for the entire study period. The predominant classes represented within the previously delineated GAC are 3,7, 9, 10 (Figure 4). Figure 5 shows the classification criteria outlined above applied to the gridded sample points with corresponding environmental variable values that represent summarization by month, which provides insight into the seasonality of this core area. Figure 6 shows the mode and mode frequency of classified areas throughout the year, with the top map indicating the class that is most frequently represented in each pixel over the 12 months. This method is useful in determining stability of the study area, with thefrequency (or count) of the mode showing how many months the predominant class occurs, ranging from 2-12. Areas with higher mode count, those represented in cool colors in the bottom map of Figure 6, are relatively stable areas in the context of our classification method. Conversely, areas symbolized by warmer colors represent those where the mode frequency is low with the dominant class occurring during fewer than half of the months in the year.

With insight provided by the stability analysis, we were able to identify certain sub-regions that would be important to include as context for the data exploration summarized in this report. These zones, which focus primarily on classes 7, 8, 9, 10 and 3, represent the core area of the SS that is informed both by past work aimed at identifying this feature in space and time (Ardron et. al 2011) as well as the work performed in Deliverable 1 of this project. This core area acts as both environmental context to biological data as well as a mechanism for isolating areas of interest for human use summarizations.

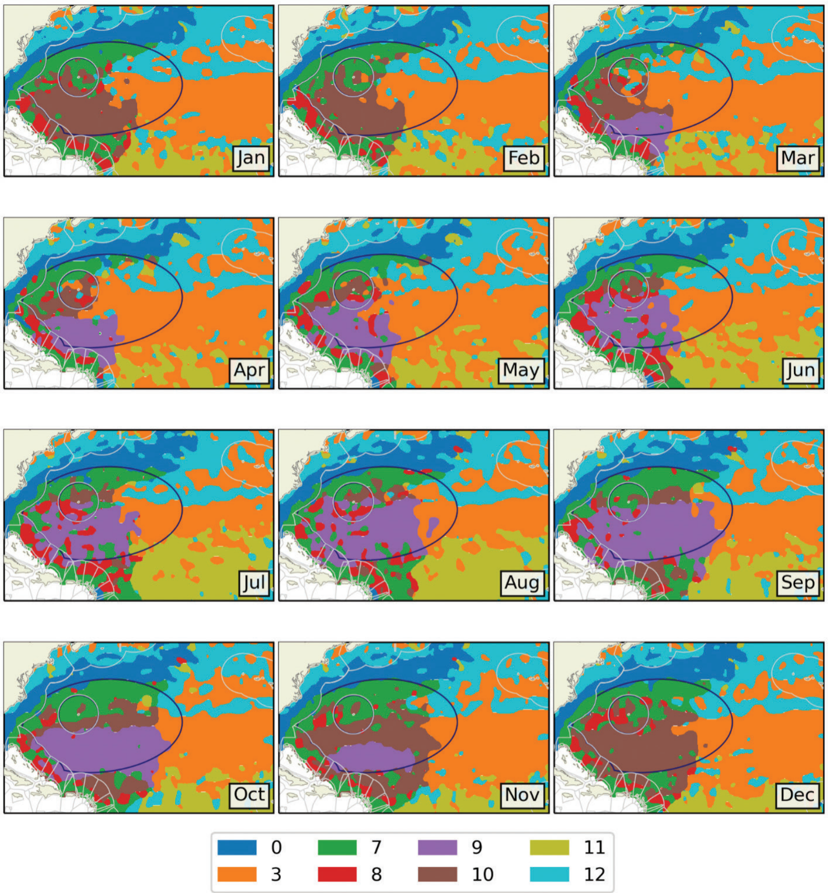


FIGURE 5. Monthly sub-region classification.

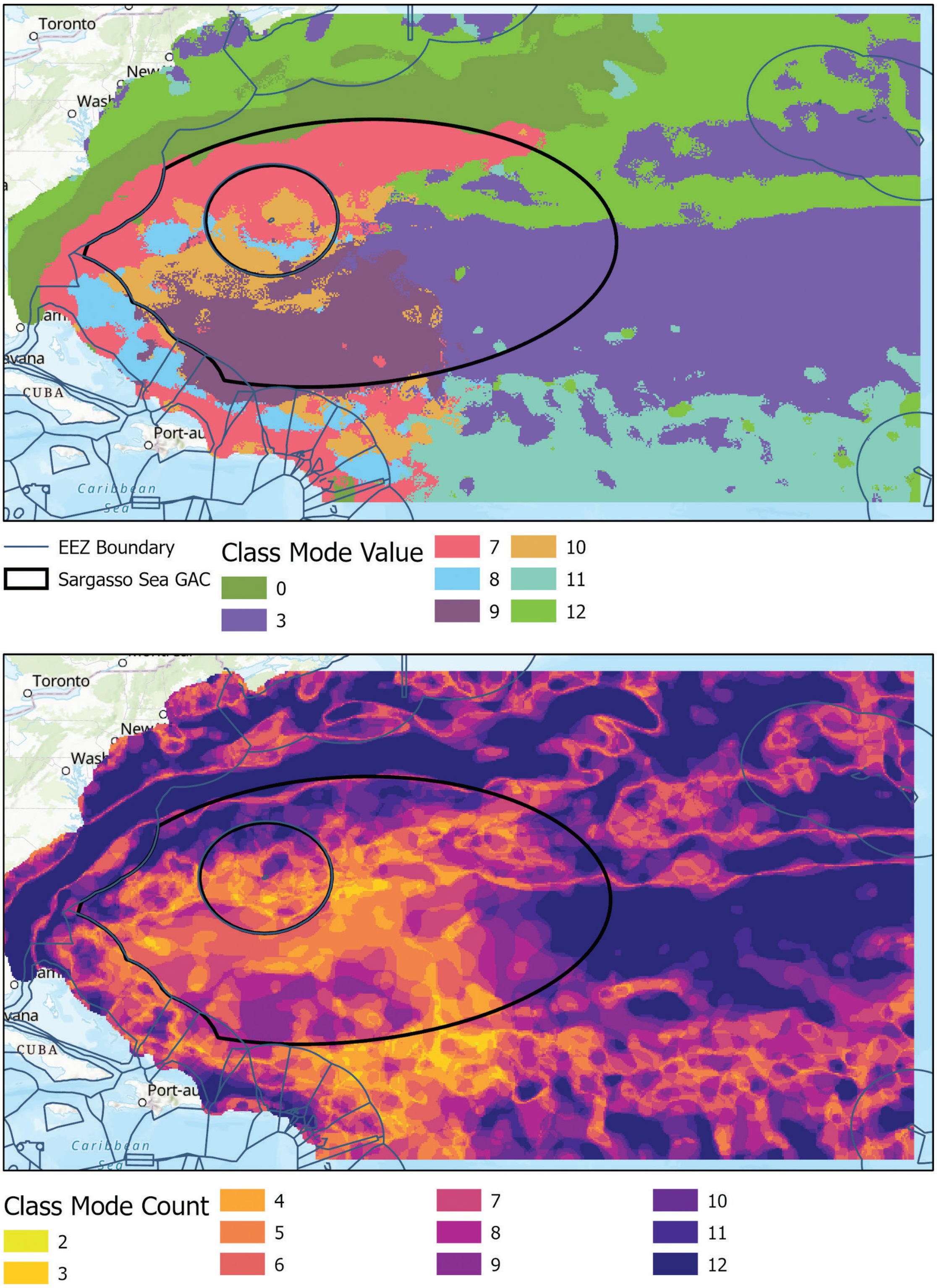


FIGURE 6. Mode of sub-region classification (top) and count of the sub-region classification mode (bottom).

Ecosystem State

Regional Biodiversity

The SS is the only large scale holopelagic seaweed habitat found in an area beyond national jurisdiction. As the geometry of the SS changes within and between years, it straddles the exclusive economic zones(EEZs) of up to 12 coastal and island nations, creating an ecological bridge of *Sargassum* on the western boundary of the feature. The importance of the SS for multiple marine species has been acknowledged, but more research is needed to understand how the SS supports endemic species, as well as those that depend on the SS during specific life-stages or migrate across the feature.

The Ocean Biodiversity Information System (OBIS) of UNESCO represents the most comprehensive, spatially explicit database of marine biodiversity observations in the world (Grassle and Stocks 1999; Zhang and Grassle 2002; Costello and Vanden Berghe 2006). We summarized OBIS biodiversity data within the AOI to provide contextual biological information to our more in-depth analysis of the species assemblage within the MFE. Figure 7 shows the number of species records from the OBIS database in the AOI (with records spanning a temporal range of 1833-2022), which indicates how many species identification records a given cell contains while Figure 8 shows species richness or the number of differentspecies occurring within a cell.

Figure 9 shows ES(50) index (also known as the Hurlbert Index) within the SS AOI. This biodiversity richness metric is defined as the expected number of marine species in a random sample of 50 individual records. ES(50) assumes that individuals are randomly distributed, the sample size is sufficiently large, the samples are taxonomically similar, and that all samples have been taken in the same manner. While, overall, coverage of OBIS records is somewhat limited in this study area, species richness and ES(50) index help describe the status of baseline knowledge of regional biodiversity within the AOI, revealing areas of particular research focus as well as gaps in this space.

The number of OBIS records within the MFE can help to describe the rich biological community observed throughout the water column. 6,793 unique species have been recorded within the MFE (Figure 8) from records

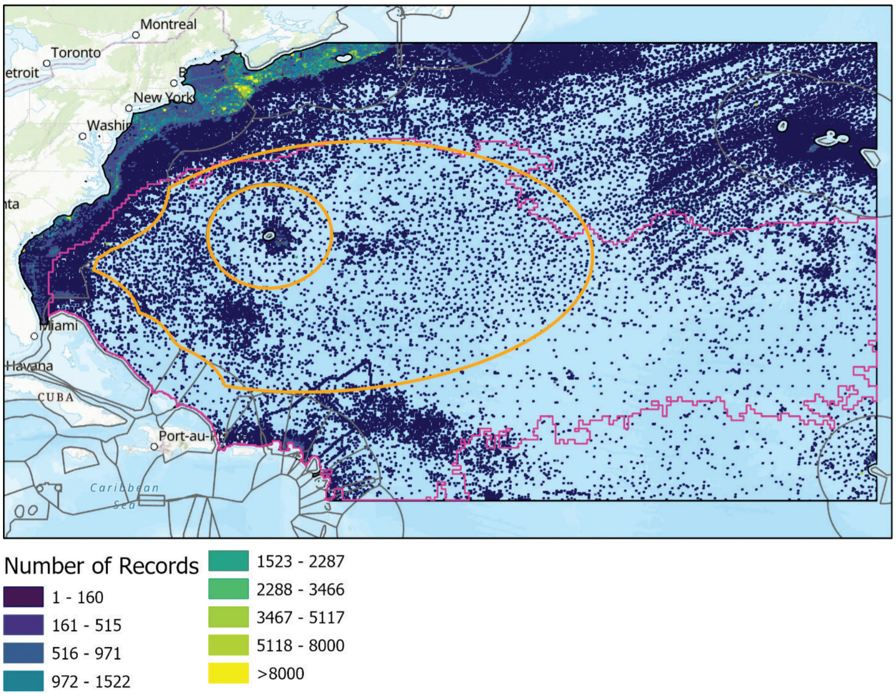


FIGURE 7. **Number of OBIS species observation records in the SS AOI.**

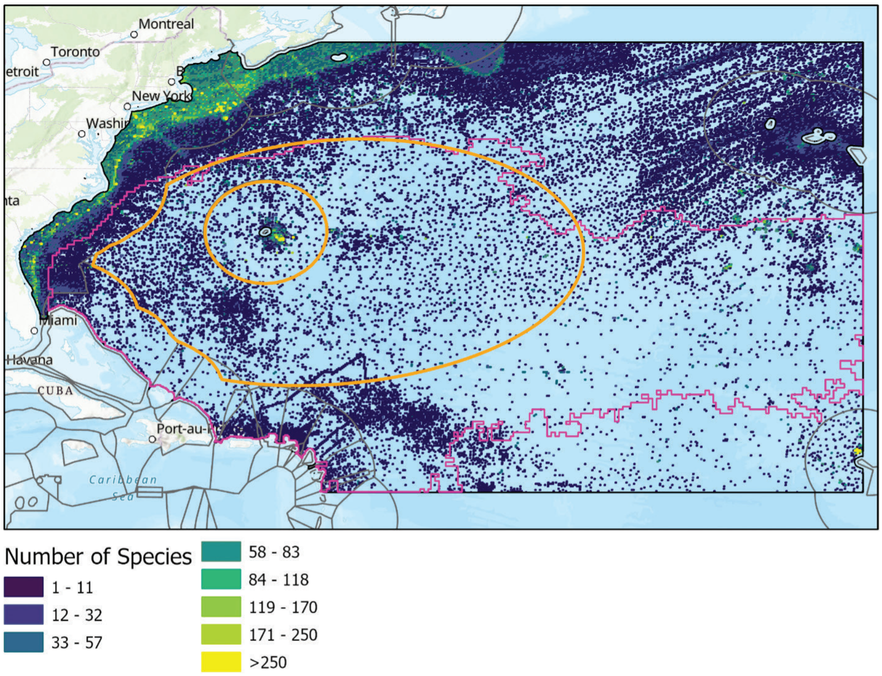


FIGURE 8. Number of different species recorded in each cell for the SS AOI.

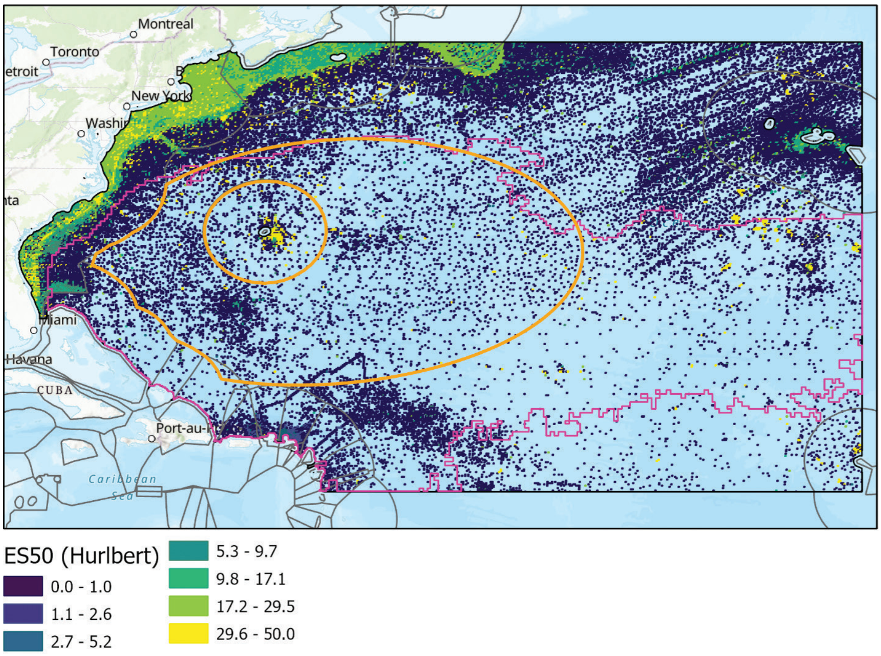


FIGURE 9. ES(50) (Hurlbert) diversity index for the SS AOI.

spanning a temporal range of 1833-2022. The taxonomic breakdown of these records reveals that at least 53 phyla, 130 classes and 1,535 families are represented within the MFE. It is important to note that the composition of the biological community in the SS has not yet been studied thoroughly; this is reflected by the low number of records in various portions of the feature (Figure 7). This limited understanding of biodiversity in the CRTD is also reflected in the asymmetry in the frequency distribution of biodiversity records (Figure 10).

31% of the 6,793 species found in the MFE and 3,132 species found in the GAC only had one record in the OBIS database, showcasing the ecological knowledge gaps that remain in the region. Of the 224,841 OBIS records in the MFE, 20.9% (n = 47,023) belonged to just 10 species, representing 0.14% of the species richness. Of these 10 species, 8 were identified to the genus and species levels, and included four species of temperate and tropical

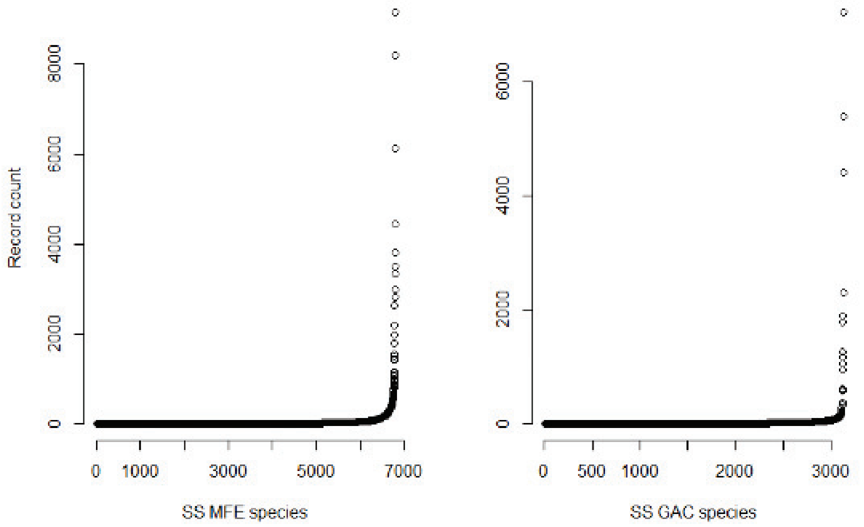


FIGURE 10. **Frequency distribution of OBIS biodiversity records**

tunas: *Thunnus albacares*, *T. obesus*, *T. alalunga* and *T. orientalis*), one species of billfish (*Xiphias gladius*), one species of eel (*Anguila rostrata*), one species of pelagic bony fish (*Coryphaena hippurus*) and one species of seabird *(Fregata magnificens*). One species of tuna, *T. orientalis*, was recorded within the SS AOI but was likely a mislabeled Atlantic bluefin tuna (*T. thynnus*), instead of its Pacific relative.

Given the transboundary nature of the SS, which straddles both the High Seas and EEZs, the co- occurrence of species within and beyond national jurisdiction was assessed and may be interpreted as an indicator of ecological connectivity in the region. Of the 6,793 species found within the MFE, 3,957 (58.2%) were found within the national jurisdiction of adjacent coastal and island nations, while 4,870 species (71.7%) were recorded in the High Seas. A cross-reference of the unique species lists revealed that 2,033 species (30%) occurred both within and beyond national jurisdiction, suggesting connectivity between the biological communities of the SS and adjacent jurisdictional waters. This aligns with evidence showing that regional oceanographic features, such as the Gulf Stream and anticyclonic eddies, play a central role in species dispersal (Devine et al. 2021; Chang et al. 2018) with aggregations of species occurring at the heart of the North Atlantic Gyre by the same mechanisms that aggregate *Sargassum* in this area. Together, the transportation and collection of biota by way of the oceanographic features in and around the SS support the argument that they may enhance cross-stream transport between coastal areas and the High Seas (Bower and Rossby, 1989), potentially driving the co-occurrence revealed by our analysis of OBIS species records.

OBIS records act as valuable information outlining general species assemblages of the region. The large temporal range and detailed nature of this dataset provides insight into ecological connectivity of the area as well as spatial trends in biodiversity. Although the OBIS database is valuable baseline knowledge, the limitation in drawing more specific conclusions on regional biodiversity and ecological connectivity stems from the inconsistent spatial coverage and frequency of sample records within the MFE and GAC. While we use the information from OBIS as a starting point for a deeper look into species assemblages and sensitive biological communities of the region, the distribution of OBIS records demonstrates the need for enhanced data collection efforts in the MFE and GAC.

Recognized Areas of Importance

Several areas within the GAC have already been recognized as important areas for marine communities, based on different criteria. Areas that have been identified to support habitats used by multiple species for breeding, feeding/development, and migration include two ecologically or biologically significant areas (EBSAs) and two vulnerable marine ecosystems (VMEs) overlapping the GAC. In addition, one important bird area (IBA), one marine key biodiversity areas (KBAs), and seven coastal or marine protected areas (PAs) are within Bermudan jurisdiction (Figure 11).

The two overlapping EBSAs are part of a collection of 336 areas around the world that have been described as special marine areas based on a set of seven scientific criteria (Figure 11; Secretariat of the Convention on Biological Diversity 2012, 2014), often with evidence on how marine species, populations, or communities use the area as justification. The Sargasso Sea EBSA (Convention on Biological Diversity 2015b) overlaps almost completely with the GAC while the New England and Corner Rise Seamounts (Convention on Biological Diversity 2015a) overlaps with relatively little area in the northern region. The Sargasso Sea EBSA is described as hosting a diverse marine community dependent on the areas' resources (Convention on Biological Diversity 2012, Secretariat of the Convention on Biological Diversity 2012, 2014). Kot et al. (2014) found that a relatively high number of migratory species (n = 17) were mentioned within the SS EBSA's description and contributed to the justification for meeting the CBD criteria as an EBSA.

Currently, the Northwest Atlantic Fisheries Organization (NAFO) has identified 30 VMEs that are in force until December 31, 2026 within its Convention Area (FAO 2023a). The two VMEs that overlap the GAC (New England Seamounts and Corner Rise Seamounts) were identified because they met the five criteria used to define VMEs (FAO 2009) and are described as areas containing a chain of seamounts with highlydiverse deep-sea biological communities that need protection from potentially significant impacts of bottom fishing activities (FAO 2009; FAO 2023a, 2023b, 2023c). These VMEs were adopted in 2006 to be closed to bottom fishing, with areas overlapping both EBSAs described in the AOI and covering areas similar to the New England and Corner Rise Seamounts EBSA (Figure 11).

Important areas designated within the Bermuda EEZ include the Cooper's Island and Castle Islands global IBA and the Cooper's Island and Castle Islands global KBA (both defined as the same area; BirdLife International 2022, 2023b, 2023c). Currently, there are more than 13,000 IBAs worldwide that meet the set of 11 criteria as a significant site for the conservation of bird populations (Donald et al. 2019; BirdLife International 2022). Over 16,000 KBAs have been identified (BirdLife International 2023c) based on 11 criteria that are used to justify important sites that contribute to "the global persistence of biodiversity" of many different taxa (IUCN 2016). The Cooper's Island and Castle Islands IBA and KBA contain "sites with significant populations of globally threatened species" (A1) and "significant concentrations of congregatory species (A4; BirdLife International 2020; BirdLife International 2023b).

Currently, there are no PAs that overlap the GAC (UNEP-WCMC and IUCN 2023). PAs within the Bermuda EEZ included the five nature reserves (Castle Harbour Islands, Lambda Island, Pearl Island, Saltus Island, Stokes Point), one private reserve (Morgan and Palm Island [BNT]), and one park (South Shore Park Southampton).

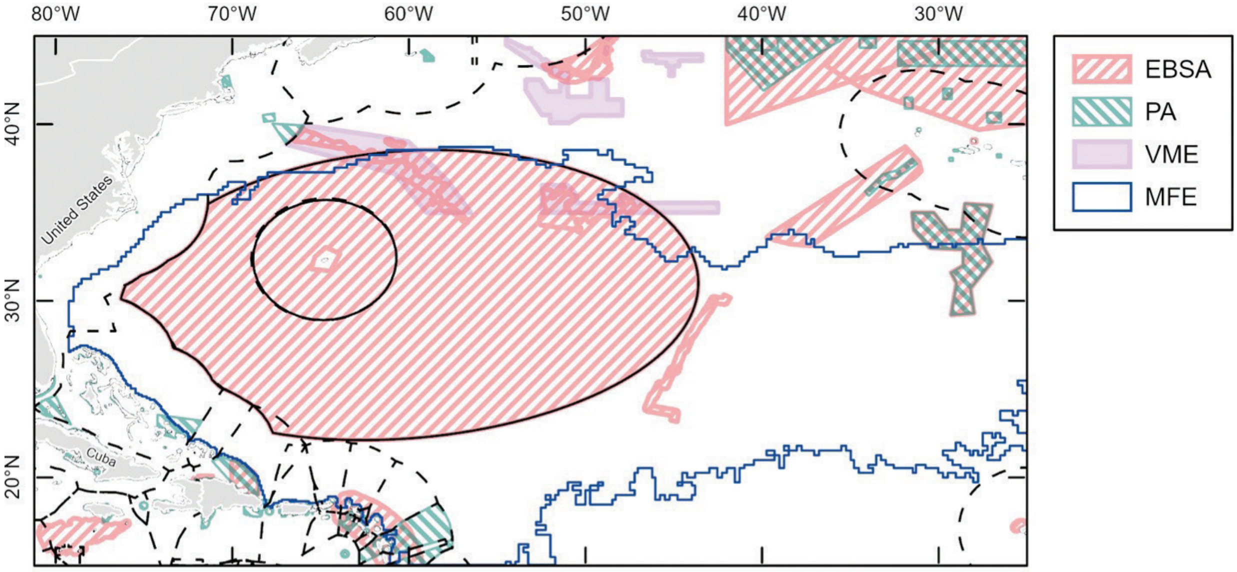


FIGURE 11. **Recognized areas of importance in the SS study area. Data sources: ecologically or biologically significant areas (EBSA; Convention on Biological Diversity 2022); protected areas (PA; UNEP-WCMC and IUCN 2023); current vulnerable marine ecosystems, with a 2026 end year (VME; FAO, 2023a, 2023b, 2023c); Sargasso Sea geographical area of collaboration (GAC; Ardron et al. 2011); Sargasso Sea maximum feature extent (MFE; current study); exclusive economic zone (EEZ; Flanders Marine Institute 2019); country (Global Administrative Areas Database 2018).**

The Castle Harbour Islands nature reserve, which includes areas within the Cooper's Island and Castle Islands IBA and KBA, was established in 1979 to preserve feeding and nesting habitats of protected birds (Laws of Bermuda 1979).

The summarization of the spatial distribution of these Recognized Areas of Importance within and around the AOI is valuable for several reasons. Demarcation of critical habitat for marine communities distinguishes areas to be prioritized for conservation into the future. Additionally, the specificity of why some of these areas are delineated, such as the Central America Humpback Whale Corridor, offer an initial step towards elucidating which species occurred in the area and provide a potential tool to aid in species-specific conservation. The available information associated with these areas will be important to consider when prioritizing necessary conservation or management measures for the AOI.

Threatened Marine Species

We performed a more in-depth analysis of the threatened marine communities found in the SS AOI, including a three-tiered approach to examine various aspects of the distribution and abundance of thesespecies. Threatened species were identified using criteria outlined by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, which is one of the most highly recognized public repositories on the ecological status of biodiversity having completed over 15,000 assessments for marine species. For the purposes of this analysis, we classified "Threatened" as all marine species currently categorized by the IUCN Red List as "Critically Endangered," "Endangered," or "Vulnerable" (IUCN 2022). We chose to examine the community of threatened species associated with the SS because their categorization as belonging to any of these three groups suggests that these species are particularly sensitive to disturbances at any life history stage with greater long-term repercussions to each species' respective population. The assessment of this feature as a critical site for any species categorized as threatened can therefore act as a useful metric for determining the overall ecological value of the feature in the greater context of regional biodiversity. It can also provide insight into the state of this ecosystem by demonstrating what portion of the overall species assemblage is considered threatened, acting as a reflection of the health of biological communities associated with the Sargasso Sea and adjacent areas.

Tier 1 of this approach included identification of threatened species within the GAC using the OBIS database (OBIS 2022) with records for the GAC spanning a temporal range of 1868-2022. We included allthreatened marine animal species that had at least one observation archived in the OBIS database recorded within the corresponding extent area (MFE or GAC, respectively; Grassle and Stocks 1999, Zhang and Grassle 2002, Costello and Vanden Berghe 2006, OBIS 2023). Within the MFE, there were 100 threatened marine fish, invertebrate, marine mammal, and sea turtle species with 29 in the GAC (Table 2). It is important to note that we discovered some instances in which species showed one OBIS record within the GAC or MFE but, based on consultation of literature related to confirmed distribution of the species in question, was not included in the final species list. The eyespot skate (*Atlantoraja cyclophora*), for example, showed one OBIS record within the GAC but sources indicate that range distribution is generally limited to the east coast of Brazil (Figueiredo et al. 2002). Additionally, we identified 31 specieswithin the GAC are listed in the appendices of the Convention on Migratory Species of which 16 were classified as Threatened under the IUCN Red List (Table 3). These results reflect the importance of the SS as an area of use by a broad range of species in need of better conservation and management across jurisdictional boundaries.

Of the 6,793 species that have been observed in the MFE and archived within OBIS (OBIS 2023), the IUCN Red List of Threatened Species ecological status assessments were available for only for 18.5% (n =1,255). Of the 3,132 species that were recorded in the SS GAC, ecological status assessments were available for 19.8% (n = 620). The assessment of 45 of these species concluded that enough information was not available for a complete assessment and were categorized as "Data Deficient" (Table 2). Overall,threatened species made up for a small portion of the assessed species assemblage of the GAC, with only 4.5% of records categorized as such (Table 2). However, it is important to consider that a large percentage of the species recorded as existing in the GAC are without IUCN assessment, suggesting that these percentages may not fully capture the threatened biological communities associated with this feature.

The second tier of this more focused analysis of threatened marine species included assessment of modeled suitable habitat distribution and known range of threatened species found in the GAC (Table 3; OBIS 2023) to help demonstrate the potential area use of

TABLE 2. A breakdown of species with OBIS observations in the GAC that have been assessed by the IUCN.

IUCN Red List category	Number of Species	Proportion of SS species assessed (%)
Critically Endangered	6	0.9
Endangered	8	1.2
Vulnerable	16	2.4
Near Threatened	9	1.4
Least Concern	581	87.4
Data Deficient	45	6.7

sensitive marine communities within the AOI. We assessed suitable habitat coverage for each of these species within the study region, both cumulatively and on at the individual species level using data from the AquaMaps tool (Kaschner et al.

2019), which produces global, public-access layers of habitat suitability for thousands of marine species globally. These layers show the estimated habitat suitability of a given species at 1° x 1° obtained from species distribution models which were parameterized using abiotic variables such as depth, water temperature, salinity, primary productivity, and association with sea ice or coastal areas.

We combined the AquaMaps data for all SS threatened species to identify areas of the SS with the highest cumulative habitat suitability. Areas of high habitat suitability for each species were derived from applying a mean probability distribution threshold to each layer. The cumulative suitable habitat overlap was calculated by stacking the binary layers of habitat suitability for each of the 30 IUCN threatened species. The maximum number of overlapping cells was 20 (Figure 12), which was found within the coastal waters of North American and Caribbean countries. The range of cumulative suitable habitat scores within the GAC ranged from 0-2 species across the lower half of the feature, to a high of 10 - 12 species in the northern third of the GAC.

The second tier of this more focused threatened marine species analysis also included an overlay of known range and modeled suitable habitat distribution of a subset of species found in the GAC (OBIS 2023). These 13 marine vertebrate species were selected to summarize potential area use because they are of greatest

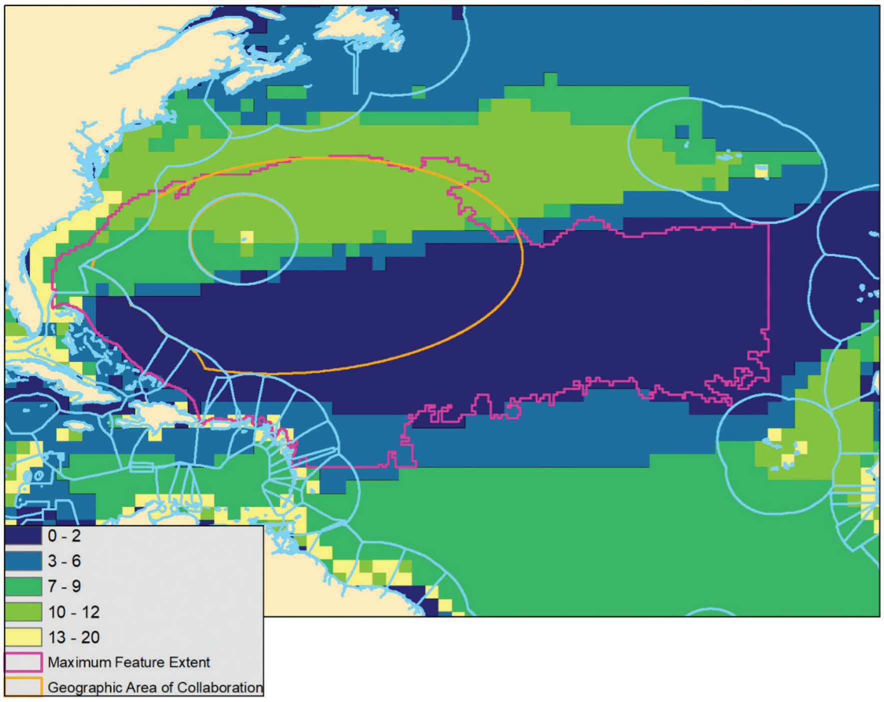


FIGURE 12. Cumulative habitat suitability score derived from AquaMaps models. A total of 30 binary suitable habitat layers for IUCNThreatened species were stacked to delineate the areas of the GAC and MFE for which there was a higher accumulation of suitable habitat.

TABLE 3. **Threatened vertebrate species in the GAC. The single asterisk denotes species that were included in the AquaMaps cumulative habitat suitability analysis, while the double asterisk is used for species for which the range polygon coverage analysis was also conducted**

Scientific Name	Red List Category	Red ListCriteria	Year Published	PopulationTrend	CMS listedspecies
*Carcharhinus longimanus***	CR	A2bd	2019	Decreasing	X
*Sphyrna lewini***	CR	A2bd	2019	Decreasing	
*Eretmochelys imbricata***	CR	A2bd	2008	Decreasing	X
*Anguilla anguilla***	CR	A2bd+4bd	2020	Decreasing	X
*Lepidochelys kempii***	CR	A2bd	2019	Unknown	X
*Carcharhinus plumbeus***	EN	A2bd	2021	Decreasing	
*Isurus oxyrinchus***	EN	A2bd	2019	Decreasing	X
*Isurus paucus***	EN	A2d	2019	Decreasing	X
*Chelonia mydas***	EN	A2bd	2004	Decreasing	X
*Cynoscion regalis***	EN	A2b	2020	Decreasing	
*Anguilla rostrata***	EN	A2bd	2017	Decreasing	X
*Hippoglossoides platessoides***	EN	A2bcd	2022	Decreasing	
*Pterodroma hasitata***	EN	B2ab		Decreasing	
*Lamna nasus**	VU	A2bd	2019	Decreasing	X
*Alopias superciliosus**	VU	A2bd	2019	Decreasing	X
*Rioraja agassizii**	VU	A2bd	2020	Decreasing	
*Hippocampus erectus**	VU	A2cd	2017	Decreasing	
*Dermochelys coriacea**	VU	A2bd	2013	Decreasing	X
*Thunnus obesus**	VU	A2bd	2021	Decreasing	
*Makaira nigricans**	VU	A2bd	2022	Decreasing	
*Balaenoptera physalus**	VU	A1d	2018	Increasing	X
*Balistes capriscus**	VU	A2bd	2015	Decreasing	
*Mola mola**	VU	A4bd	2015	Decreasing	
*Pomatomus saltatrix**	VU	A2bd	2015	Decreasing	
*Caretta caretta**	VU	A2b	2017	Decreasing	X
*Amblyraja radiata**	VU	A2bcd	2020	Decreasing	
*Physeter macrocephalus**	VU	A1d	2019	Unknown	X
*Carcharhinus falciformis**	VU	A2bd	2021	Decreasing	X
*Alopias vulpinus**	VU	A2bd	2022	Decreasing	X

TABLE 4. Range polygon information for the 14 particularly sensitive species chosen to assess area use of the SS study region. IUCN = IUCN Red List of Threatened Species (https://www.iucnredlist.org**).**

Scientific Name	IUCN Red List Category	Citation for digital distribution data
Anguilla anguilla	CR	AESG 2020
Carcharhinus longimanus	CR	IUCN SSC Shark Specialist Group 2018
Eretmochelys imbricata	CR	Wallace et al. 2010
Lepidochelys kempii	CR	Wallace et al. 2010
Sphyrna lewini	CR	IUCN SSC Shark Specialist Group 2018
Anguilla rostrata	EN	ASSG 2014; Durif et al. 2022b
Carcharhinus plumbeus	EN	IUCN SSC Shark Specialist Group 2020
Chelonia mydas	EN	Wallace et al. 2010
Cynoscion regalis	EN	IUCN Marine Biodiversity Unit / GMSA 2020
Hippoglossoides platessoides	EN	IUCN Marine Biodiversity Unit / GMSA 2021
Isurus oxyrinchus	EN	IUCN SSC Shark Specialist Group 2018
Isurus paucus	EN	IUCN SSC Shark Specialist Group 2018
Pterodroma hasitata	EN	BirdLife International and Handbook of the Birds ofthe World 2016

conservation concern (categorized by the IUCN Red List as "Critically Endangered" (CR) or "Endangered" (EN; Table 4) and therefore represent particularly sensitive marine communities associated with the SS. This overlay was explored to help demonstrate the potential area use of these species within the AOI. We assessed known range for this subset of species using polygons from the IUCN (sources for these species can be found in Table 4), which we overlaid with individual habitat suitability prediction layers from AquaMaps.

An exploration of the congruence between the AquaMaps habitat suitability layers of EN and CR species with the expert range polygons reveals areas of agreement and disagreement. While some of the IUCN range polygons seem to delineate important areas of aggregation (European Eel; Figure 14), other range maps seem to cover the entire possible range of the species (Oceanic whitetip shark; Figure 13).

Divergences were also observed in terms of the range of the species. Areas of high predicted habitat suitability and known range were harmonious for certain species, such as the longfin mako shark (Figure 14), with range polygons confirming the areas of high habitat probability. For other species, known range polygons did not align well with habitat predictions. For example, the overlay analysis for the green sea turtle (Figure 15) showed known range distribution in the High Seas areas around the SS while habitat suitability predictions were limited to the coastal areas along the U.S. There are several potential reasons for this disparity. For one, the AquaMaps predictions may not capture all life stages of a given species. In the case of the green sea turtle, the time that this species spends in the open ocean is widely acknowledged as "the lost years" (Mansfield et al. 2014). This knowledge gap may be the source of limitation for the AquaMaps models, which, by excluding these High Seas areas, also avoid uncertaintiesassociated with this stage in the species' life history. Conversely, the IUCN range polygons may take a different approach to managing this uncertainty, opting to include the maximum area that this species has been known to occur in rather than limiting the range to only those areas of certainty. Further research is required to understand where this phenomenon might be the source of other discrepancies between predicted suitable habitat and known range polygons, however it offers valuable insight into the potential limitations of our methodologies.

Our findings suggest two primary takeaways, the first of which is that more research is needed to confirm the range of sensitive species in the SS in addition to updates to habitat suitability modeling to account for the most up-to-date information regarding behavior of these species. The second is that, although results from our analysis

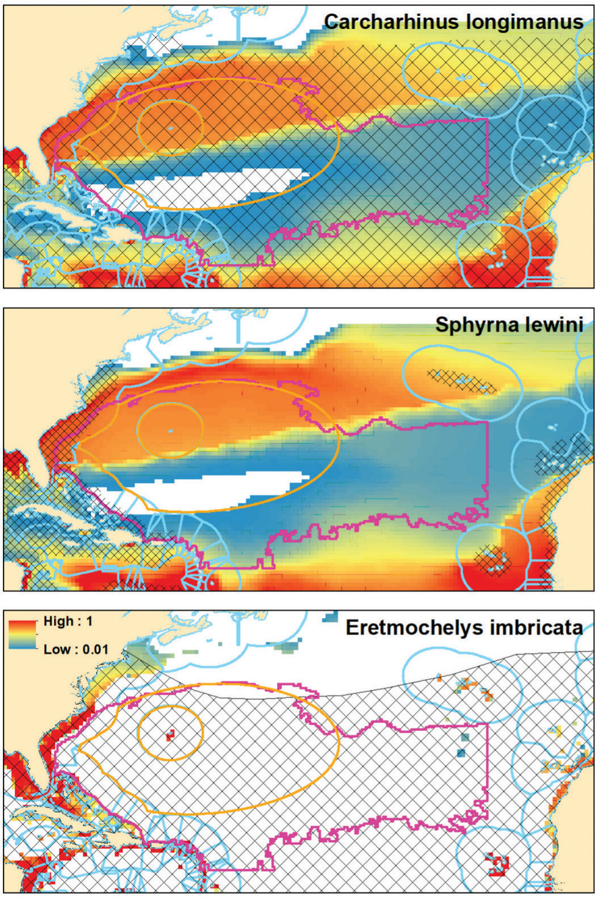


FIGURE 13. **Combination of IUCN species range polygon (hatched layer) and habitat suitability index from AquaMaps (heatmap)foroceanic whitetip shark (Carcharhinus longimanus - top), scalloped hammerhead shark (Sphyrna lewini - middle) and hawksbillsea turtle (Eretmochelys imbricata – bottom).**

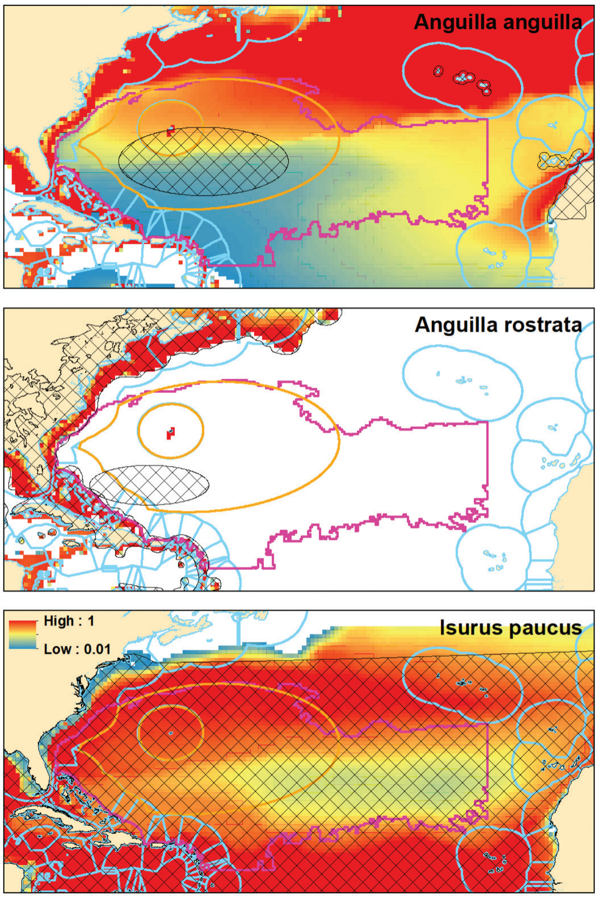


FIGURE 14. **Combination of IUCN species range polygon (hatched layer) and habitat suitability index from AquaMaps (heatmap) forEuropean eel (Anguilla anguilla-top), American eel (Anguilla rostrata - middle) and longfin mako shark (Isurus paucus – bottom).**

reveal areas of disagreement between modeled habitat and known range, these metrics indicate that it is likely that sensitive marine species occur in all areas of the SS.

To explore the intersection of particularly sensitive marine species habitat in the SS, we performed an overlap of the known range polygons for each of these 13 species. Figure 18 shows results from this analysis, with areas of higher overlap indicated by light green and yellow. While, based on this analysis, the range of all 13 of these species that show distribution within the AOI do not overlap anywhere, the significant areas of overlap between known range for up to 10 threatened species demonstrates the importance of this feature as habitat for vulnerable marine communities. Despite the need for additional analysis that we've outlined above, this presents a compelling piece to the argument in favor of ecosystem-based conservation of the SS to preserve the health and biodiversity of this feature and the surrounding areas.

A review of OBIS records related to the presence of threatened species within the MFE and GAC reveals that there are existing knowledge and data gaps when it comes to the population status assessment of many threatened species known to exist in and around this feature. Despite these gaps, compelling evidence suggests that there is a robust community of sensitive marine species that interact with this feature, many of which are also migratory, transiting between this High Seas feature and adjacent jurisdictional waters. In fact, the assessment of cumulative suitable habitat for threatened species associated with the Sargasso Sea shows that there are broad areas of overlap in high predicted probability, indicating the co-occurrence of these species within the GAC. The review of spatial overlap between predicted habitat probability and known range polygons of some of the more sensitive species associated with this feature did reveal some disagreement between these two metrics and does not provide clarity on the exact distribution of the sensitive marine species we have highlighted here.

However, areas of overlap between the ranges of these species, particularly on the southwestern edge of the GAC, complemented by areas of high cumulative habitat suitability in the northern half of the GAC demonstrate the high conservation value of this feature and provides a compelling argument for protection of the SS as a whole.

Focal species

The third tier of our threatened species analysis involved a more in-depth examination of the life stages and movements of a subset of focal species found in the GAC. Focal species included the American eel *A. rostrata*, European eel *A. anguilla*, loggerhead sea turtle *C. caretta*, humpback whale *M. novaeangliae*, blue shark *Prionace glauca*, Bermuda petrel *Pterodroma cahow*, and swordfish *X. gladius* (Table 5).

These case study species depend on the habitats within the SS for specific activities (e.g., breeding, feeding/development, migrating) and recent research on their ecology has improved our understanding of how the SS supports the overall marine community. These species were also prime examples of how the SS contributes to supporting biodiversity within the region as well as other connected areas outside of the region.

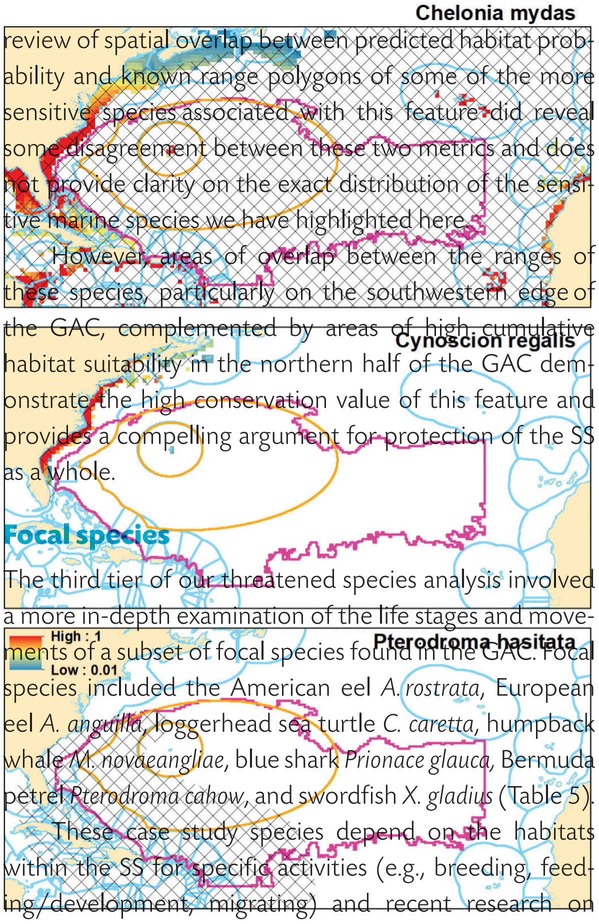


FIGURE 15. Combination of IUCN species range polygon (hatched layer) and habitat suitability index from AquaMaps (heatmap) forgreen sea turtle (Chelonias mydas - top), saltwater trout (Cynoscion regalis- middle) and black-capped petrel (Pterodroma hasitata – bottom).

American and European eels breeding habitat

As adults, both American and European eel species live in freshwater systems and migrate thousands of miles towards the SS to spawn and subsequently die (Schmidt 1923; Kleckner et al. 1983; Friedland et al. 2007; Béguer-Pon et al. 2015, 2017a). Adult American eels migrate from North America, Central America, and small portions of South America to spawn (Kleckner et al. 1983; ASSG 2014) while adult European eels migrate from Europe to spawn (AESG 2020; Hanel et al. 2022). Aggregations of spawning American eel are estimated to occur in the southwest portion of the SS while European eel aggregations are estimated slightly east of these areas, in the central-southern area (Figure 19; Schmidt 1922; 1923; Schoth and Tesch 1982; AESG 2020; Durif et al. 2022a). Spawning areas for both eel species include regions in the southern SS with some overlap (Figure 19; Schmidt 1922; Vladykov 1964; McCleave et al. 1987; Tesch 2003; Durif et al. 2022a) that could contribute to hybridization (e.g.,

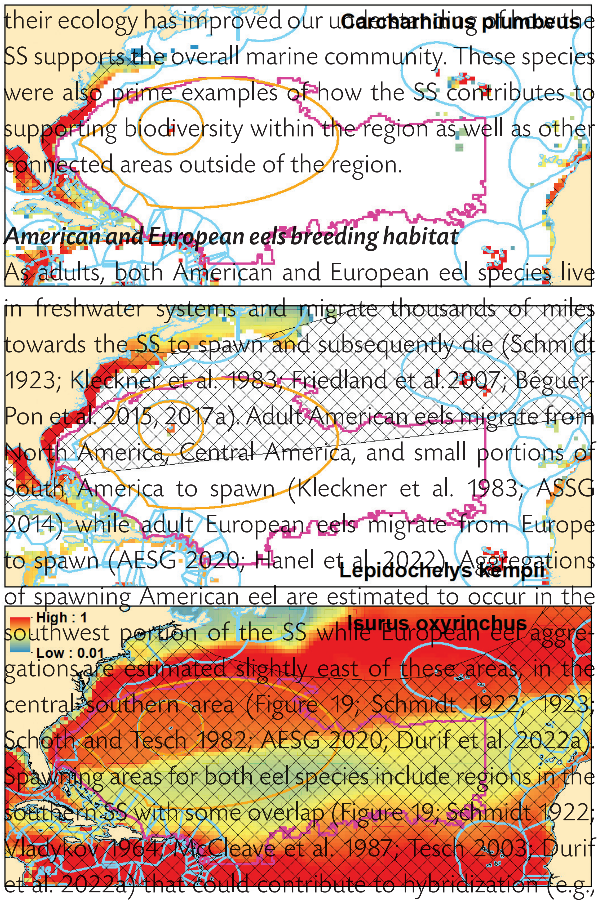


FIGURE 16. Combination of IUCN species range polygon (hatched layer) and habitat suitability index from AquaMaps (heatmap) forSandbar shark (Carcharhinus plumbeus - top), Kemp's ridley sea turtle (Lepidochelys kempii- middle) and shortfin mako (Isurus oxyrinchus – bottom).

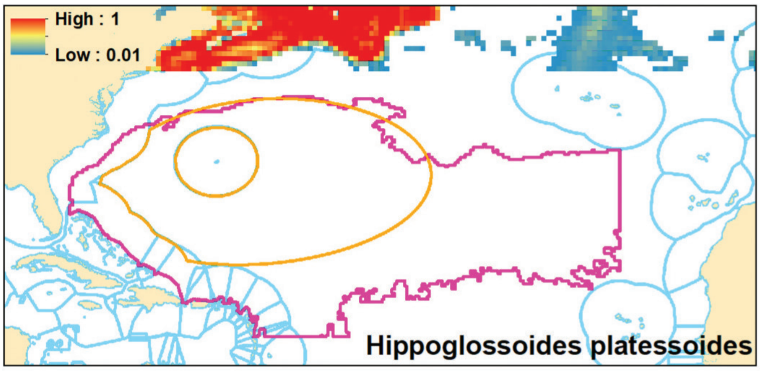


FIGURE 17. Habitat suitability index from AquaMaps (heatmap) for American plaice (Hippoglossoides platessoides).

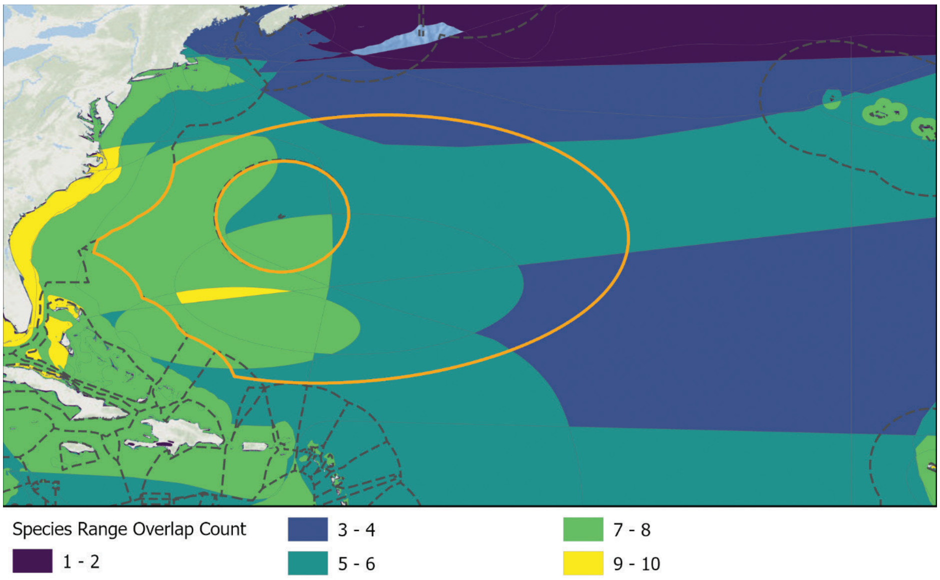


FIGURE 18. IUCN species range map polygon overlap count.

Avise et al. 1990; Albertet al. 2006; Als et al. 2011).

The American eel larvae, or leptocephali, are shown to be associated with hydrographic fronts that provide foraging habitats during their westward and northward transport out of the Sargasso Sea, withinthe Gulf Stream (Tesch et al. 2003; Munk et al. 2010). Data collected on European eel leptocephali suggests that they feed on Hydrozoa plankton in the SS (Ayala et al. 2018) and re associated with frontal currents but move out of the SS towards the Azores and Europe (Tesch et al. 2003; Munk et al. 2010; Westerberg et al. 2018a). Recent tagging studies have gathered data on the migration of adults from both species; Béguer-Pon et al. (2015, 2017a) tagged and released adult American eels near Nova Scotia, Canada that migrated towards regions west of the Grand Banks off Newfoundland and the AOI. Wright et al. (2022a) tagged and released adult European eels near the Azores that were extrapolated to migrate towards the GAC (Figure 19). However, more information is needed to better describe migratory corridors to the final spawning area (see Fricke and Kaese 1995; Béguer-Pon et al. 2015, 2017a; Durif et al. 2022a).

The timing of the migration towards the SS to spawn can vary depending on the starting location, but itis hypothesized to occur during the fall and winter with a peak in spawning activity during spring (Tesch and Wegner

TABLE 5. The list of focal species, current IUCN Red List status, and a summary of OBIS observation data (number of records and range of years with observation data) found within the GAC or MFE regions (OBIS 2023b). The year range refers to the range of years that data were collected, with some years within the range lacking data.

		GAC		MFE		Global	
Species	**Red List status**	**Records (n)**	**Year range**	**Records (n)**	**Year range**	**Records (n)**	**Year range**
Anguilla anguilla	CR	49	1964–989	79	1951–1989	25,076	1776–2020
Anguilla rostrata	EN	2,295	1912–2007	3,689	1862– 2007	15,687	1860–2022
Caretta caretta	VU	566	1979–2018	1,115	1965–2018	137,400	1758–2023
Megaptera novaeangliae	LC	17	1913– 2019	150	1913–2019	314,719	1770–2023
Prionace glauca	NT	379	1993–2005	787	1957–2011	42,905	1758–2021
Pterodroma cahow	EN	0	–	0	–	21	1996–2014
Xiphias gladius	NT	4,413	1992–2005	20,725	1958–2005	197,773	1758–2019

1990; Tesch 2003; Durif et al. 2008a; Monteiro et al. 2020). Compared to European eels,

McCleave (2008) and Westerberg et al. (2018b) estimate that seasonal spawning in the SS peaks earlierfor American eel, around late winter to early spring. However, Righton et al. (2016) tracked the spawning migration of European eels and found that spawning may begin earlier than previously estimated, starting in December with a February peak in activity, and may employ a mixed-strategy for fall migrations that consisted of short and long durations.

Currently, both the American (Jacoby et al. 2017) and European eels (Pike et al. 2020) are species of conservation concern, with declining populations that resulting mainly from threats better understood during their freshwater and coastal marine life-stages (Haro et al. 2000; Dekker and Casselman 2014). Oceanic changes within the SS associated with climate change may be influencing the declining recruitment of American and European eels (Friedland et al. 2007). Righton et al. (2021) reported that a major knowledge gap was the effects of climate change on populations, after summarizing the current knowledge anguillid eels.

Because the AOI appears to contain the only spawning area for both American and European eels, this contributes to two criteria for the justification of the Sargasso Sea EBSA: "special importance for life- history stages of species" (C1), and "importance for threatened, endangered, or declining species and/or habitats" (C2; Figure 11; Convention on Biological Diversity 2015b). The description of the EBSA includes a summary of expert knowledge on the importance of the SS area in supporting eels, other marine species, and biodiversity (Secretariat of the Convention on Biological Diversity 2012). After the Sargasso Sea EBSA was described, the Hamilton Declaration on Collaboration for the Conservation of the SargassoSea was signed to further initiatives for conserving Sargasso Sea ecosystems (Freestone and Morrison 2014; Roe et al. 2022).

Combining results from different research initiatives enables a more comprehensive view of the Anguillid populations that depend on habitats within the GAC. Although much research has been conducted on Anguillids in freshwater systems, more information is still needed to identify possible migratory corridors at-sea and better delineate spawning areas (Righton et al. 2012, 2021). The majority of observations recorded in the OBIS database for both eel species were outside of the AOI. Within the AOI, a limited number of observations are currently available for European eel in the OBIS database; over 2,000 records within the GAC and over 3,000 records within the MFE were available for American eel (Table 5; OBIS 2023b). Updated data on Anguillids may become available in the future within the OBIS database, or in other relevant data repositories, such as the Movebank database (e.g., Kays et al. 2022; Wikelski et al. 2022; Stein 2023a, 2023b). As additional data are collected in the future, a centralized location for surveys, models, and/or tracking data for *Anguillid* spp. would facilitate knowledge transfer in support of area-based management decisions for the AOI.

Loggerhead sea turtle foraging and development habitat

Loggerhead sea turtles have a wide geographic extent, using habitats in all major ocean basins except for the Antarctic and Arctic Oceans, with the Northwest Atlantic regional management unit (RMU) foundwithin the AOI (Figure 20; Wallace et al. 2010). The AOI supports the developmental stages of immature (neonates and juveniles) Atlantic loggerhead sea turtles and, to a lesser extent, feeding and breeding habitat for mature adults that nested in Bermuda (Meylan et al. 2011). Nesting loggerhead sea turtle populations were thought to be extirpated and do not typically occur in Bermuda (Godley et al. 2004); however, nests were found on Coopers Island in the summers of 1990 and 1995 (Bacon et al. 2006; Gray2018; Kot et al. 2023b).

Tagging data shows that oceanic juvenile loggerhead sea turtles travel from foraging grounds in North Carolina, USA across the north Atlantic, including the northern portions of the GAC (Figure 20; McClellan and Read 2007; McClellan et al. 2009; McClellan and Read 2010, 2018). Neonates released near nesting sites of southeast Florida have been tracked to the SS in the winter, after traveling north within the Gulf Stream, with occurrences that associate with meso-scale eddies (Mansfield et al. 2014, 2021). In addition to early neritic and oceanic stage sea turtles thought to be opportunistically foraging in the AOI,various other areas north (Georges Bank), east (Azores), and west (U.S. continental shelf) of the SS also support feeding and development (Carr 1987; Mansfield et al. 2014, 2021). Based on ocean circulation models and behavior, the density of loggerhead sea turtle hatchlings originating from nests in the northwestern Atlantic are predicted to be relatively high along areas near the coast and overlapping the GAC (Putman et al. 2012, 2020). Around Bermuda, loggerhead sea turtles are observed to use the highly productive *Sargassum* rafts and are occasionally distributed near wrecks (Bacon et al. 2006).

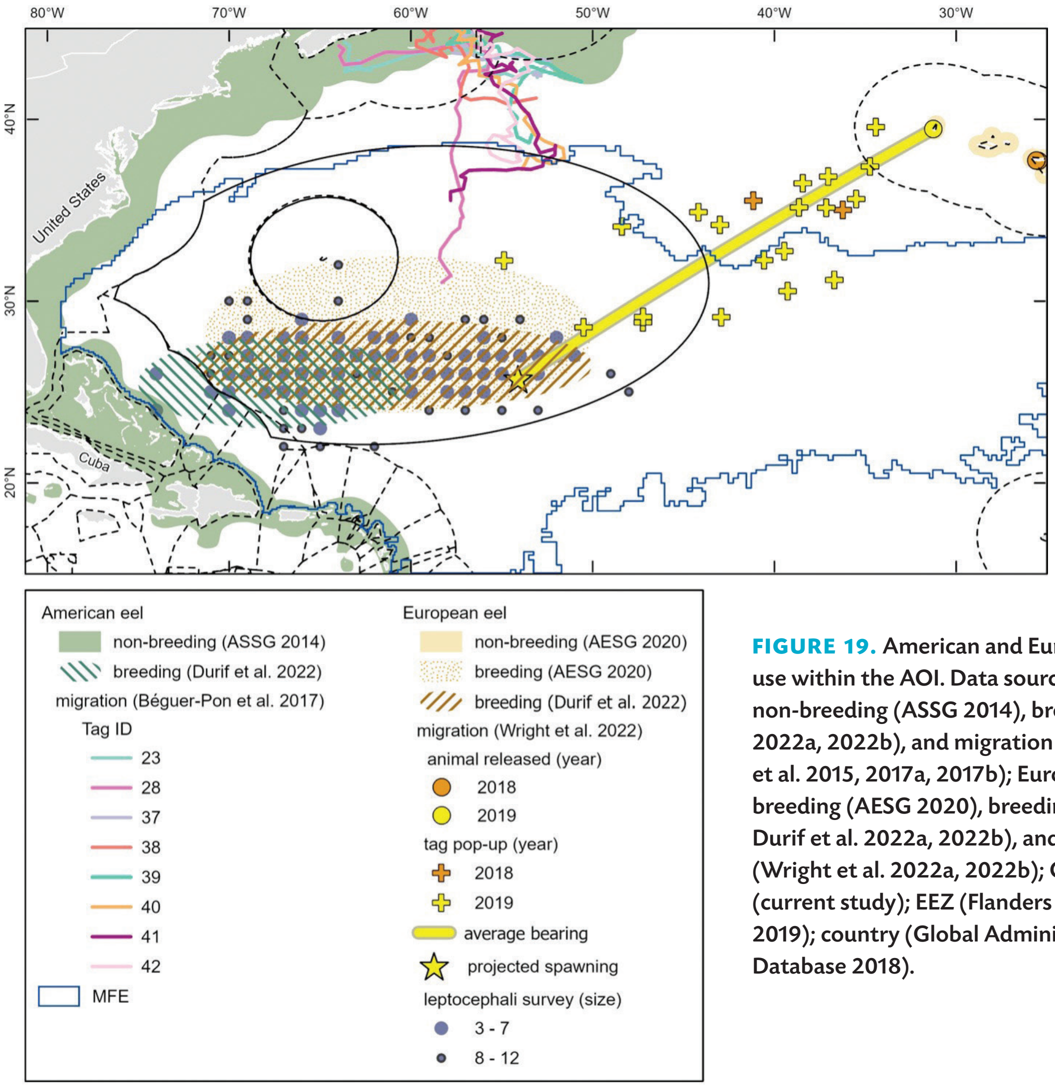


FIGURE 19. American and European eel area use within the AOI. Data sources: American eel non-breeding (ASSG 2014), breeding (Durif et al. 2022a, 2022b), and migration areas (Béguer-Pon et al. 2015, 2017a, 2017b); European eel non-breeding (AESG 2020), breeding (AESG 2020; Durif et al. 2022a, 2022b), and migration areas (Wright et al. 2022a, 2022b); GAC and MFE (current study); EEZ (Flanders Marine Institute 2019); country (Global Administrative Areas Database 2018).

When loggerhead sea turtles are present in the AOI (near Bermuda), they have the potential to be affected by the same anthropogenic threats that other marine species encounter, such as marine debris ingestion or entanglement, vessel strikes, and incidental take (Godley et al. 2004). Although most strandings of loggerhead sea turtles reported in Bermuda have been small (< 40 cm) as a result of winter storms (Bacon et al. 2006; Bernews 2011; CIT-SSC-2015 2015), other juveniles have occasionally been stranded with fishing gear (Godley et al. 2004). More research was warranted on each of these threats, especially if trends show an increased intensity over time in the AOI (Godley et al. 2004).

Many EBSAs overlap the range of northwest Atlantic loggerhead sea turtle population, including both EBSAs in the AOI (Figure 11; Secretariat of the Convention on Biological Diversity 2021). However, loggerhead sea turtles are only included in the description of the Sargasso Sea EBSA because nursery habitats in the area are used to justify two of the seven criteria (C1 and C2; Convention on Biological Diversity 2015b). The description of the EBSA includes a summary of expert knowledge on the importance of the AOI in supporting loggerhead sea turtles, other marine species, and biodiversity (Secretariat of the Convention on Biological Diversity 2012).

More research on area use and migratory connectivity has been conducted on loggerhead sea turtles, especially on the northwest Atlantic population, compared to other sea turtle species in the region (OBIS 2023b; Kot et al. 2022, 2023b). Kot et al. (2021) analyzed loggerhead sea turtle tracking data available in the AOI and showed that the High Seas was directly connected areas in the northwest Atlantic (Bermuda, U.S. Atlantic coast, and Canada Atlantic coast EEZs) as well as several areas in the northeast Atlantic, based on their movements. Improvements in tagging technology to collect tracking data and estimate home ranges continue to provide better information for all different life-stages (Godley et al. 2008). Because of the complexity of the loggerhead sea turtle's life-history and varied movements, additional tracking data could help elucidate the proportion of the population that depend on the GAC compared to other regions.

Combining results from different research initiatives enables a more comprehensive view of the loggerhead sea turtle population that depends on habitats within the GAC. Within the OBIS database, a small proportion of data were found and available in the GAC and MFE (Table 5; OBIS 2023b). Updated data on Northwest Atlantic loggerhead sea turtles could continue to be available on OBIS and other relevant data repositories, such as the Animal Telemetry Network (ATN; https://portal.atn.ioos.us/#metadata/137205/species Block et al. 2016), Movebank (https://datarepository.movebank.org/entities/taxon/24cfa983-dc33-4626-a701-4ed8e8148a5b; Kays et al. 2022; Wikelski et al. 2022), OBIS-Spatial Ecological Analysis of Megavertebrate Populations (OBIS- SEAMAP; https://seamap.env.duke.edu/species/173830, Halpin et al. 2009), seaturtle.org/Satellite Tracking and Analysis Tool (STAT; http://www.seaturtle.org/tracking/projects.shtml; Coyne and Godley 2006), and the OBIS-SEAMAP/State of the World's Sea Turtles (SWOT; https://seamap.env.duke.edu/swot; Mast et al. 2007; Halpin et al. 2009; Mast et al. 2020; Kot et al. 2023b) databases.

Humpback whale migratory habitat

Humpback whales have been observed in every ocean and undertake on long migrations throughout their life (IUCN 2012). Sub-species of Atlantic humpback whales have been divided by geography, with the North Atlantic humpback whales occurring in the Northern Hemisphere separately from three stocksin the Southern Hemisphere (Johnson and Wolman 1984; Engel and Martin 2009; Rosenbaum et al. 2009; Ramos et al. 2023). In the North Atlantic Ocean, areas considered as their primary range includethe northern waters (north of the AOI) and the Caribbean (south of the AOI), while their secondary range overlaps with the AOI (Jefferson et al. 2015).

Two distinct population segments in the north Atlantic, as defined by the U.S. NOAA NMFS, have been identified based on their primary breeding areas: 1) West Indies, and 2) Cape Verde Islands/Northwest Africa (Bettridge et al. 2015). A relatively small portion of North Atlantic humpback whales have been found to use waters around the Cape Verde Islands as a summer breeding ground with movements to and from winter feeding grounds near Norway and Iceland without passing through the AOI (Wenzel etal. 2003, 2009). In contrast, the largest breeding aggregation of North Atlantic humpback whales occur in the Caribbean Sea and are further be separated into distinct feeding stocks based on genetics data (Palsbøll et al. 1995) and fidelity to foraging sites (Katona and Beard 1990; Smith et al. 1999; Stevick et al. 1998; Kennedy et al. 2014; Horton et al. 2020).

North Atlantic humpback whales were known to migrate between winter breeding grounds near the West Indies and summer feeding grounds at higher latitudes (e.g., waters near Iceland-Denmark Strait, western Greenland near Svalbard, Newfoundland [Canada], Gulf of St. Lawrence, and Gulf of Maine [U.S.]), with some populations using the AOI as a pass-through or stop-over near Bermuda for opportunistic foraging (Figure HUMPBACK; Martin et al. 1984; Stone et al. 1987; Kennedy et al. 2014; Johnson et al. 2022; Grove et al. 2023). Grove et al. (2023) used photo ID techniques to demonstrate Bermuda's importance as a stop-over site for humpback whales between December and May, with abundances in Bermuda that varied annually and an overall increasing trend since 2011. Sightings of North Atlantic humpback whales feeding in other areas outside of known foraging grounds, such as the New York Bight (Brown et al. 2022) and the waters near the U.S. mid-Atlantic (Swingle et al. 1993; Barcoet al. 2002), suggested that more information was needed to better understand population structure and area use.

More data on area use, marine connectivity, and the movements of humpback whales are available compared to other marine mammals (Kot et al. 2023a). Geographic connections have mainly been determined using photo ID methods to identify unique individuals and genetic analyses to map humpback whale gene flows (e.g., Baker et al. 1990; Katona and Beard 1990; Stevick et al. 2003; Wenzelet al. 2003; Rizzo and Schulte 2009; Stevick et al. 2016; Wenzel et al. 2020). Humpback whale movements have also been tracked using satellite telemetry tags during their stay at North Atlantic foraging grounds (e.g., Robbins 2021a, 2021b; Kettemer et al. 2022; Robbins 2022a, 2022b, 2022c) or atthe breeding grounds (e.g., Fossette et al. 2014; Kennedy et al. 2014), but tracking migrations between northern and southern sites are more rare (Kennedy and Clapham 2018), especially for showing pathways through the GAC.

Because humpback whales have been observed to pass through the GAC, the AOI's contribution to supporting

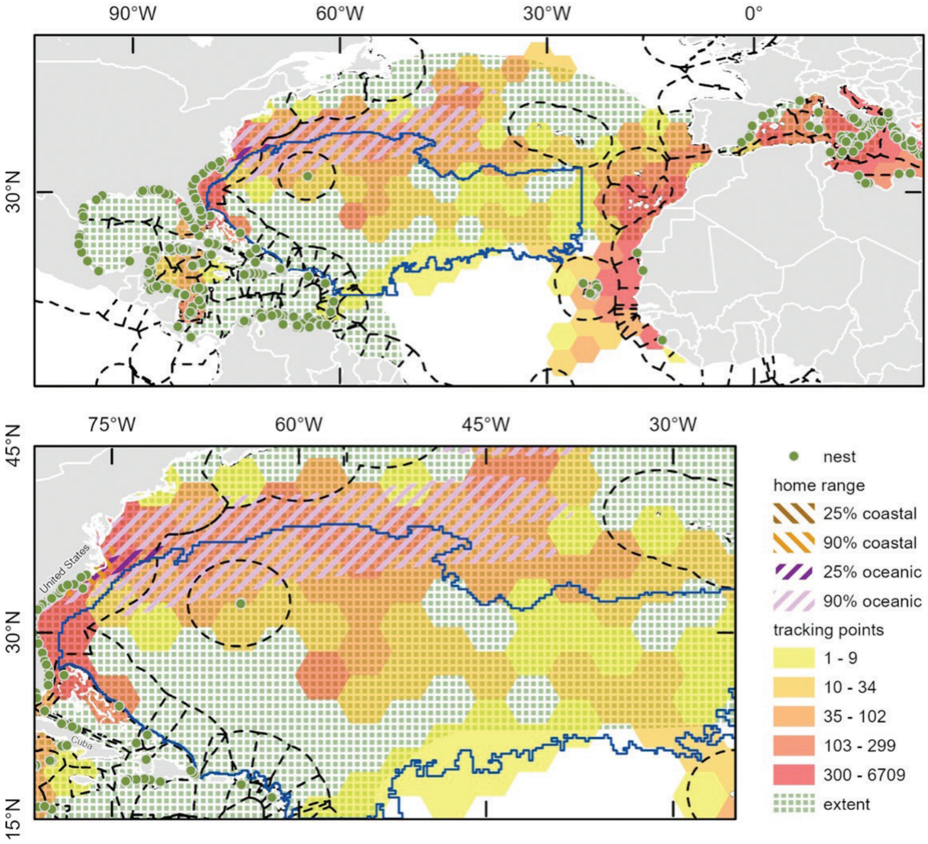


FIGURE 20. **Loggerhead sea turtle area use within the entire extent of the northwest Atlantic RMU (top) and AOI (bottom). Data sources: nesting beach (Mast et al. 2007; Halpin et al. 2009; Mast et al. 2020; Kot et al. 2023b) home range of northwest Atlantic juvenile coastal and oceanic loggerhead sea turtle populations (25% and 90% kernel density estimates; McClellan and Read, 2007; McClellan et al. 2009; McClellan and Read 2010, 2018; Dunn et al. 2019; Migratory Connectivity in the Ocean 2023); tracking points (sum number of tracking points in 1.62 × 105 km hexagon, binned using quintiles; Kot et al. 2022); extent of the northwest Atlantic RMU (Wallace et al. 2010); GAC and MFE (current study); EEZ (Flanders Marine Institute 2019); country (Global Administrative Areas Database 2018). A subset of loggerhead sea turtle tracking points in Kot et al. (2022) was used to develop the home range estimates.**

North Atlantic humpback whale stocks warranted more investigation (Figure 21). Kennedy et al.(2014) tracked 22 humpback whales traveling from breeding sites near the Dominican Republic and Guadeloupe, through the AOI, to different northern foraging sites; one female and her calf seemed to stay near Bermuda for three days. One female humpback whale was tracked while migrating from the Gulf of Maine to waters near the Dominican Republic, moving through the GAC in January (Center for Coastal Studies 2022; Robbins 2022c). Kettemer et al. (2022) tagged a female humpback whale in foraging grounds near Norway which visited other northeast Atlantic foraging grounds, migrated to breeding grounds near the West Indies, and then returned to the foraging grounds near the Norway tagging site. This female was tracked from Iceland to a putative calving site estimated to be north of the AOI, where she continued with her calf to migrate through the GAC in March - April going south and then back through the GAC in May - June going north towards Iceland (Kettemer et al. 2022). Globally, the amount of research on the areas used by humpback whales has increased significantly in the last 25years, but larger gaps remain about their migrations and juvenile area use (Kot et al. 2023a).

Supplemental information could come from increasing the sample size and developing methods to model movement patterns of North Atlantic humpback whales (Guarini and Coston-Guarini 2022).

Though still protected under the U.S. Marine Mammal Protection Act (16 U.S.C. 1361-1407), humpback whales are currently not listed under the U.S. ESA and are listed as "Least Concern" under the IUCN Redlist (Cooke 2018). North Atlantic humpback whales are one of the most frequently hunted marine mammals, but many populations have recovered after conservation measures were in place to prohibitwhaling (Smith 1983; Stevick et al. 2003; Roman et al. 2013). Historical records of sightings and catchesare relatively low in the AOI, compared to breeding areas in the North Atlantic (Smith et al. 2012).

Anthropogenic threats in the region continue to be vessel ship strikes and fisheries gear entanglements (Johnson et al. 2005; Roman et al. 2013; RWSC 2023). Noise from anthropogenic marine activities could also contribute to cumulative stress; Blair et al. (2016) observed changes in North Atlantic humpback whale behavior in response to vessel noise, which has the potential to affect fitness and survivorship.

In general, there is a lack of direct evidence of anthropogenic threats affecting humpback whales within the AOI, mainly because it is difficult to observe and study these impacts during their offshore migrations. Unusual mortality events, strandings data, and occasional observations showing the negative impacts of anthropogenic threats in their feeding and breeding areas support the need for continued conservation measures even after their populations showed recovery (e.g., Johnson et al.

2005; Robbins 2009; Pace et al. 2014; Robbins and Pace 2018; Stepanuk et al. 2021). Potential risks havealso been estimated by analyzing the overlapping areas that North Atlantic humpback whales use outside of the AOI and stressors such as fishing fleets and vessel traffic (e.g., Brown et al. 2019; Aschettino et al. 2020; Stepanuk et al. 2021). Van der Hoop et al. (2013) estimated that the greatest number of humpback whale mortalities reported in the U.S. Atlantic EEZ was from entanglement in fishing gear, followed by natural causes, and vessel strikes. Henry et al. (2020) reported an increase in injury and mortality in U.S. Atlantic and Gulf of Mexico and Canadian Atlantic EEZs from 2012 to 2016.

However, information was not available to provide estimates for the AOI.

Globally, humpback whales are mentioned in at least 58 EBSAs and featured as having a principal role in the description to justify one or more EBSAs (Kot et al. 2014). For the EBSAs overlapping the GAC, humpback whales are mentioned as passing through the Sargasso Sea EBSA and their known ecology was used to justify the C2 criteria (Figure 12; Kot et al. 2014; Convention on Biological Diversity 2015b). Thedescription of the EBSA includes a summary of expert knowledge on the importance of the SS area in supporting humpback whales, other marine species, and biodiversity (Secretariat of the Convention on Biological Diversity 2012, 2014).

Currently, there are 209 IMMAs globally defined, with the humpback whale listed as a qualifying species (only) for 60 IMMAs, listed as a supporting species (only) for 27 IMMAs (total n = 107 IMMAs; Figure 12; IUCN Marine Mammal Protected Areas Task Force 2022a, 2022b; Tetley et al. 2022). To date, areas forthe North Atlantic regions have not been assessed for the identification of IMMAs though the expert- driven process covering new regions was still ongoing (Tetley et al. 2022).

Combining results from different research initiatives enables a more comprehensive view of the humpback whale populations that depend on habitats within the GAC. Within the OBIS database, a limited number of records were within the GAC compared to other regions (Table 5; OBIS 2023b). However, over 50,000 records collected on humpback whales in the North Atlantic between 1901-2023from over 140 datasets are publicly available within the OBIS database, a majority of which were observed north and east of the SS areas of interest (OBIS 2023b). These observations overlap with breeding and feeding areas of North Atlantic humpback whales (Riede 2000, 2004; OBIS 2023b) with information on individuals that potentially depended on the AOI. Updated data on North Atlantic humpback whales may become available in the future within the OBIS database, or in other relevant data repositories, such as the ATN (https://portal.atn.ioos.us/#metadata/137092/species; Block et al. 2006), Movebank (e.g., Kays et al. 2022; Wikelski et al. 2022; Kettemer and Rikardsen 2023; Robbins 2023), and OBIS-SEAMAP https://seamap.env.duke.edu/species/180530; Halpin et al. 2009) databases. Knowledge gaps remain on how specific areas within the GAC supported humpback whale populations and the critical sites they depended on at sea, within their geographic extent, which may hinder effective conservation.

Bermuda petrel endemic habitat

The Bermuda petrel is endemic to Bermuda, with a resident geographic extent that overlaps with most of the AOI, extending into areas north of the GAC and MFE in the Atlantic, and spanning across to Europe (Figure

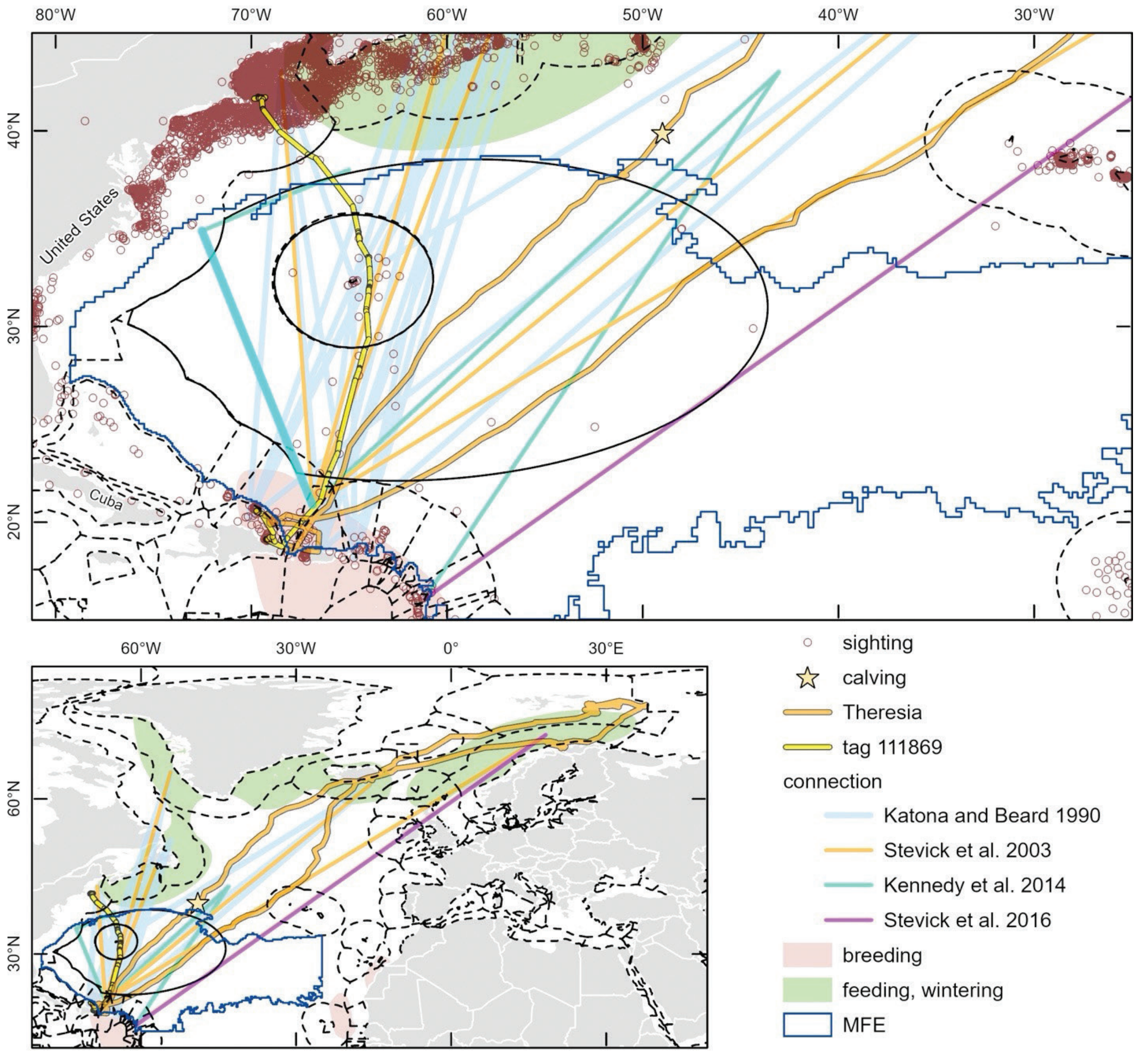


FIGURE 21. **Humpback whale area use in the AOI (top) and the entire extent of the connections intersecting the GAC (bottom). Data sources: sighting (record in OBIS 2023b; putative calving site and tagging data from 2019 for Theresia (Kettemer et al. 2022); tagging data from 2019 for tag 111869 (Coyne and Godley 2005; Halpin et al. 2009; Robbins, 2022c); connections as described from the literature (Dunn et al. 2019; Migratory Connectivity in the Ocean 2023); breeding and feeding, wintering extents (Riede 2000, 2004); GAC and MFE (current study); EEZ (Flanders Marine Institute 2019); country (Global Administrative Areas Database 2018). A subset of humpback whale sightings (records) in OBIS (2023) were used to develop the Robbins (2022) tracking data.**

PETREL; BirdLife International 2018; Raine et al. 2021). Bermuda petrel mainly nest on small islands of eastern Bermuda with a breeding season starting in late October and lasting until their chicks hatch between February and March (Madeiros et al. 2012). Results from tracking adult Bermuda petrels show that they travel to foraging sites near the Azores and can continue east towards Europe and north to the northern Atlantic before returning to Bermuda (Madeiros et al. 2014).

Conservation efforts to boost their nesting activity by preserving habitats and establishing more nesting sites have been successful, but Bermuda petrel populations are affected by several threats that continueto slow their recovery. These threats include habitat loss, invasive species, storms, and rising sea levels due to climate change (Madeiros 2005; Dobson et al. 2008; Allcorn et al. 2009; Carlile et al. 2012; Madeiros 2021). Additionally, ongoing projects to investigate potential sources of ocean plastics near important habitats in Bermuda can contribute to our understanding of anthropogenic threats that may affect the Bermuda petrel at-sea and on land (Rouja 2022).

The distribution of the Bermuda petrel is used to justify the Cooper's Island and Castle Islands IBA and KBA, the Cooper's Harbour Island nature preserve, and the Sargasso Sea EBSA (Figure 12). These recognized areas encompass several islands containing all the Bermuda petrel nesting sites, along with main breeding habitats for other seabird species (Dobson and Madeiros 2008; Copeland 2016; BirdLife International 2022, 2023b, 2023c). The description of the EBSA includes a summary of expert knowledgeon the importance of the SS area in supporting Bermuda petrel, other marine species, and biodiversity (Secretariat of the Convention on Biological Diversity 2012, 2014).

Further protections for feeding and nesting habitats for Bermuda Petrel also exist, with the establishment of the Castle Harbour Islands nature reserve in 1979, which overlaps with the Cooper's Island and Castle Islands IBA and KBA (Laws of Bermuda 1979). Although the Bermuda petrel's geographic distribution includes waters in the U.S. EEZ with occasional occurrences in certain coastal states, it is listed as "endangered' under the U.S. ESA (83 FR 20092-20095) without critical habitats designated for conservation (RWSC 2023).

Combining results from different research initiatives enables a more comprehensive view of the Bermuda petrel population that depends on habitats within the GAC. There is a lack of information on Bermuda petrel area use at sea, especially in ABNJ where they spend time migrating between breeding and foraging areas within its resident extent. The OBIS database currently does not have any recorded observations of Bermuda petrel within the GAC or MFE (Table 5; OBIS 2023b). However, 21 oceanic records collected between 1996-2014, during shipboard surveys, are publicly available for regions northwest of the SS areas of interest (USGS 2021; OBIS 2023b). These observations were within their geographic resident extent (BirdLife International and Handbook of the Birds of the World 2018) but did not overlap their known breeding and feeding areas (Riede 2000, 2004).

The main breeding and feeding, wintering areas of Bermuda petrels were identified within the Bermuda EEZ (Riede 2000, 2004), outside of the GAC, but new data and information from tracking movements, mark-recapture techniques, and surveys may be needed to update core area use (Figure 22). In general, there were limited data on Bermuda petrel migratory connectivity (Kot et al. 2023a), though recently tagged adults during chick-rearing stages showed regional connectivity between nesting sites in Bermuda and foraging sites in the northern Atlantic (telemetry data archived on Movebank.org; Raine et al. 2021; Kays et al. 2022; Wikelski et al. 2022). Male Bermuda petrels have also been tracked using global positioning system (GPS) tags during the incubation stage of the breeding season, showing movements from Bermuda to areas throughout the GAC (telemetry data archived on the Seabird Tracking Database: https://data.seabirdtracking.org/dataset/1577; BirdLife International 2023a).

Updated data on Bermuda petrel may become available in the future within the OBIS and Seabird Tracking Database, or in other relevant data repositories, such as the eBird (https://ebird.org/species/berpet; Sullivan et al. 2009; Wood et al. 2011; Sullivan et al. 2014) and Movebank (e.g., Kays et al. 2022; Wikelski et al. 2022; Raine 2023) databases.

Blue shark habitat

The blue shark (*P. glauca*) is a wide-ranging species that occupies both temperate, subtropical and tropical waters in the Atlantic basin and has displayed long-distance displacements in the SS GAC acrossseasons (Campana et al. 2021). The predicted distribution of blue sharks within the GAC varies across seasons, age class, and sex (Druon et al. 2022). Overall, the predicted distribution of blue sharks mostly overlaps with the northern and northeast portions of the GAC, showing slightly higher probabilities of presence from July to September (Druon et al. 2022). Vanderperre et al. (2016) assessed habitat suitability for juvenile blue sharks and found that sex-specific variability does exist in the seasonal habitat suitability for this species in the North Atlantic. Suitable habitat for juvenile females is concentrated in the northern part of the SS GAC across all seasons while suitable habitat for males ranges in distribution throughout the year.

This species is one of the most widely caught sharks in the North Atlantic, averaging 39,102 t from 2011- 2015 according to the ICCAT recommendation 19-07. As a result of high catch rates, the North Atlantic population became one of the first for which a total allowable catch (TAC) was established. Globally, blue sharks are retained for their fins, and according to the IUCN Red List the demand for meat is likely increasing. The steepest population declines have occurred in the North and South Atlantic, and to a lesser magnitude in the Indian Ocean. As of the latest IUCN Red List assessment, blue sharks are considered as Near Threatened globally with the status

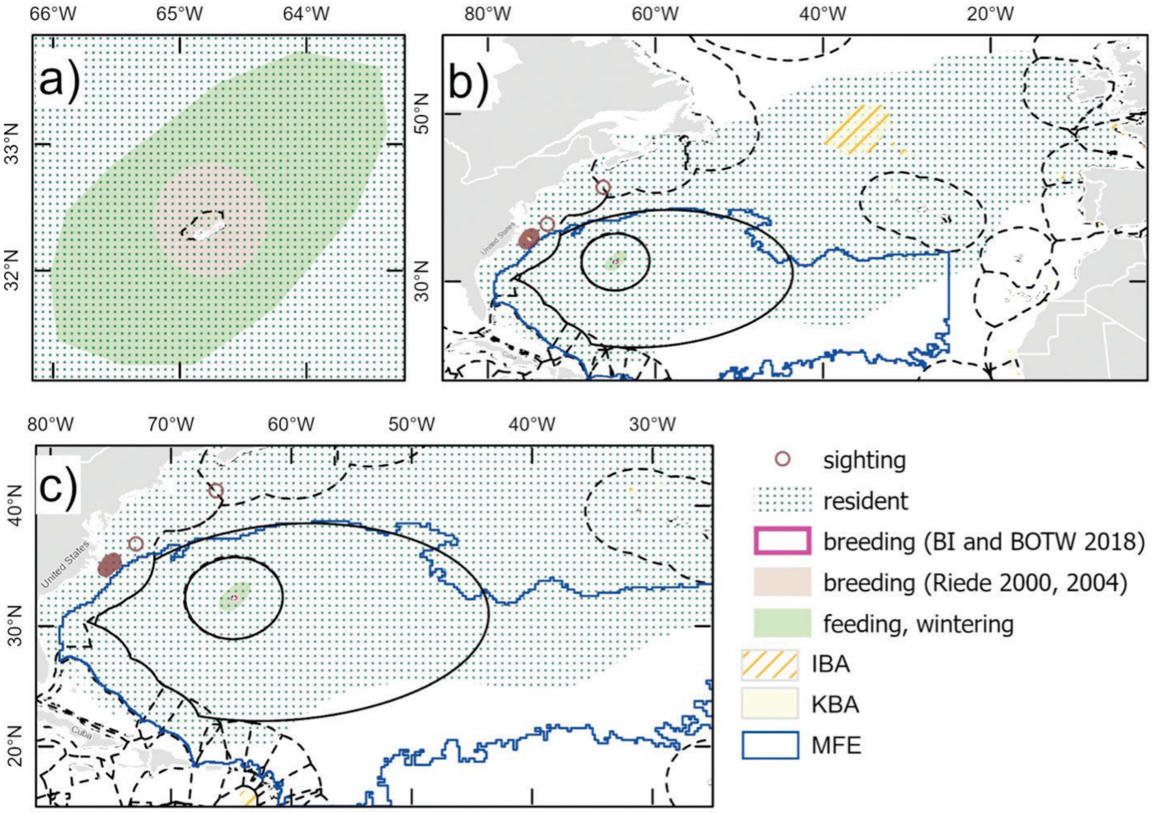


FIGURE 22. **Bermuda petrel area use within the a) Bermuda EEZ, b) entire resident extent, and c) AOI. Data sources: sighting (record in OBIS 2023b); resident and breeding areas (BirdLife International [BI] and Handbook of the Birds of the World [BOTW] 2018); breeding and feeding/wintering areas (Riede 2000, 2004), IBA (BirdLife Internationl 2022); KBA (BirdLife International 2023); GAC and MFE (current study); EEZ (Flanders Marine Institute 2019); country (Global Administrative Areas Database 2018).**

of the North Atlantic population listed as Endangered (ICCAT 2015; Rigby 2019).

As of now, no important shark and ray areas (ISRA) workshops have been conducted in the North Atlantic. While the EBSA process which identified the significance of the SS did not highlight its importance for blue sharks, recent satellite tagging data has recognized this feature as important habitat for various shark species that were previously unknown to inhabit the area. For example, basking sharks migrate to the Sargasso Sea during the winter at depths ranging from 200 to 1000 meters (Skomal et al. 2009). Large female porbeagle sharks have been tracked migrating over 2,000 km from Canadian waters to the Sargasso Sea, potentially for pupping (Dulvy et al. 2008, Campana et al. 2010). A female white shark was also observed traveling from Massachusetts to the Sargasso Sea during the winter months, suggesting that this area may serve as critical nursery habitat for threatened shark species, including blue sharks (G. Skomal and S. Thorrold 2011, pers. comm).

Swordfish core habitat and spawning grounds

Swordfish (*X. gladius*) is one of the most widely caught species of large pelagic in the North Atlantic Ocean. Areas immediately south of the GAC, across the southern U.S. East Coast, Gulf of Mexico and northern Caribbean, have been identified as important spawning grounds for swordfish (Govoni et al. 2003; Luckhurst et al. 2014; Suca et al. 2018). Telemetry data shows that swordfish can be found within the GAC and MFE throughout the year (Neilson et al. 2014; Braun et al. 2019). The seasonal distribution of swordfish in the SS varies across age class and sex and is primarily concentrated in the western and northern portions of the GAC and MFE (Neilson et al. 2014).

In terms of the global population of this species, the North Atlantic stock represents around 10% based on the maximum sustainable yield (MSY). The U.S. longline fishery is the most prominent fishery targeting swordfish in the western portion of the North Atlantic (Schirripa et al. 2017). The fleet catches swordfishacross the northern and western borders of the Sargasso Sea GAC and MFE and mostly at night and in areas outside of oceanic eddies (Hsu et al. 2015). It has also been suggested that the catch rates of swordfish in the North Atlantic vary is response to the Atlantic Multidecadal Oscillation (AMO), including within the GAC and MFE (Schirripa et al. 2017).

The latest global IUCN Red List assessment of Swordfish categorized this species as Near Threatened following a negative abundance trajectory of at least a 22% reduction over the past three generational time-spans (Collette et al. 2022). According to the stock assessment by ICCAT, however, the swordfish population in the North Atlantic is not experiencing overfishing (F/FMSY = 0.78) and is not considered overfished (B/BMSY = 1.04). The MSY is estimated at 13,059 tons and models indicate a potential increase in the North Atlantic stock of Swordfish between 1994 and 2014.

Remote Sensing of *Sargassum*

Remote sensing approaches for monitoring pelagic *Sargassum* features remains an active area of research and data development. These developments have been driven by new satellites and sensors that have improved the coverage and resolution of monitoring, while also enabling the development of new algorithms for feature extraction and areal coverage calculations.

In recent years, the focus of much of this work has shifted from the Gulf of Mexico and Sargasso Sea to a new area of *Sargassum* abundance, the Greater Atlantic *Sargassum* Belt (Wang et al. 2019). This new location for the genesis of *Sargassum*, observed since 2011 (Gower et al. 2013), is thought to represent a regime shift in the formation and transport of *Sargassum* (Johns et al. 2020). This shift has changed the focus of much *Sargassum* remote sensing research to focus on this new geography, the wider Caribbean and central western region of the tropical Atlantic. This regime shift, and its subsequent negative impacts on tourism, have changed the output datasets and applications to be more about near real time monitoring, tracking and prediction of mat dispersion and less on observing *Sargassum* as a pelagic habitat with research on its long term climatologies and distribution patterns.

There are several dimensions to explore in current remote sensing research on *Sargassum*, which are discussed in the following section:

Development and evaluation of algorithms that can identify floating *Sargassum* from satellite imagery. Two of the common algorithms used in current research are described in the following section.

Data availability of datasets produced from these algorithms. The space and time coverage of theseseveral of these derived data products are described in the following section.

Methods to aggregate *Sargassum* detections from these datasets to produce areal coverage maps representing aggregation over longer time periods. One approach to this is described in the following section.

Algorithms and Data Availability

To detect and quantify *Sargassum* from satellite imagery, several indices have been developed based on the reflectance properties of photosynthetic vegetation. The so-called "chlorophyll red edge" is a difference of reflectance in photosynthetic plants; from low reflectance in the visible spectrum to high reflectance at wavelengths above 730nm (Gower et al. 2006). For marine applications there is a peak in ocean surface radiance near 705nm, associated with high levels of chlorophyll-a linked with floating macroalgae or plankton blooms (Gower and King 2008).

Several different satellite sensors that are measuring radiance in the relevant wavelengths to supply these algorithms including MODIS, VIIRS, and OLCI (Sentinel 3). As a result, output datasets are produced at a variety of different spatial and temporal resolutions. Further processing is needed to develop the results from these indices into gridded *Sargassum* areal coverage data products (Wang and Hu 2016).

Another limit on recent developments in *Sargassum* remote sensing is that many high-resolution sensors do not cover open-ocean waters, leaving these areas mainly covered by medium-resolution sensors (Hu et al. 2023), which may not detect the more dispersed forms of drifting *Sargassum* (Ody etal. 2019; Goodwin et al. 2020).

While these algorithms are well-described, a new application of these algorithms across a wide spatial and temporal extent is beyond the scope of the SARGADOM data synthesis effort. Instead, this work focused on assessing the space and time coverage of existing datasets that currently implement thesealgorithms. The availability of these existing dataset at the time and space scales needed for the Sargasso Sea extent is variable.

New data development is needed to produce datasets using these algorithms, focused on the full extent of the AOI and covering the time scales to support possible management actions. In addition, the detection limitations mentioned in the *in-situ* observation section should be noted during the scoping ofsuch new research (Ody et al. 2019; Goodwin et al. 2020).

Maximum Chlorophyll Index (MCI)

The Maximum Chlorophyll Index (MCI) index relies on observing or interpolating surface reflectance around 709nm. *Sargassum* presence is linked with high MCI index values (Gower et al. 2006). Here is thealgorithm as detailed for Sentinel 3 A/B OLCI in Gower and King (2020): If $L_{865} < 15$ mW m^{-2} sr^{-1} nm^{-1}, then $\text{MCI} = L_{709} - L_{681} - 0.379(L_{754}\text{-}L_{681})$ where $L865$ represents level 1 radiances (as measured at the satellite) at a wavelength of 865 nm, and similarly for other wavelengths, and the factor 0.379 represents the wavelength ratio (708.75–681.25) / (753.75–681.25)

NOAA Coast Watch Daily MCI

- Temporal: daily imagery, from 1/2/2021 - current
- Spatial: ~300m
- Extent: 6°S - 35°N; 98°W - 10°E
- ERDDAP: https://oceanwatch.aoml.noaa.gov/erddap/griddap/DAILY_MCI_OLCI.html
- Data viewer: https://cwcgom.aoml.noaa.gov/cgom/OceanViewer/

Alternative Floating Algae Index (AFAI)

The Alternative Floating Algae Index (AFAI) was proposed by Wang and Hu (Wang and Hu 2016) as animprovement to the original Floating Algae Index (FAI; Hu 2009). Algorithm details from Wang and Hu(2016):

$$FAI = R_{rc,NIR} - R'_{rc,NIR}$$

$$R'_{rc,NIR} = R_{rc,RED} + (R_{rc,SWIR} - R_{rc,RED})\ x\ (\lambda NIR - \lambda RED) / (\lambda SWIR - \lambda RED)$$

For MODIS FAI calculations: $\lambda_{RED} = 645$ nm, $\lambda_{NIR} = 859$ nm, and $\lambda_{SWIR} = 1240$ nm
For MODIS AFAI the bands are: $\lambda_{RED} = 667$ nm, $\lambda_{NIR} = 748$ nm, $\lambda_{SWIR} = 869$ nm

Datasets using the AFAI are available from several different sources and satellites. Here are several available datasets that highlight the range of spatial and temporal resolutions and geographic coverage.

MODIS Terra and Aqua

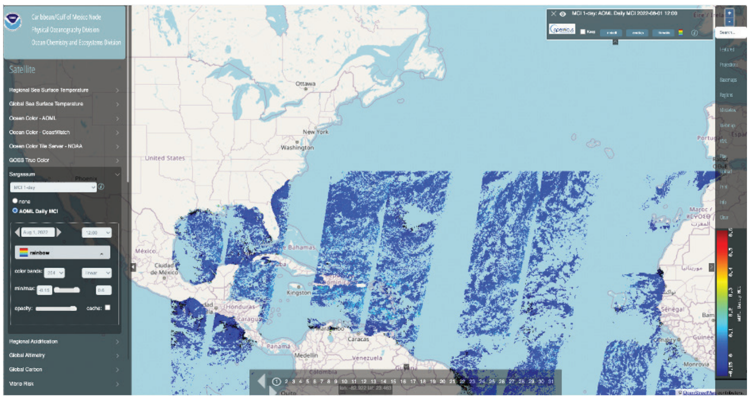


FIGURE 23. MCI imagery from OLCI Sentinel 3 for Aug 1, 2022.

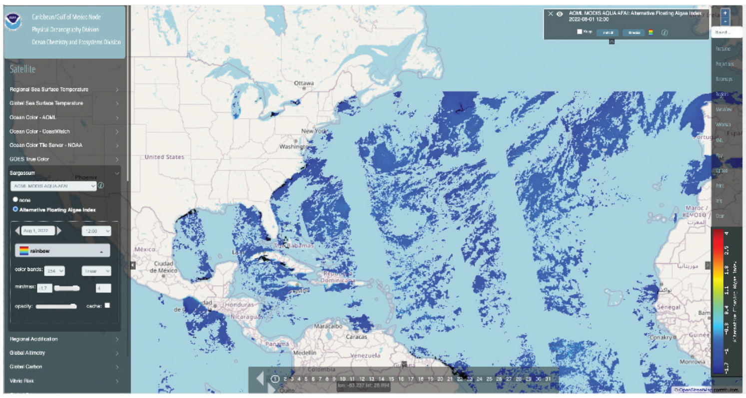


FIGURE 24. AFAI imagery from MODIS AQUA for Aug 1, 2022.

- Temporal: daily imagery, from July 2022 - current
- Spatial: ~1.1 km
- Extent: 10°S – 45°N; 100°W – 20°E
- Aqua - https://oceanwatch.aoml.noaa.gov/thredds/AFAI.html?dataset=MODIS_AQUA_AFAI
- Terra - https://oceanwatch.aoml.noaa.gov/thredds/AFAI.html?dataset=MODIS_TERRA_AFAI
- Data viewer: https://cwcgom.aoml.noaa.gov/cgom/OceanViewer/

VIIRS on NOAA-20 and SNPP

- Temporal: daily imagery, from July 2022 - current
- Spatial: ~830 m
- Extent: 45°S - 45°N; 100°W – 20°E
- NOAA-20 - https://oceanwatch.aoml.noaa.gov/thredds/AFAI.html?dataset=VIIRS_NOAA20_AFAI
- SNPP - https://oceanwatch.aoml.noaa.gov/thredds/AFAI.html?dataset=VIIRS_SNPP_AFAI
- Data viewer: https://cwcgom.aoml.noaa.gov/cgom/OceanViewer/

USF AFAI – 1-day, 3-day, 7-day cumulative AFAI

- Temporal: daily imagery, from June 2016 - current
- Spatial: ~1.6 km
- Extent: sections of 0° - 38°N; 98°W - 16°W
- https://cwcgom.aoml.noaa.gov/thredds/AFAI.html
- Data viewer: https://cwcgom.aoml.noaa.gov/cgom/OceanViewer/

Exploratory MCI maps for 2021

As part of the exploration of available datasets, we performed an aggregation exercise on available MCI data from the Ocean and Land Color Imager (OLCI) sensor on Sentinel 3 A/B. The following maps are based on the MCI dataset from NOAA Coast Watch, produced at a daily timestep for 2021. This is a simple operation to count the number of days where a given pixel had a very high MCI observation (above 99th percentile MCI level for the entire daily image). This analysis was performed for all of 2021 and for winter (January - March), spring (April - June), summer (July - September), and fall seasons (October - December). The available MCI dataset only extend northward to 35°N which limits the mapping in the northern portion of the SS, reinforcing the current focus of these approaches on the new Great Atlantic *Sargassum* Belt.

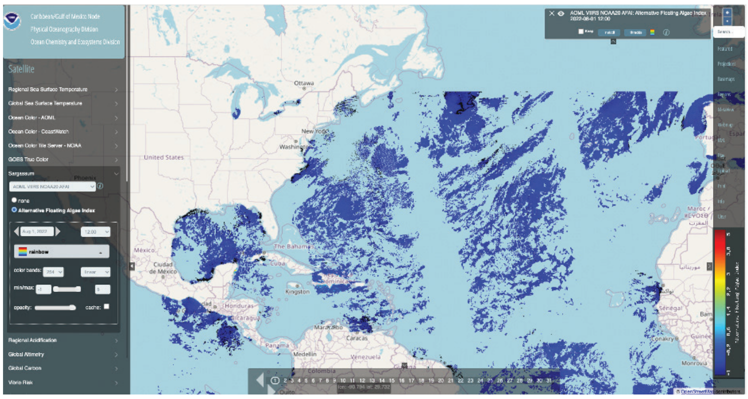


FIGURE 25. AFAI imagery from VIIRS NOAA-20 for Aug 1, 2022.

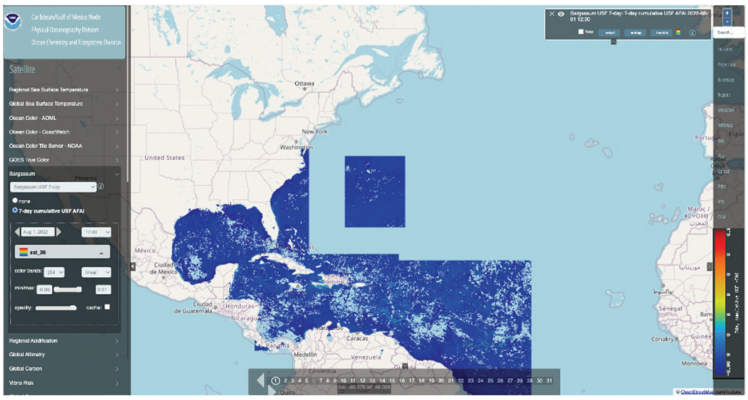


FIGURE 26. 7-day cumulative AFAI imagery from USF for Aug 1, 2022.

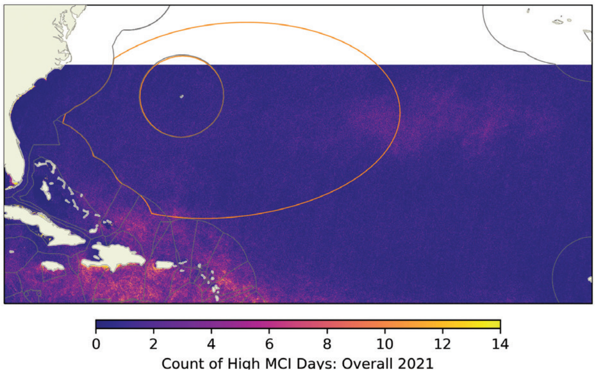


FIGURE 27. **Count of days with high MCI values, all 2021.**

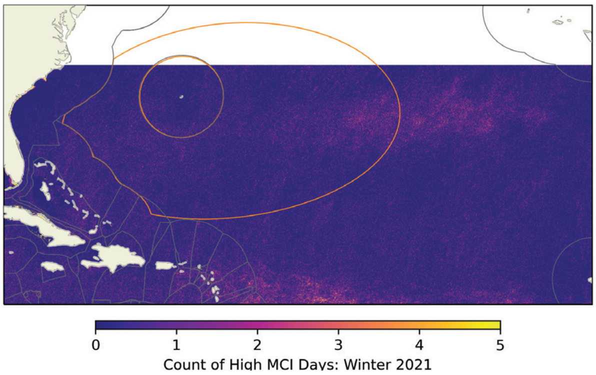


FIGURE 28. **Count of days with high MCI values, winter 2021.**

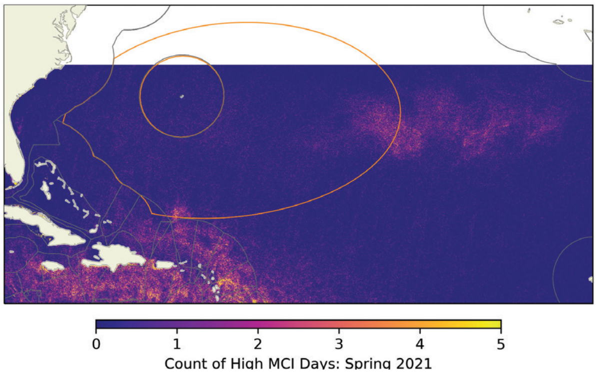


FIGURE 29. **Count of days with high MCI values, spring 2021.**

While this approach does show some interesting patterns on the distribution of *Sargassum* in the northeastern Sargasso Sea and Caribbean, many of the recent remote sensing papers about *Sargassum* recommend a series of additional spectral processing steps to accompany the MCI algorithm (Gower and King 2020). This processing could then feed into an aerial coverage approach like that outlined in Wang and Hu (2016).

Areal Coverage Approaches

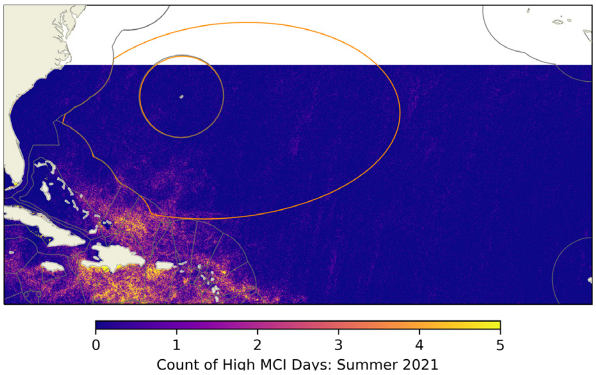


FIGURE 30. **Count of days with high MCI values, summer 2021.**

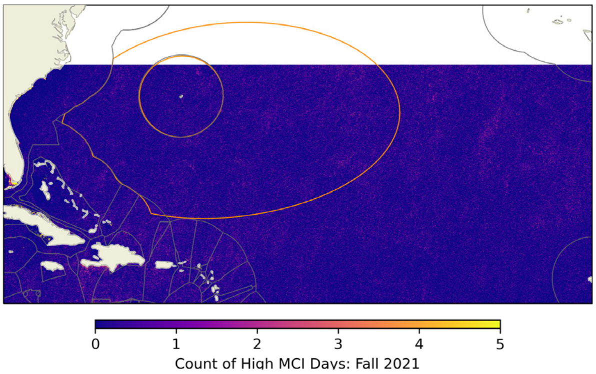


FIGURE 31. **Count of days with high MCI values, fall 2021.**

Once any of the abovementioned *Sargassum* detection algorithms are completed, further steps are needed to create areal coverage maps that might be useful to support management decisions. The workflow to process these data into areal coverage maps are also complex (Wang and Hu 2016). Here isa workflow diagram on using MODIS AFAI to create areal coverage maps (Figure 32).

In situ Observation

In parallel with the new literature on remotely sensed approaches to detect and map *Sargassum*, there continue to be new efforts to map *Sargassum in situ* from shipboard surveys. These results can improve and standardize the characterization of the aggregation patterns of *Sargassum* rafts (fragments/clumps, windrows, or mats), characterize the faunal associations with these forms, and provide verification opportunities for satellite analysis. Both papers highlight the need for more *in situ* work to help refine new satellite approaches and to better characterize their uncertainty.

A recent paper with sampling across the SS noted that many *in situ Sargassum* observations were belowthe detection limit for algorithms based on medium-resolution satellites like MODIS. Most *in situ* observations of *Sargassum* in the Sargasso Sea were of a dispersed form with more aggregated forms like windrows and mats much less common. (Goodwin et al. 2020).

Other *in situ* surveys worked more explicitly to link observed *Sargassum* aggregation forms across a range of satellite platforms and spatial resolutions (1 km-10 km). Linking each satellite with an appropriate scale of analysis and *Sargassum* form typology is another useful step in quantifying what is possible to observe from satellites and how monitoring at the ocean-basin scale might be achieved. This work also reported a lack of detection of *Sargassum* in the SS with the MODIS sensor (Ody et al. 2019).

The literature on remote sensing applications to detect *Sargassum* continues to grow, while also shifting to focus on *Sargassum* as a nuisance in geographies outside of the SS. Newly available satellite data at higher spatial resolutions are now online and are being evaluated as to what concentration and aggregation form of *Sargassum* they can detect.

The implementation details of the detection algorithms, resolution of the datasets involved, and complexity of the areal coverage approaches suggests that a dedicated study of *Sargassum* accumulation and seasonal patterns in the Sargasso Sea from satellite remote sensing would be anappropriate next step.

The most straightforward place to start this could be to begin with additional work using existing datasets like the Coast Watch MCI or AFAI implementations. These datasets do have limitations in space and time coverage. The Coast Watch MCI dataset is the highest resolution dataset (300 m), has an archive of data back to 2020, but it does not extend northward beyond 35°N. The Coast Watch AFAI datasets are lower resolution (VIIRS at 800 m, MODIS at 1.1 km) and do cover the full extent, but only extend back to late July 2022. A more involved alternative would be to use Sentinel 3 OLCI data to calculate MCI for the region. Despite these limitations, we feel that a dedicated analysis through these available index datasets or raw satellite imagery, informed by the literature above, could improve our understanding of the distribution of *Sargassum* across the SS at spatial and temporal resolutions linked to management actions.

Human Use

Shipping Summarizations

The Sargasso Sea (SS) is an important area for international shipping, serving as a major shipping route for vessels traveling between North America and Europe. As a measure of human use pressures on the SS, we investigate the patterns and impacts of vessel traffic in and around the SS.

We used vessel tracking data from the automatic identification system (AIS) organized by Global Fishing Watch (GFW; https://globalfishingwatch.org/) to delineate and summarize vessel traffic in the study area. These

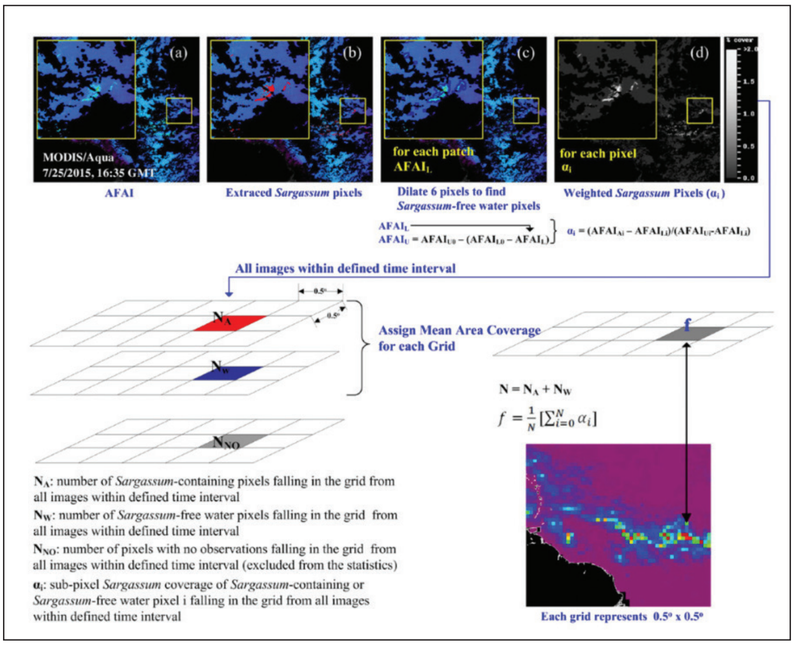


FIGURE 32. Sargassum areal coverage workflow. [Figure 7 from Wang and Hu, 2016. Original caption: The process used to generate the monthly mean Sargassum area coverage maps using original AFAI images. The AFAI image in (a) is used to extract Sargassum-containing pixels in (b). These pixels arediliated to find the nearest water pixels (dark blue color around the Sargassum patches in (c)) to be used to calculate AFAIL for each Sargassum patch. (b) and (c) are used to calculate (d), the required input to generate monthly means for the predefined grids. The calculation of the mean Sargassum coverage for a grid during the time interval month) is illustrated.]

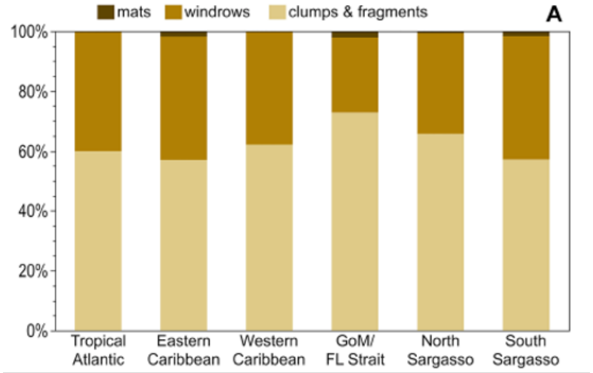


FIGURE 33. Observations of in situ Sargassum forms [Figure 4A from Goodwin et al. 2020. Original caption: Holopelagic Sargassum aggregation by region and Beaufort Force. Proportion of highest rankedaggregation states by (A) region and (B) BF. As only one positive holopelagic Sargassum observation each was made at BF 0 and 8, these levels not shown; holopelagic Sargassum was absent from the observation at BF 9. GoM, Gulf of Mexico; FL, Florida.]

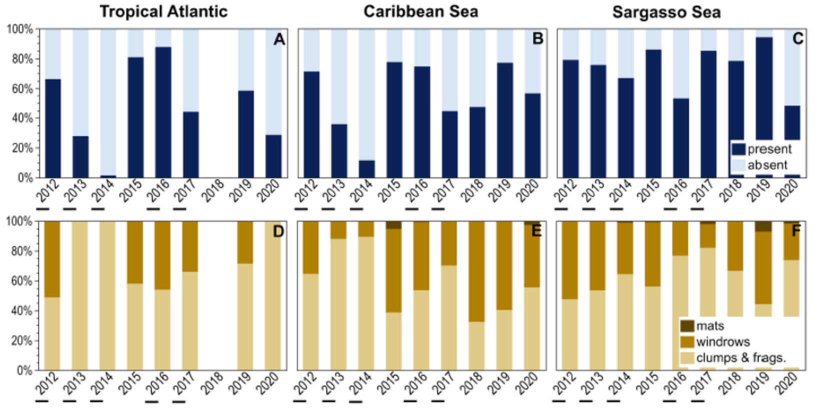


FIGURE 34. Observations of in situ Sargassum forms over time [Figure 5 from Goodwin et al. 2020. Original caption:
Annual patterns of holopelagic Sargassum presence and aggregation type. (A–C) Annual (October through May) proportional presence and (D–F) ranked aggregation states in the Tropical Atlantic, merged Eastern and Western Caribbean regions, and merged North and South Sargasso Sea regions. Low annual mean satellite-derived areal coverage (<500 km2) of holopelagic Sargassum in the central Atlantic Ocean indicated by underscores; all other years were high coverage. Remote sensing data as monthly means, derived using the same approach as in Wang and Hu (2016) and Wang et al. (2019), were provided by the Optical Oceanography Laboratory at the University of South Florida (https://optics.marine.usf.edu).]

data are not available to the public and are the input data that GFW uses to produce their public apparent fishing effort dataset. Due to the reliability and completeness of the data, we focused on AIS data for three years from 2019 through 2021. In total, we extracted nearly 68 million records of AIS messages (point location data) and produced 71 million vessel tracks, segmented by the 10 km x 10 km grid cells within the study area (e.g., Figure 37). The segmented vessel tracks were used to produce statistical summary products calculated by the grid cell (Table 7). We also created animations of variousthemes as visually appealing representation of vessel traffic, which is also useful for identifying unusualchanges of the vessel traffic over time (Table 8). These animations will be made available through the SARGADOM project portal.

Annual summaries of vessel traffic in the study area helps capture the overall patterns of the traffic (Figure 38). While most of the area within the SS is covered by some vessel traffic, there are several heavily trafficked shipping lanes between major U.S. ports, the Caribbean, South America, and Europe.

Before exploring the shipping patterns in detail, it is important to remember that the temporal period for these AIS data includes the COVID-19 pandemic. The World Health Organization declared the COVID-19 pandemic on March 11, 2020, and government measures

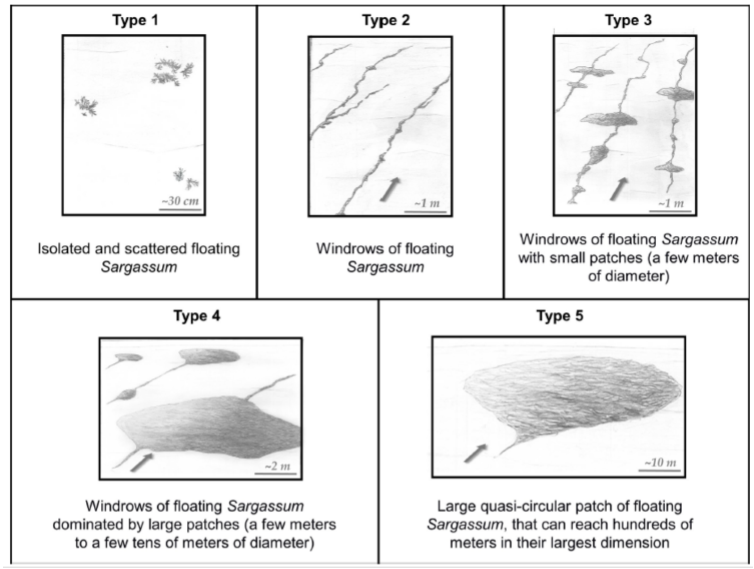


FIGURE 35. Typology of Sargassum aggregation forms [Figure 2 from Ody et al. 2019. Original caption: Five-class typology of Sargassum rafts illustrated with schematic drawings. Drawings are based onobservations from the ship deck ~6 m above water level. Wind direction is indicated by an arrow. Original drawings by Emma Rozis.]

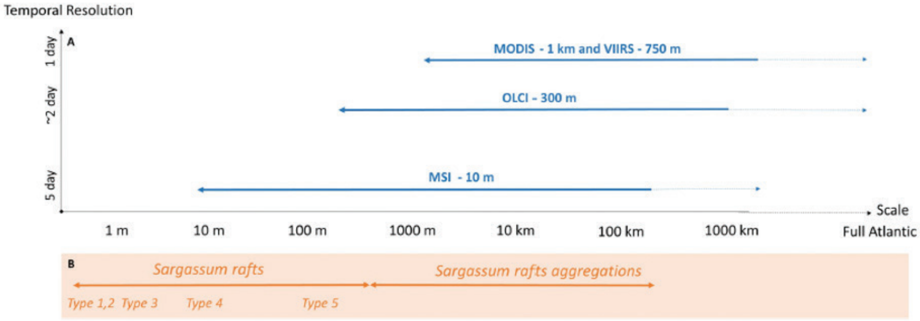


FIGURE 36. Satellite sensor resolution and observable Sargassum aggregation forms [Figure 8 from Ody et al. 2019. Original caption: Capability of the MODIS (Aqua and Terra), VIIRS, OLCI (S3A and S3B) and MSI (S2A and S2B) satellite sensors in terms of spatial resolution, temporal resolution and spatial coverage to describe Sargassum aggregations at various scales (B), and comparison within in situ Sargassum raft scales (B). Solid lines on (A) indicate the different scales attained by the sensor with one image. Dotted lines indicate the maximum spatial coverage reached by each sensor, with a frequency limited by its temporalresolution. Note the logarithmic scale of the x-axis.]

on mobility restrictions reached their maximum levels in April 2020 (March et al. 2021). Vessel traffic in 2020 was already declining in January and February from 2019, the decline accelerated in March 2020 and reached a low point in May. Traffic decreased in for all vessel types and was particularly drastic for cargo and passenger vessels (Figure 39).

Between 2019 and 2020, more than 60% of the study area experienced the decline of vessel traffic from the previous year (Figure 39), however vessel traffic appeared to increase along coastal areas of the U.S. (Figure 40).

Monthly averages from January to December over three years were calculated by vessel type (cargo, fishing, passenger, and tanker) and provide an understanding on spatial and temporal patterns of thevessel traffic and which types of vessels contribute to the heavy traffic seen in Figure 37.

While cargo vessels cover most of the study area, there are a few high traffic shipping lanes from the major U.S. ports to the eastern Atlantic and the Caribbean and from Caribbean to the eastern Atlantic (Figure 41). Throughout the entire SS AOI, the major routes do not show significant seasonality, though thenortheast of the SS has less traffic in the summer months.

Compared with the cargo and tanker traffic, the passenger vessels concentrate on narrow transit lanes

(Figure 42). Tourism to the Caribbean is in high demand during the winter months and low in the summermonths. November and December experienced a significant increase of the traffic from United States and Europe to the Caribbean. Bermuda is a popular tourist destination and there is heavy traffic from

U.S. ports and the eastern Atlantic except in the winter months.

While the tanker traffic spreads over the SS AOI, there are very high concentrations of traffic toward Florida and likely the Gulf of Mexico (Figure 43). There is no obvious seasonality in tanker traffic, althoughwe did note somewhat more traffic during winter months when compared to the summer.

To better understand the seasonality of the traffic patterns, the monthly vessel occupancy time (the cumulative time that the vessels spent within the study area, per day of the month, in hours) were plotted over three years (2019-2021) for each vessel type (cargo, fishing, passenger and tanker) as wellas all vessel types combined (Figure 44). The fishing vessels in these plots were those in transit, excluding the time when fishing vessels were conducting fishing activities.

When aggregated, the traffic volume in the study area did not show significant seasonality, particularly in 2019 where the vessel occupancy time was between

TABLE 6. Dataset sources used in the Human Use section.

Dataset	Citation	Data Used	Access
GFW AIS data	NA	Raw AIS data forshipping summarizations	Not publicy available
GFW AIS Data	Copyright 2016-2023, Global Fishing Watch, Inc., www.globalfishingwatch.org.	Apparent fishing effort spatial data	https://globalfishingwatch.org/datasetsand-code/
ICCAT Effort Data	https://www.iccat.int/en/index.asp	Reported fishing effort	https://www.iccat.int/en/accesingdb.html
Plastics Dataset	Isobe A, Azuma T, Cordova MR, Cózar A, Galgani F, Hagita R, Kanhai LD, Imai K, Iwasaki S, Kako S, Kozlovskii N, Lusher AL, Mason SA, Michida Y, Mituhasi T, Morii Y, Mukai T, Popova A, Shimizu K, Tokai T, Uchida K, Yagi M, Zhang W (2021) A multilevel dataset of microplastic abundance in the world's upper ocean and the Laurentian Great Lakes. Microplastics and Nanoplastics 1:16.	Particle count and weight monthly gridded data	https://microplastics.springeropen.com/articles/10.1186/s43591-021-00013- z#Sec2
Extended continental shelf submissions	http://www.continentalshelf.org/onestopdatashop.aspx	Extended continental shelf submission polygons	http://continentalshelf.org/onestopdatashop/6350.aspx
International Seabed Authority deep sea mining lease blocks	https://www.isa.org.jm/minerals/exploration-areas	Deep Seabed Mining Lease Block Polygons	https://www.isa.org.jm/minerals/maps
Cable Schematics	https://www.cablemap.info/	Rough cable schematic	https://koordinates.com/layer/3722-undersea-telecommunication-cables/
Climate Modeling Data (CMIP6)	Eyring V, Bony S, Meehl GA, Senior CA, Stevens B, Stouffer RJ, Taylor KE (2016) Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geoscientific Model Development 9:1937–1958.	Sea Surface Temperature	https://esgf- node.llnl.gov/projects/cmip6/
Global Dataset on Introduced Species	Costello M, Dekeyzer S, Galil B, Hutchings P, Katsanevakis S, Pagad S, Robinson T, Turon X, Vandepitte L, Vanhoorne B, Verfaille K, Willan R, Rius M schematic (2021) Introducing the World Register of Introduced Marine Species (WRiMS). Manag Biol Invasions 12:792–811.	Introduced species	see publication details
Ship Strike Summarizations	Winkler C, Panigada S, Murphy S, Ritter F (2020) Global numbers of ship strikes: an assessment of collisions between vessels and cetaceans using available data in the IWC ship strike database. SC/68B/HIM/09 Ref1. International Whaling Commission Scientific Committee.	IWC ship strike data summarized by FAO region	see publication details
Shiping Lane Noise Emissions	Jalkanen J-P, Johansson L, Andersson MH, Majamäki E, Sigray P (2022) Underwater noise emissions from ships during 2014–2020. Environ Pollut 311:119766.	Spatial data for noise output energy from shipping activity	see publication details
Northwest Atlantic Fisheries Organization Effort Data	https://www.nafo.int/	Effort data for the NAFO subareas	https://www.nafo.int/Data

15,000 and 17,000 hours / day (Figure 44, top left pane) throughout the year, with the exception of May, which recorded a slightly increased vessel time of over 18,000 hours / day. As previously mentioned, 2020 and 2021 had lower vessel occupancy time than 2019. Cargo vessels contributed the most to the traffic in the study area and showed higher traffic from January through May versus the rest of the year (Figure 44, top middle pane). Transiting fishing vessels showed the most pronounced seasonality, with a large spike in occupancy time during the period from May-August (Figure 44, top right pane). Occupancy patterns for passenger vessels were more complex.

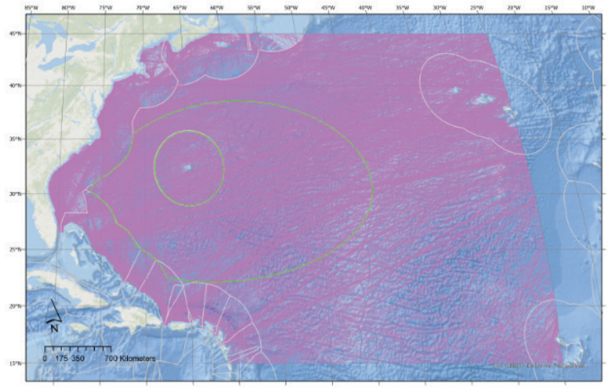


FIGURE 37. **Example of segmented vessel tracks within the study area in January 2019.**

Given that 2019 was the pre-pandemic year, traffic dynamics in 2019 may represent typical trends, with lower occupancy time in the summer (Figure 44, lower left pane) which corresponds to the off season for tourism. Similar to cargo traffic, tanker traffic was slightly higher in the first half of the year than the second half. Overall, 2019 (pre-pandemic) had a larger vessel occupancy time than 2020 and 2021 with the exception of January - March 2020, where the traffic was equal to or more than 2019 (Figure 44, lower middle pane).

Several heavy traffic routes passing through the middle of the SS study area as well as along the U.S. coasts and can be consistently identified across all three sample years (Figure 45) and are mostly occupied by cargo vessels. Using vessel identification numbers and matching them with GFW's vessel database, it is possible to find out

TABLE 7 **Products from GFW AIS data**

Product	Type	Count
Locations of monthly AIS messages within a rectangular area encompassing the study area	Point	36 (12 / year x 3 years)
Vessel tracks connecting AIS messages per month	Line	36 (12 / year x 3 years)
Monthly segmented vessel tracks within the study area	Line	36 (12 / year x 3 years)
Monthly statistical summaries of vessel tracks per 10 km x 10km grid cell of the study area	Polygon	36 (12 / year x 3 years)
Monthly summary tables associated with the polygon summaries, split by vessel type	Table	216 (6 vessel types x 12 / year x 3 years)
Weekly statistical summaries of vessel tracks per grid cell of the study area	Polygon	153 (12 / year x 3 years)
Weekly summary tables associated with the polygon summaries	Table	153 (12 / year x 3 years)
Monthly statistical summaries of vessel tracks over three years per vessel type and grid cell of the study area	Polygon	72 (6 vessel types x 12 months)
Annual statistical summaries of vessel tracks per vessel type and grid cell of the study area	Polygon	18 (6 vessel types / year x 3 years)

TABLE 8. **Vessel traffic animations**

Animation theme	Length	Count
Hourly vessel movements for one month	15 s	36
Hourly vessel movements for three months	45 s	12
Year-round 8-hour vessel movements	2 m 8 s	3
Monthly (12 months) heatmap changes	15 s	36
Weekly (51 weeks) heatmap changes	15 s	3

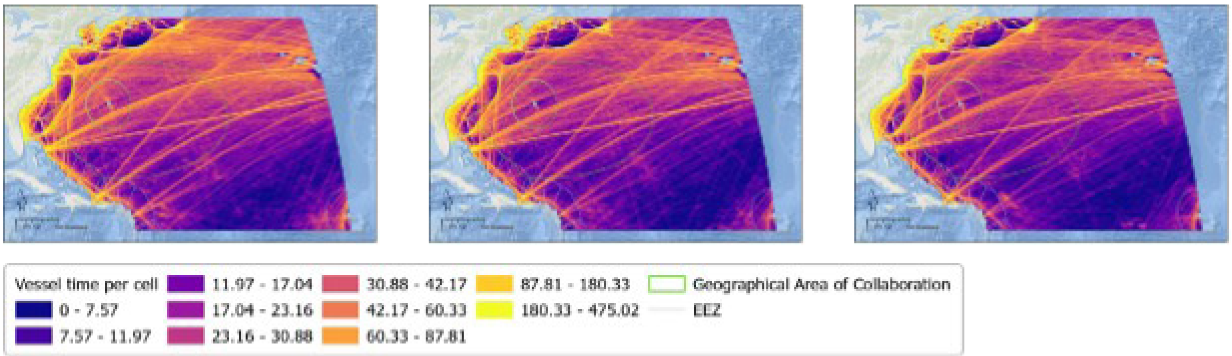


FIGURE 38. Annual summary of vessel traffic (vessel time in hours) in 2019 (left), 2020 (center) and 2021 (right).

FIGURE 39. Traffic changes in June between 2019 and 2020 for all vessel types (left), cargo (center) and passenger (right).

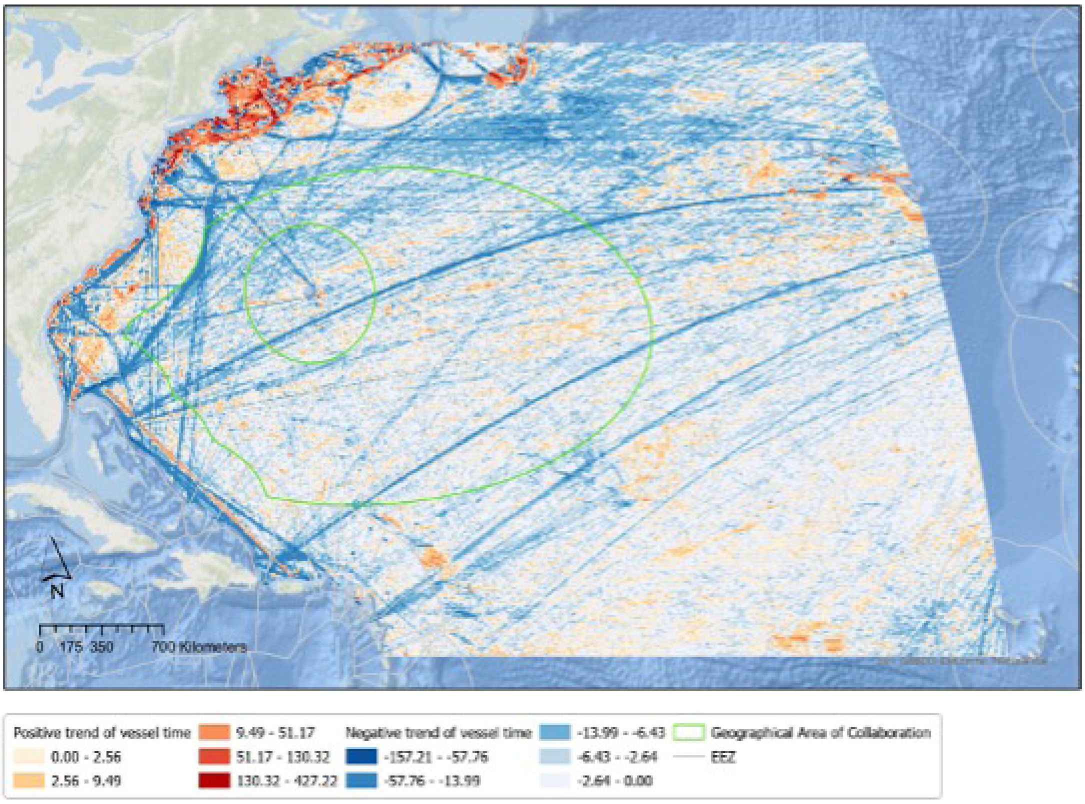


FIGURE 40. Comparison of vessel time in hours between 2019 and 2021.

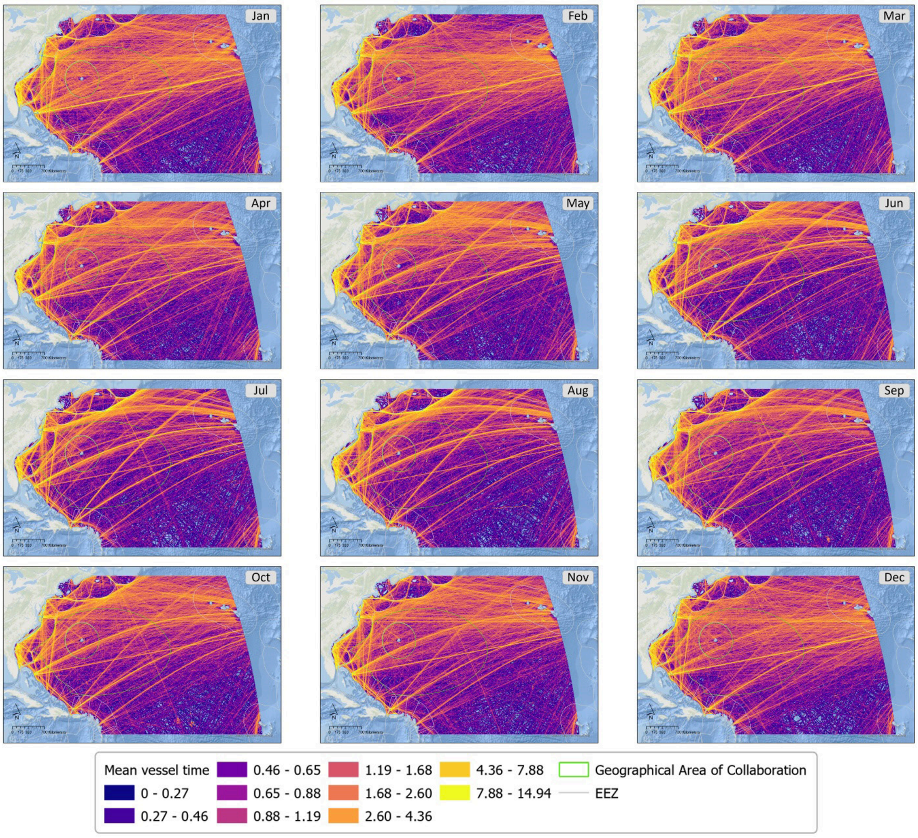


FIGURE 41. Monthly average of cargo vessel time in hours over three years.

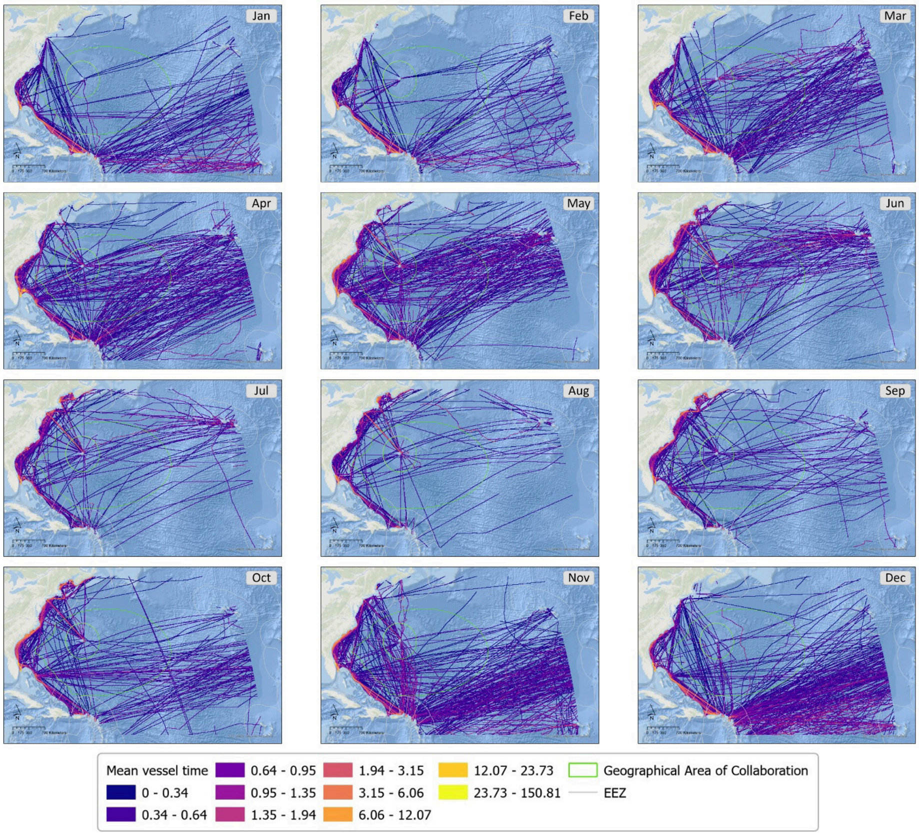


FIGURE 42. Monthly average of passenger vessel time in hours over three years.

the departing and destination ports of the vessels that pass or cross these shipping lanes. Major departing and destination countries / territories of these vessels include United States, United Kingdom, Panama, Netherlands, Spain, Gibraltar, and Egypt. There is not a significant seasonality of the traffic, but traffic appears to decrease slightly between August-October (Figure 46).

With the presence of these prominent vessel traffic lanes through the center of the SS, it's important to consider how the characteristics of vessel traffic might contribute to potential environmental impacts. For example, noise pollution associated with vessels degrades the soundscape of the underwater environment, negatively impacting marine mammal communities' ability to communicate, forage and perform other essential functions associated with the ability to both perceive and emit noise underwater (Putland et al. 2018; Salazar et al. 2019). Furthermore, physical interaction with ships, otherwise known as ship strikes, often result in significant injury or death for marine mammals' (Berman-Kowalewski et al. 2010) (for more information on the ecological impacts of maritime vessel activity, see the Impacts of Shipping section). Both noise pollution and ship strikes are directly related to vessel load as well as the speed at which they travel (Vanderlaan and Taggart 2006; Hildebrand 2009).

Therefore, elucidating information about these two metrics helps to provide insight into potential methods for managing the frequency and magnitude of these outcomes (Rockwood et al. 2017).

Figure 47 shows the distribution of mean vessel speed (left) and tonnage (right) of cargo vessels transiting the GAC broken down by year. The speed and tonnage of the cargo vessels summarized as an annual mean was around 14 knots and 44,000 tons, respectively, for three years (Figure 47). The speed at which vessels appear to transit the SS is approaching that which has been shown to cause significant damage to marine mammals in the event of a ship strike, with speeds above 15 knots likely resulting in death for the animal (Vanderlaan and Taggart 2006). Although results from our analysis indicate that mean vessel tonnage has decreased over the study period, studies show that the global cargo vessel fleet today is significantly larger than 20 years ago (UNCAD 2020) and that commercial shipping activity is projected to continue increasing in the coming years (Kaplan and Solomon 2016). It is therefore important to continue monitoring vessel traffic to understand how these predictions reflect trends seen in shipping activity in and around

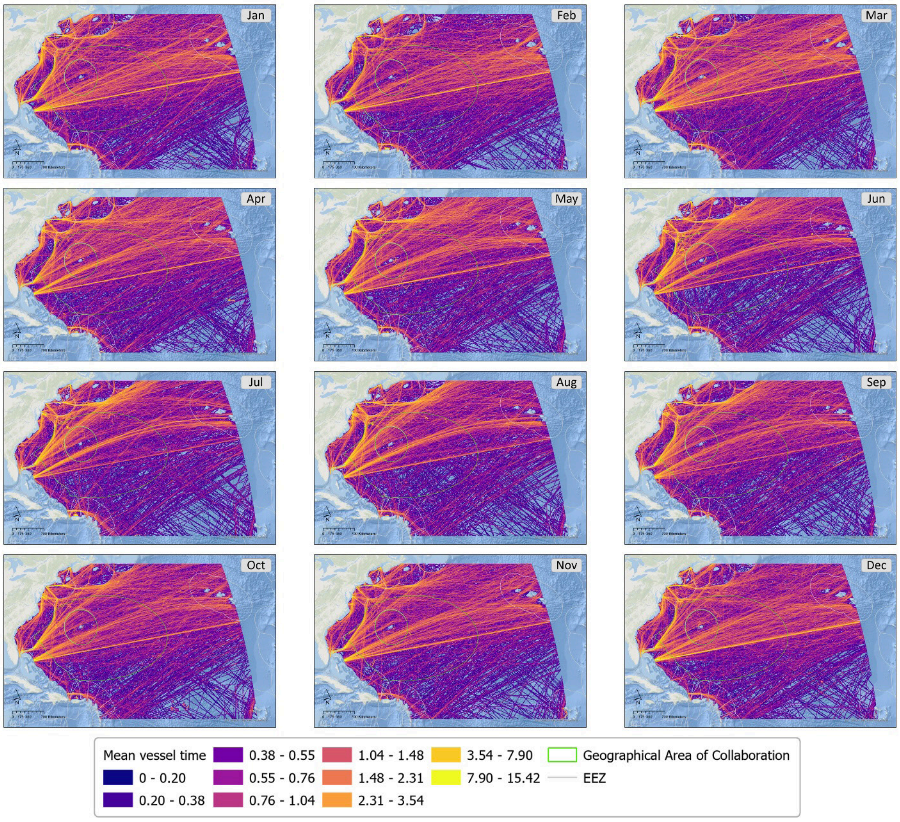


FIGURE 43. **Monthly average of tanker vessel time in hours over three years.**

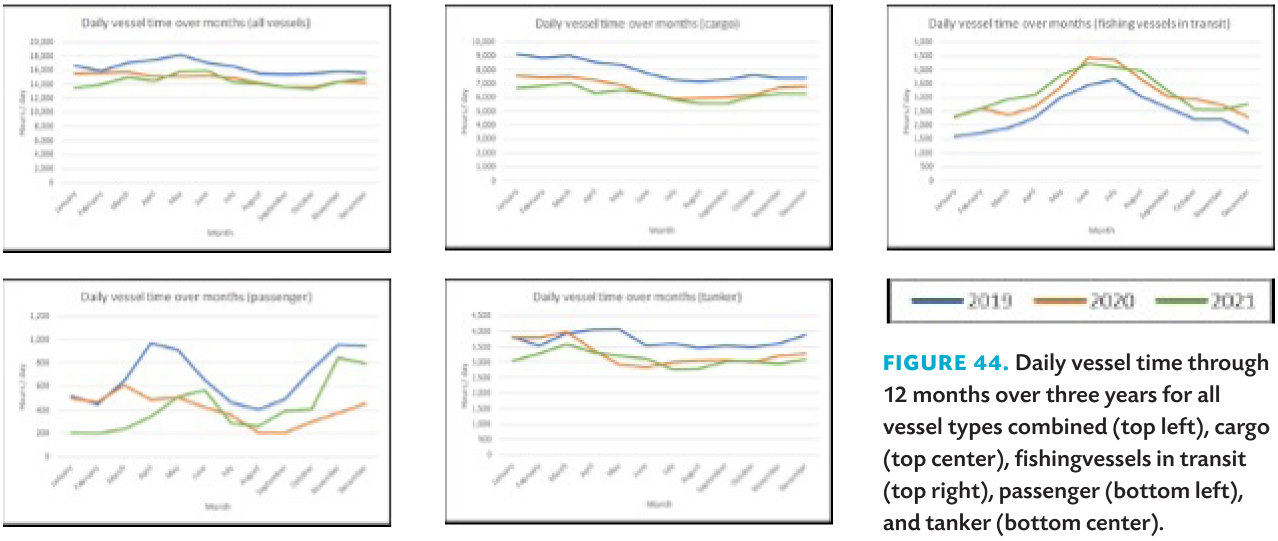


FIGURE 44. **Daily vessel time through 12 months over three years for all vessel types combined (top left), cargo (top center), fishingvessels in transit (top right), passenger (bottom left), and tanker (bottom center).**

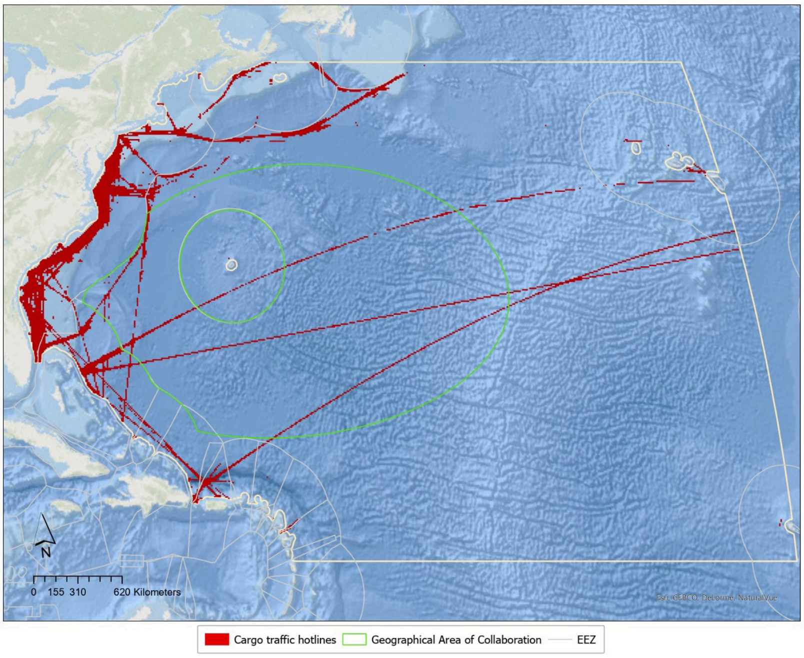


FIGURE 45. **Cargo vessel heavy shipping lanes in the SS AOI.**

the SS, and to assess implications for the impacts of the shipping sector on the SS ecosystem. Additionally, further investigation is needed to determine if this decrease in mean tonnage was a potential result of reduced traffic during the COVID-19 pandemic.

Impacts of Shipping

There are various ecological impacts associated with maritime traffic which can be categorized into two primary groups including (1) pollution and (2) physical harm and disturbance (Roberts 2011). The former encompasses both operational pollutant discharge, such as sewage and ballast water, as well as accidental pollutant discharge, such as oil spills. The latter includes disturbance from underwater noise and direct interaction between animals and ships (known as ship strikes) or ships and the ecosystem.

The impacts of operational discharge are multifaceted, with practices such as ballast discharge and waste disposal at sea common in the commercial shipping industry (Roberts 2011). The disposal of garbage and sewage at sea are not closely monitored, with data outlining the frequency and distribution of these practices on the High Seas depending largely on reporting. Generally, there is a dearth of data outlining the concentration, distribution, and composition of refuse in High Seas areas (see Gaps Analysis), making it difficult to understand the contribution of the commercial shipping industry. Ballast water discharge is widely considered one of the primary vectors for the spread of introduced and invasive species (Bailey 2015). It is estimated that, globally, 3500 million tons of ballast water (and associated biota including microbes, benthos, phytoplankton, zooplankton, and fish) are transferred annually by merchant shipping (Endresen et al. 2004). Although ballast water is one of the best studied vectors of aquatic invasive species related to maritime traffic, creating direct linkages to the presence of non-native and

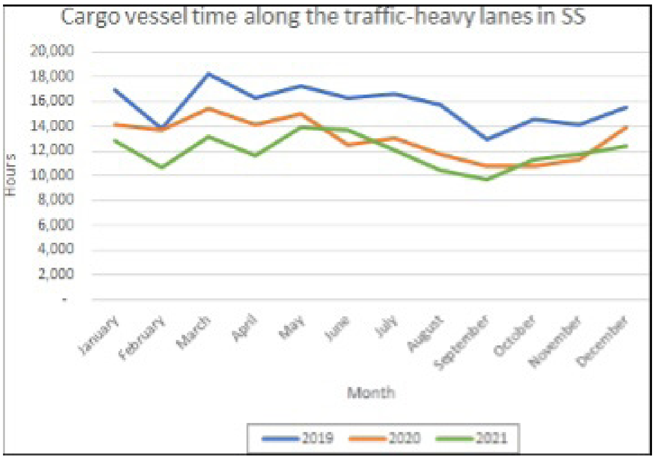


FIGURE 46. Monthly vessel time in hours of cargo vessels that followed or crossed the main shipping lanes within SS over three years(2019 - 2021).

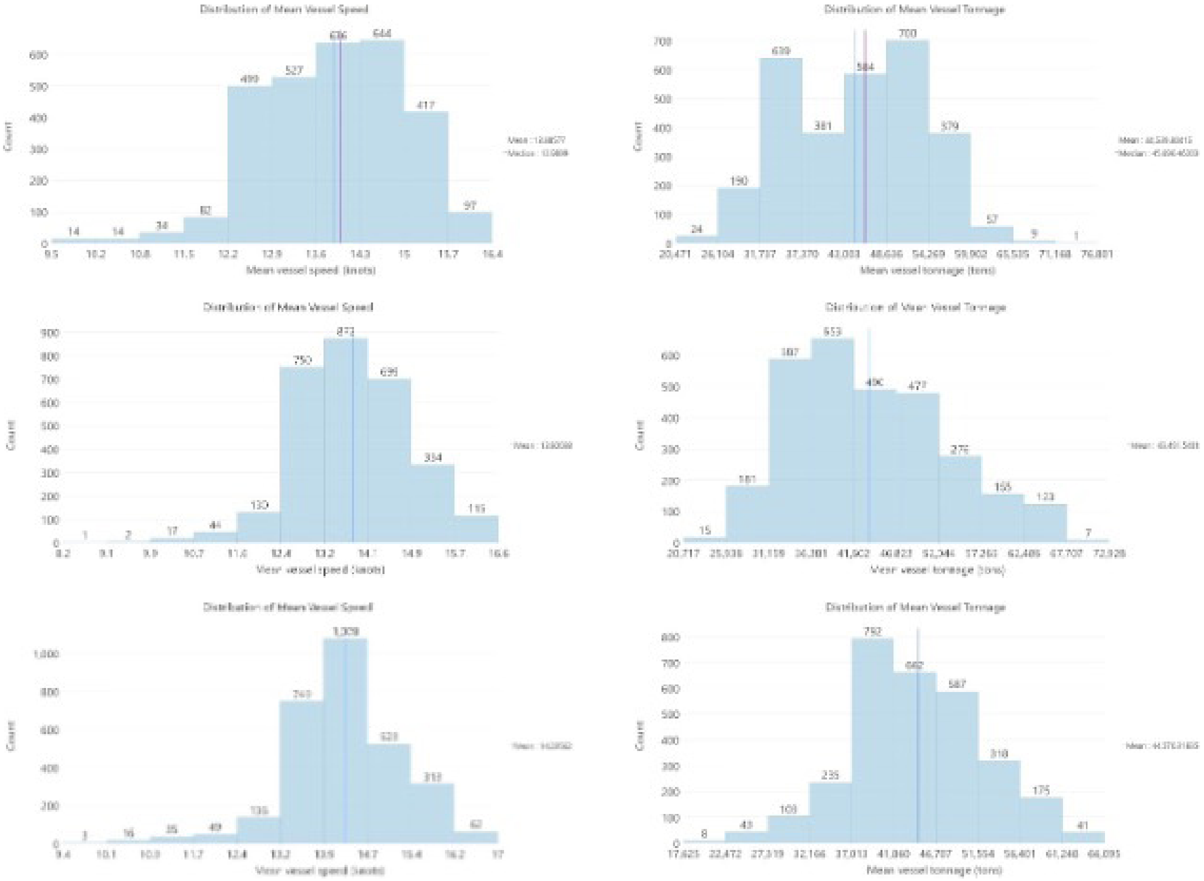


FIGURE 47. Distribution of the mean of cargo vessel speed (knots; left) and tonnage (tons; right) in 2019 (top), 2020 (middle) and 2021 (bottom).

invasive species with specific ballast discharge behaviors is challenging due to a dearth of reporting data on ballast discharge events. Figure 1 from Costello et al. 2021 (Figure 48) shows the numberof introduced and invasive species globally based on reports compiled in the World Register of Introduced Marine Species (https://marinespecies.org/introduced/). Although this schematic does not specify spatial distribution of these species, it highlights the greater concentration of introduced species present in the North Atlantic, which is likely related to the presence of several principal vessel traffic routes, and adjacent large ports, in the SS region.

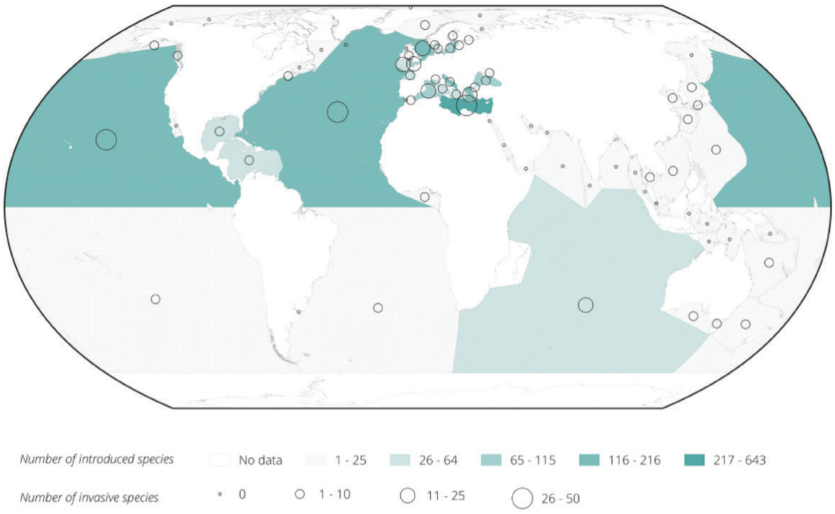


FIGURE 48. Introduced and invasive species presence globally. [Figure 1 from Costello et al. 2021 Original caption: Map indicating the numbers of Introduced and Invasive species in seas as reported in the WorldRegister of Introduced Marine Species.]

Although the principal source of shipping pollution is routine operational discharge, which can compriseof oil, chemicals, and polycyclic aromatic hydrocarbons (PAHs; Roberts 2011), illicit and accidental discharge of contaminants continues to occur on the High Seas. Bilge dumping entails the disposal of contaminated bilgewater by large vessels out at sea as a way to circumnavigate guidelines on treatment and disposal. Bilge dumping events can be detected using satellite imagery (Huang et al. 2022; Appendix 1, Figure 3), and Sky Truth's Project Cerulean (https://skytruth.org/Cerulean/) is in the process of developing an online mapping resource for oil slick and bilge dumping detection. Although this resourcewill provide invaluable information about the distribution and scope of oil contamination events, this methodology is still limited by the coverage of the remote sensed imagery it uses for detection (see the Gaps Analysis section). This resource will also help to detect larger contamination events, such as tankerspills. Data on spill events in national waters are commonly recorded and catalogued by government entities (see the Gaps Analysis section; Appendix 1, Figure 4), but spatial and compositional data on spill events in the High Seas are limited. While the International Tanker Owners Pollution Federation (ITOPF)collects and compiles these data, the organization does not provide direct access to this database (https://www.itopf.org/knowledge-resources/data-statistics/statistics/).

The other environmental impact category associated with vessel traffic includes physical harm and disturbance to the surrounding ecosystem which primarily involves ship strikes, noise pollution, and damage to the physical environment. Large whales are particularly vulnerable to ship strikes (Laist et al. 2001) and the North Atlantic has some of the highest recorded rates of interactions between whales and vessel traffic globally (Winkler et al. 2020). Many species native to the SS and adjacent region, such as humpback whales and North Atlantic right whales (*Eubalaena glacialis*), are commonly impacted by interactions with vessels of all types and size classes (Jensen and Silber 2003; Brown et al. 2019; Knowlton and Krauss, 2020). Figure 49 shows ship strike reports from the International Whaling Commission (IWC; www.iwc.int/ship-strikes) strike database, which includes information derived from publicly available evidence, including peer-reviewed research articles, scientific and technical reports, online newspaper articles and videos, social media platforms, IWC National Progress Reports, as well as direct witness reports (IWC 2014). Here, we have adapted a summarization of these data by Food and Agriculture Organization (FAO) Major Fishing Area, originally performed by Winkler et al. (2020), and included an overlay of the various SS study boundaries. While IWC database may be the most extensive compilation of ship strike data world-wide, it is by no means complete. Underreporting remains the central barrier to creating a comprehensive record of ship strikes globally and future efforts to understand physical interactions between cetaceans, as well as other impacted species, will depend on improved reporting.

Noise pollution impacts many vocalizing marine species, impeding their ability to communicate during key life stages, sometimes having chronic and long-term impacts for certain populations (Putland et al. 2018). Commercial shipping activity contributes significantly to underwater noise and the propulsion systems of commercial ships are a dominant source of low frequency radiated underwater noise (Hildebrand 2009). Figure 50 summarizes study by Jalkanen at al. (2022) showing the underwater noise attributed to maritime vessel traffic. Data was generated for three, one-third octave bands with central frequencies of 63, 125 and 2000 Hz, which were chosen for their significance among various biological communities (Jalkanen et al. 2022). Figure 50 notably shows the highest output of noise occurs at the lowest frequency (63 Hz) out of all three bands, with outputs for 125 and 200Hz reflecting similar spatial patterns but overall lower emissions.

Finally, maritime traffic can inflict physical damage on the surrounding environment by running aground, anchor deployment, or interaction with ship propellers, for example. Of primary concern in the SS region is the effect of ship disturbance on *Sargassum* mats. Given the critical role that the structure of these mats plays in the SS ecosystem, there is a need to form a better understanding of how ship propellers and disturbance associated with ship transiting could compromise the structure of the *Sargassum* aggregations. As described above, there are methodologies for detecting *Sargassum* aggregations, as well as determining vessel transit activity. Although methodologies exist for detecting *Sargassum* aggregations and assessing vessel transit behavior (see above), even down to the individual vessel track, no methodology exists to connect these to better understand the impact of the latter on the former.

With several high concentration vessel lanes transiting the SS region, connecting major U.S. ports to the eastern Atlantic and the Caribbean, maritime traffic activity is a concern in the spatial management and conservation of this feature. These heavy traffic routes pass through the core of the SS study area and are temporally consistent in their spatial location. Breakdown of vessel traffic throughout the SS shows that passenger, cargo, tanker, and fishing vessels all show a degree of seasonality in transit hours throughout the year, with the most pronounced trends appearing in fishing and passenger vessel categories. Vessel speed and tonnage are two important metrics to consider when assessing the vessel traffic that transits the SS, with broader implications for the magnitude of impact that this sector has on the surrounding environment. These impacts range from direct physical harm and disturbance resulting from interactions with ships, to indirect harm attributed to exposure to pollutants associated with vesseloperation. Although pollution, both operational and incidental, from vessel activity is difficult to pinpoint and lacks robust spatial data, physical harm resulting from vessel activity can be more easily linked to traffic patterns in the SS region. While there are still improvements to be made in ship strike reporting, noise energy resulting from maritime traffic can be spatially modeled and the output of various frequencies significant to different biological communities present a potential starting point for understanding areas of particular concern that should be addressed by management initiatives.

Fishing

Independent Fishing Effort Data

Industrial fishing effort can be monitored by satellite from vessel AIS signals. In addition to assessing theamount of shipping traffic in the SS, we used Global Fishing Watch (GFW) apparent fishing effort data (Kroodsma et al. 2018) as derived from AIS tracking, to summarize fishing effort in the study area. Like the shipping summarizations, we limited the data summarized for fishing effort to 2017 through 2020 based on data availability and coverage. The apparent fishing data was summarized into annual effort for each year, as well as an average monthly effort from 2017-2020. These summaries were done for all fishing gears and longline fishing vessels.

Generally, fishing effort for all gear types in the SS was somewhat limited and did not exceed 50 hours of effort for a given 10kmx10km cell in any of the included study years (Figure 51). Much of the effort was concentrated in the northeast portion of the Sargasso Sea, though fishing effort in that region was mainly clustered in an area outside of the GAC. When longline fishing effort was extracted for this region, it was clear this is the main type of fishing gear used in the SS, as the same trends were seen inthe longline effort for this region (Figure 52).

When looking at the total monthly fishing effort from 2017-2020, vessels with flags for the United States, Canada, and Spain had the greatest effort for all gear types (Figure 53). When the monthly effort was subset to drifting longlines, the countries with consistently high

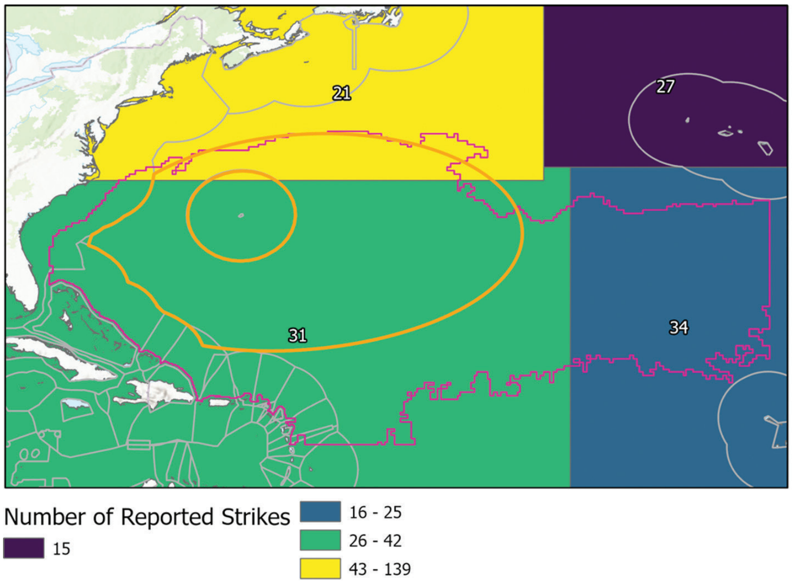


FIGURE 49. **Ship strikes to cetaceans summarized by FAO fishing area per Winkler et al. 2020.**

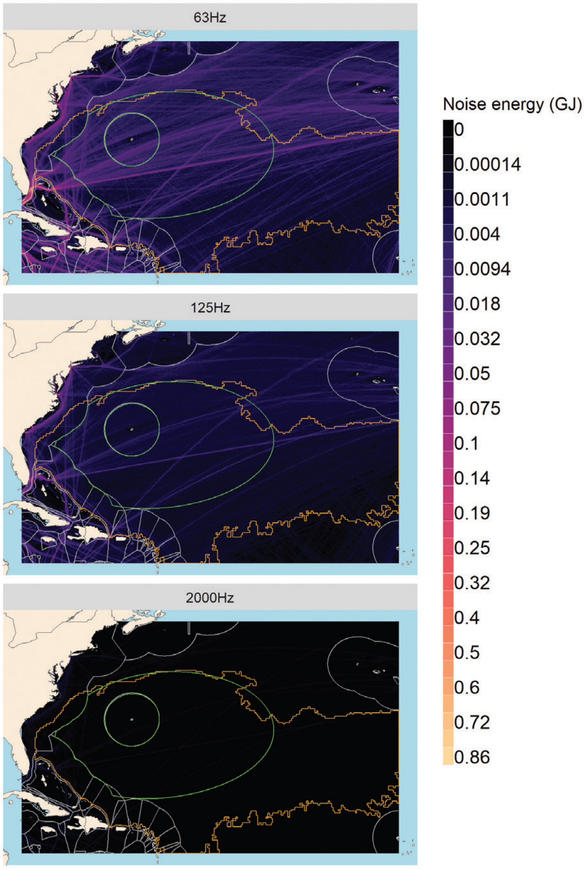


FIGURE 50. **Underwater noise attributed to maritime vessel traffic at different frequencies.**

effort were Spain, Portugal, and Taiwan. Taiwanese vessels had much higher effort for all years in the months of January to August, suggesting seasonal trends in their effort. China and Japan also had high monthly longline effort; however these were largely concentrated outside of the GAC.

Within the GAC, results were similar to those shown in Figure 53. The monthly effort for all gear types and drifting longlines were virtually the same owing to the fact that drifting longline was the main gear typedeployed (Figure 54). For all four years, the effort was higher in the first half of the year and decreased drastically in the second half of the year.

For all gear types, there was a drastic difference in fishing effort within and outside of the GAC (Figure 55). The average monthly fishing effort peaked in February at roughly 5,000 hours of effort, while the average monthly fishing effort for that same month outside the GAC was nearly 30,000 more hours. For the area outside the GAC, the peak was in July, with lower effort from November to March. The opposite was true for the GAC, where the highest effort occurred from January to June and declined from July to December. Much of the effort outside of the GAC occurred within EEZs, specifically those of the United States and Canada. The average monthly effort within EEZs for the entire SS region was muchhigher than effort occurring in Areas Beyond National Jurisdiction (ABNJ; Figure 56). Similar to average monthly effort outside of the GAC, the effort in EEZs peaked in July and was consistently higher than effort in ABNJ. There was more variability for monthly effort in ABNJ than there was within the GAC, suggesting there are seasonal trends influencing fishing effort within the GAC that may not be

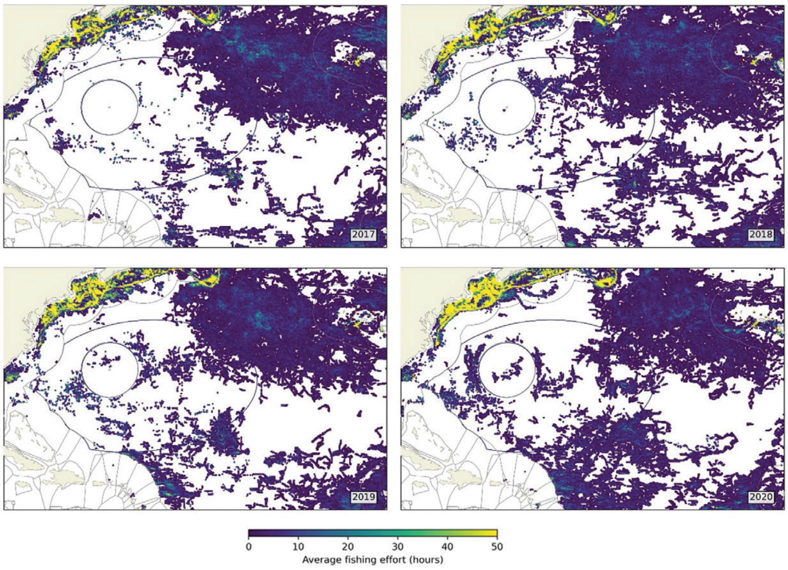


FIGURE 51. Total annual fishing effort for 2017-2020 using GFW AIS data.

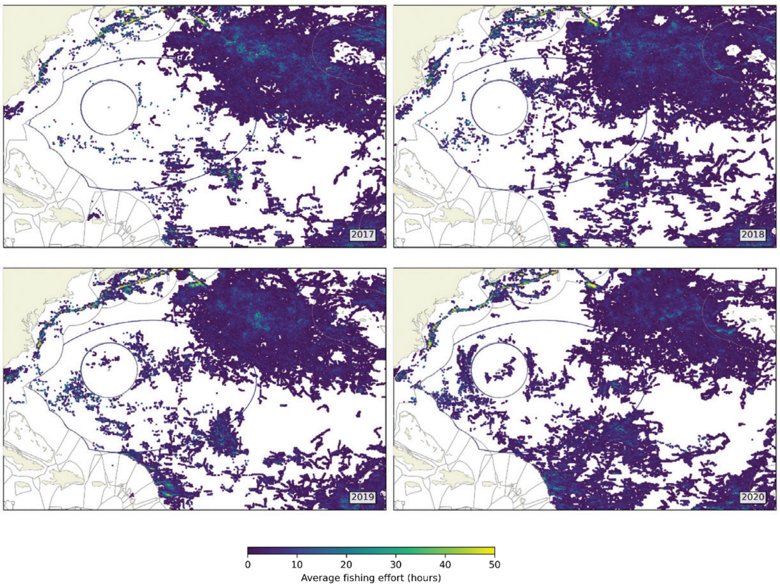


FIGURE 52. Total annual longline fishing effort for 2017-2020 using GFW AIS data.

factors forthe wider region.

The six vessel flag countries that mainly concentrate fishing effort within or near the SS are China, Spain, Korea, Portugal, Taiwan, and St. Vincent. Spain and Portugal fishing effort in 2020 was concentrated in the northeast portion of the SS, while Korea, Taiwan, and St. Vincent were distributed in the central and western SS. Chinese fishing effort during 2020 occurred in the western region and the southeast region of the SS (Figure 57).

The average monthly fishing effort for all gear types (Figure 58) mainly differed from the monthly longline fishing effort (Figure 59) in areas outside of the SS, particularly the US EEZ. Monthly longline fishing effort from 2017 - 2020 showed some seasonal shifts in the location of concentrated effort. From January to March the effort was mainly located in the mid to northeast SS, then shifted northward throughout the rest of the year, occurring mainly outside the SS from June to September. From April to August, there was some longline effort in the southern portion of the SS as well. For any given month, the fishing effort for any 10 km x 10 km cell within the SS did not exceed 10 hours.

ICCAT Reported Fishing Effort and Management

The entirety of Sargasso Sea GAC and MFE fall within the boundaries of the ICCAT, one of five regional fisheries management organizations (RFMO) which are tasked with the management of tuna and tuna- like species. ICCAT was established in 1966, however, the

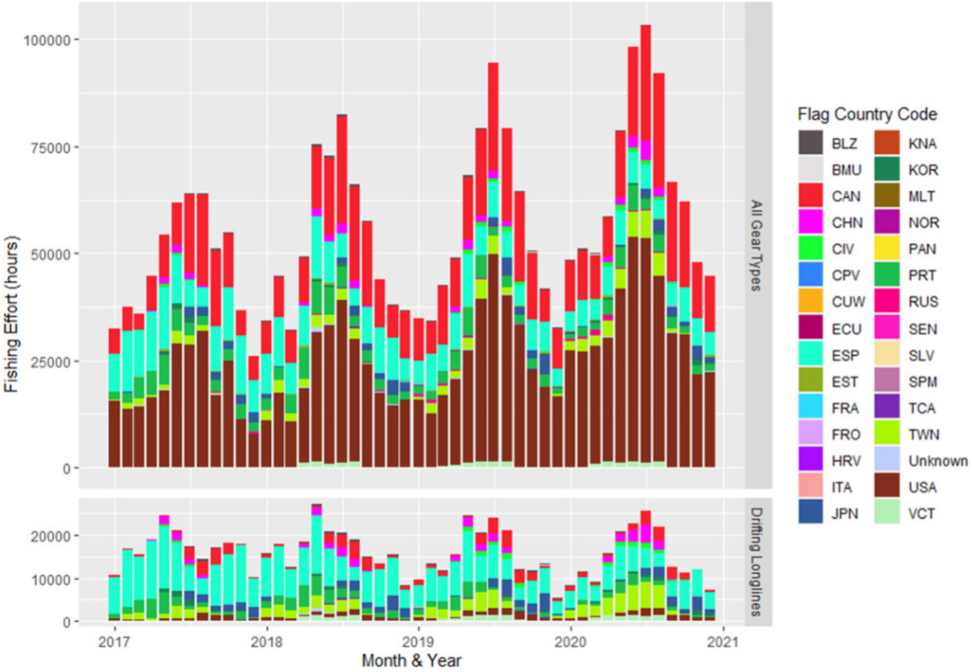


FIGURE 53. Total monthly fishing effort for 2017-2020 for all gears (top) and drifting longlines (bottom) by vessel flag using GFW AISdata. See Table 9 for country code definitions.

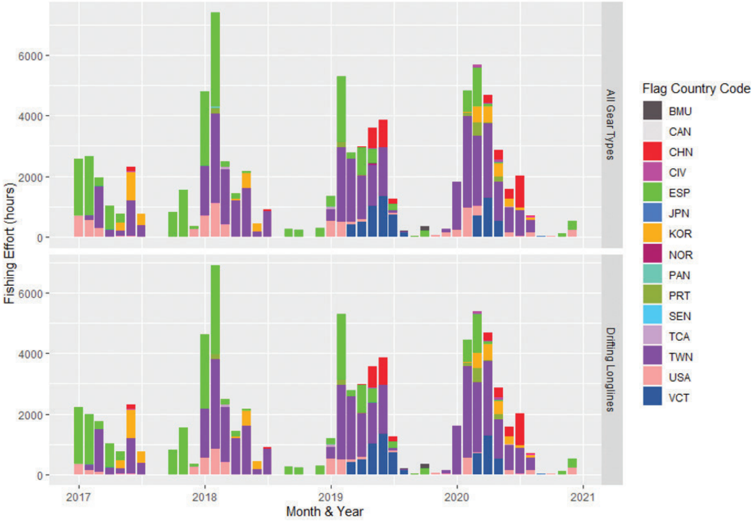


FIGURE 54. Total monthly fishing effort for 2017-2020 for all gears (top) and drifting longlines (bottom) by vessel flag for the GACusing GFW AIS data. See Table 9 for country code definitions.

fishing industry for the species now overseen by ICCAT was well established before. ICCAT has 53 contracting parties. These contracting parties are countries and regional economic integration organizations that have formally agreed to be bound by the ICCAT Convention and participate in the conservation and management of tuna and tuna-like species in the Atlantic Ocean. Of the 53 contracting parties, less than half (n = 21) have fished within the GAC historically (1956 - 2021) and only 16 have done so recently (2010 - 2021).

Since the start of ICCAT's longline time series in 1956, the importance of the MFE and GAC has been relatively low (Figure 60). Of the 16.5 billion hooks set within ICCAT's convention area between 1956 and 2021, 6.5%

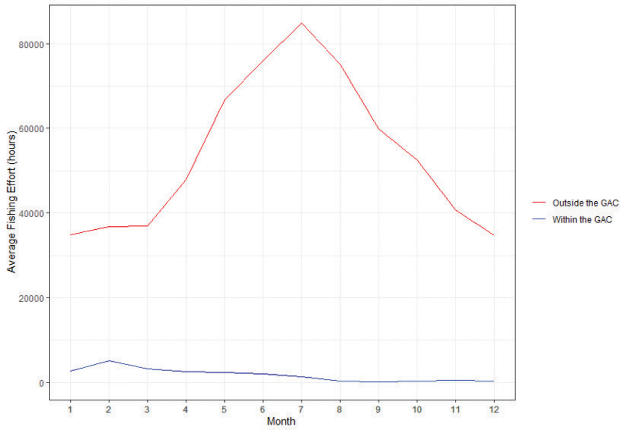


FIGURE 55. **Average monthly fishing effort from 2017-2020 for all gears within the GAC and outside of the GAC using GFW AIS data.**

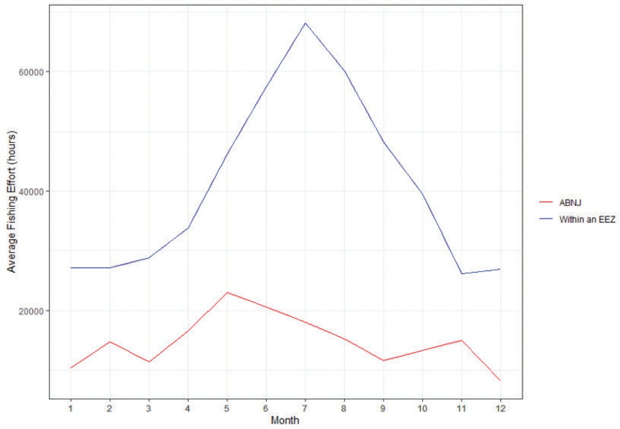


FIGURE 56. **Average monthly fishing effort from 2017-2020 for all gears within EEZs and in ABNJ using GFW AIS data.**

were set within the MFE and 3.1% within the GAC; more recently (2010 - 2021), those numbers drop to 3.9% and 1.7% respectively.

Of the total 517 million fishing hooks set by longliners within the GAC between 1956 and 2021, 60.0% of the effort can be attributed to vessels operating under the flag of Taiwan, while 23.4% were associated with Japanese vessels and 7.6% to South Korean flagged longliners. European and U.S. flagged vessels ranked fourth and fifth at 3.4% and 2% of the historic fishing effort. Contemporaneously (2010 - 2021), not only is there less reported fishing effort within the GAC, but there has also been a change in the composition of the principal fleets operating within the feature. Taiwanese-flagged vessels represented 38.7% of the total fishing effort, followed by Spanish longliners at 19.7% and vessels flagged to Belize and Trinidad and Tobago with 12.8% of longline fishing effort. Compared to the Central and South Atlantic, the presence of longliners in North Atlantic Ocean is rather moderate (Figure 61).

Of the 175 million longline fishing hooks set within ICCAT in 2021, only 1.4% were set within the GAC, 75% of which were set by Taiwan. Bycatch incidence by Taiwanese vessels in the Atlantic Ocean is not significant in the SS region but seems to be more prevalent in the fleets operating in the Central and South Atlantic, targeting bigeye tuna and albacore tuna respectively. The second and third most active fleets in the GAC during 2021 were the United States and Chinese fleets, each accounting for approximately 10% of hooks.

The ICCAT Subcommittee on Ecosystems has proposed dividing the convention area into seven ecological regions based on biogeography, oceanographic characteristics, species distributions, and fishing fleet patterns (Juan-Jordá et al. 2019). This aims to guide ecosystem planning and assessments. The Tropical Atlantic Ecoregion has a proposed Pilot Ecosystem Plan that identifies ecosystem components and pressures. The ICCAT Sub-Committee on Ecosystems has reviewed the use of ecosystem indicators, focusing on Mean Trophic Level of the catch (MTLc) as an indicator of the purse seine fishery's impact. However, cumulative impacts on the food web structure and biodiversity in the Tropical ecoregion remain poorly understood. Studies have shown the trophic preferences of tunas and their dependence on mesopelagic fishes. Skipjack plays a central role as a predator and prey species, while yellowfin and bigeye are part of different trophic levels. The ICCAT Scientific Committee is being consulted on the ecoregion proposal, and pilot studies are being developed to demonstrate the applicability of ecosystem-based advice products. The GAC and MFE are both almost completely covered by the Northern Subtropical Atlantic Ecoregion (Figure 62), one of the eight ecoregions that were delineated within the ICCAT convention area. Unlike the Tropical Atlantic Ecoregion, a Pilot Ecosystem Plan has not yet been proposed for the Northern Subtropical Atlantic Ecoregion.

NAFO Reported Fishing Effort

In the overlapping area where the northern boundary of the Sargasso Sea meets the southern boundary of the NAFO RFMO, several factors come into play (Figure 63).

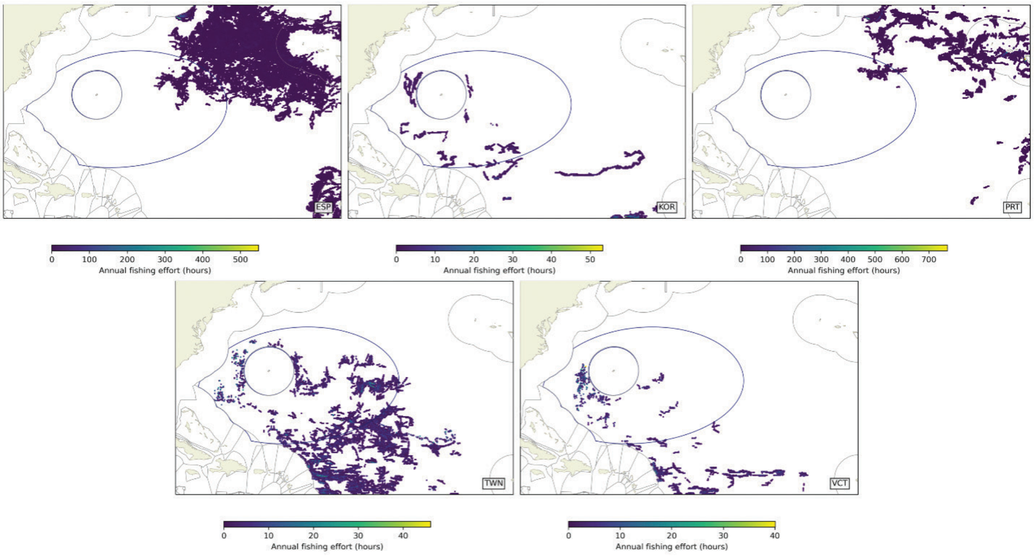


FIGURE 57. Fishing effort (hours) in 2020 by all gear types for China, Spain, Korea, Portugal, Taiwan, and St. Vincent.

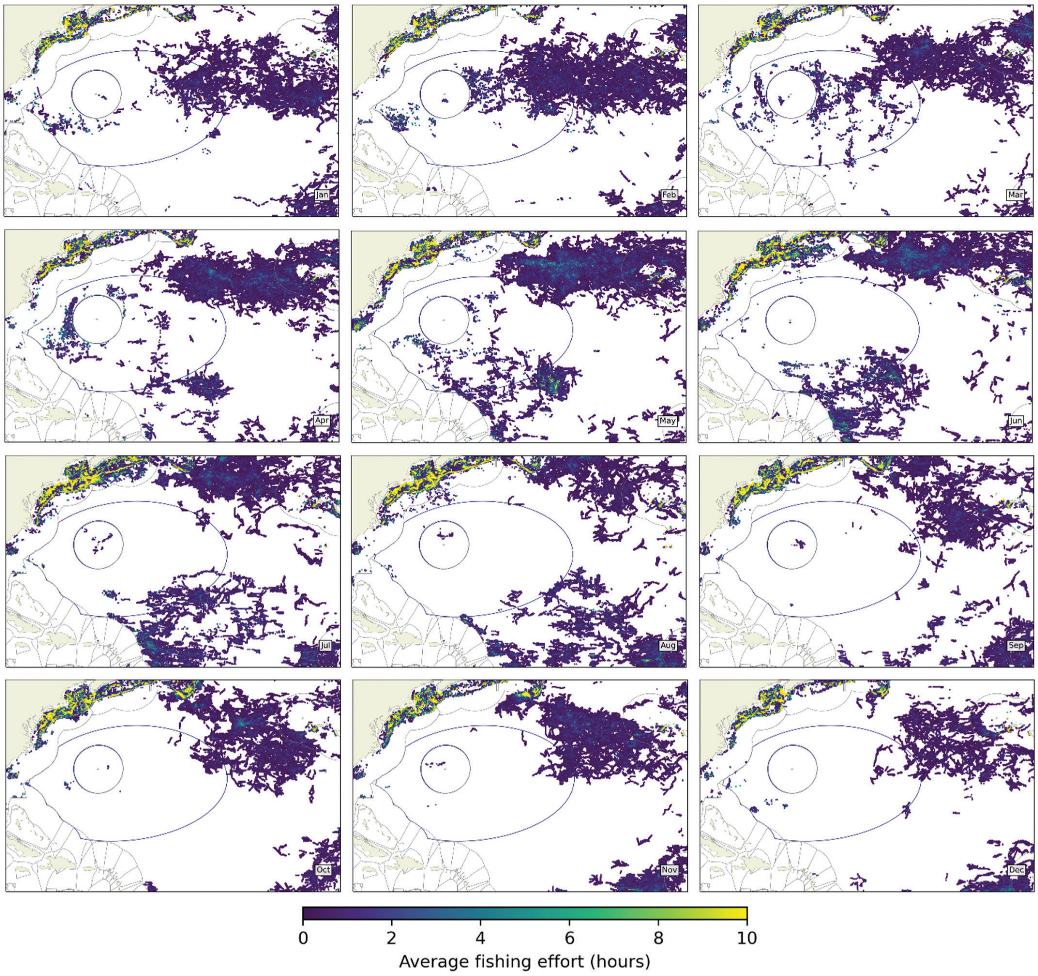


FIGURE 58. The average monthly fishing effort for all gear types from 2017-2020.

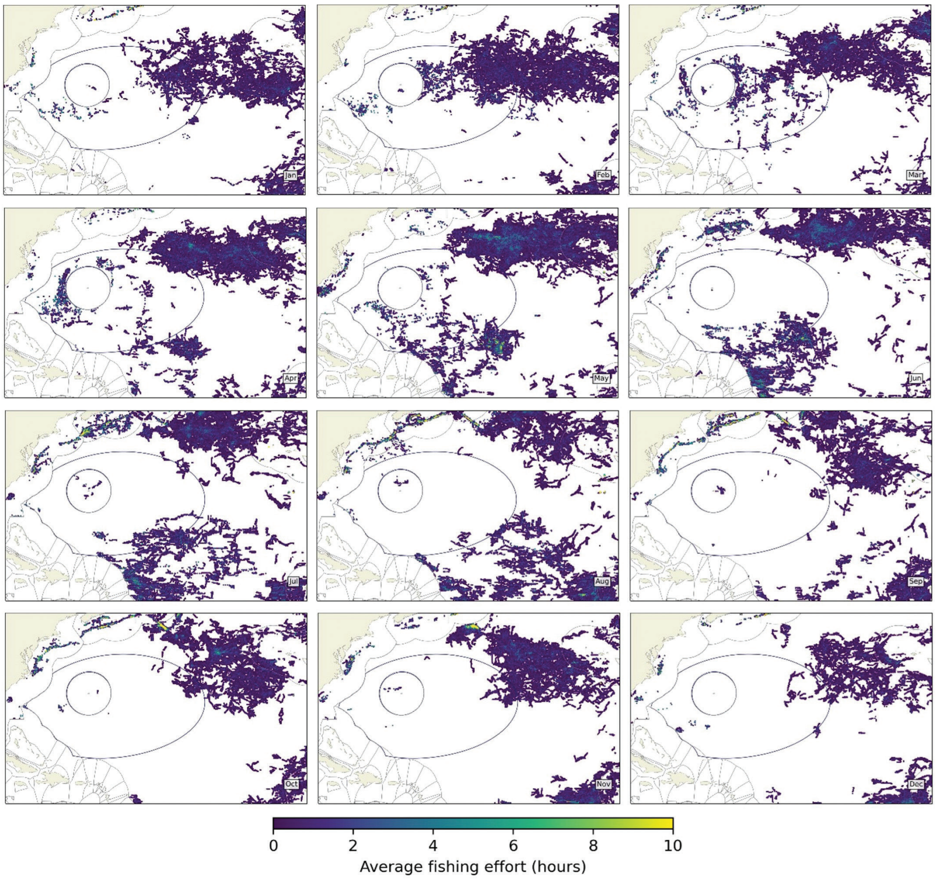


FIGURE 59. The average monthly longline fishing effort from 2017-2020.

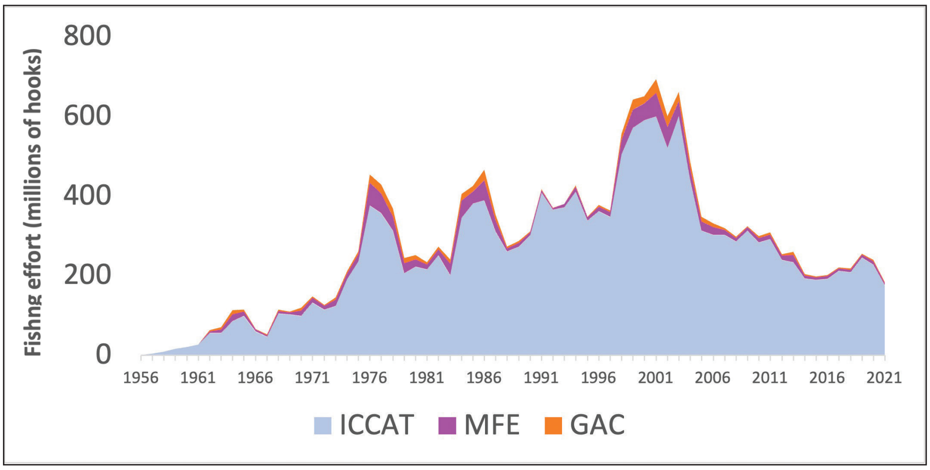


FIGURE 60. Stacked time series of longline fishing effort within ICCAT between 1956 and 2021. Blue shows the total fishing effort within ICCAT, while the pink shows fishing effort within the SS maximum feature extent (MFE) and the orange shows the fishingeffort within the geographic area of collaboration (GAC).

Notably, vulnerable marine ecosystems (VMEs) have been designated within this region, emphasizing the need for conservation measures and sustainable management practices. Furthermore, fishing activities for non-tuna fisheries take place in this overlapping area, which falls under the jurisdiction of NAFO. NAFO plays a crucial role in managing and regulating these fishing activities to ensure the protection of VMEs and the overall sustainability of the marine ecosystems in this shared region. This highlights the importance of cooperative efforts between organizations and stakeholders to maintain the health and resilience of these overlapping marine environments.

Three main fishing gears predominate in the overlapping NAFO subareas (6C, 6D, 6E, 6F, 6G, 6H): set lines, drifting longlines and bottom otter trawl (side or stern not specified). Fishing activity between 2010 - 2018 were

TABLE 9. **The flag country codes and corresponding country name.**

Flag Country Code	Flag Country
BLZ	Belize
BMU	Bermuda
CAN	Canada
CHN	China
CIV	Côte d'Ivoire
CPV	Cabo Verde
CUW	Curaçao
ECU	Ecuador
ESP	Spain
EST	Estonia
FRA	France
FRO	Faroe Islands
HRV	Croatia
ITA	Italy
JPN	Japan
KNA	Saint Kitts and Nevis
KOR	Korea
MLT	Malta
NOR	Norway
PAN	Panama
PRT	Portugal
RUS	Russia
SEN	Senegal
SLV	El Salvador
SPM	Saint Pierre and Miquelon
TCA	Turks and Caicos Islands
TWN	Taiwan
USA	United States of America
VCT	Saint Vincent and Grenadines

dominated by Spain (99.3% of catches), while Portugal accounted for 0.7% of the caught volume. The total amount of fishing during that time period added up to 22,100 hours fished, which were linked to 2,864 fishing days. Of the 18 taxa caught by the Spanish and Portuguese fleets in the overlapping NAFO subareas, 13 could be identified to the species level and are mostly large pelagic species which are not considered NAFO-managed species, these are: sailfish, white marlin, blue marlin, mahi mahi, swordfish, albacore tuna, bonito, bigeye tuna, yellowfin tuna, alfonsinos, porbeagle shark (NAFO species), shortfin mako and blue sharks. The cumulative monthly catch between 2010-2018 shows a spike in fisheries captures in the month of May (16,106 t.), which corresponds to 37.7% of the total of 42,677 tons extracted in the region (Figure 64).

Taxonomically, the catches were skewed towards five species, which together accounted for 99% of the total catch volume: blue shark (83%), swordfish (6%), shortfin mako (5%), bigeye tuna (3%) and alfonsino (2%). It is therefore reasonable to conclude that there is a well-established blue shark fishery across the northern boundary of the SS, which is dominated by the Spanish fishing fleet. Of the six NAFO subareas which overlap with the GAC and MFE, fisheries catches are concentrated in three of them: 6F (6%), 6G (23%) and 6H (71%) (Figure 65); the first two overlap significantly with the GAC and MFE boundaries, while only the western portion of the latter overlaps with the feature.

Economic connectivity of fisheries

The connectivity among the jurisdictional waters of adjacent coastal and island nations of the SS region (U.S. Atlantic coast, Bahamas and Bermuda) and the parts of the SS GAC beyond national jurisdiction canbe explored through the lens of the economic value of fished species which co-occur across jurisdictional boundaries. First, we removed OBIS and SAU records that were missing species information or not identified to the species level. Of the 2,212 unique species identified within the GAC of the SS and the 266 species identified across the three coastal and island nations in the SAU database, 98 species were found both within and beyond national jurisdiction. The landed value of the species fished within the national jurisdiction of these states which were also found in the GAC, accounted for 48.3% of the total landed value of species within national jurisdictions (Figure 53).

Not all of the species commercial fisheries interest which are found in the High Seas portion of the GAC and

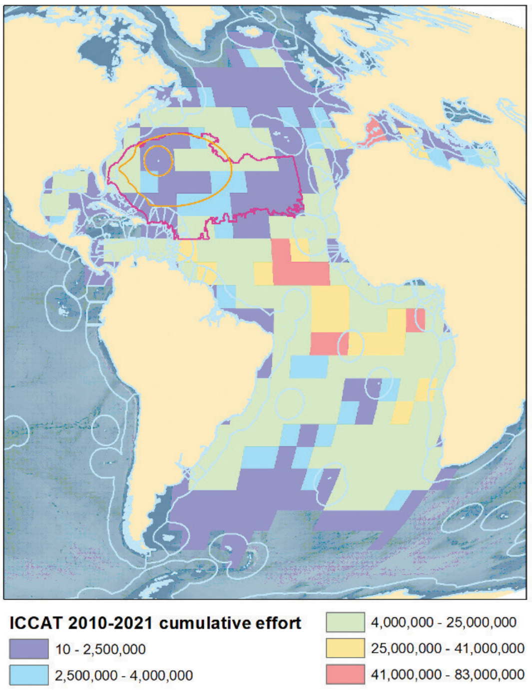


FIGURE 61. Cumulative longline fishing effort reported by contracting parties to the International Commission for the Conservation of Atlantic Tuna (ICCAT) between 2010 and 2021.

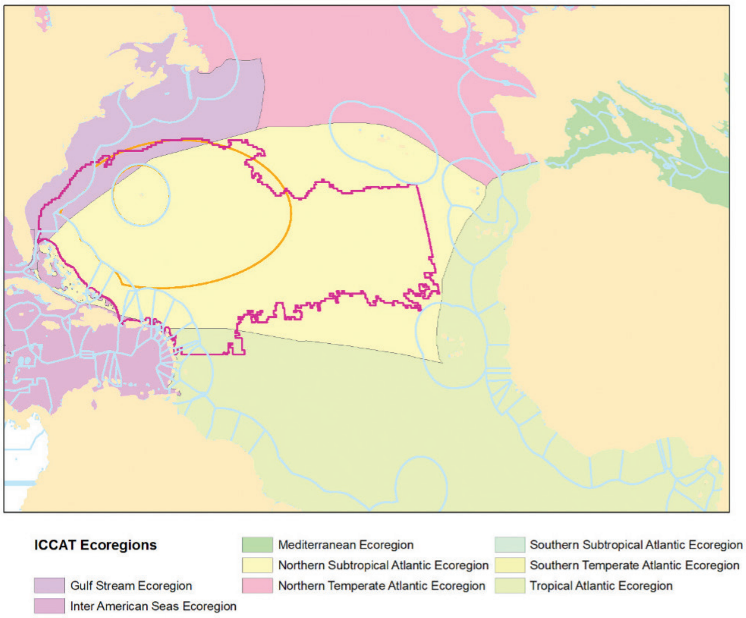


FIGURE 62. Distribution of the eight ecoregions that were developed for the International Commission for the Conservation of Atlantic Tunas (ICCAT).

within the coastal jurisdiction of adjacent coastal states are overseen by the two RFMOs which overlap with the Sargasso Sea. While the Western Central Atlantic Fishery Commission (WECAFC) is not a recognized RFMO capable or orchestrating transboundary fisheries management, its primary goals are to encourage sustainable fisheries practices, facilitate the exchange of scientific information, develop collaborative management strategies, and address common challenges faced by countries in the region regarding fishery resources. WECAFC can therefore play an important role in ensuring the sustainability and conservation of those species which are not currently overseen by NAFO nor ICCAT.

Beneficial Ownership of Fishing Vessels

Note: An in-depth analysis of beneficial ownership in the SS, which includes highly sensitive information, is ongoing and currently being prepared as a manuscript for publication. Therefore, the exact corporations and their behavior in the Sargasso Sea cannot be included in the public version of this report until the scientific paper is accepted and published. This emerging literature will include all information pertaining to beneficial ownership of the Sargasso Sea fishing fleet in the original report of this work. We included the following information on beneficial ownership to provide context to the forthcoming analysis and act as a placeholder until such time as that information becomes public.

Corporate accountability is an emerging tool for attributing responsibility for anthropogenic impacts to biodiversity from extraction and climate change contributions (Carmine et al. 2020; Lazarus, McDermid, and Jacquet 2021; Frumhoff, Heede, and Oreskes 2015). For fishing activity, corporate accountability is only possible with beneficial ownership information. Beneficial ownership, or the ultimate parent company or owner of a legal entity, is a unique data layer for fishing activity due to the ubiquitous inaccuracy of fishing vessel registries (Carmine et al. 2020; Inter-American Development Bank and Organization for Economic Cooperation and Development 2019). Often the listed owner of a fishing vessel on a vessel registry, whether it is a government vessel registry or regional fisheries management organization (RFMO) website, is a shell company obscuring the ultimate parent company owner and fishing effort

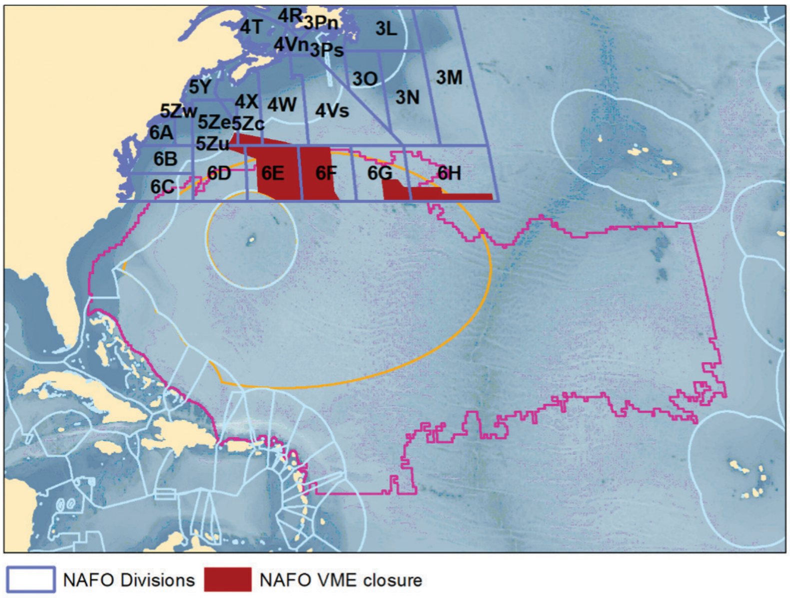


FIGURE 63. Overlap between the GAC and MFE with the southern boundary of the North Atlantic Fisheries Organization. Variousseamounts and VMEs have been closed to fishing in the overlapping area.

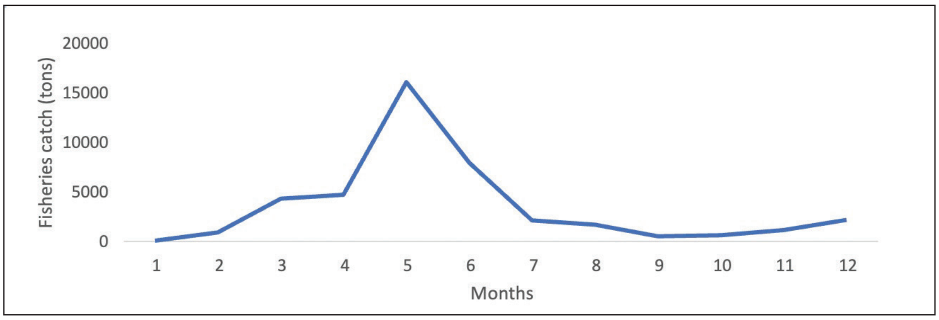


FIGURE 64. Cumulative monthly species catch within NAFO subareas 6C, 6D, 6E, 6F, 6G and 6H (2010 - 2018)

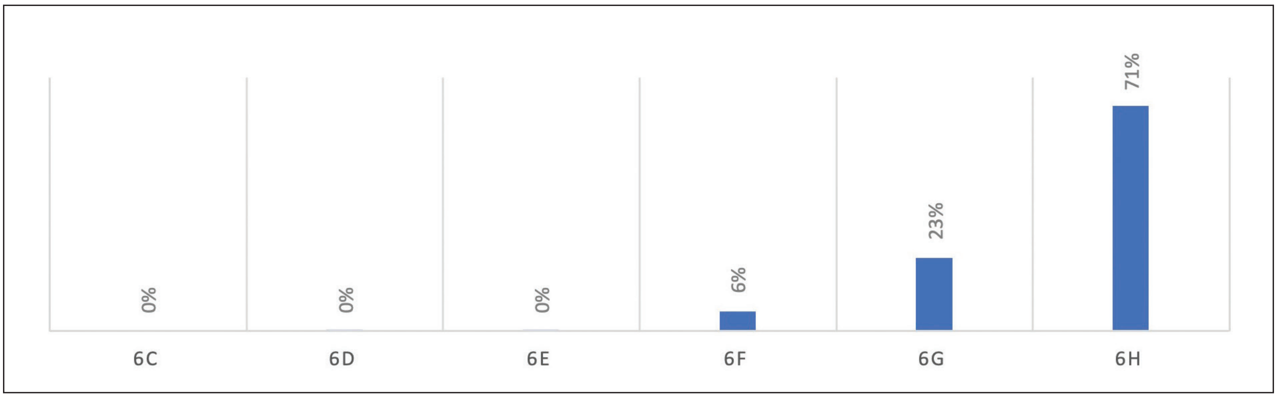


FIGURE 65. Catch distribution across the six overlapping NAFO subareas with the SS GAC and MFE (2010 - 2018).

TABLE 10. List of 98 unique species of commercial fishing importance within the EEZ of States adjacent to the SS also found in theHigh Seas portion of the SS GAC according to OBIS records.

Acanthocybium solandri
Albula vulpes
Alopias superciliosus
Alopias vulpinus
Anguilla rostrata
Aphanopus carbo
Archosargus probatocephalus
Aulostomus maculatus
Auxis thazard
Bairdiella chrysoura
Balistes capriscus
Balistes vetula
Brevoortia tyrannus
Brotula barbata
Canthidermis sufflamen
Caranx crysos
Caranx ruber
Carcharhinus falciformis
Carcharhinus galapagensis
Carcharhinus longimanus
Carcharhinus plumbeus
Centropristis striata
Chaetodon sedentarius
Chloroscombrus chrysurus
Coryphaena hippurus
Cyclopterus lumpus
Cynoscion nebulosus
Cynoscion regalis
Decapterus macarellus
Decapterus punctatus
Diodon hystrix
Diplectrum formosum
Elagatis bipinnulata
Fundulus majalis
Galeocerdo cuvier
Gymnothorax moringa
Haemulon aurolineatum
Hemiramphus brasiliensis
Heteropriacanthus cruentatus
Hippocampus erectus
Hippoglossoides platessoides
Holocentrus rufus
Istiophorus albicans
Isurus oxyrinchus
Isurus paucus
Kajikia albida
Katsuwonus pelamis
Kyphosus sectatrix
Lamna nasus
Lampris guttatus
Leiostomus xanthurus
Lepidocybium flavobrunneum
Lobotes surinamensis
Lutjanus griseus
Makaira nigricans
Menticirrhus americanus
Menticirrhus littoralis
Micropogonias undulatus
Mola mola
Morone americana
Morone saxatilis
Mugil cephalus
Myxine glutinosa
Naucrates ductor
Orthopristis chrysoptera
Pagrus pagrus
Paralichthys dentatus
Peprilus paru
Peprilus triacanthus
Pogonias cromis
Pomatomus saltatrix
Priacanthus arenatus
Prionace glauca
Ruvettus pretiosus
Sarda sarda
Sardinella aurita
Scomberesox saurus saurus
Scomberomorus cavalla
Scophthalmus aquosus
Selar crumenophthalmus
Seriola dumerili
Seriola rivoliana
Seriola zonata
Sphyraena barracuda
Sphyrna lewini
Stenotomus chrysops
Stephanolepis hispida
Tetrapturus pfluegeri
Thunnus alalunga
Thunnus albacares
Thunnus atlanticus
Thunnus obesus
Thunnus thynnus
Trachinotus carolinus
Trachurus lathami
Trichiurus lepturus
Urophycis tenuis
Xiphias gladius

accountability. Understanding beneficial ownership of fishing in the Sargasso Sea can provide additional leverage for protection through forms of national and international regulations as well as through newer tactics of social change through shame and leverage points for corporate accountability (Jacquet 2015; Jouffray et al. 2020; Miller et al. 2016).

The GAC and MFE are not areas that experience a significant amount of industrial fishing effort. While there are areas of aggregated commercial fishing in and around the GAC, the importance of this feature to industrial efforts of the North Atlantic is relatively low. Yet the presence of industrial effort and any associated environmental impacts are still important to consider when establishing management and conservation measures for this ecologically important feature. The presence of fishing vessels in the region, while not excessive, increases the opportunity for vessel strikes, pollutant discharge, bycatch, and underwater noise emissions (see Shipping Section) in addition to having broader implications for large pelagic species targeted by these fisheries. Thus, understanding beneficial ownership of fishing in the SS can provide additional leverage for protection through forms of national and international regulations as well as

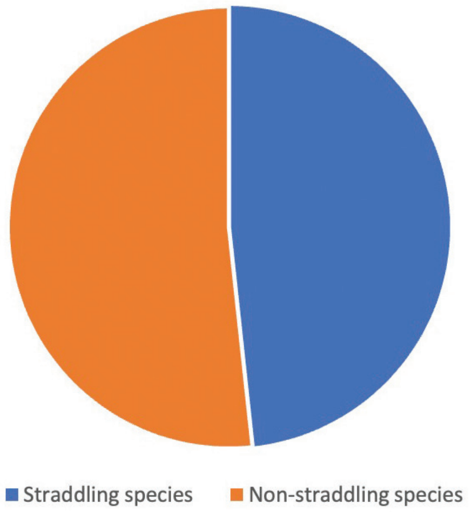


FIGURE 66. Economic value of the domestic fisheries within the EEZs of Bahamas, Bermuda and U.S. East Coast (48.3%) of the valueof national fisheries in these 3 countries is derived from species also found in the High Seas portion of the GAC.

through newer tactics of social change through brand reputation or other leverage points for corporate accountability.

Spikes in distant water fishing activity should not go without consideration of adjacent coastal states. With the new BBNJ agreement, protection of the SS could be prioritized through area-based management tools including MPAs. However, institutions and governments are ill-equipped to keep pace with corporations that overexploit the High Seas through fishing (Jacquet et al. 2023). Private interests, such as those of seafood corporations that rely on High Seas catch, operate at a speed that is beyond the scale of consensus-based institutions. Corporate bad practices should not go without repercussions on the international stage but do so because of the disparate speeds at which institutions work compared to corporations. Therefore, an exclusive reliance on status quo management and regional planning through consensus-based mechanisms would likely miss the mark. Emerging leverage points for accountability, such as shame or the utilization of leverage points in stock markets, should be implemented to promote accountability among corporate bad actors for overexploitation of resources associated with the SS.

Pollution

Plastics

Plastic pollution is pervasive throughout the marine environment, impacting oceans globally (Eriksen et al. 2014). Aggregation of these pollutants is often dictated by wind and current forces and studies show that plastic concentration corresponds with broader oceanographic patterns with accumulation happening at the center of gyres (Eriksen et al. 2019). The North Atlantic Subtropical Gyre is the site of significant plastic aggregation (Law et al. 2010) with wider implications for the SS ecosystem. We summarized monthly microplastic abundance in the SS study region using data from Isobe et al. 2021, which synthesizes 8,218 pelagic microplastic samples from the world's oceans to generate a global dataset of microplastic abundance in the world's upper ocean and the Laurentian Great Lakes. This dataset includes raw, calibrated, processed, and gridded data, which was generated using an optimum interpolation method. Here we summarize both particle count (Figure 67) and weight (Figure 68) monthly gridded data throughout the study region.

Currently, there is little information on larger plastic pollution in the High Seas, primarily due to the logistical complications of comprehensive sampling in these areas. Additionally, while critical to effective management and prevention of plastics entering our oceans, tracing the sources of these pollutants remains difficult. While it is widely acknowledged that waste inputs from land into the ocean are substantial (Jambeck et al. 2015), significantly more research is needed to assess precisely where pollutants enter the marine environment in the context of the North Atlantic and, more specifically, the SS. Despite these knowledge gaps, the modeled distribution of marine microplastics shown here supports other research suggesting that the North Atlantic Subtropical Gyre as a site of significant plastic aggregation, with meaningful implications for the broader SS ecosystem health.

Resource Extraction

Deep Seabed Exploration

Large mineral deposits, which are rich in valuable metals such as copper and zinc, are distributed in the deep ocean across the globe. Deposits of these materials occur on abyssal plains and at the upper continental shelf slopes in addition to forming at hydrothermal vents and seamounts (Christiansen et al. 2020). The impacts of deep seabed mining activities to the benthic ecosystem are widely studied and it is likely that these activities impact pelagic biota as well, although the severity and scale of these impacts are less clear.

The International Seabed Authority (ISA) has entered into 15-year contracts with twenty-one contractors for exploration for polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts in the international seabed area (the Area). This region is defined as "the seabed and ocean floor and the subsoil thereof, beyond the limits of national jurisdiction." In the North Atlantic, several contracts exist for exploration of the Mid-Atlantic Ridge as a site for polymetallic sulphide extraction. Figure 69 shows the location of these existing lease areas, which intersect with the eastern boundary of the SS AOI.

In addition to ISA lease blocks in the Area, stakeholders are exploring access to deep seabed mining resources that exist within the boundaries of national waters. The United Nations Convention on the Law of the Sea (UNCLOS) outlines the areas of national jurisdiction as a 12 nautical-mile territorial sea; an EEZ of up to 200 nautical miles and a continental shelf. Under UNCLOS, coastal states have rights to the resources within their EEZ, including access to any resources within the seabed and subsoil. Some states have extended or are in the process of extending jurisdiction beyond the EEZ further into the adjacent continental shelf. Extended continental shelf (ECS) areas include jurisdiction over the seabed and subsoil, enabling nations to explore mineral resources that may not otherwise exist within the traditional 200 nautical mile EEZ. Figure 70 shows existing ECS submissions, some of which overall with the GAC and represent potential areas of deep seabed mining exploration in the future. While the impacts of seabed resource extraction on pelagic marine ecosystems, such as the SS, are not entirely clear, it is important to monitor the exploration of these resources and the status of ECS submissions to ensure that potential negative impacts from these practices are addressed in the early stages of development.

Cable Laying

Communications cables are laid on the seafloor, extending across the Atlantic between land-based stations. While their location on the seafloor limits the scope of impact to a pelagic ecosystem such as the SS, submarine cables are subject to regulations by managing nations including management protocols pertaining to installation, maintenance, repair, and removal. Consequently, it is important to assess overlap between undersea telecommunications infrastructure and the SS study area to understand how these regulations may affect this feature into the future. Figure 71 shows the approximate location of known existing telecommunication cables across the SS AOI, which has been compiled based on widely available public data (Koordinates 2021).

Climate Change

Global climate change is a significant stressor to marine ecosystems, amplifying and expanding the scope of impact from other human activities such as fishing (O'Hara et al. 2021). As the global climate warms, marine ecosystems experience shifts to biogeochemical characteristics (Reygondeau et al. 2020) with broader implications for species assemblages. Many marine species are sensitive to these temperature changes. The European eel, for example, migrates from the Mid-Atlantic Ridge to spawning grounds in and around the Sargasso Sea, requiring water temperatures within a narrow range of 22°C - 24°C to successfully breed (Wright et al. 2022). We implemented data from a selection of models from the Coupled Model Intercomparison Project Phase 6 (CMIP6) to evaluate projected changes to the SS ecosystem into the future. This collective database contains ensembles of environmental scenarios that blend both observed oceanic data collected in the past decades and predicted

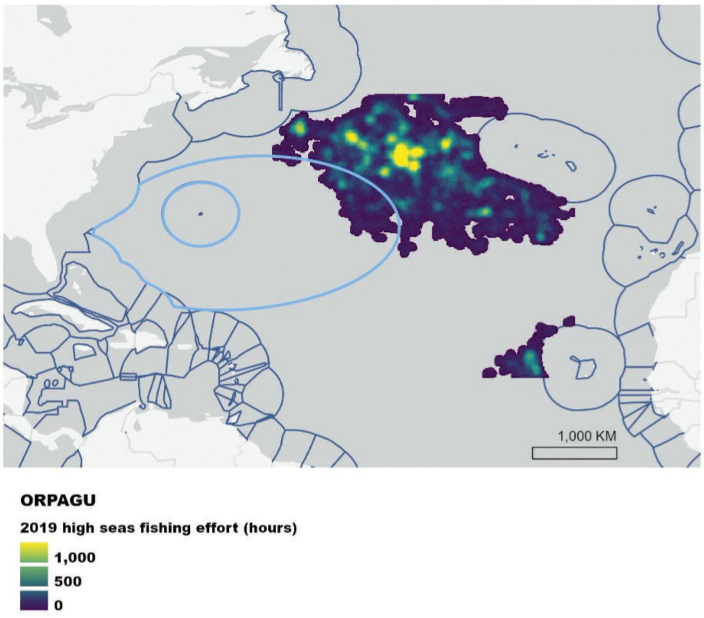


FIGURE 67. High Seas fishing effort for PRPAGU, 2019

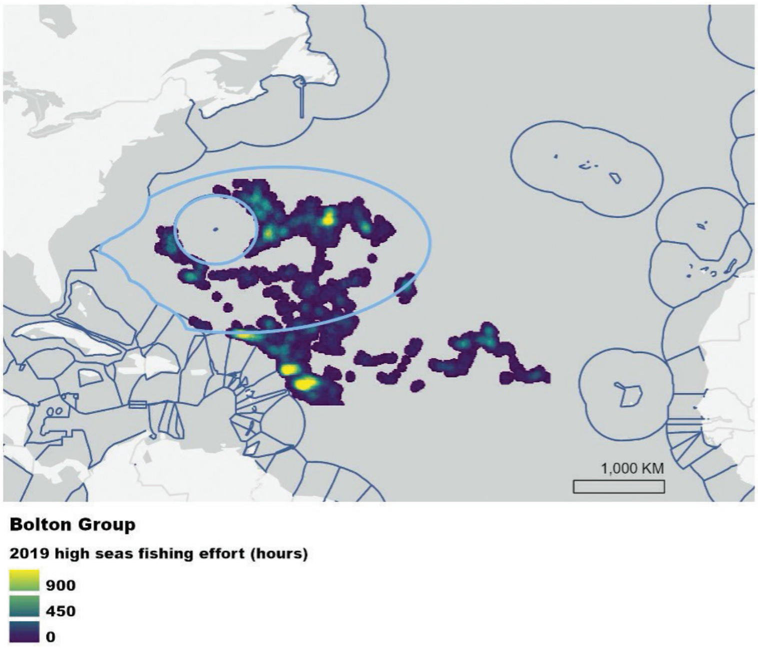
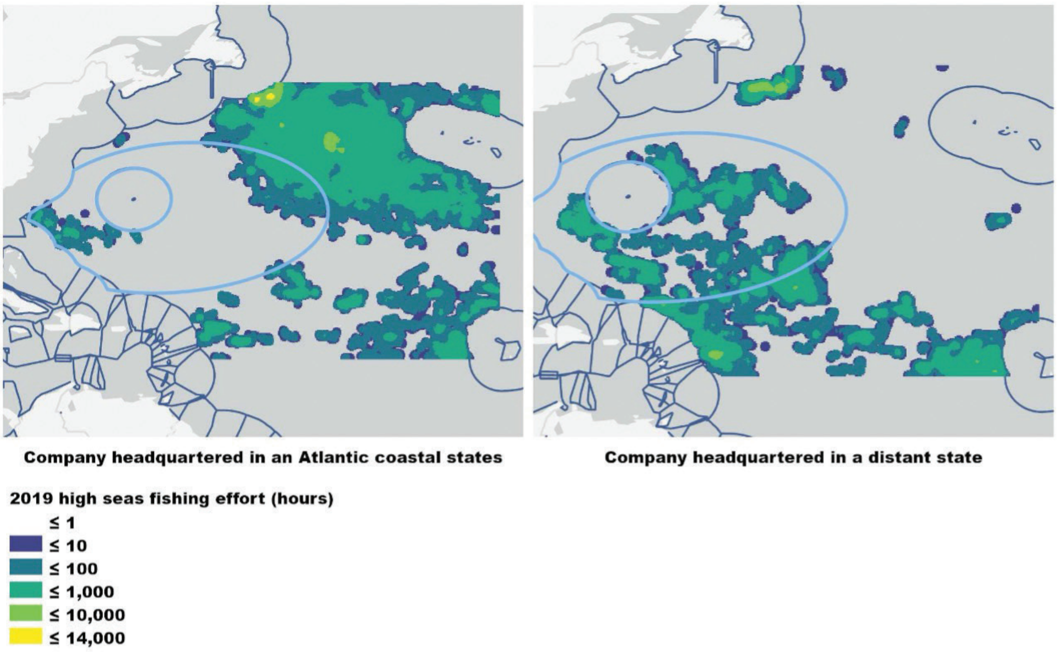


FIGURE 68. HIgh Seas fishing effort for the Bolton Group, 2019


Company headquartered in an Atlantic coastal states

Company headquartered in a distant state

FIGURE 69. High Seas fishing effort for Atlantic coastal states and distant states, 2019

oceanic patterns for a century from now.

CMIP6 offers historical climate data ranging from 1850 to 2014 with a spatial grid resolution of 0.25 degrees and a temporal resolution of one day. CMIP6 provides future climate projections for various socio-economic expectations, or shared socio-economic pathways (SSPs), from 2015 to 2100. SSP1 represents a sustainable future, while SSP2 follows historical patterns, SSP3 focuses on regional rivalry, SSP4 predicts increased inequality, and SSP5 assumes rapid economic and technological progress based on fossil fuel consumption. We evaluated SST at three different SSP scenarios: SSP2-4.5 (low carbon emission), SSP3-7.0 (moderate carbon emission), SSP5-8.5 (high carbon emission). We evaluated changes to SST using two metrics: spatial visualizations of projected changes in temperature and detection of marine heatwave

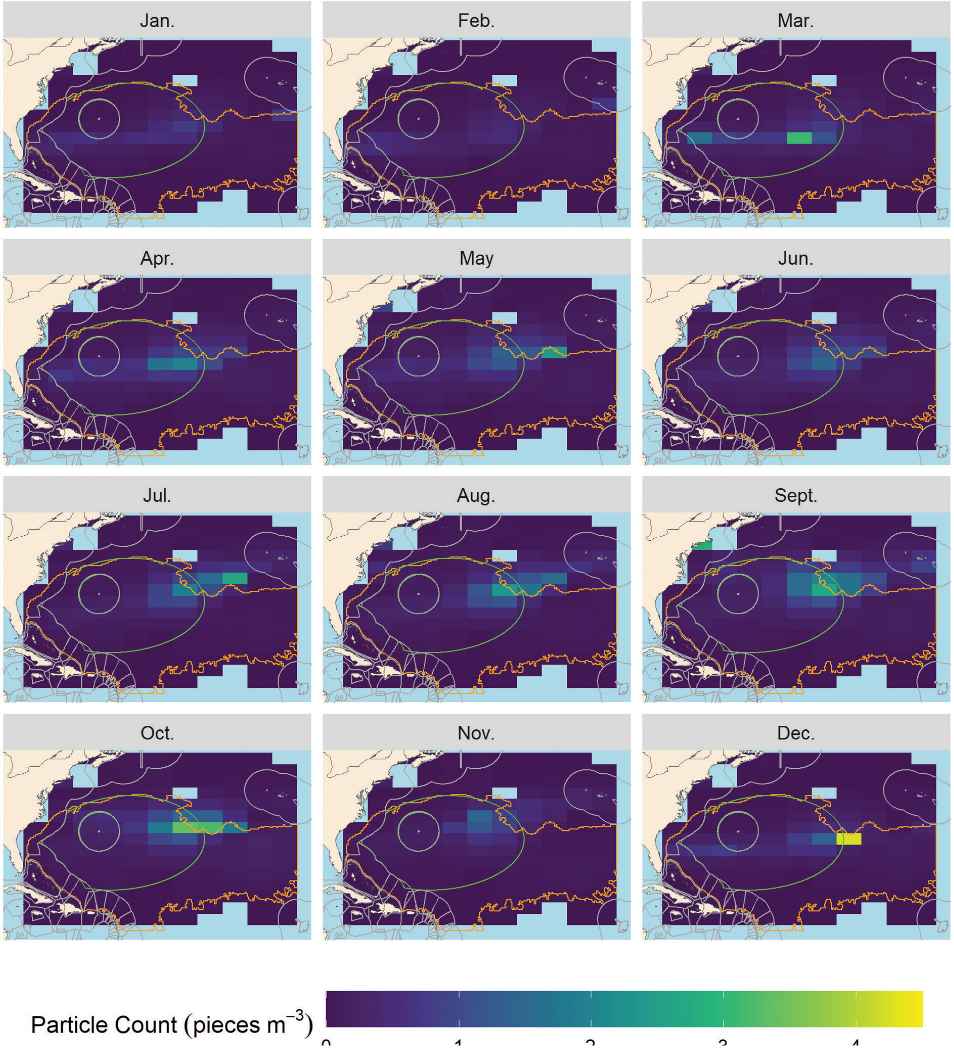


FIGURE 70. Monthly microplastic distribution by particle count in the SS AOI.

events and their frequency into the future.

Difference of Means Spatial Analysis

The spatial data visualizations approach identified sub-regions within the AOI that might experience dramatic physical changes in the event of any one of these climate scenarios. These figures focus on displaying projected changes in sea surface temperature in the short term and long term as compared to historical records. We defined the historical time period as 2005 - 2014 (inclusive), the short-term time period as 2035 - 2044 (inclusive), and the long-term time period as 2090 - 2099 (inclusive). We produced spatial representations of the difference between the ten-year mean of historical records and that of future forecasts as:

$$\Delta\ 10\ \text{Years Mean}_{\text{time\_period}} = \text{Scenario 10 Years Mean}_{\text{time\_period}} - \text{Historical 10 Years Mean}_{2005\text{–}2014}$$

$$\Delta\ 10\ \text{Years Monthly Mean}_{\text{time\_period}} = \text{Scenario 10 Years Mean}_{\text{time\_period}} - \text{Historical 10 Years Mean}_{2005\text{–}2014\ \text{month}}$$

Equation 1 produces the difference in 10 years annual mean between the simulated scenario and historical data while equation 2 does the same for monthly climatologies for each pixel in the study area. We calculated the two difference of means for sea surface temperature in the SS for three climate scenarios across the two time periods (Table 11). While we calculated the difference of means for all months of the year, results are shown here using the four representative months based on results from our sub-region analysis (described above). These months represent four different classification profiles: maximum extent of the high-productivity core (January), moderate coverage of the two core classes (April), high variability in the core area (July), maximum coverage of the low-productivity core class (September).

All three climate scenarios show moderate to severe

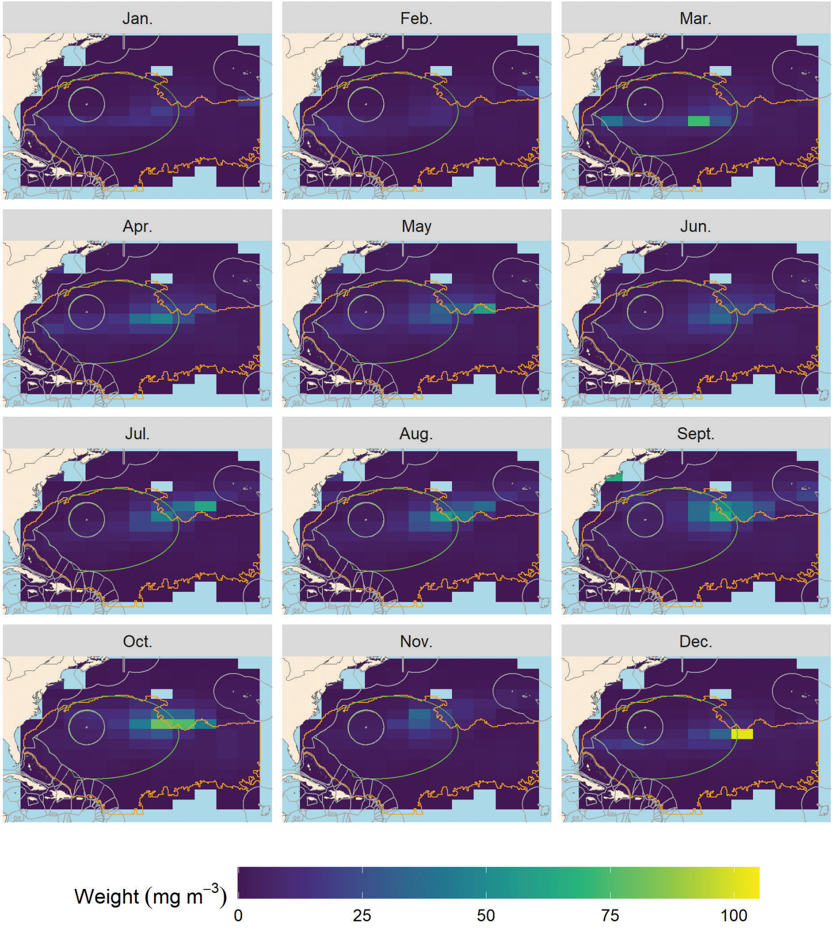


FIGURE 71. Monthly microplastic distribution by weight in the SS AOI.

warming in around the SS, with the most profound change in SST occurring in the SSP5-8.5 scenario (Figure 72). While temperature increase is relatively more uniform across the ocean surface in the short-term, drastic changes are expected in certain regions in the long-term. In both time periods across all scenarios, the center of the GAC, which overlaps with the North Atlantic Gyre, appears to be a hotspot for warming in the study area. While this phenomenon is less pronounced in the short-term, the long-term period of all three scenarios shows significant warmingthat extends laterally from the center of the GAC to the eastern side of the study extent. This is particularly accentuated in the long-term period of SSP5-8.5, where a strip of intense warming (~ +3° C) extends across the study region in the annual average (Figure 72, bottom right pane) as well as all monthly averages (Figs. 73-76, bottom right panes). Figs. 73 and 76, which show the difference of means analysis for the months of January and September respectively, show stark contrast between the significant warming of this core area in the long-term and the Gulf Stream, which bounds the SS feature to the west. While SST was not incorporated into our sub-region classification methodology for the SS study region, the intense warming revealed by this analysis has the potential to impact those variables that were included, such as primary productivity, with greater implications for the physical conditions of the SS ecosystem and associated biological communities.

Marine Heatwave Analysis

Marine heatwaves (MHW) have been observed globally and are expected to increase in intensity and frequency with the progression of global climate change, having significant impacts to marine ecosystems (Wernberg et al. 2013). Here, we used the hierarchical methodology described in Hobday et al. (2016) to identify past and future heatwave events which are identified as anomalously warm temperatures occurring for a prolonged period as a discrete event. Anomalously warm is qualified as daily SST that exceeds the 90th percentile of a 30-year climatology. A prologued event occurs when anomalously warm conditions last for over 5 days. Finally, a heatwave event

TABLE 11. **List of layers produced by the difference of means spatial analysis.**

	10-years Difference in Monthly Mean (12 layers each)	10-years Difference in Annual Mean (1 layer each)
Short-term	SSP 2-4.5	SSP 2-4.5
	SSP 3-7.0	SSP 3-7.0
	SSP 5-8.5	SSP 5-8.5
Long-term	SSP 2-4.5	SSP 2-4.5
	SSP 3-7.0	SSP 3-7.0
	SSP 5-8.5	SSP 5-8.5

must be discrete with well- defined start and end times. By this definition, gaps between events of two days or less with subsequentfive day or more events are considered a continuous event (Hobday et al. 2016).

We used three metrics to evaluate a qualified MHW: heatwave frequency (the number of events observed within a defined time-period), the duration (length of the heatwave event, in days), and intensity (the magnitude of temperature anomaly observed). We determined maximum intensity, average intensity, and cumulative intensity of the heat wave event based on the temperature deviance, which is calculated by subtracting the baseline temperature value from the SST of a given day. Maximum intensity was determined by identifying the most extreme intensity between each qualified heat wave of the focal timeframe. Cumulative intensity of the heatwave event was calculated as the integral of intensity over the duration of the event. Finally, we summed total cumulative intensity of all heatwaves within one year to get total cumulative intensity by year.

The baseline temperature used to evaluate these metrics for each day during a given timeframe was calculated as the mean of daily SST observations within an 11-day window including the day of interest (5 days before and 5 days after) for 30 years (for a total of 330 SST observations). Figure 77 from Hobday etal. (2016), shows an example comparison of this climatological mean (blue line), the 90th percentile (dashed line) and the daily SST (red line). We performed these analyses for scenarios SSP5-8.5 and SSP2- 4.5, using corresponding baseline climatologies for the various time frames. These included a historic (1984 - 2014), short term (2015 - 2045) and long term (2070 - 2100) timeframe. We calculated unique 30-year baseline climatologies for heatwave detection at each timeframe, in addition to performing heatwave detection in the long-term time scale using the baseline climatology from the short-term period.

Historic Heatwaves

The upper pane of Figure 78 shows daily SST (black line), climatological mean (blue line) and 90th percentile (green line) from 1984 to 2014 in the SS. The consistent fluctuation in the green and blue lines reflects the regular seasonality of the study area. The most severe heatwave during this period is represented inthe lower pane with the areas shaded in red indicating the maximum intensity heatwave (MIH) and the smaller orange shaded areas showing weaker heatwave events. The MIH shown in this figure is somewhat isolated in nature, with no visible weaker events immediately preceding or following it.

Short-term Heatwaves

The upper panes of figures 79 and 80 show daily SST (black line), climatological mean (blue line) and 90th percentile (green line) from 2015-2045 in the SS, with Figure 79 corresponding to SSP2-4.5 and Figure 80 corresponding to SSP5-8.5. Both SPP2-4.5 and SSP5-8.5 show one milder heat wave occurring in the months preceding the MIH however the MIH shown in the SSP5-8.5 scenario appears to be slightly more prolonged that that of the SSP2-4.5 scenario. Additionally, the MIH for scenario SSP5-8.5 occurs earlier in the timeline (2036) than SSP2-4.5 (2038).

Long-term Heatwaves

Figs. 81 and 82 show daily SST (black line), climatological mean (blue line) and 90th percentile (green line) from 2070-2100 in the SS, with Figure 81 corresponding to SSP2-4.5 and Figure 82 corresponding to SSP5-8.5. While the MIH of SSP2-4.5 is preceded and followed by more moderate heatwave events, SSP5-8.5 appears to have one moderate heatwave preceding it with a longer

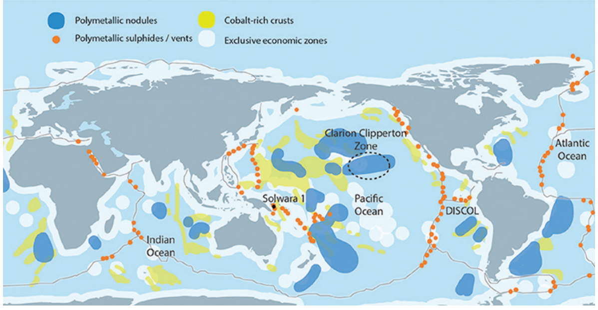


FIGURE 72. **Fig. 1 from Miller et al. 2018 showing the location of the three principal marine mineral deposits.**

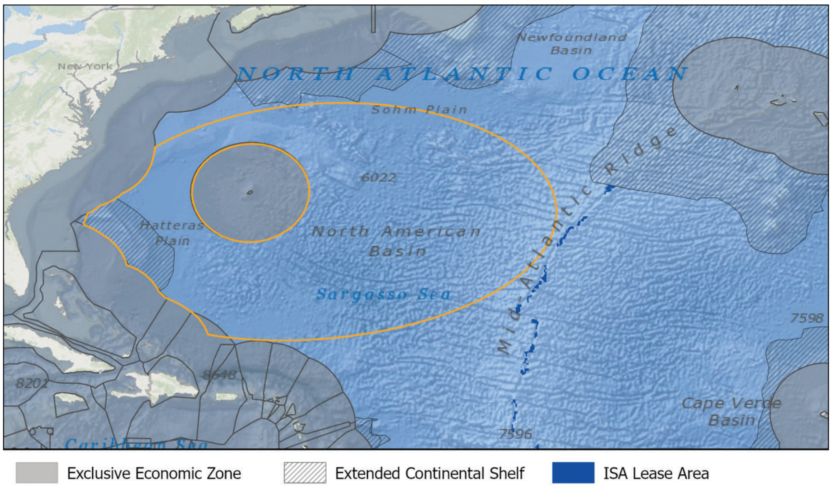


FIGURE 73. Extended Continental Shelf and ISA Lease Areas

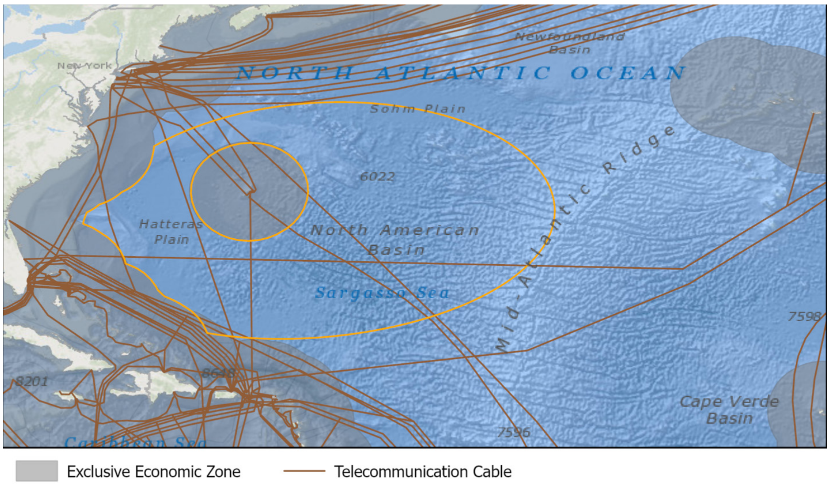


FIGURE 74. Undersea Telecommunications Cables, approximate locations

overall duration (~4 months) as compared to SSP245 (~2 months). Similar to the short-term heatwave detection, the MIH of SSP5-8.5 occurs earlier in the timeline than that of SSP2-4.5, beginning in the first half of 2090 while the latter begins in the second half of 2094.

Figs. 83 and 84 show daily SST (black line) from 2070 - 2100 for SSP2-4.5 and SSP5-8.5 respectively using the climatological mean (blue line) and 90th percentile (green line) derived from 30 years of preceding (2041-2070) SST data of each scenario for heat wave detection. The extended timeline (2041-2100) is show in the upper panes of both figures. While daily SST begins to routinely exceed the 90th percentile as time progresses in both scenarios, the degree to which this occurs becomes more drastic in SSP5-8.5, reflecting more intense warming associated with this scenario. Predictably, SSP5-8.5 shows the MIH occurring sooner than SSP2-4.5 and lasting significantly longer (~ 8.5 years vs. ~ 7 months) although the MIH of both scenarios are preceded and followed by more moderate heatwaves.

Cumulative Intensity

Figure 85 shows the annual cumulative intensity over 30 years for the short term (top) and the long term (bottom) based on SPP scenario, with the sum of the annual intensity indicated in the top left of the figure. Results indicate that, generally, annual cumulative intensity of MHWs for scenario SSP5-8.5 is more intense than that of SSP2-4.5. Annual cumulative intensity of SSP2-4.5 for both short and long- term timeline is characterized by more frequent peak events (between 7 and 8) of similar intensity while SSP5-8.5 is characterized by fewer events (between 4 and 5) of more variable intensity.

With the outcomes of a changing climate including shifts in ocean temperatures, the exploration of climate model predictions in the context of the SS provides critical insight into potential changes to the profile of this feature into the future. The difference of means spatial

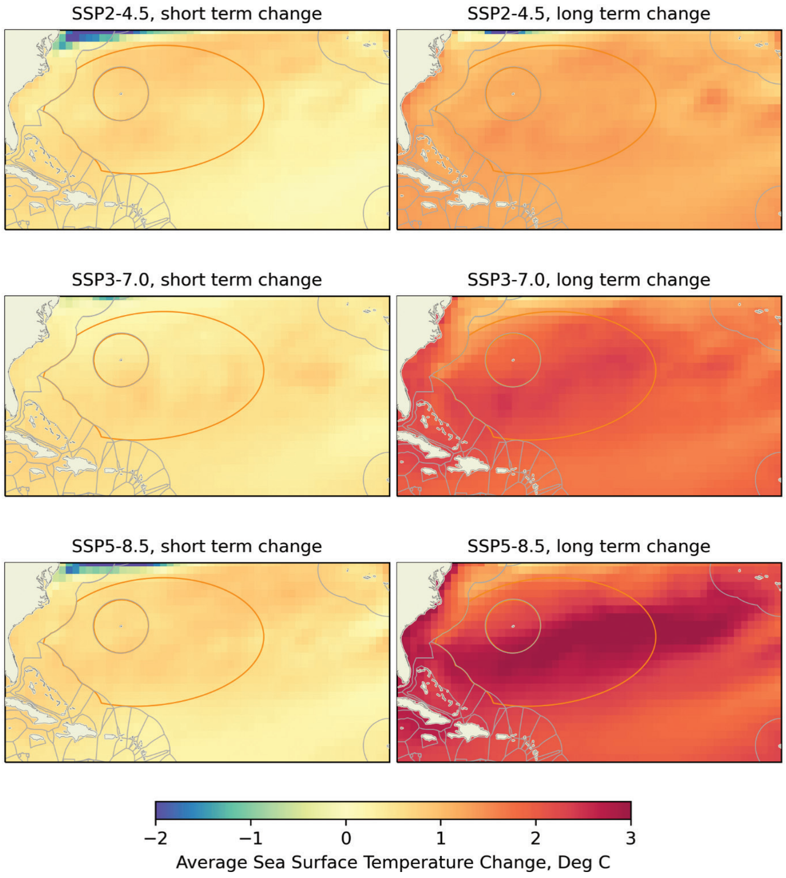
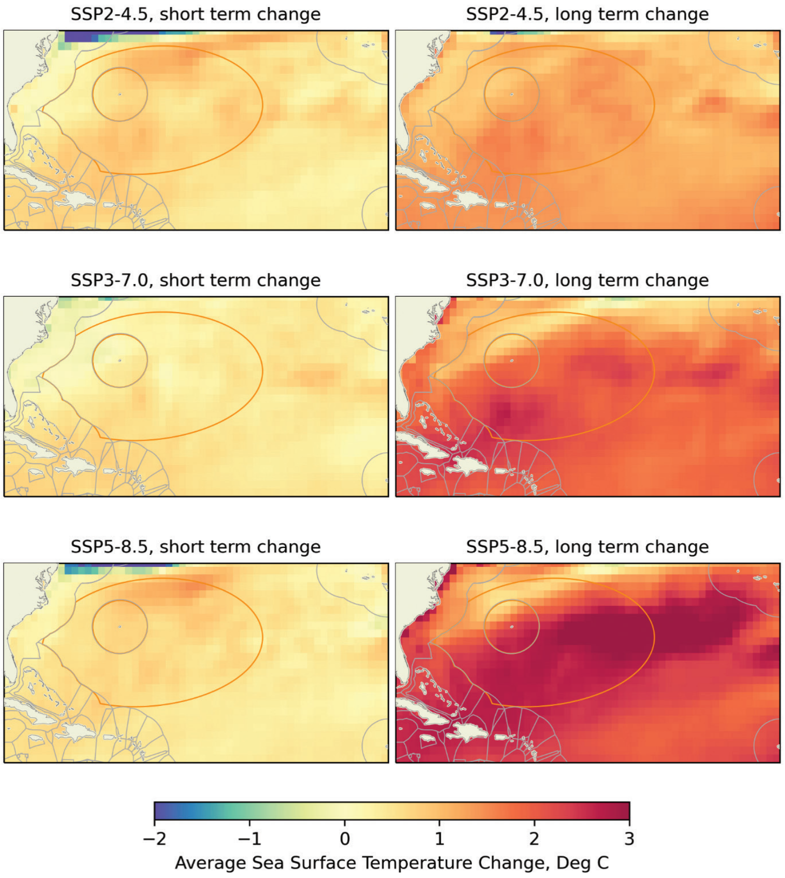


FIGURE 75 Change in annual mean SST over two timeframes, short term (2035 - 2044) and long term (2090 - 2099) across three different climate scenarios (SSP2-4.5, SSP3-7.0, SSP5-8.5).

FIGURE 76 Change in mean SST for the month of January over two timeframes, short term (2035 - 2044) and long term (2090 - 2099) across three different climate scenarios (SSP2-4.5, SSP3-7.0, SSP5-8.5).



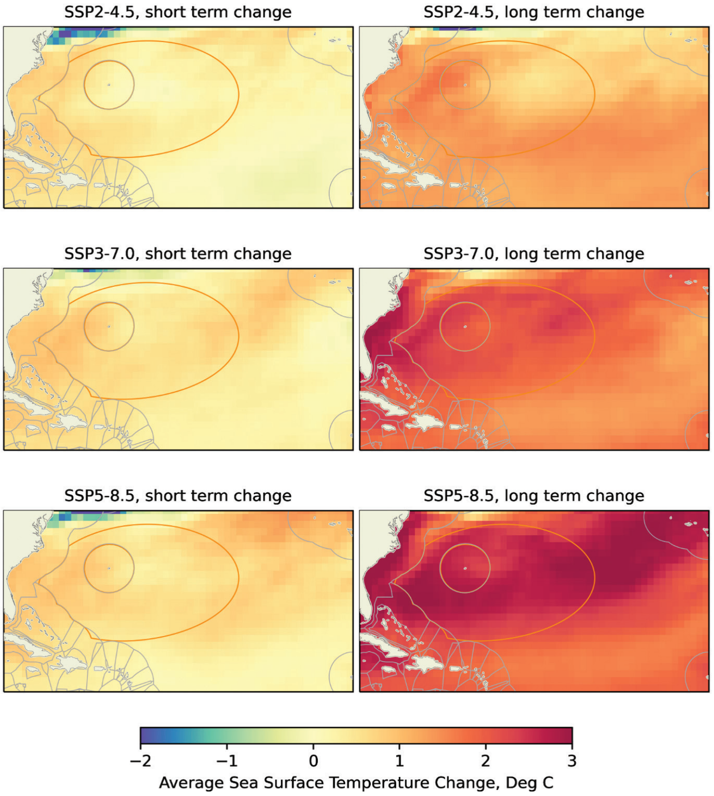
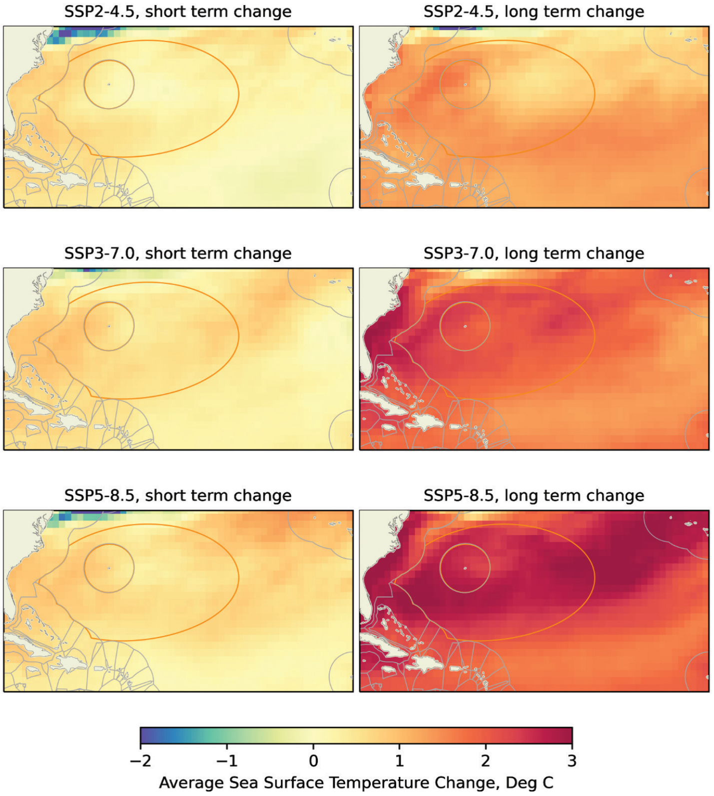


FIGURE 77. Change in mean SST for the month of April over two timeframes, short term (2035 - 2044) and long term (2090 - 2099) across three different climate scenarios (SSP2-4.5, SSP3-7.0, SSP5-8.5).

FIGURE 78. Change in mean SST for the month of July over two timeframes, short term (2035 - 2044) and long term (2090 - 2099) across three different climate scenarios (SSP2-4.5, SSP3-7.0, SSP5-8.5).



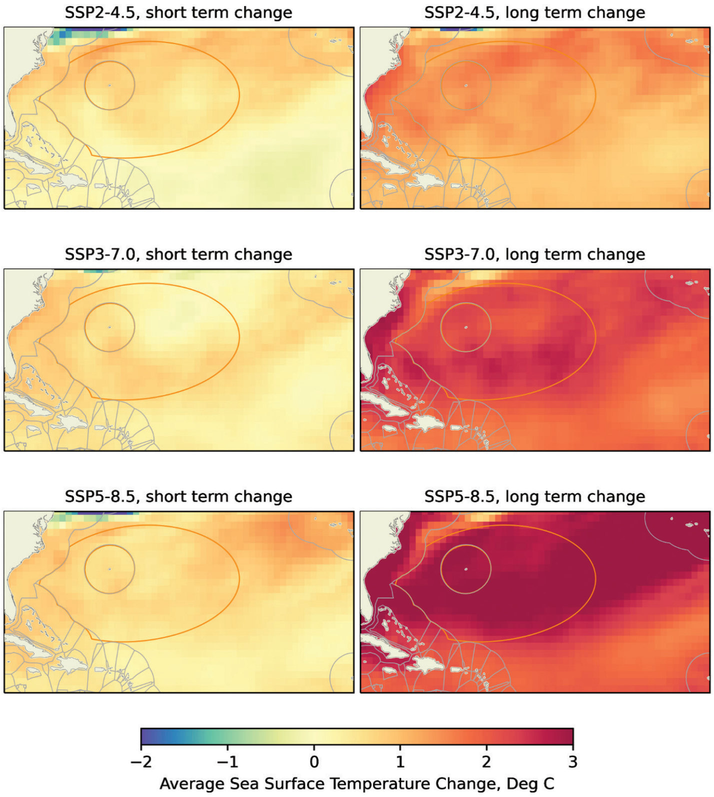


FIGURE 79. Change in mean SST for the month of September over two timeframes, short term (2035 - 2044) and long term (2090 - 2099) across three different climate scenarios (SSP2-4.5, SSP3-7.0, SSP5-8.5).

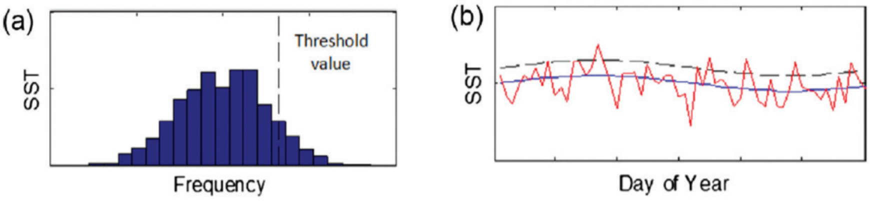


FIGURE 80. Figs. 1a and 1b from Hobday et al. (2016) showing threshold values defined by the 90th percentile value (a) and variation in 90th percentile values and climatological mean throughout the year (b)

approach identified subregions within the AOI that might experience dramatic physical changes in the event of any one of the three climte scenarios we explored. While the short-term prediction under all three scenarios did not display pronounced spatial trends in SST warming, the long-term predictions unanimously showed areas of increased warming around the central GAC as well as areas to the eastern of the GAC. With dramatic changes to SST, which may reflect broader alterations to oceanographic dynamics, our analysis suggests that, under any of the three climate scenarios, the spatiotemporal characteristics of the SS are likely to shift. These changes to the physical characteristics of this feature will likely result in shifts to the species assemblages associated with the SS, with potentially profound impacts to some of the more sensitive species.

In addition to considering the impacts of potential spatiotemporal changes to the SS resulting from climate change, the frequency and magnitude of marine heatwaves are also ecologically significant outcomes of global climate change and will likely impact the ecology of this feature. The cumulative intensity (duration, frequency, and intensity) of regional heatwaves also shows positive trends over both the short- and long-term evaluation periods, but only in the more severe SSP5-8.5 predictions. The specific impacts of these changes will vary by organism and specific geography but are nonetheless cause for concern

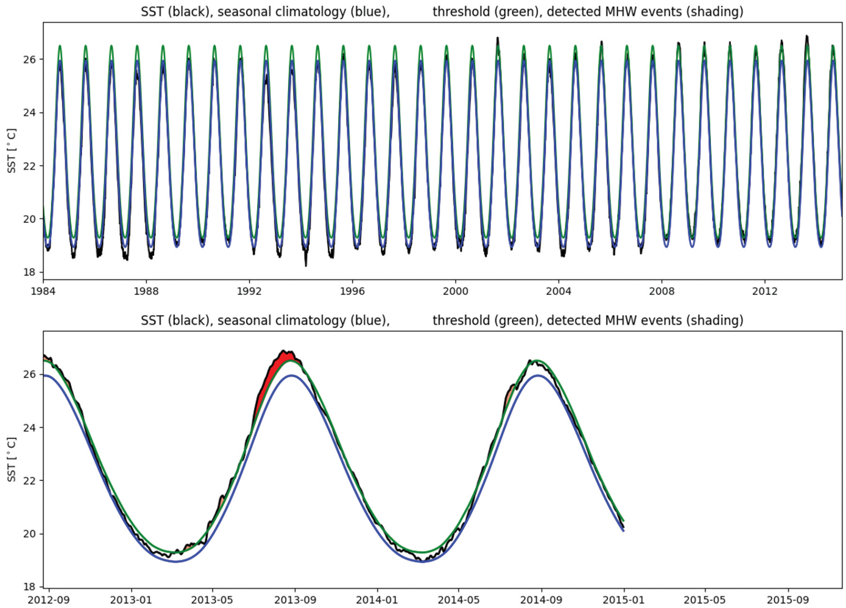


FIGURE 81. Maximum intensity historic heatwave event for the SS study area using a baseline climatology derived from data from the same period.

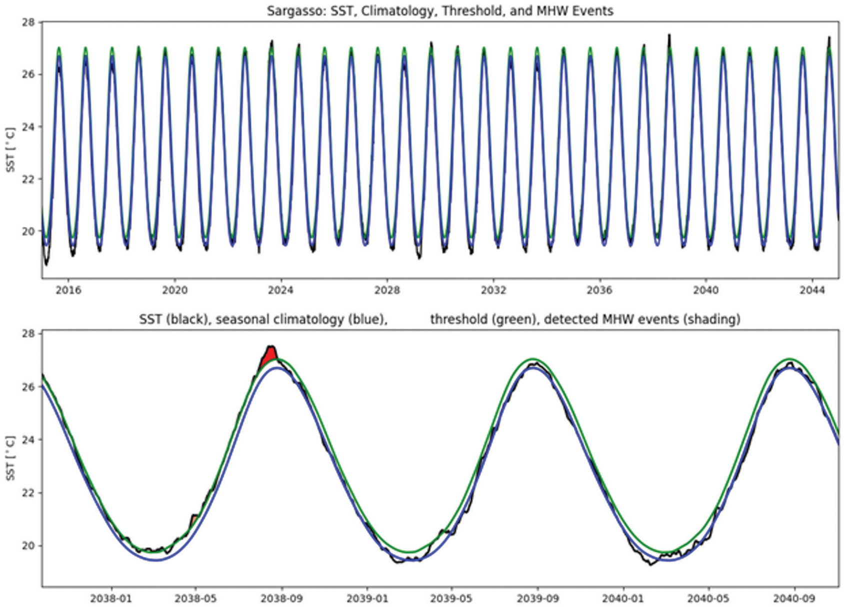


FIGURE 82. Maximum intensity heatwave event for the short-term (2015-2045) future period under climate scenario SSP2-4.5 using a baseline climatology derived from data from the same period.

Discussion and Conclusion

Summarization of Ecosystem State

The assessment of regional biodiversity in and around the SS shows underlying gaps in spatial data within this area, highlighting a need for enhanced efforts to understand broader biodiversity metrics of this feature and the High Seas areas around it. Additionally, the absence of population status assessments for many threatened species known to exist in and around this feature limit our ability to create a comprehensive understanding of the sensitive marine communities that rely on the SS. Despite these gaps, compelling evidence suggests that there is a robust community of sensitive marine species that interact with this feature, many of which are also migratory and transit between this High Seas feature and adjacent jurisdictional waters. Although our analysis revealed some disparities in known range and suitable habitat predictions of sensitive species, these are two useful metrics for assessing the significance of the SS for these communities. The spatial evaluation of these metrics reveals critical habitat of several sensitive species cover a significant portion of the feature extent, with are broad areas of high cumulative

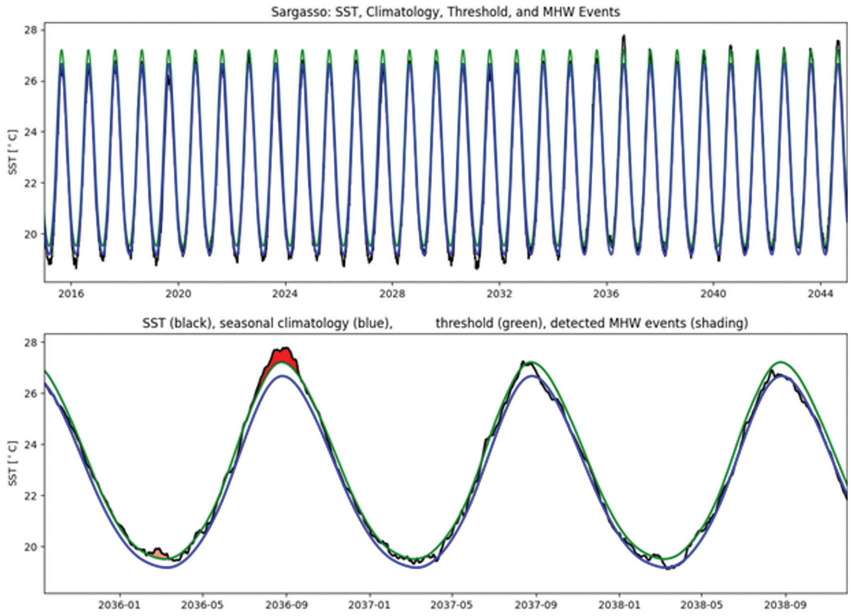
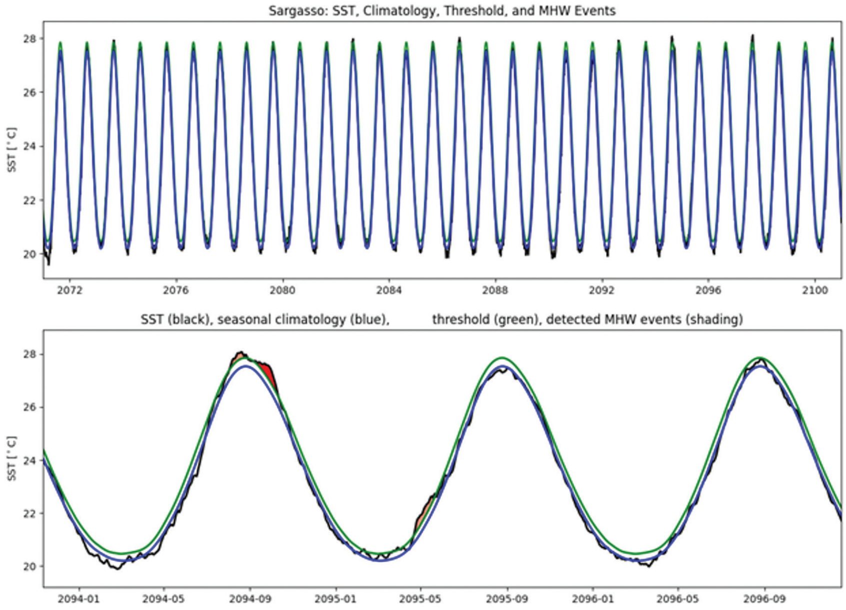


FIGURE 83. **Maximum intensity heatwave event for the short-term (2015-2045) future period under climate scenario SSP5-8.5 using a baseline climatology derived from data from the same period.**

FIGURE 84. **Maximum intensity heatwave event for the long-term (2070-2100) future time frame under climate scenario SSP2-4.5 using a baseline climatology derived from data from the same period.**



habitat suitability suggesting the co-occurrence of these species both within and in proximity to the GAC. Indeed, several species of high conservation value, such as the American eel, use this area for spawning ground, while others, such as loggerhead sea turtles, use the area for juvenile development. Furthermore, this area is a critical migratory corridor for many species, such as the humpback whale, and home to several endemic species, such as the Bermuda petrel. Recognition of the SS and associated critical habitat for marine communities has been delineated in areas that may be considered as worth conserving into the future, and the evaluation of overlap between ecologically critical areas of this feature and human use is important to determining potential areas for future management measures.

Plastic Pollution and Sensitive Species

Plastic pollution is pervasive throughout the marine environment and the North Atlantic Subtropical Gyre is the site of significant plastic aggregation (Law et al. 2010). Aggregation of these pollutants is often dictated by wind and current forces and studies show that plastic

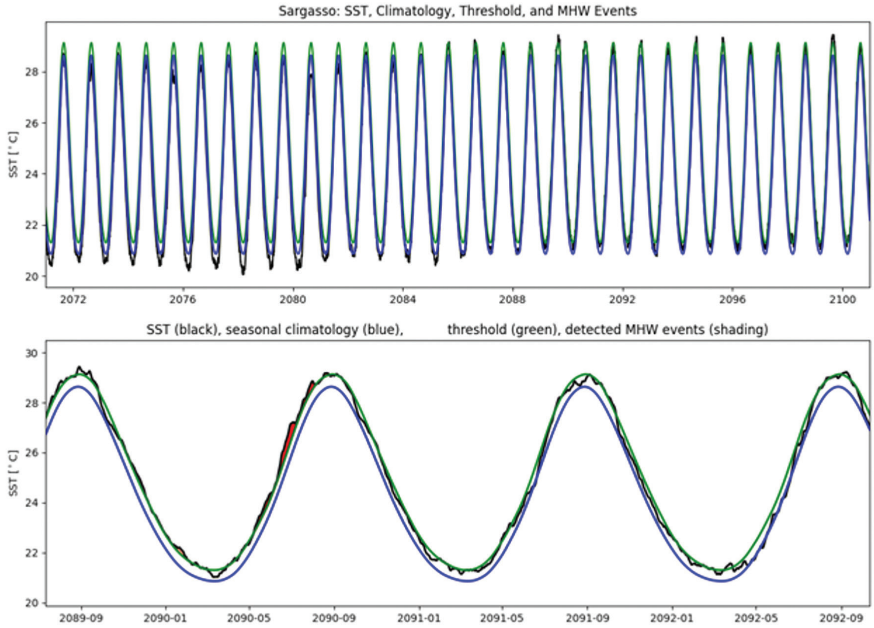
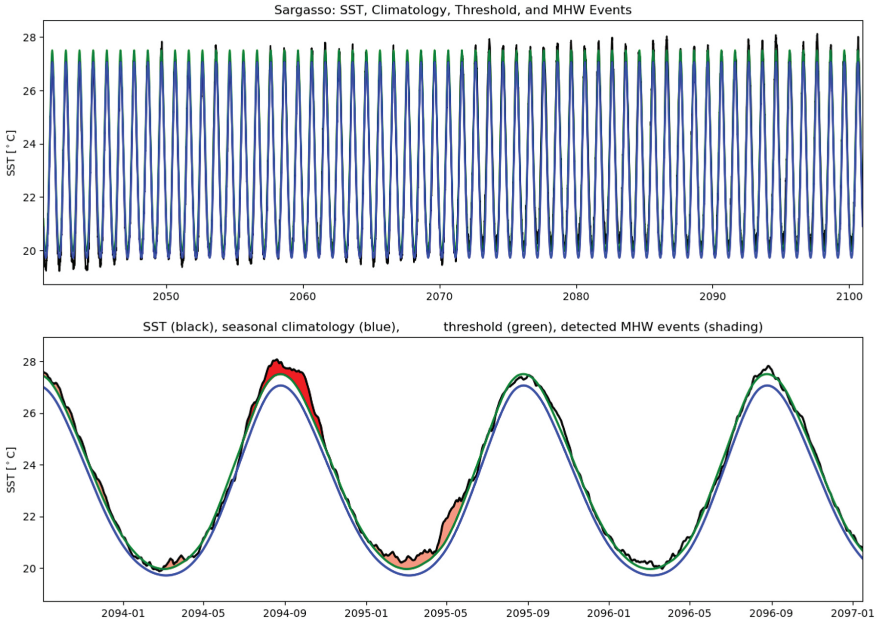


FIGURE 85. Maximum intensity heatwave event for the long-term (2070-2100) future time frame under climate scenario SSP5-8.5 using a baseline climatology derived from data from the same period.

FIGURE 86. Maximum intensity heatwave event for the extended long-term (2040 - 2100) future time frame under climate scenario SSP2-4.5 using a baseline climatology derived from the period 2041 - 2070 under the same climate scenario.



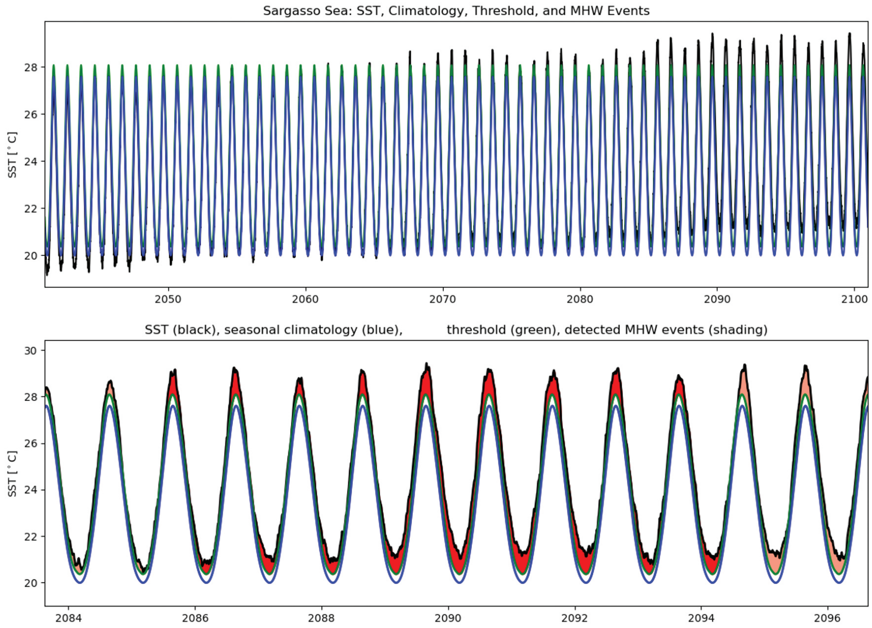
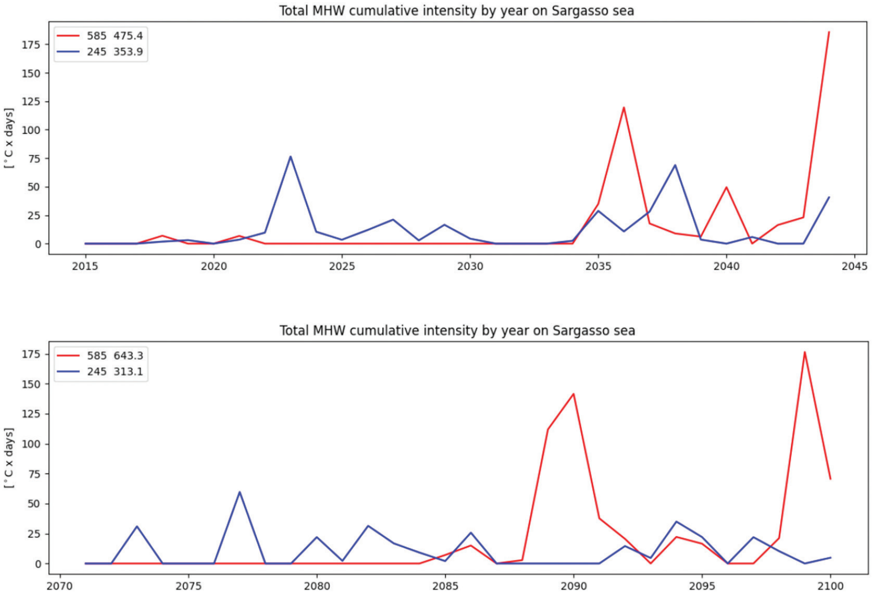


FIGURE 87. Maximum intensity heatwave event for the extended long-term (2040 - 2100) future time frame under climate scenario SSP5-8.5 using a baseline climatology derived from the period 2041 - 2070 under the same climate scenario.

FIGURE 88. Annual cumulative intensity of marine heatwaves from 2015-2044 (top) and 2071-2100 (bottom) in the SS.



GAPS ANALYSIS

The following gap analysis aims to inform a larger, project-wide gaps analysis with structure outlined by the DPSIR framework and coordinated by partners of the SARGADOM project.

Topic	Field	Metric	Gap
Pollution	Marine Debris	Macro Plastic Distribution and concentration	Data Coverage
Pollution	Marine Debris	Derelrict Fishing Gear Spatial Data	Data Coverage
Pollution	Oil Contamination	Oil Slick/Spill Detection (Bilge Water Discharge Events)	SAR Data Coverage
Pollution	Tanker Spills Events	Reporting Data	Data Access
Pollution	Contamination Events	Reporting Data	Data coverage
Fishing	Ecosystem Impact	Development of a Pilot Ecosystem Plan	Data availability
Fishing	Beneficial Ownership	Coporate Governance Structure	Transparency of Corporate Structure Information
Commercial Vessel Traffic	Non-Native Species Dispersal	Ballast Discharge Event Spatial Data	Data availability
Commercial Vessel Traffic	Physical Harm to the Ecosystem	Cetacean Ship Strike Spatial Data	Data Availability: Data resolution
Commercial Vessel Traffic	Physical Harm to the Ecosystem	In-situ Noise Data	Data availability
Commercial Vessel Traffic	Physical Harm to the Ecosystem	Development of methodology to assess risk of ship strike to cetacean communities	Existing methodological limitations
Focal Marine Species	Sargassum Aggregation	Remotely sensed sargassum detection	Data Coverage in Space and Time
Focal Marine Species	Threatened Species Range and Distribution	Habitat Suitability	Model Limitations
Focal Marine Species	Threatened Species Range and Distribution	Species Range Categorization	Data Limitations
Regional Biodiversity	Species Distribution Records	Detailed species occurrence records	Data Coverage
Regional Biodiversity	Threatened Species Population Abundance	IUCN Species Status Assessment	Data Limitations

Explanation	Relevant Figure	Text References
Data collection efforts concentrated along coastlines and there is little coverage in the high seas.		Pg. 101, 123
Inconsistent data coverage all-around. Organizations like Global Ghost Gear Initiative and (https://www.ghostgear.org/resources) have begun to publish data on derelict fishing gear, but coverage remains limited.		
Work has been done by organizations like SkyTruth (https://skytruth.org/2020/02/title-a-systematic- search-for-bilge-dumping-at-sea-2019-in-review/) and the methods exist to make detections from remote sensed data (https://uit.no/Content/396835/IGARSS2012_skrunes_final.pdf; https://skytruth.org/oil- spill-reports/oil-spill-reporting-resources/how-we-determine-oil-spill-volume/). Resources exist for detection and response to oil spills (https://www.un-spider.org/links-and-resources/data-sources/daotm- oil-spill) but evaluating slicks and spills for high seas regions is limited by SAR data coverage.	Appendix 1; Figures 1, 2, and 3 Pg. 75	
Limited spatial data. Information available in a report by ITOPF (https://www.itopf.org/fileadmin/uploads/itopf/data/Photos/Statistics/Oil_Spill_Stats_brochure_2022. pdf) but without associated spatial data/		Pg. 76
Contamination incident reporting is mostly confined to national waters with little coverage in the high seas.	Appendix 1; Figure 4	
The ICCAT Sub-Committee on Ecosystems has reviewed the use of Mean Trophic Level of the catch (MTLc) as an indicator of relative impact from fisheries, however cumulative impacts on the food web structure and biodiversity remain poorly understood. Currently, a Pilot Ecosystem Plan has been proposed for the Tropical Atlantic Ecoregion, while the same for the Northern Subtropical Atlantic Ecoregion has yet to be initiated.		Pg. 88, 126
It is imperative to note that fishing vessel corporate governance structure is not confirmed with the fishing corporations themselves. If a company is not publicly traded, we are unlikely to ever confirm the true ownership structure.		Pg. 95
Although ballast water is one of the best studied vectors of aquatic invasive species related to maritime traffic, creating direct linkages to the presence of non-native and invasive species with specific ballast discharge behaviors is challenging due to a dearth of reporting data on ballast discharge events.	Figure 36	Pg. 74
Underreporting remains the central barrier to creating a comprehensive record of ship strikes globally and future efforts to understand physical interactions between cetaceans, as well as other impacted species, will depend on improved reporting.	Figure 37	Pg. 76, 124
Enhanced in situ data collection is also needed to better understand the profile of ambient noise in and around the Sargasso Sea.	Figure 38	Pg. 77, 124
Although summarizations presented in this report suggest potential areas of conflict between shipping traffic and sensitive species, more in-depth analyses are needed to determine exactly how these groups interact in situ and how this translates into collision risk. With the estimation of ship strikes limited to extremely coarse data (see Shipping section), the establishment of area-based closures would require a more accurate assessment of how, when and where vessels interact with certain species.		Pg. 78, 124
Existing high resolution remote sensing for Sargassum detection is focussed primarily on the tropical Atlantic and does not include enough temporal depth to build spatial patterns or climatoligies for the SS	Appendix 1; Figures 1 and 2	
All Aquamap models are projected using climatological information and therefore only provide a multiannual snapshot of the habitat suitability for each species, offering no insights on the seasonal range changes.		Pg. 28 Pg. 49
While some of the IUCN range polygons provide information on breeding and non-breeding ranges for some species, there is no intra-annual information which in turn does not allow for the exploration of seasonal changes.		Pg. 30
The distribution of OBIS records demonstrates the need for enhanced data collection efforts in the SS MFE and GAC		Pg. 21
Of primary importance in managing the impacts of global climate change on the CRTD ecosystem is the enhanced understanding of regional biodiversity and ecological connectivity. Foremost would be the expansion of efforts towards performing IUCN assessments for species that occur in this feature.		Pg. 30

concentration corresponds with broader oceanographic patterns (Eriksen et al. 2019). With the same mechanisms driving aggregation of *Sargassum* and other anthropogenic pollutants, such as microplastics (Barstow 1983), it is likely that areas of pollutant accumulation overlap spatially with *Sargassum* mats. It will therefore be critical to monitor pollutants, such as microplastics to maintain the health of sensitive populations associated with this feature.

For example, sea turtles are one of several marine species that are susceptible to plastic ingestion (Witherington et al. 2012; López-Martínez et al. 2021). The SS supports the developmental stages of the Atlantic loggerhead turtle (see Focal Species section) in addition to acting as an opportunistic foraging site for other sea turtle species (Carr 1987; Meylan et al. 2011; Mansfield et al. 2014, 2021). For sea turtles that forage in and around the SS, the aggregation of microplastic pollutants has significant implications for their overall health and fitness (Miller et al. 2020; López-Martínez et al. 2021). Given the ecological significance of the SS as a feeding area for a wide array of species, the enhanced understanding of the distribution of plastic, as well as other contaminants, within this area is critical.

Our summarization of microplastic distribution provides valuable insight into how these pollutants may behave in and around the SS, revealing a degree of seasonality in aggregations that could help inform management decisions. However, a lack of robust spatial data on marine plastic distribution as well as sources of these pollutants is a major barrier to identifying areas of concern. Additionally, more information is needed to understand the behavior of other marine pollutants in this study area.

Although mechanisms of aggregation may be the same for oil, chemical and microplastic contaminants, the results outlined here are likely not a reliable proxy for other pollutants. The paucity of data pertaining to this other class of contaminants prevented us from evaluating their spatial distribution and impact on this environment as a parallel to microplastics (see the Gaps Analysis section).

Vessel Traffic and Biological Communities

The area in and around the SS is an important corridor for maritime traffic, serving as a major shipping route for vessels traveling between North America and Europe. Cargo vessels have the highest transit time and make up for the largest portion of total vessel traffic that intersects with the GAC, making this a focal sector when addressing impacts of vessel traffic to the ecology of this feature. Cargo vessel traffic shows mild seasonality in the high-traffic lanes connecting the major U.S. ports to the eastern Atlantic and the Caribbean, with a small decrease in traffic volume from June through September. This high-traffic cargo lane has significant implications for biological communities of the SS, with noise pollution and mortality from ship strikes directly related to vessel load as well as the speed at which they travel (Vanderlaan and Taggart 2006; Hildebrand 2009). Although results from our analysis indicate that mean vessel tonnage has decreased over the study period, studies show that the global cargo vessel fleet today is significantly larger than 20 years ago (UNCAD 2020) and that commercial shipping activity is projected to continue increasing in the coming years (Kaplan and Solomon 2016). It is therefore important to continue monitoring vessel traffic to understand how these predictions reflect trends seen in shipping activity in and around the SS, and to assess implications for the impacts of the shipping sector on the SS ecosystem.

Noise pollution associated with vessel traffic degrades the soundscape of the underwater environment, impacting marine communities' ability to communicate, forage, and perform other essential functions (Putland et al. 2018). For example, cargo vessels emit low-frequency underwater noise (< 1,000 Hz), which can mask vocalizations, increase stress, and result in habituation to ship presence among cetaceans (McKenna 2011). Low frequency noise emissions are also relevant for many fish species (Hawkins et al. 2018; Mitson and Knudsen, 2003) and research suggests that both the American and European eel are sensitive to underwater noise at these frequencies (Popper et al. 2020). The spatial distribution of shipping-related underwater noise shows that high energy output at lower frequencies is associated with two central shipping routes that transit in proximity to both American and European eel breeding areas. Both American and European eels migrate thousands of miles towards the SS to spawn from the fall to spring. Both species are particularly sensitive and have actively declining populations.

While more research is required to assess how fishes are impacted by noise emissions from vessel (Hawkins and Popper, 2017), eels represent a particularly sensitive species that uses this feature to support various stages of its life history and could be affected by vessel activity in the region.

Ship strikes from large vessels often result in significant injury or death for marine mammals (Berman- Kowalewski et al. 2010). One of the many cetacean species impacted by physical interactions with maritime traffic is the humpback whale, which has recovered from severely depleted numbers and can be found throughout the Atlantic (see above). North Atlantic humpback whales migrate through the SS, with some populations using the AOI for opportunistic foraging. Although humpbacks are not of critical conservation concern, vessel strikes continue to be one of the primary anthropogenic threats to this species in the region (Roman et al. 2013; RWSC 2023) and there is limited data pertaining to vessel strike incidence for the SS area. With Bermuda as an important stop-over site for this species between December and May, high in cargo vessel activity during the latter month and an increase in passenger and tanker vessel traffic during the former suggests potential impacts to migrating humpbacks. There is also significant overlap between some of the major shipping lanes that transit the northern half of the GAC and high predicted suitable habitat distribution. Generally, vessel strikes in the FAO region overlapping with the SS were some of the highest in the North Atlantic. Together, these elements suggest that shipping activity in the SS negatively impacts humpbacks whales, as well as the broader cetacean community that occurs within this feature. Together, the summarization of the life history and ecology of species, like the humpback whale, European, and American eels, as well as the assessment of inter and intra-annual vessel traffic dynamics can help inform meaningful management initiatives.

Speed restrictions are a widely used measure for reducing the frequency of ship strikes. Research shows that speed restrictions of 10 knots reduce mortality rates in large cetacean species resulting from of the vessel interactions (Vanderlaan and Taggart 2007; NOAA 2008; Conn and Silber 2013) and have also been shown to substantially reduce noise impacts to these communities (Findlay et al. 2023). With the intersection between high-traffic vessel lanes and the SS, the implementation of vessel speed restrictions could be an effective method for reducing harmful interactions with whales. These measures might focus on the period when vessel volume along high-traffic lanes appear highest: January, March, April, and May. Additionally, vessel speed restriction measures might be implemented primarily in areas where high volume vessel traffic lanes overlap with critical biological habitat, such as spawning grounds for the European and American eel.

Another mechanism for mitigating vessel traffic impacts to sensitive communities include area-based closures. This process begins with defining priority areas for sensitive species, such as estimations of ship-whale interactions to inform the selection of areas with the highest conservation impact. Although the above report reveals potential areas of conflict between shipping traffic and sensitive species, significantly more in-depth analyses are needed to determine exactly how these groups interact *in situ*. With the estimation of ship strikes limited to extremely coarse data (see shipping section above), the establishment of area-based closures would require a more accurate assessment of how, when and where vessels interact with certain species. Currently, many studies assume that interactions occur based on spatial overlap between known species range and vessel activity. While this may be likely, a more in-depth analysis of the timing of species' habitat uses and resultant interactions with maritime traffic will be crucial for creating accurate and effective area-based closures.

It's important to highlight the implications of data availability on the effective assessment the shipping sector and its impact on the SS. Our syntheses of data pertaining to ship strikes and underwater noise levels in the study area highlight the need for enhanced data collection and evaluation. For ship strikes, this means improved interaction reporting and the application of methodologies for assessing the probability of cetacean-whale interactions. Enhanced spatial coverage of *in situ* data collection is also needed to better understand the profile of ambient noise in and around the SS. These data, along withspecies distribution information and vessel traffic summarizations (see above) will be crucial to evaluating the impacts of vessel traffic on biological communities of the SS. Elements of our analyses, such as vessel traffic summarizations, are a key component of determining outcomes from direct and indirect interactions with shipping traffic for the biological communities of the SS. These elements will be integral in developing more in-depth analyses to inform effective management strategies.

Fishing Effort and Sustainability in the Sargasso Sea

Generally, industrial fishing activity in the SS region is largely aggregated outside the SS GAC, with fishingeffort in adjacent jurisdictional and High Seas waters greatly exceeded that of the SS GAC. Fishing in these surrounding areas is relatively robust and largely made up of pelagic longline fisheries that target species such as swordfish and albacore tuna. Most commercial fishing occurs in adjacent jurisdictional waters, primarily in coastal areas around Canada and the U.S., but also in the High Seas area northeast of the GAC. For the area outside the GAC, the peak effort occurs in July and declines from November to March. The opposite is true for the GAC, where the highest effort occurs from January to June and declines from July to December. During this time, effort extends into the GAC primarily from the northeast and, to a lesser degree, from the south/southeast. There is more variability of monthly effort in ABNJ outside of the GAC than there is within the GAC, suggesting there are seasonal trends influencing fishing effort within the GAC that may not be factors for the wider region. However, an assessment of ecological connectivity through the co-occurrence of captured species shows that economically valuable fishes are captured both within and beyond jurisdictional waters, suggesting that both areas support economically important fish populations.

In the overlapping area between the Sargasso Sea and the NAFO convention area, there are several protected seamounts closed to bottom fishing while the main fishing gear observed in this overlap area is drifting longlines. Spain dominates fishing activities in the overlapping NAFO subareas, with Portugal contributing a smaller proportion. The catch primarily consists of large pelagic species such as blue sharks, mako sharks and swordfish. Fishing activities show a peak in May, accounting for a significant portion of the total catch volume. Blue sharks are the dominant species caught in the northern boundary of the Sargasso Sea, with the Spanish fleet playing a major role. Fisheries catches are concentrated in NAFO subareas 6F, 6G, and 6H, with 6H having the highest catch volume. Since blue sharks are not one of the main species managed by NAFO, this raises questions about the sustainability of this established fishery and whether area-based management tools could be used to manage some ofthe fishing grounds within the SS GAC.

The entirety of Sargasso Sea GAC and MFE fall within the boundaries of the ICCAT RFMO. Effort data from ICCAT suggests that, although commercial fishing activity occurs within this region, catch from within the SS GAC is not significant in the context of the greater North Atlantic fisheries. Since the start of ICCAT's longline time series in 1956, the importance of the MFE and GAC has been relatively low. For example, of the 175 million longline fishing hooks set within ICCAT in 2021, only 1.4% were set within the GAC. Taiwan appears to be responsible for the majority of longlining effort in the GAC followed by Japan and South Korea. Bycatch incidence by these vessels is not significant in the SS region and management initiatives focused on sustainable fishing practices exist in this region.

Effective management of fisheries and associated ecological impacts in the SS can be separated into two primary areas of interest: improving the body of knowledge surrounding ecosystem pressures and addressing known sustainability issues. The ICCAT Subcommittee on Ecosystems has proposed dividing the convention area into seven ecological regions based on biogeography, oceanographic characteristics, species distributions, and fishing fleet patterns (Juan-Jordá et al. 2019), aiming to guide ecosystem planning and assessment of potential pressures. Currently, the ICCAT Sub-Committee on Ecosystems has reviewed the use of Mean Trophic Level of the catch (MTLc) as an indicator of relative impact from fisheries, however cumulative impacts on the food web structure and biodiversity remain poorly understood. Currently, a Pilot Ecosystem Plan has been proposed for the Tropical Atlantic Ecoregion, while the same for the Northern Subtropical Atlantic Ecoregion has yet to be initiated. The initiation of a dialogue with ICCAT, particularly regarding a Pilot Ecosystem Plan, will be paramount to the establishment of any conservation management measure (CMM), especially throughout the consultation phase required by the BBNJ treaty for the designation of new area based management tools (ABMT).

NAFO plays a crucial role to ensure the protection of VMEs and the overall sustainability of the marine ecosystems in this shared region. This highlights the importance of cooperative efforts between organizations and stakeholders to maintain the health and resilience of these overlapping marine environments. With a substantial portion of catch made up of pelagic species, such as blue sharks, that are not managed by NAFO, the sustainability of these fisheries is uncertain. Area-based management tools could be used to preserve certain fishing grounds within the GAC while protecting areas that are important to overlapping biological communities. In fact, in the overlapping area between the Sargasso Sea and NAFO, there are several protected seamounts and VMEs which could inform any proposed fisheries management measure under the new BBNJ agreement. Additionally, mechanisms presented in the Beneficial Ownership section above may be a particularly useful to management efforts in this area. As a largely High Seas feature with distant water organizations dominating catch, the incorporation of corporate accountability mechanisms for the management of the SS may help boost effectiveness of new management strategies. While there are certain limitations to corporate accountability mechanisms, including access to ownership data resulting from the lack of corporate transparency, the combination of these and more traditional regional planning through consensus-based mechanisms might offer the most effective management strategies.

Global Climate Change

As the global climate warms, marine ecosystems experience shifts to biogeochemical characteristics (Reygondeau et al. 2020) with broader implications for species assemblages. In the SS, the physical oceanographic and environmental variables we have implemented in the description of this feature in space and time (see above) are likely to change. The outcomes of these changes for biological communities and ecosystem structure can be both direct and indirect. Many marine species are sensitive to changes in temperature, salinity, and pH levels. Indeed, some of the sensitive species highlighted in this report (see Focal Species section) use environmental cues to orchestrate key life history stages. For example, the European eel, migrates from the Mid-Atlantic Ridge to spawning grounds in and around the Sargasso Sea, requiring water temperatures within a narrow range of 22°C - 24°C to successfully breed (Wright et al. 2022). The projected changes to SST temperatures in the North Atlantic shown by our difference of means analysis will likely affect this migration, with serious impacts to a species already suffering from significant population depletion. In addition to shifts in behavior of sensitive species that occur within this feature, drastic changes in SST are also likely to impact the integrity of the SS as habitat for these communities. Graba-Landry et al. (2020) showed that elevated temperature impacts the survival of a *Sargassum* algae (*S. swartsii*) and while it remains to be seen specifically how temperature impacts the two dominant *Sargassum* species of the SS, warming patterns revealed in our analyses suggest broader implications for the integrity of *Sargassum* mats.

Changes to the biogeochemical conditions of the SS will also likely impact species assemblages and biodiversity in the region. In Deliverable 1 of this project (summarized above) we used primary productivity (among other variables) in the characterization of potential sub-regions of this feature to provide environmental context for the ecosystem and human use information we have summarized in this report. Climate-induced stressors, such as changes in ocean temperature and increased CO2 levels in ocean waters, can alter the community composition of phytoplankton and reduce overall primary productivity (Gao et al. 2012; Roxy et al. 2015). Primary productivity acts as a foundation for marine food webs (Brown et al. 2010; Blanchard et al. 2012) and high levels of primary productivity have generally been associated with biodiversity hot spots (Ramírez et al. 2017). Changes to primary production dynamics will likely result in alterations to trophic linkages with broader implications for the recruitment success of higher trophic levels and regional biodiversity in the SS.

The co-occurrence of species in the SS as well as within and beyond national jurisdiction suggests connectivity between the biological communities of these areas. This aligns with evidence showing that regional oceanographic features, such as the Gulf Stream and anticyclonic eddies, play a central role in species dispersal (Chang et al. 2018; Devine et al. 2021) with aggregations of species occurring at the heart of the North Atlantic Gyre by the same mechanisms that aggregate *Sargassum* in this area.

Together, the transportation and aggregation of biota by way of the oceanographic features in and around the SS provide evidence for cross-stream transport between coastal areas and the High Seas(Bower and Rossby 1989), potentially driving the regional biodiversity. Given the evidence of strongecological connectivity within the SS, declines in primary productivity in sub-regions of the AOI and related changes to species assemblages will likely have cascading effects on broader regional biodiversity.

Of primary importance in managing the impacts of global climate change on the SS ecosystem is the enhanced understanding of regional biodiversity, ecological connectivity and resilience. Foremost wouldbe the expansion of efforts towards performing IUCN assessments for species that occur in this feature. A large percentage of the biological community of the SS is without an IUCN assessment which limits ourability to accurately evaluate what proportion of the overall species assemblage is considered threatened. This metric is valuable in the assessment of the SS as a critical site for sensitive marine communities and evaluation of its ecological health and resilience. More broadly, these assessments would help describe the ecological role of the SS in the context of regional biodiversity in the North Atlantic. It would also be beneficial to improve the spatial coverage of biodiversity data, such as the OBIS database, to ensure that estimations of biodiversity and ecological connectivity presented here areas complete as possible. Finally, research regarding the effects of climate change on the Gulf stream andassociated oceanographic dynamics are ongoing and a consensus has yet to be established on how exactly climate change may impact these phenomena. Advancements in this field will be crucial for understanding the physical aspects of changes to the SS, which will undoubtably have implications for species assemblages and regional biodiversity in this area of the North Atlantic.

Implications for the Biodiversity Beyond National Jurisdiction Treaty

By establishing a list of 22 indicative criteria for identifying area-based management tools in the High Seas, the new BBNJ treaty provides a framework for the conservation and sustainable management of areas beyond national jurisdiction based on a wide range of indicators. Leveraging the wealth of scientific information available in the SS is of paramount importance in designing the most appropriate measures which are capable of abating the specific threats to marine biodiversity in the region. The BBNJ treaty underscores the crucial role that scientific information plays in shaping effective and evidence-based management measures, marking a significant step toward a more sustainable and resilient future for our global marine ecosystems. Here we provide an initial overview of the indicators which may be best supported by the scientific information compiled throughout this report.

While no official definitions for the indicative criteria under Annex I of the BBNJ treaty text have yet been provided, given the similarity of these with the range of criteria used to describe ecologically or biologically significant areas (EBSAs) under the Convention on Biological Diversity (CBD), definitions for the latter were used to inform the interpretation of the available scientific information. There seems to be sufficient evidence in support of the following 10 indicative criteria towards the design of area-based management tools in the GAC area, for which we provide suggested interpretations:

(a) Uniqueness: Refers to the distinctiveness or exceptional nature of a particular area or ecosystem in terms of its biological, ecological, or physical characteristics (see Deliverable 1 Report and this report).

(b) Rarity: Relates to the scarcity or limited occurrence of a specific species, habitat, or ecosystem type within a given geographic area (see Deliverable 1 Report and this report).

(c) Special importance for the life history stages of species: Describes areas that play a critical role in the life cycle of species, such as breeding, spawning, nursery, feeding, or migration grounds (see Focal Species Section).

(e) Importance for threatened, endangered, or declining species or habitats: Refers to areas that are crucial for the survival, recovery, or conservation of species or habitats facing significant threats or population decline (see Threatened Species and Focal Species sections).

(f) Vulnerability, including to climate change and ocean acidification: Denotes areas that are particularly susceptible to negative impacts from climate change, ocean acidification, or other stressors, potentially leading to ecological disruption or species loss (see Deliverable 1 report, Threatened Species, and Focal Species sections of this report).

(i) Biological diversity and productivity: Encompasses areas with high species richness, genetic diversity, or productivity, indicating their ecological significance and value (see Regional Biodiversity section).

(m) Ecological connectivity: Describes the interconnectedness or functional linkages between different habitats or ecosystems, facilitating the movement of species, nutrients, or ecological processes (see Regional Biodiversity section and Economic Connectivity of Fisheries section).

(n) Important ecological processes occurring therein: Pertains to areas where critical ecological functions, such as nutrient cycling, energy flow, or ecosystem dynamics, take place (see Deliverable 1 Report).

(o) Economic and social factors: Considers the economic and social aspects associated with the use, conservation, or sustainable management of High Seas biodiversity, including potential benefits and impacts on human societies (see Human Use section).

(q) Cumulative and transboundary impacts: Refers to the combined or additive effects of various activities or stressors on High Seas biodiversity, including those that cross national boundaries or affect multiple areas (see Regional Biodiversity, Focal Species, Economic Connectivity of Fisheries, Fishing Effort, Shipping, and Discussion and Conclusion sections).

Various seamounts and VMEs have been protected from bottom fishing across the northern portion of the SS, which overlaps with the NAFO regional fisheries body. The BBNJ treaty has provisions that allow for the recognition of existing ABMTs in other sectoral or regional bodies as measures compatible with the objectives of the treaty. By integrating existing measures into the management plan of a SS ABMT, proponents could help build bridges between NAFO and the new BBNJ instrument.

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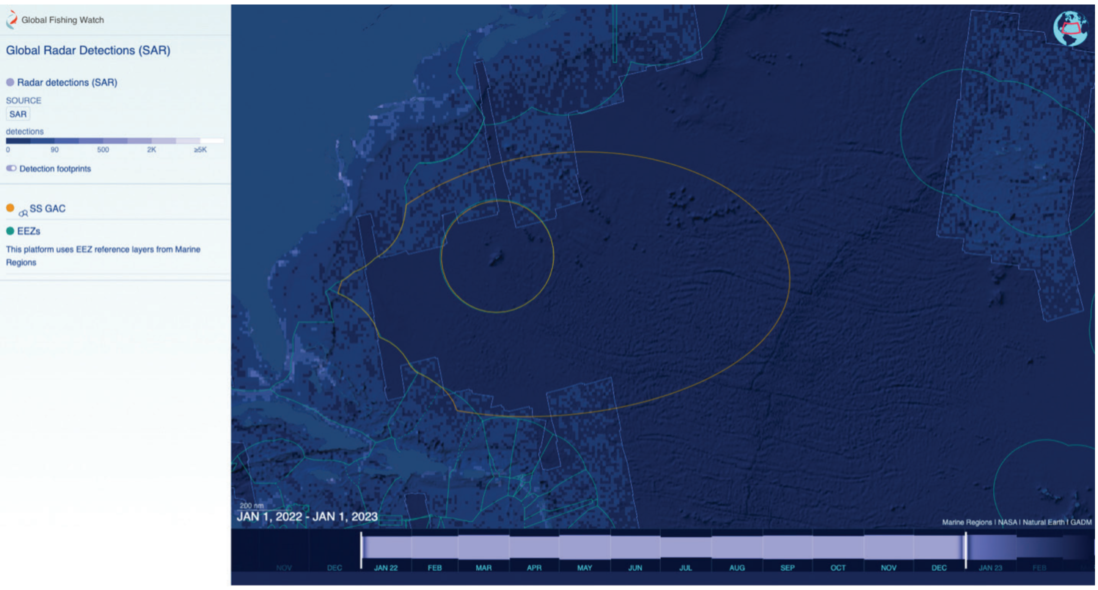
Appendix 1: Gap Analysis Figures



This platform uses EEZ reference layers from Marine Regions

FIGURE 1. Synthetic Aperture Radar coverage and detections for 2022, Sargasso Sea Geographical Area ofCollaboration (from https://globalfishingwatch.org/)

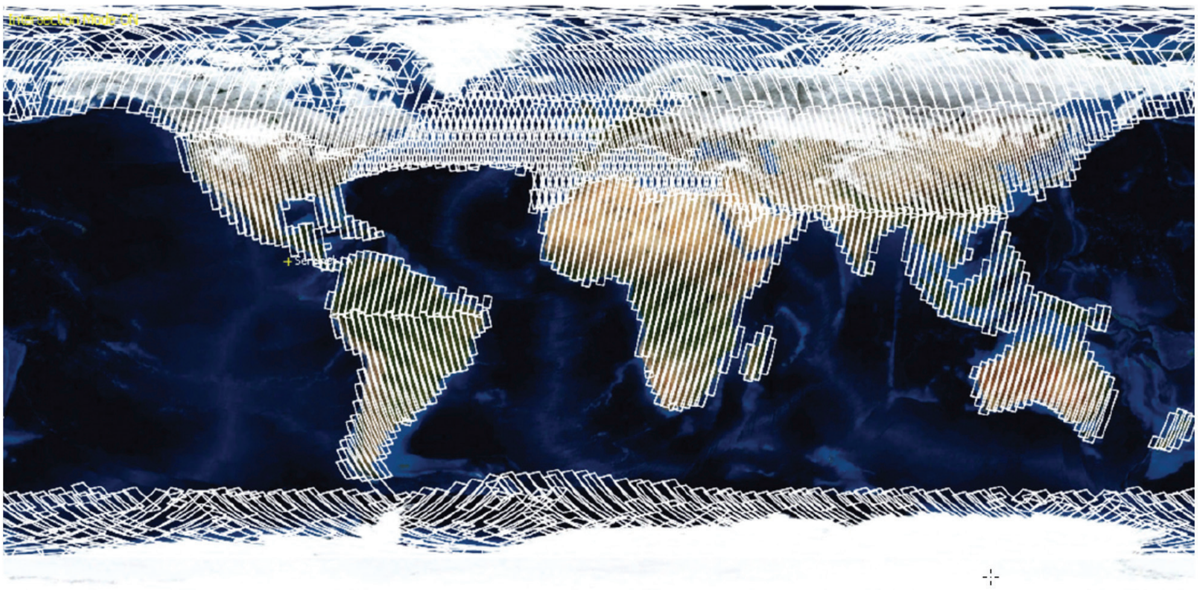
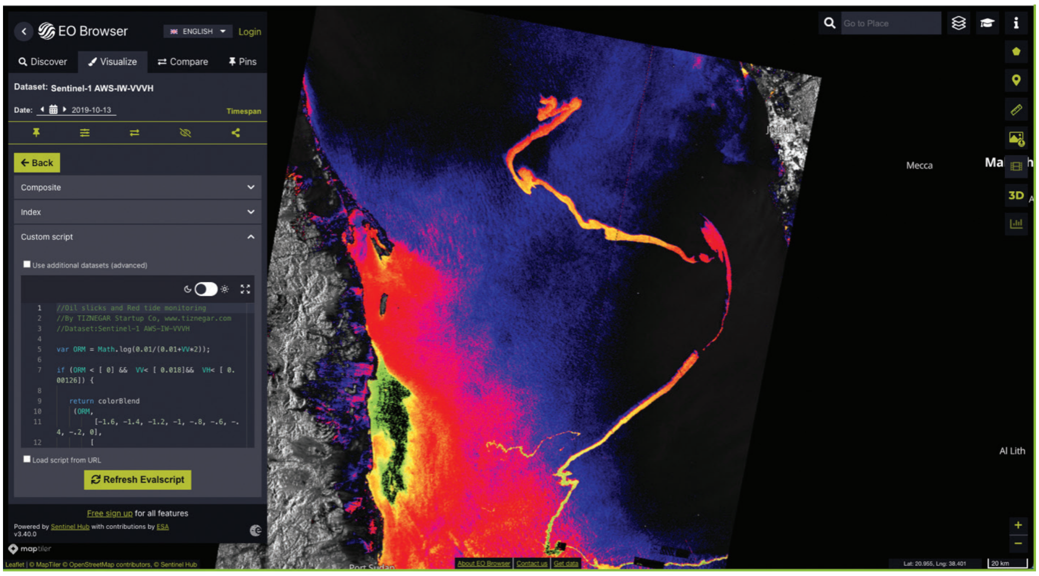


FIGURE 2. Global synthetic aperture radar coverage for Sentinel 1 satellite (from: https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/satellite-description/geographical- coverage).



Dataset: Sentinel-1 AWS-IW-VVVH

Date: 2019-10-13

☐ Use additional datasets (advanced)

```
//Oil slicks and Red tide monitoring
//By TIZNEGAR Startup Co, www.tiznegar.com
//Dataset:Sentinel-1 AWS-IW-VVVH

var ORM = Math.log(0.01/(0.01+VV*2));

if (ORM < [ 0] &&  VV< [ 0.018]&&  VH< [ 0.
00126]) {

    return colorBlend
     (ORM,
          [-1.6, -1.4, -1.2, -1, -.8, -.6, -.
4, -.2, 0],
          [
```

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FIGURE 3. Oil spill detection imagery in the Red Sea with Sentinel 1 SAR data (from the Sentinel Data Hub, https://apps.sentinel-hub.com/).

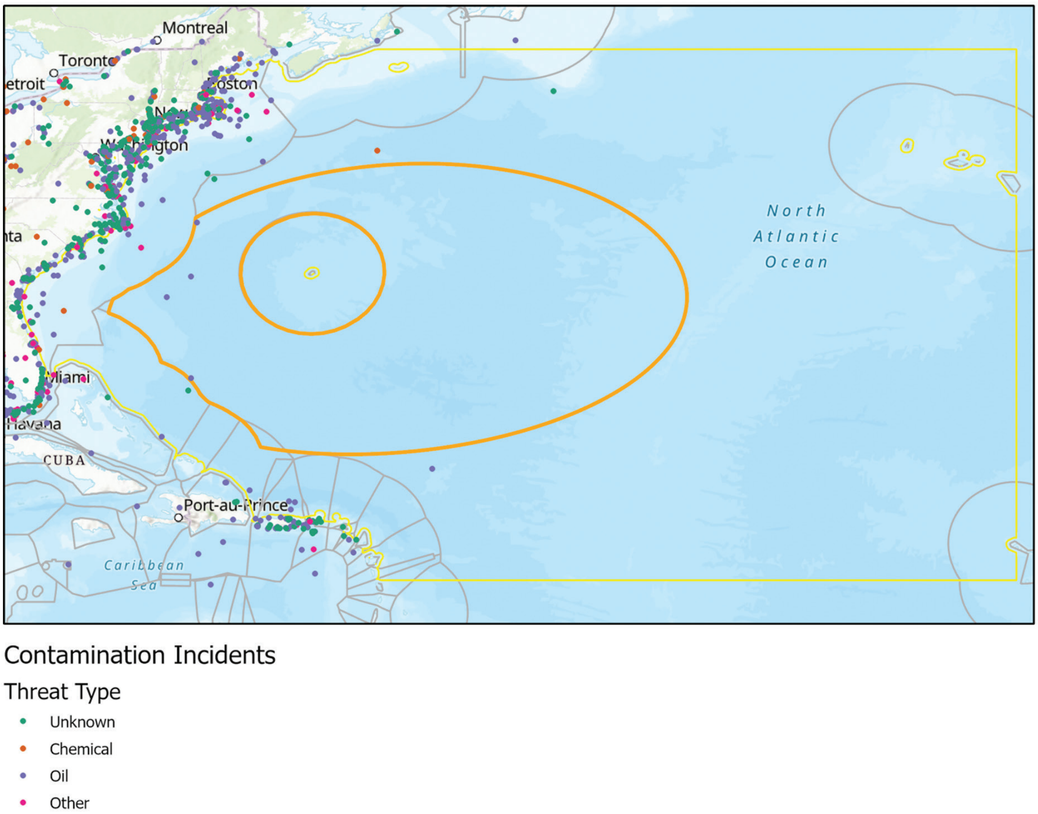

FIGURE 4. Incident events from https://incidentnews.noaa.gov/raw/index; reporting is mostly limited to national waters and doesn't include the High Seas area, including the SS AOI.

SARGADOM

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