## Title
A Little Bit of Sargassum Goes A Long Way: Observations and Mapping of Sargassum fluitans and Sargassum natans from NOAA Ship Okeanos Explorer's ROV Deep Discoverer



## Author
Pries, Ashley

## Publication Date
2020-06-01

# **A Little Bit of *Sargassum* Goes A Long Way: Observations of *Sargassum fluitans* and *Sargassum natans* from NOAA Ship *Okeanos Explorer's* ROV *Deep Discoverer***

Ashley Pries
Masters of Advanced Studies Candidate – Marine Biodiversity and Conservation
Scripps Institution of Oceanography, UCSD

June 11, 2020

*Capstone Advisory Committee:*

Heidi Batchelor, M.A. (Chair)
Scripps Institution of Oceanography, Marine Physical Laboratory

Amanda N. Netburn, PhD
NOAA Office of Ocean Exploration and Research

Victoria Hermanson, M.A.S.
NOAA Southwest Fisheries

*Capstone Advisory Committee Approval*:

Signature: heidi batchelor Date: 06/09/2020
Heidi Batchelor, M.A., SIO (Chair)

Signature: ______________ Date: 6/11/2020
Amanda Netburn, PhD, NOAA

Signature: ______________ Date: 6/10/2020
Victoria Hermanson, M.A.S., NOAA

**Abstract**

The ocean's biological pump connects the surface ocean, where light-driven photosynthetic processes fix dissolved carbon dioxide ($CO_2$) to the ocean's mesopelagic zone (approx. 200 – 1000 meters) and beyond. It is a process that depletes the ocean's surface of $CO_2$ relative to the $CO_2$ in deep water through mechanisms such as the sinking of organic material to the deep ocean (Volk and Hoffert, 2013).

The Atlantic Ocean features high productivity of the macroalgae genus *Sargassum* floating on the ocean's surface in the Sargasso Sea, and in recent years giant blooms of the brown macroalgae *Sargassum* have been observed stretching from the west coast of Africa to the Gulf of Mexico, the largest macroalgae bloom that has ever been recorded (Wang et al., 2019). The sinking of macroalgae from surface waters to the seafloor is considered to be an important carbon sink, but one that is little understood. With the logistical challenges of accessing the deep sea, the record of *Sargassum* appearing on the seafloor remains limited.

This project utilized an archived exploratory dataset that is freely available to the public, in order to make novel discoveries in previously unexplored areas. The following report documents the presence and distribution of *Sargassum* falls in the deep sea during six dives conducted by NOAA Ship *Okeanos Explorer*'s ROV *Deep Discoverer* off the Southeastern United States, in the Gulf of Mexico, and in the Caribbean. *Sargassum* was observed on each of the dives, in numbers ranging from 6 to 30 observations per dive, with *Sargassum* being observed an average of every 171 linear meters. This suggests that *Sargassum* does make its way to the deep sea, in potentially significant amounts.

**Introduction**

*Macroalgae*

Macroalgae, like those in the genus *Sargassum,* provide many important ecological, environmental, and economic services. For instance, algae fix carbon dioxide ($CO_2$) by providing long-term storage of organic carbon in coastal sediments and in the deep ocean (Raven, 2017). This prevents it from returning to the atmosphere as a heat-trapping gas, as the $CO_2$ can remain sequestered in the deep ocean for hundreds to thousands of years. Algae are also being studied for potential use as a biofuel, and the cultivation of seaweed aquaculture beds is being proposed as a possible strategy to reduce ocean surface $CO_2$ by increasing the area in which macroalgae, or seaweed, grow (Duarte et al., 2017). However, when it occurs in abundance, macroalgae can outcompete or smother other photosynthetic organisms and can wash ashore in noxious heaps (Rodríguez-Martínez et al., 2019).

*Sargassum Biology*

*Sargassum* is a genus of brown macroalgae that is widespread in temperate, subtropical and tropical waters. *Sargassum* bodies are typically highly differentiated into a holdfast, a cylindrical main axis, leaflike blades, and air bladders, or pneumatocysts, in the axils of blades (Graham et al., 2009). A robust and flexible body helps it withstand strong water currents. There are two species of *Sargassum* that occur in the Atlantic Ocean off the coast of the United States and in the Gulf of Mexico: *Sargassum fluitans* and *Sargassum natans.* These forms are unique in that they are free-floating and do not have a holdfast. They are the only species of *Sargassum* that are holopelagic, meaning that they remain pelagic throughout their entire life cycle, and free-floating *Sargassum* is found only in the Atlantic Ocean (Doyle and Franks, 2015).

These free-floating species can occur in extensive rafts that harbor distinctive communities of organisms adapted to the buoyant *Sargassum* habitat. *Sargassum natans* and *Sargassum fluitans* reproduce through fragmentation, a type of vegetative asexual reproduction where a thallus breaks into two or more parts, each of which then forms a new thallus (Lee, 2008). *Sargassum*'s fast growth rate contributes to its rapid spread.

Hereafter in this paper both *Sargassum fluitans* and *Sargassum natans* will be referred to as *"Sargassum"*.

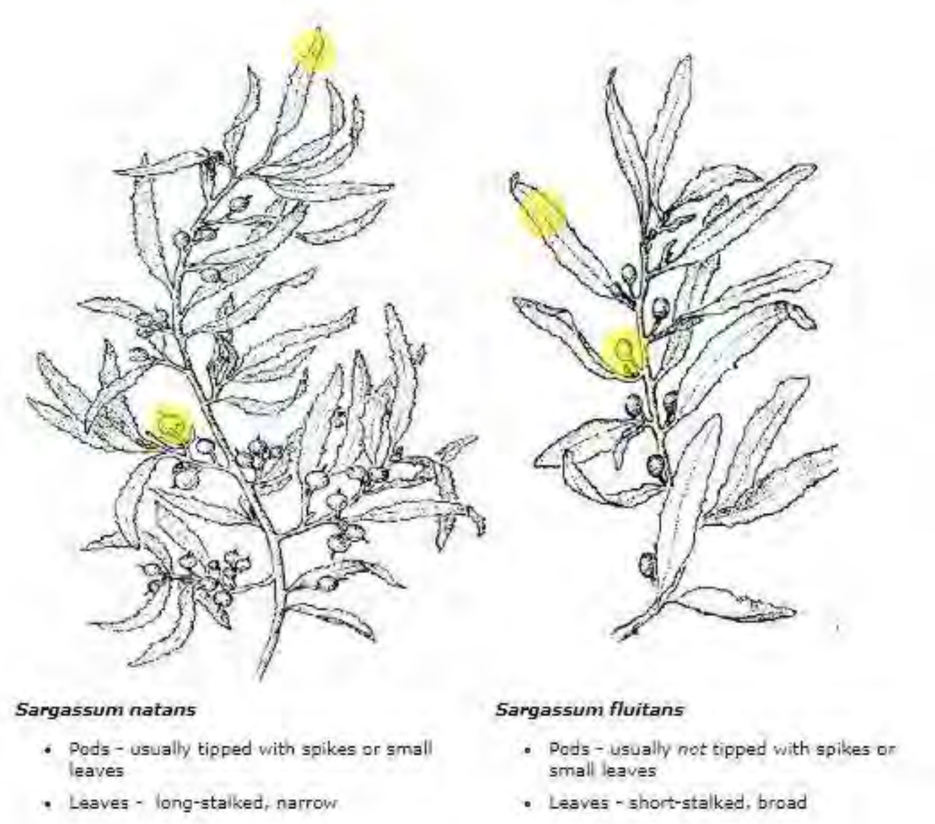



*Figure 1 Drawing of Sargassum natans and Sargassum fluitans displaying morphological differences. Illustration by Julia S. Child (Schneider and Searles, 1991)*

## *Sargassum Blooms*

The North Atlantic Gyre is circular system of ocean currents in the Atlantic Ocean that, through the rotating pattern of ocean currents and effects of wind and weather, have amassed the *Sargassum* in an area known as the Sargasso Sea, the only sea to be bounded by currents rather than by land (NOAA, Oct. 2019). The surface waters off the southeastern United States are dynamic and constantly in motion due to wind-driven waves and the northward flow of the Gulf Stream. The Gulf Stream acts as a conduit that transports the floating pelagic brown algae through the Caribbean, into the Gulf of Mexico, and off the coast of the southeastern United States, and evidence suggests that much of the *Sargassum* transported through the Gulf of Mexico originates from the North Equatorial Recirculation Region in addition to the Sargasso Sea (Franks et al., 2016).

In addition to the *Sargassum* mats in the Sargasso Sea, since 2011 giant floating *Sargassum* mats in the Atlantic have increased in density and aerial extent to generate an 8,850 km-long belt, called the Great Atlantic *Sargassum* Belt, that often extends from West Africa to the Gulf of Mexico (Wang et al., 2019). Beaches in the Gulf of Mexico and the Caribbean have in recent years seen high quantities of *Sargassum* washing up, presenting a logistical challenge for cities to manage the tons of seaweed piling up on their shores (Conley and Oliver, 2019, Lamb, 2018).

In recent years increasing effort has been made to quantify the amount of *Sargassum* on the surface through methods such as satellite imagery analysis, numerical models, and field measurements. For instance, a 2019 study by Wang et al. analyzing satellite data from 2000 to 2018 found a significant increase in abundance of the *Sargassum* biomass that forms the Great Atlantic *Sargassum* Belt beginning in 2011, with the highest biomass estimated at more than 20 million metric tons in June 2018 (Wang et al., 2019). The abundance of *Sargassum* on the ocean surface and washing up on beaches has spurred the development of *Sargassum* monitoring systems (Valentini and Balouin, 2020, Duffy et al. 2019).

Climate plays a significant role in the transport, aggregation, or scattering of pelagic *Sargassum* by affecting hydrographic processes such as air pressure systems and currents as well as affecting algal productivity (Sanchez-Rubio et al., 2018). A changing climate may have unexpected impacts on the productivity of *Sargassum* as well as its ability to be transported, aggregated, or scattered. As the process of *Sargassum* dying, deteriorating enough to sink, and sinking to the depths is poorly understood, disruption to weather patterns and ocean currents may have unforeseen consequences on this important carbon sink.

*Sargassum Ecology*

*Sargassum* is abundant in the Atlantic Ocean and forms an essential surface habitat that supports a diverse assemblage of marine organisms, including fish, invertebrates, sea turtles, marine birds, and marine mammals. Floating *Sargassum* mats serve as a primary nursery area for many fishes, some of which are commercially important (dolphinfishes, jacks and amberjacks), and they provide a source of energy in an otherwise nutrient-poor area of the Atlantic (Casazza and Ross, 2010). These *Sargassum* mats provide essential habitat for approximately 120 species of fish and more than 120 species of invertebrates (Doyle and Franks, 2015).

Carbon sequestration is the process of storing carbon dioxide and other forms of carbon out of the atmosphere for long periods of time. Marine primary producers such as phytoplankton, seaweeds and seagrasses are more efficient carbon sequestering agents than their terrestrial counterparts (Arenas and Vaz-Pinto, 2015). Through photosynthesis, *Sargassum* converts sunlight, carbon dioxide, and ocean nutrients into sugars and other carbon compounds. This organic material, and the carbon it contains, can then end on a number of different pathways, such as washing up on beaches, being eaten by a consumer, or sinking to the bottom of the ocean. Once it ends up in deep ocean currents or seafloor sediments hundreds of meters below the surface, the carbon is prevented from being exchanged with the atmosphere over extended timescales, over several hundred to several thousand years (Volk and Hoffert, 2013). Traditionally, seagrasses and mangroves have been considered the dominant form of oceanic carbon sequestration; however, in recent years researchers have been looking at macroalgae like *Sargassum*'s role as an important carbon sink (Kokubu et al., 2019, Raven, 2017).

The gravitational sinking from the surface to the seafloor, sometimes many hundreds of meters below the surface, is poorly understood, and future study is warranted to quantify the amount of *Sargassum* that ends up on the floor of the deep sea. The mechanisms behind the delivery of drifting macroalgae to marine sediments include wind-induced Langmuir circulation that can entrain floating macroalgal fragments at depth, where pressure can collapse their gas vesicles, rendering the macroalgae negatively buoyant and removing them from the surface (Krause-Jensen and Duarte, 2016). Additionally, *Sargassum* living in the shaded understory of floating *Sargassum* may be prevented from photosynthesizing and lose its buoyancy as the organism dies and starts to degrade.

A 2017 study by Baker et al. estimated the mass of *Sargassum* that is sedimented in the seafloor to be comparable to the *Sargassum* biomass observed at the surface (Baker et al., 2017). This study quantitatively analyzed approximately 27,000 photos of the seafloor taken by automated underwater vehicle (AUV) on three deployments to estimate the surface area covered by *Sargassum* in the photos. The average surface area coverage per picture was then compared with the ratio of *Sargassum* containing pictures to total pictures per AUV deployment to determine a total biomass per deployment. Surface collected *Sargassum* was used to determine an average weight per centimeter squared, to then estimate the biomass of *Sargassum* per square meter in each inspected photo. Analysis of the AUV photos revealed a biomass density ranging from 0.07 $g/m^2$ to $^2$3.75 $g/m^2$, which corresponds to the biomass estimated for *Sargassum* at the ocean's surface (Baker at al., 2017).

Krause-Jensen and Duarte estimated that 11 percent of macroalgal particulate organic carbon (POC) export, or 35 TgC yr–1) reaches the deep sea (Krause-Jensen and Duarte, 2016). However, the factors that are thought to contribute to organic carbon export in the open ocean are driven by a complicated combination of ecological, biogeochemical, and physical oceanographic processes. Developing a predictive understanding of carbon export pathways, like gravitational sinking, is critical for diagnosing present and future rates of ocean carbon sequestration.

Analyses like those mentioned above offer valuable insight into the quantities of *Sargassum* reaching the deep seafloor; however continued investigation in order to replicate results, identify new data sets for a field of study with few opportunities for direct observation, and expand on applications is necessary to understand these important environmental processes. Questions that remain include: What conditions on the surface promote higher rates of *Sargassum* sinking, and how does this sinking impact the fish and invertebrate species associated with floating *Sargassum*? How long does it take before the pneumatocysts fail and the *Sargassum* starts to sink? In what sort of deep-sea habitats does *Sargassum* tend to accumulate, and what oceanographic features contribute to the greatest rate of carbon sequestration for this *Sargassum* detritus? What happens to the *Sargassum* that falls to the deep sea (i.e., is consumed before sedimentation, or buried in sediment? What is the rate of decay in different environments?)

*Okeanos Explorer*

The main objective of NOAA Ship *Okeanos Explorer* (oceanexplorer.noaa.gov/okeanos) operations is to conduct initial exploration of areas that have not previously been explored to enabled follow on research. This exploration is important to (a) fundamentally understand and effectively manage US submerged resources, (b) enable novel insights into benthic ecosystems, and (c) to establish baselines of these habitats to better understand their vulnerability and resilience to change (Kennedy, 2019).

NOAA Ship *Okeanos Explorer* is a 68-meter vessel equipped with a suite of mapping sonars and outfitted with a dual body Remotely Operated Vehicle (ROV) system, *Deep Discover (D2*) and *Seirios*. A unique aspect of *Okeanos Explorer* operations is its ability to collaborate with a host of shore-based scientists in real time through telepresence technology (Peters et al. 2019). Onboard and shore-based scientists collaborate through the use of live-streaming video, a shared conference phone line, a text chatroom, and the SeaTube annotation system to provide real-time, minute-to-minute feedback and scientific expertise during the ROV dives (Kennedy et al., 2016 and Selig et al, 2019).

In keeping with this mission, *Okeanos Explorer* and NOAA's Office of Ocean Exploration and Research (OER) are currently engaged in a collaborative campaign to increase knowledge about deep water communities. The Atlantic Seafloor Partnership for Integrated Research and Exploration, or ASPIRE, is a major multi-year, multi-national collaborative ocean exploration field program focused on raising collective knowledge and understanding of the North Atlantic Ocean (NOAA OER, ASPIRE). The campaign provides data to inform and support research planning and management decisions in the region. Two of the expeditions reviewed – EX1811 and EX1903L2 – were part of this ASPIRE campaign.


*Figure 2 NOAA Ship Okeanos Explorer at sea. Image by Art Howard/NOAA OER*

*Deep Discoverer* and *Seirios* ROVs

There are two ROV's onboard the *Okeanos Explorer*: *Deep Discoverer* (*D2*) and *Seirios,* both operated by the Global Foundation for Ocean Exploration (GFOE). All ROV dives examined in this project were conducted with NOAA's dual body ROV system *Deep Discover (D2*) and *Seirios,* although only video from *D2* was reviewed. The main capability of *Deep Discoverer* is the ability to capture high-definition video, with the vehicle's primary camera able to zoom in on a three-inch long organism from 10 feet away. *D2*'s 20 LED lights provide 150,000 lumens of light, illuminating the otherwise dark depths of the ocean. *D2* is equipped with two manipulator arms, five Niskin bottles, and a rotary suction sampler to collect biological, geological, and water samples (Kennedy et al., 2016).

Known as a 'camera sled,' configuration, *Seirios* is equipped with a scanning 360-degree sonar as well as a series of cameras, including one high-definition camera and several standard-definition cameras (NOAA, ROV *Seirios*). Three rear-mounted LED light banks aimed forward and below the vehicle illuminate *D2* from above. *Seirios* is directly tethered via to the *Okeanos Explorer* via a cable and is further tethered to *D2*. This cable provides the ROVs with power and serves as a pathway for data transfer between the vehicles and the ship. This tandem robot configuration allows high-definition imagery to be captured for an undisturbed look at the seafloor.

Both *Seirios* and *D2* are outfitted with a complement of sensors to measure parameters like conductivity, temperature, dissolved oxygen, salinity, and depth to better characterize each of the areas that are explored.

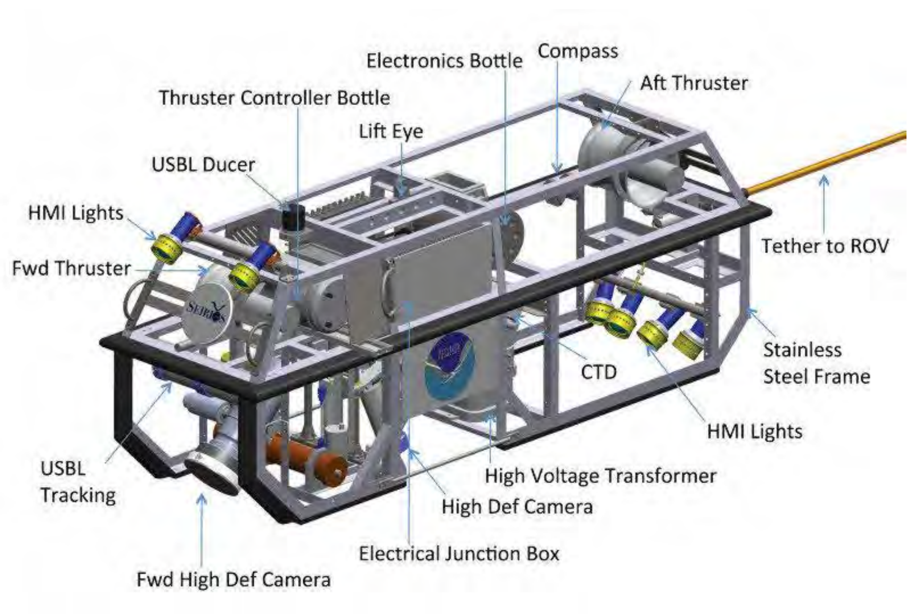



*Figure 3 Schematic of the Seirios ROV. From Office of Ocean Exploration and Research*

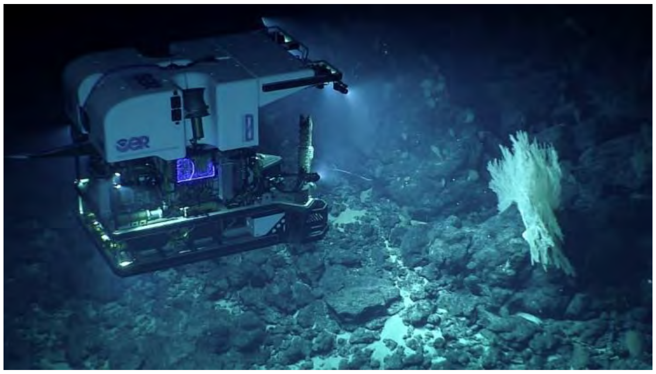



*Figure 4 ROV Deep Discoverer documents the benthic communities at Paganini Seamount during the Deep-Sea Symphony: Exploring the Musicians Seamounts expedition. Image by NOAA Office of Ocean Exploration and Research*

### *Annotation*

Since 2016, all of the *Okeanos Explorer* ROV video footage is uploaded to SeaTube, a platform for a distributed network of scientists to view and annotate the ROV footage both in real time and post hoc. SeaTube is a portal developed by Ocean Networks Canada (ONC) to archive dive videos, dive logs, navigational data, and metadata for deep ocean exploration (Jenkyns and Pirenne, 2013). Footage review is done manually; annotations are then stored and can be accessed by other users. Users can make annotations and search for text within a selected dive or throughout the entire archive. Additional features include annotation taxonomy support, user-generated playlists, and the ability to capture screen shots and video clips and bookmark videos (Selig et al., 2019). The most recent version of SeaTube, SeaTube V3, was used for this project, and can be accessed at this website: https://data.oceannetworks.ca/SeaTubeV3*

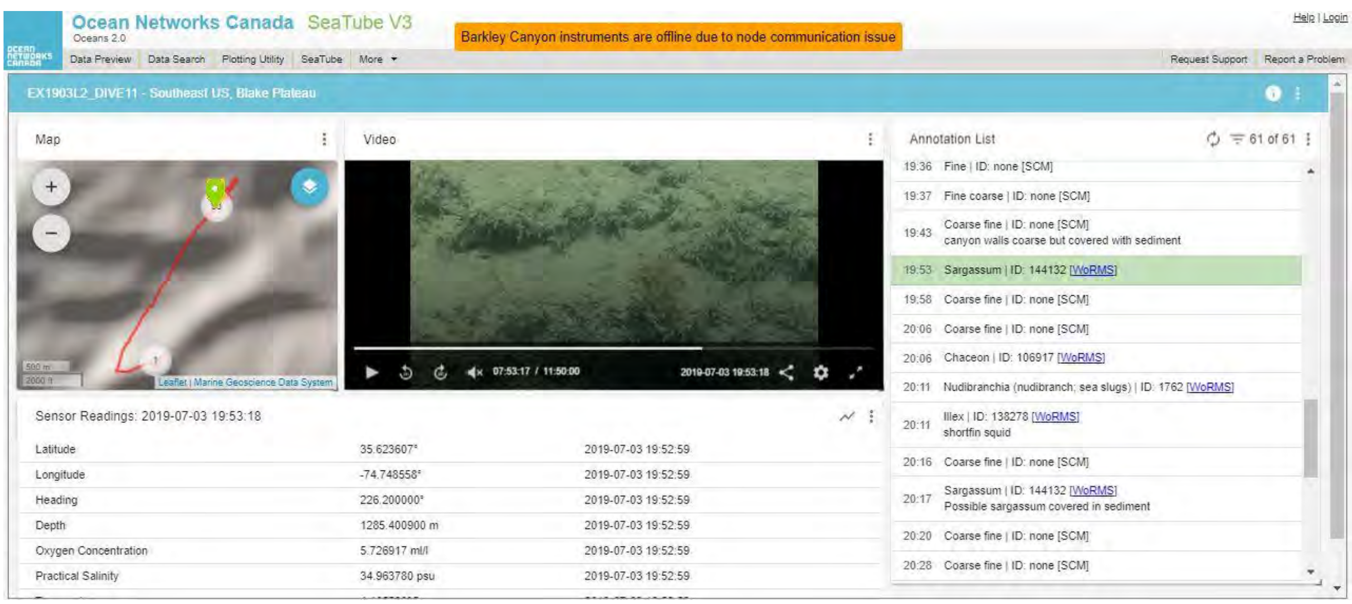



*Figure 5 Screen shot of the SeaTube V3 annotation tool. https://data.oceannetworks.ca/SeaTubeV3*

---

* An account is required to access SeaTube V3. SeaTube V2 does not require an account and can be accessed at https://data.oceannetworks.ca/SeaTubeV2

Before beginning this project, a search for the term “seaweed” in the 21 NOAA OER expeditions from 2016 to 2019 that are stored in the SeaTube system, each expedition of which averages approximately 12 dives per expedition, returned only one result. A search for “*Sargassum*” returned only 70 results as of 17 February 2020. *Sargassum* annotations appear sporadically in these records, but there is no evidence of a methodical review of *Sargassum* specifically taking place during any of the *Okeanos Explorer* dives.

This capstone project built upon this sparse documentation of *Sargassum* by providing a catalogue of instances of *Sargassum* occurring on the sea floor. This can then potentially be used to identify patterns, aid in management, and inform future research. A better understanding of how much *Sargassum* washes ashore, and how much sinks to the depths, will help scientists and managers respond to *Sargassum* blooms as they arise and to predict ocean carbon export pathways.

**Objectives**

Objectives for this project were as follows:

1) To document *Sargassum* instances on the seafloor off the southeastern United States and in the Gulf of Mexico and the Caribbean based on ROV imagery
2) To inform the scientific and management community about where *Sargassum* is known to fall to the deep seafloor
3) To provide baseline observations that could be used for ongoing monitoring of *Sargassum* flux to seafloor

**End Products**

1) Catalogue of *Sargassum* observations in annotation platform, SeaTube V3, for subset of *Okeanos Explorer* ROV dives. The annotations in this system serve as a publicly-available science logbook which can then be accessed by the science and management community.
2) Site characterizations describing the general features of the dive as well as any unusual oceanographic features
3) Map of *Sargassum* observations and analysis of data for selected dives to determine average observation depth and average number of linear meters per *Sargassum* observation

**Methodology for achieving the end product**

The overarching workflow for this project was to:

1) Review ROV footage from NOAA *Okeanos Explorer* expeditions to detect *Sargassum* visually for specific dives
2) Document observations of *Sargassum* in annotation platform, SeaTube V3
3) Review chatroom discussions, video footage, and dive plans to gather information characterizing each site

4) Extract and process oceanographic data (temperature, depth, salinity, and turbidity) collected during the *Okeanos Explorer* ROV dives
5) Display map of *Sargassum* locations and analyze data using ArcGIS Pro software

<u>ROV Video Footage Review</u>

Video from the ROV cruises was accessed via the SeaTube V3 annotation system. Expeditions selected for review were prioritized based on region and recency of the expedition. Within the selected expeditions (EX 1803 Gulf of Mexico April – May 2018, EX1811 Puerto Rico and U.S. Virgin Islands October – November 2018, and EX1903L2 Southeastern U.S. June – July 2019), dives with different types of oceanographic features (for instance a canyon versus coral mounds) and depths were selected to sample a variety of site characterizations. The chatroom logs from scientists discussing the expedition as it was taking place were also reviewed to help characterize each dive site.

Each of the dives was reviewed from time the start of the ROV's descent from the surface to the end of its ascent back to the surface to account for the possibility of *Sargassum* being observed in the water column; however, no *Sargassum* was observed in the water column.

Observations of *Sargassum* were all made manually, by reviewing the selected footage from the *Deep Discoverer* ROV. An object was identified as *Sargassum* based on its shape, color, texture, and movement. Figure 6 shows screen grabs of the ROV video at the point at which various *Sargassum* annotations were made during the dives to show the variability of what the *Sargassum* looks like when it reaches the seafloor. When there was an object in question that was potentially *Sargassum* but identification was questionable, higher-resolution footage of that part of the dive was accessed and viewed in NOAA's OER Video Portal (https://www.nodc.noaa.gov/oer/video/). If after reviewing the high-resolution footage the object could not with absolute certainty be identified as *Sargassum*, the annotation included the note "likely *Sargassum*" to indicate a degree of uncertainty. All other observations were simply identified to the *Sargassum* genus referencing the World Register of Marine Species (WoRMS) system of classification. They were not identified to the species due to the two local species of *Sargassum* being morphologically similar.

For each *Sargassum* observation entered as an annotation in SeaTube, the position, depth, temperature, salinity, and dissolved oxygen were recorded as measured by sensors on the *D2* ROV. All annotations are saved in the SeaTube annotation system and can be searched for and viewed by any user of the system. Annotations were exported as a CSV file and uploaded to ArcGIS Pro for visualization.

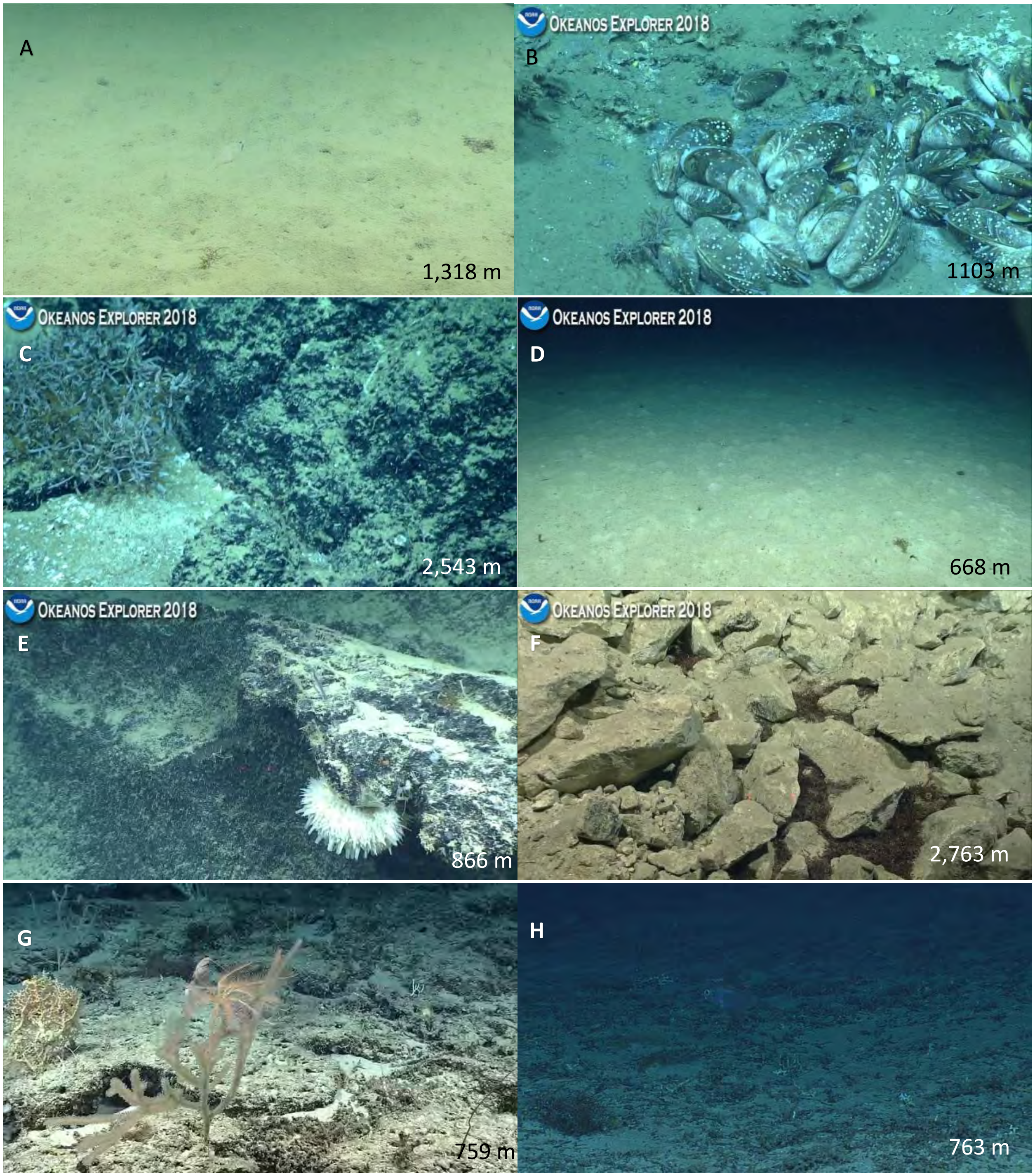



*Figure 6. Images of Sargassum encountered on the NOAA Ship Okeanos Explorer expeditions. The images were taken by the ROV Deep Discoverer on the seafloor during A) EX1903L2 Dive 11 65 km off the Outer Banks, North Carolina, B) EX1803 Dive 6 250 km off Louisiana, C) EX1803 Dive 8 220 km off Alabama, D) and E) EX1811 Dive 6 8 km off southeast Puerto Rico, F) EX1811 Dive 10 off northwest Puerto Rico, G) and H) EX1903L2 Dive 2 150 km off southeast Florida. The depth recorded by Seirios at the time of the Sargassum observation is in the bottom right of each pane. Images generated by SeaTube V3.*

Data Analysis and Visualization

Conductivity, temperature, and depth (CTD) data was collected from the *Seirios* ROV. Measurements downloaded from *Seirios* include depth, temperature, oxygen, salinity, elapsed time, latitude, longitude, and turbidity. After downloading the raw data, Sea-Bird data processing software was used to convert the raw data into a format that could be used in ArcGIS Pro.

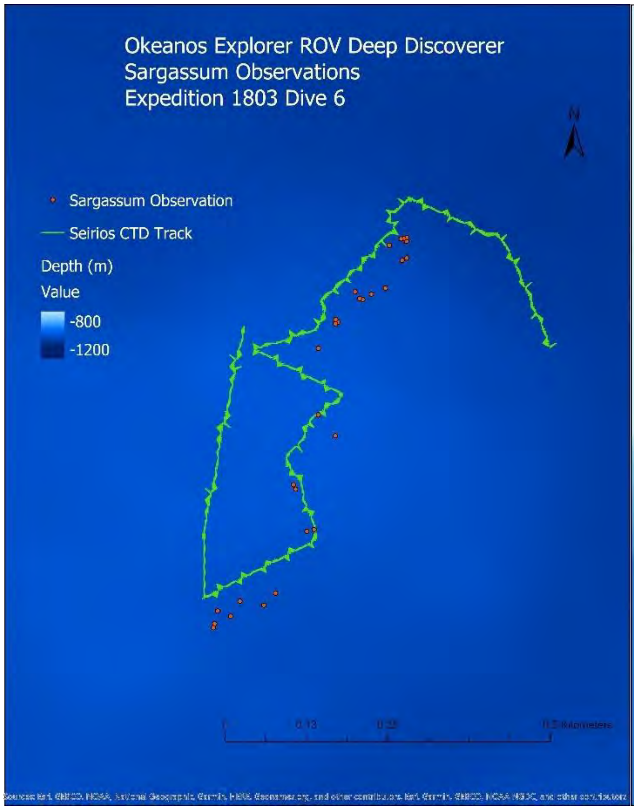
```
* Sea-Bird SBE 9 Data File:
* FileName = E:\raw_data\EX1903L2_DIVE02_20190622_CPCTD.hex
* Software Version Seasave V 7.26.7.107
* Temperature SN = 5018
* Conductivity SN = 3470
* Number of Bytes Per Scan = 41
* Number of Voltage Words = 4
* Number of Scans Averaged by the Deck Unit = 1
* System UpLoad Time = Jun 22 2019 12:49:42
* NMEA Latitude = 29 06.61 N
* NMEA Longitude = 079 26.65 W
* NMEA UTC (Time) = Jun 22 2019  12:49:41
* Store Lat/Lon Data = Append to Every Scan
* System UTC = Jun 22 2019 12:49:42
*END*
14F5C01BE8A581327F000000000000890FFFFD2FFFFFF5EAFFFFFF1635943C9C704166E0A024B82E6F
14F5B61BE8A181327F000000000000890FFFFD3FFFFFF5EAFFFFFF1635943C9C704066E0A024B81E70
14F5BC1BE8A181327F000000000000890FFFFD4FFFFFF5EAFFFFFF1635943C9C704066E0A024B82E71
14F5BB1BE8A581327F000000000000890FFFFD5FFFFFF5EAFFFFFF1635943C9C704066E0A024B82E72
14F5B21BE89B813287000000000000890FFFFD5FFFFFF5EAFFFFFF1635943C9C734166E0A024B81E73
14F5B11BE8A1813287000000000000891FFFFD5FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E74
14F5B71BE8A581328E000000000000892FFFFD5FFFFFF5EAFFFFFF1635943C9C734066E0A024B82E75
14F5AD1BE89B81328E000000000000892FFFFD6FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E76
14F5AC1BE8A1813295000000000000892FFFFD6FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E77
14F5AD1BE89F81329D000000000000893FFFFD5FFFFFF5EAFFFFFF1635943C9C734066E0A024B82E78
14F5A81BE89B81329D000000000000893FFFFD4FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E79
14F5AD1BE89B8132A4000000000000893FFFFD4FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E7A
14F5B11BE8A18132A4000000000000894FFFFD3FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E7B
14F5AD1BE8928132AC000000000000894FFFFD3FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E7C
14F5B21BE8958132B3000000000000895FFFFD5FFFFFF5EAFFFFFF1635943C9C734066E0A024B82E7D
14F5AC1BE89B8132AC000000000000895FFFFD5FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E7E
14F5A91BE89F8132BA000000000000896FFFFD5FFFFFF5EAFFFFFF1635943C9C734066E0A024B82E7F
14F5A81BE8958132BA000000000000897FFFFD6FFFFFF5EAFFFFFF1635943C9C734066E0A024B81E80
```

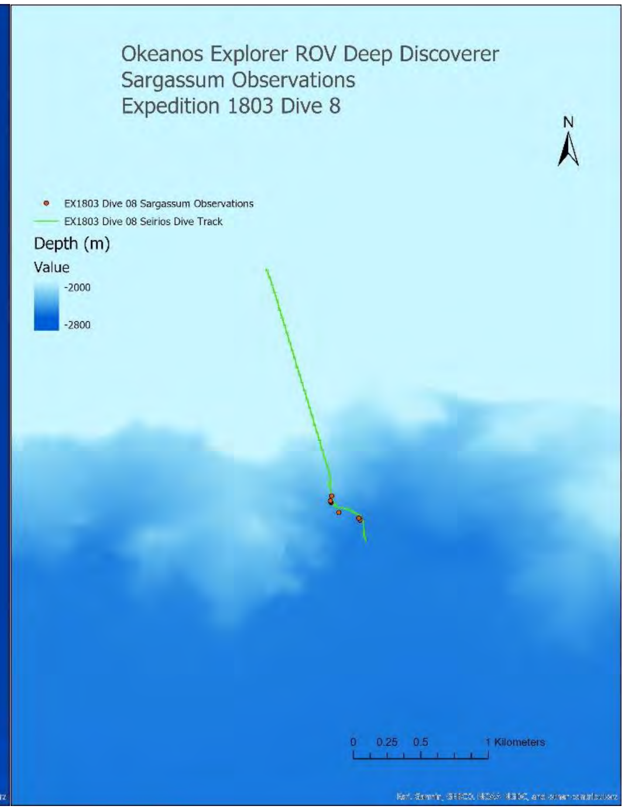
*Figure 7 Screen capture of a portion of the raw data collected by the Seirios CTD on EX1903L2 Dive 02*

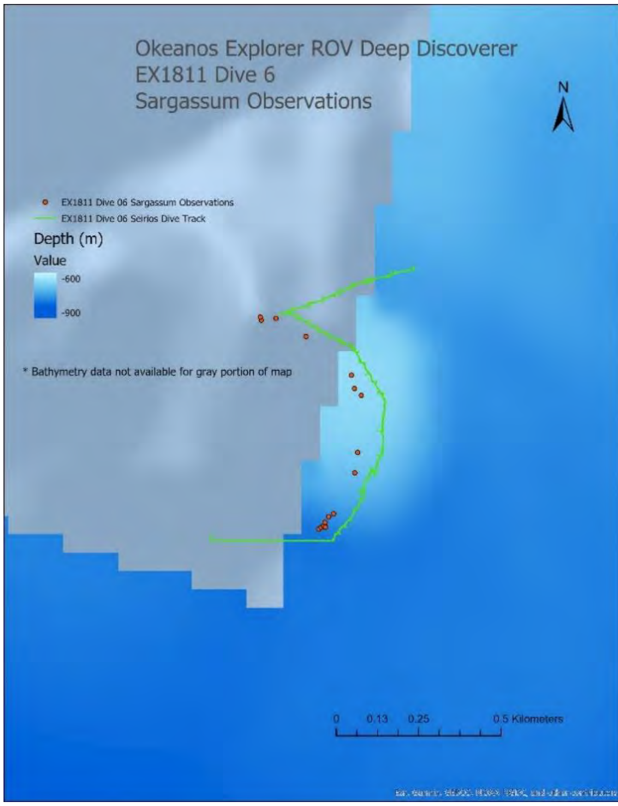
| OBJECTID | Shape | Depth_m | Temp_C | Oxygen | Salinity | time_S | latitude | longitude | Turbidity |
|---|---|---|---|---|---|---|---|---|---|
| 848942 | Point | 5.293 | 29.0388 | 6.3486 | 36.2439 | 35373 | 29.12966 | -79.448 | 0.33 |
| 848943 | Point | 5.241 | 29.0398 | 6.3487 | 36.2431 | 35373 | 29.12966 | -79.448 | 0.324 |
| 848944 | Point | 5.241 | 29.041 | 6.3488 | 36.2429 | 35373 | 29.12962 | -79.44802 | 0.317 |
| 848945 | Point | 5.196 | 29.0419 | 6.3489 | 36.2435 | 35373 | 29.12962 | -79.44802 | 0.33 |
| 848946 | Point | 5.189 | 29.0429 | 6.3485 | 36.2434 | 35373 | 29.12962 | -79.44802 | 0.33 |
| 848947 | Point | 5.151 | 29.0441 | 6.3487 | 36.2429 | 35373 | 29.12962 | -79.44802 | 0.33 |
| 848948 | Point | 5.196 | 29.0447 | 6.3484 | 36.2437 | 35373 | 29.12962 | -79.44802 | 0.324 |
| 848949 | Point | 5.099 | 29.0445 | 6.3486 | 36.2446 | 35373 | 29.12962 | -79.44802 | 0.317 |
| 848950 | Point | 5.151 | 29.0431 | 6.3527 | 36.2456 | 35373 | 29.12962 | -79.44802 | 0.311 |
| 848951 | Point | 5.047 | 29.0412 | 6.3489 | 36.2462 | 35373 | 29.12962 | -79.44802 | 0.305 |
| 848952 | Point | 5.054 | 29.0393 | 6.3489 | 36.2459 | 35373 | 29.12962 | -79.44802 | 0.317 |
| 848953 | Point | 5.002 | 29.0379 | 6.3488 | 36.2457 | 35373 | 29.12962 | -79.44802 | 0.336 |
| 848954 | Point | 5.002 | 29.0379 | 6.3486 | 36.2443 | 35373 | 29.12962 | -79.44802 | 0.342 |
| 848917 | Point | 5.436 | 29.0306 | 6.3551 | 36.2434 | 35372 | 29.12962 | -79.44802 | 0.299 |
| 848918 | Point | 5.384 | 29.0313 | 6.3512 | 36.2432 | 35372 | 29.12966 | -79.448 | 0.299 |
| 848919 | Point | 5.333 | 29.0321 | 6.3511 | 36.2426 | 35372 | 29.12966 | -79.448 | 0.299 |
| 848920 | Point | 5.526 | 29.0327 | 6.3511 | 36.2435 | 35372 | 29.12962 | -79.44802 | 0.317 |

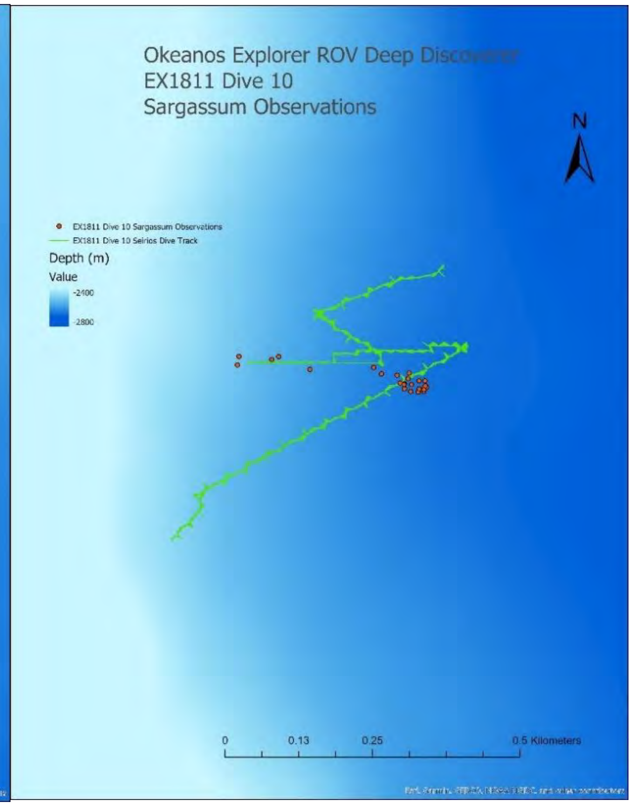
*Figure 8 Screen capture of Seirios CTD data after processing and as stored in ArcGIS Pro. The data featured is of the beginning of the ROV's descent*

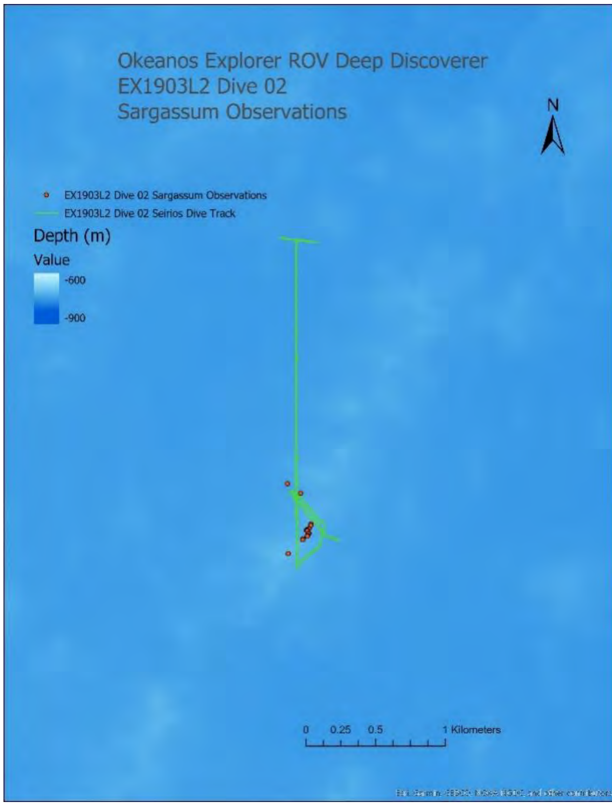
A seamless mosaic of gridded bathymetric products was downloaded into ArcGIS Pro from an image service of NOAA's National Center for Environmental Information (NCEI). This bathymetry was derived from multibeam data collected by NOAA Ship *Okeanos Explorer*.

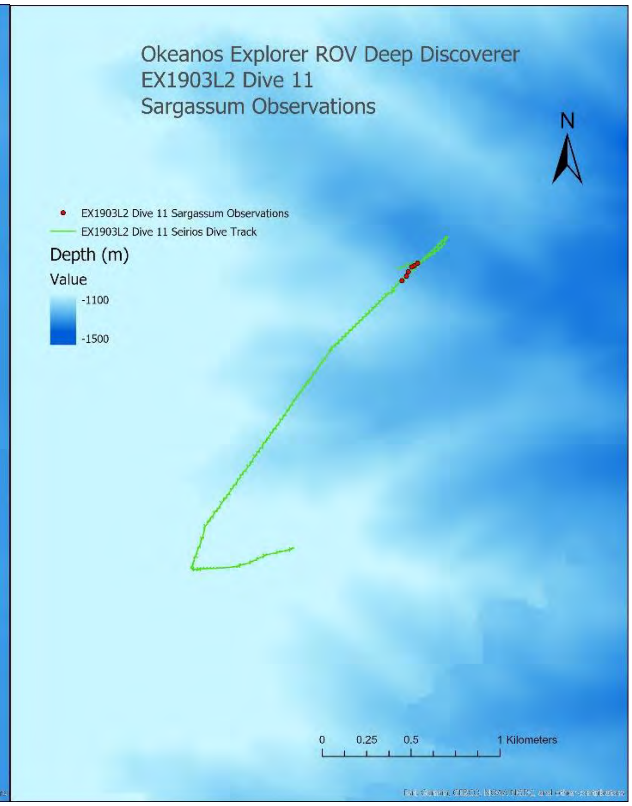



Okeanos Explorer ROV Deep Discoverer
EX1811 Dive 6
Sargassum Observations
N
EX1811 Dive 06 Sargassum Observations
EX1811 Dive 06 Seirios Dive Track
Depth (m)
Value
-600
-900
* Bathymetry data not available for gray portion of map
0
0.13
0.25
0.5 Kilometers


Okeanos Explorer ROV Deep Discoverer
EX1811 Dive 10
Sargassum Observations
N
EX1811 Dive 10 Sargassum Observations
EX1811 Dive 10 Seirios Dive Track
Depth (m)
Value
-2400
-2800
0
0.13
0.25
0.5 Kilometers




*Figures 9-14. Map of 6 dive sites showing Seirios CTD dive track and Sargassum observations*

Data was analyzed and visualized in ArcGIS Pro. Functions that were performed include:

- Create a dive track line from the *Seirios* CTD data
- Create *Sargassum* observation points from the *Deep Discoverer* CTD data
- Measure the distance travelled and calculate the number of *Sargassum* observations per linear meter of the horizontal distance traveled
- Calculate the average depth and temperature of the *Sargassum* observation locations

<u>Results</u>

Video from 6 ROV dives was reviewed, totaling 50.63 hours of video replay. A total of approximately 8,540 linear meters was travelled horizontally. *Sargassum* was observed at all 6 of the dive sites, with a total of 100 instances of *Sargassum* observed.

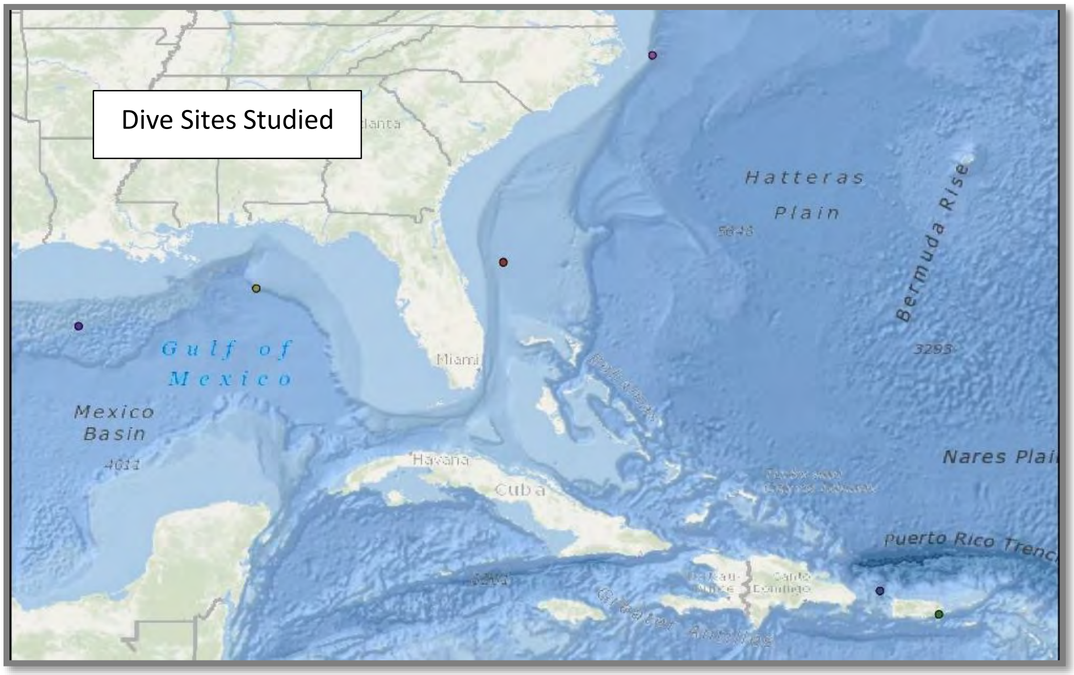



*Figure 15 Map showing the sites of the 6 Okeanos Explorer dives that were analyzed*

| Dive Name | Location | *Sargassum* Observations | Mean Depth (m) | Mean Temp (C) |
|---|---|---|---|---|
| EX1803_Dive06 | Off Louisiana | 30 | 1077.79 | 4.8 |
| EX1803_Dive08 | Off Western Florida | 7 | 2534.03 | 4.32 |
| EX1811_Dive06 | Off SE Puerto Rico | 16 | 757.25 | 8.03 |
| EX1811_Dive10 | Off NW Puerto Rico | 25 | 2725.41 | 2.89 |
| EX1903L2_Dive02 | Off Eastern Florida | 16 | 761.24 | 8.27 |
| EX1903L2_Dive11 | Off North Carolina | 6 | 1288.85 | 4.16 |

*Table 1 Summary Statistics for environmental data where Sargassum was observed during the selected ROV dives*

Site Characterizations

EX1803 Dive 06


Dive 6 of Expedition 1803 targeted Hidalgo Basin, an area that was being considered for expansion of the Flower Garden Banks National Marine Sanctuary. Specifically, Dive 6 explored a mound feature for hard-bottom communities, particularly deep-sea corals, sponges and associated fauna. There have been three previous scientific dives in this general area, all of which surveyed a mound feature located south of the Dive 6 target area and recorded deep-sea corals and chemosynthetic communities (ONC Expedition Management).

Approximately 250 kilometers south of central Louisiana, this is a relatively unexplored area that was first explored in 2014 by *Okeanos Explorer*. Salt domes were observed on these dives, in addition to a high abundance of bivalve shells and carbonate rocks. Active Louann salt affects the topography. This salt actively causes deforming and uplifts and can also cause collapsed canyons. Anthropogenic debris from the surface - fishing line, canvas, metal container – were observed at this site. Parts of this site had signs of past seepage, including bacterial mats and a high abundance of bivalves, mostly shells but some living, including some feeding on *Sargassum*.

30 observations of *Sargassum* were recorded during the dive, the highest of the 6 dives reviewed. The average depth for *Sargassum* observations was 1,077 meters.

EX1803 Dive 08


Dive 8 of Expedition 1803 targeted the northern end of the West Florida Escarpment in the DeSoto Canyon region. At the time of the expedition this area was being considered for expansion of the Flower Garden Banks National Marine Sanctuary. Specifically, Dive 8 explored the escarpment feature at depths between 2200-2600 meters for hard-bottom communities, particularly deep-sea corals, sponges, and associated fauna. There have been five previous scientific dives in this general area, all of which documented extensive and diverse deep-sea coral communities, which are the deepest high-density communities known in the Gulf of Mexico. Additionally, these previous dives also documented seeps and chemosynthetic communities in the area. However, all of the previous dives were conducted over 7 kilometers away from the unexplored Dive 8 site (ONC Expedition Management).

Approximately 220 kilometers off Alabama, this sight was characterized by a hard substrate. It also featured a steep carbonate rock wall with highly fractured detached boulders at the base of the wall.

7 *Sargassum* observations were recorded during this dive. The average depth for *Sargassum* observations was 2,534 meters.

EX1811 Dive 06


Dive 6 of Expedition 1811 targeted the potential habitats of deep-water fish species, including snappers and groupers. Exploration took place in the Inés María Mendoza Nature Reserve, also known as Punta Yeguas. The purpose of the dive was exploratory with an emphasis on identifying occurrences of deepwater fish species as well as their habitat preferences along the dive track. Deep-sea coral and sponge communities were also surveyed.

Approximately 8 km off the southeastern side of Puerto Rico, this dive took place at approximately 860 meters in depth up a steep mound, which has a prominent ridge on the crest of the mound. This area was fairly heavily sedimented with a slight current. High turbidity was observed in the water column, as was an abundance of benthic organisms swimming in the water column.

16 *Sargassum* observations were recorded on this dive, which was approximately 9 kilometers from shore. The average depth for *Sargassum* observations was 757 meters.

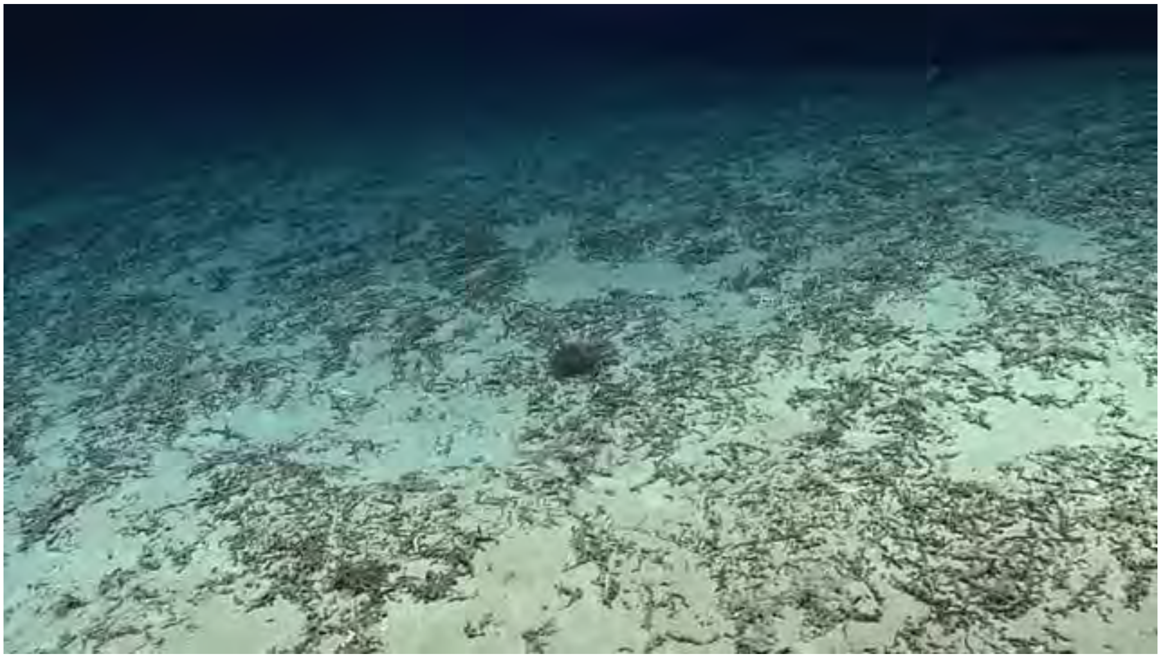
EX1811 Dive 10


Dive 10 of EX1811 was located in Mona Canyon, and traversed up the western wall of a giant landslide scarp. Seafloor bathymetry and imagery in this area may provide evidence of historical landslide activity that could pose as a potential geohazard to this region of the Atlantic Ocean. The purpose of this dive was to add additional observations to previous dives in this general area conducted by the E/V Nautilus and *Okeanos Explorer*. The second portion of the dive conducted mid-water surveys for observation of nektonic and planktonic communities.

This dive took place along the north side of the Mona passage in the Mona canyon, which is more exposed to the greater North Atlantic Ocean, approximately 50 kilometers off the northwest side of Puerto Rico. The dive started with high quantities of *Sargassum* detritus in large clumps, much larger than were observed on the other dives. When it got to steeper features, such as with large rocks on a steep canyon wall face, or on a rock avalanche geologic feature, there was much fewer *Sargassum* observations and those that were observed were in much smaller quantity. Several instances of rubbish (metal cans, etc.) were also observed.

25 *Sargassum* observations were recorded on this dive. The average depth for *Sargassum* observations was 2,725 meters.

EX1903L2 Dive 02

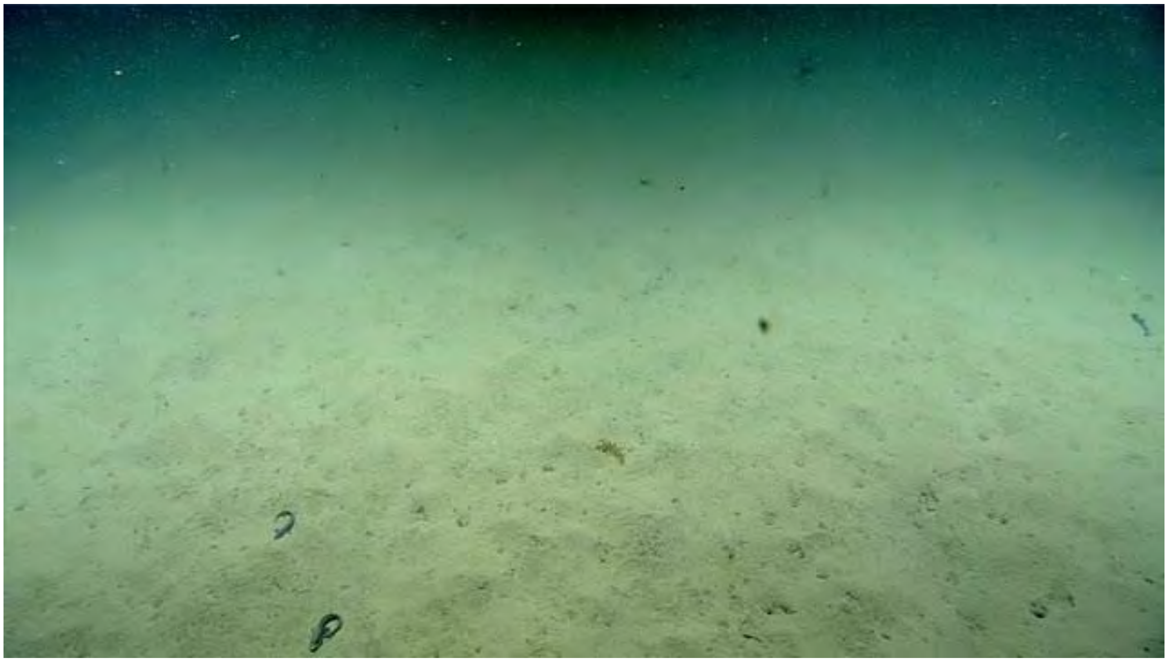


EX1903L2 Dive 02 explored a deep water coral mound in the Stetson Miami Terrace Deep Water Coral. This area was first mapped during EX1903L2.

Exploring several mounds approximately 150 kilometers off the east coast of Florida, this dive also included several hours of blue water exploration in the water column. The area explored was just inside the Gulf Stream, and it started out with a high quantity of marine snow at 500 - 700m. Coral rubble was abundant in this site, and a pancake urchin was observed eating *Sargassum*.

16 *Sargassum* observations were recorded during this dive. The average depth for *Sargassum* observations was 761 meters.

EX1903L2 Dive 11



Dive 11 of EX1903L2 explored the Deep "Dodge" Canyon, looking at the mouth of an inner canyon/ minor canyon area approximately 65 kilometers offshore of the Outer Banks, North Carolina.

This site was characterized by deep sediment, lots of marine snow, and poorer visibility. This is likely a result of organic material produced at the surface and in the midwater thick material sinking along the water column and washing down the slope to accumulate on the bottom. This is a canyon dive, more inshore, as compared to other dives which had more elevated mounds with clearer water and exposed rocky substrate.

6 *Sargassum* observations were recorded on this dive. The average depth for *Sargassum* observations was 1,288 meters.

Discussion

Because the deep sea is so little surveyed, any new observations can lend valuable insight into the dynamics of deep sea communities and how the deep sea is connected to the surface and to global environmental processes. Deep sea habitats are logistically difficult to access, and it is thus difficult to observe this *Sargassum* on the sea floor, making determinations on how much *Sargassum* is sinking, and where, difficult.

Site characterization may lend insight into why *Sargassum* is being observed more often in one site than in another. For instance, EX1903 Dive 11 was characterized by thick sediment and poor visibility, likely as a result of the high amount of marine snow that was observed both in the water column and on the sea floor. This marine snow indicates that there is likely high productivity on the surface to produce so much organic material. However, this large amount of marine snow may have quickly buried any *Sargassum* on the bottom. Although only 6 specimens of *Sargassum* were observed on this dive, the lowest out of the 6 dives surveyed, there may have been more there just buried from view.

The data collected from these 6 *Okeanos Explorer* dives significantly increases the number of confirmed direct observations of *Sargassum* in deep sea benthic communities, particularly in the SeaTube annotation system. The addition of these *Sargassum* observations increased the number of *Sargassum* annotations in SeaTube by 43%. The ability to enhance the knowledge of the geography of an organism that is poorly documented in the deep sea benthos thus demonstrates the value of making exploratory observations in understudied parts of the ocean. This report also demonstrates that publicly-available ROV video that was not originally collected for these purposes may be leveraged to observe and document.

With the vast quantities of *Sargassum* floating at the surface many miles offshore, it is very likely that this *Sargassum* is also being deposited to the seafloor hundreds of meters below the ocean's surface through gravitational sinking. *Sargassum* was observed on each of the dives reviewed for this project, in numbers ranging from 6 to 30 observations per dive. This suggests that *Sargassum* does make its way to the deep sea, in potentially significant amounts.

Macroalgal ecosystems like those in the genus *Sargassum* sequester and store significant amounts of carbon from the atmosphere and ocean and hence are now recognized for their role in mitigating climate change. Developing a predictive understanding of carbon export pathways such as gravitational sinking is thus critical to diagnosing present and future rates of ocean carbon sequestration. Further observations throughout the global ocean are required to fill in the gaps in the distribution of *Sargassum* in the deep sea.

**References**

Arenas, F., & Vaz-Pinto, F. (2015). Marine Algae as Carbon Sinks and Allies to Combat Global Warming. In L. Pereira & J. M. Neto (Authors), *Marine algae: Biodiversity, taxonomy, environmental assessment, and biotechnology* (pp. 178-193). Boca Raton, FL: CRC Press, Taylor & Francis Group. doi:10.1201/b17540-6

Baker, P., Minzlaff, U., Schoenle, A., Schwabe, E., Hohlfeld, M., Jeuck, A., Brenke, N., Prausse, D., Rothenbeck, M., Brix, S., Frutos, I., Jörger, K. M., Neusser, T. P., Koppelmann, R., Devey, C., Brandt, A., and Arndt, H. (2017). Potential contribution of surface-dwelling *Sargassum* algae to deep-sea ecosystems in the southern North Atlantic. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 148, 21–34

Casazza, T. L., & Ross, S. W. (2010, August 25). Sargassum: A Complex 'Island' Community at Sea. Retrieved February 10, 2020, from https://oceanexplorer.noaa.gov/explorations/03edge/background/sargassum/sargassum.html

Conley, L., & Oliver, D. (2019, September 18). Sargassum seaweed, invader of Florida and Caribbean beaches, may be the ‘new norm. *USA Today*. Retrieved May 30, 2020, from https://www.usatoday.com/story/travel/news/2019/09/18/sargassum-seaweed-everything-you-need-to-know-florida-caribbean-beaches/2342086001/

Coston-Clements, L., L. R. Settle, D. E. Hoss, & F. A. Cross. (1991). Utilization of the *Sargassum* habitat by marine invertebrates and vertebrates- a review. NOAA Technical Memorandum NMFS-SEFSC-296, 32 pp.

Doyle, E. & Franks, J. (2015). *Sargassum Fact Sheet. Gulf and Caribbean Fisheries Institute*. Retrievehttp://www.sargassoseacommission.org/storage/documents/GCFI_*Sargassum*_Fact_Sheet_Doyle__and_Franks_Sept_2015.pdf

Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., & Krause-Jensen, D. (2017). Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? *Frontiers in Marine Science, 4*. doi:10.3389/fmars.2017.00100

Duffy, J. E., Benedetti-Cecchi, L., Trinanes, J., Muller-Karger, F. E., Ambo-Rappe, R., Bostrom, C., . . . Yaakub, S. (2019). Toward a coordinated global observing system for seagrasses and marine macroalgae. *Frontiers in Marine Science, 6*. doi:10.3389/fmars.2019.00317

Franks, J. S., Johnson, D. R., & Ko, D. S. (2016). Pelagic Sargassum in the Tropical North Atlantic. *Gulf and Caribbean Research, 27*(1). doi:10.18785/gcr.2701.08

Graham, L. E., Wilcox, L. W., & Graham, J. M. (2009). *Algae*. 2nd ed. San Francisco, CA: Pearson/Benjamin Cummings. doi: ISBN: 0321559657

Jenkyns, R., Gervais, F., and Pirenne, B. (2013). "SeaScribe: An annotation software for Remotely Operated Vehicle dive operations," *2013 OCEANS - San Diego*, San Diego, CA, pp. 1-5, doi: 10.23919/OCEANS.2013.6741250.

Kennedy, B. R. C., Elliott, K. P., Cantwell, K., and Mesick, S. (2016). Telepresence enabled exploration with NOAA ship *Okeanos Explorer*. Bell, K.L.C., Brennan, M.L., Flanders, J., Raineault, N.A., and Wagner, K., eds., in The E/V Nautilus and NOAA Ship Okeanos Explorer 2015 field season. *Oceanography* 29 (1), supplement, pp. 50–51. doi: 10.5670/oceanog.2016.supplement.01

Kennedy, B. R., Cantwell, K., Malik, M., Kelley, C., Potter, J., Elliott, K., . . . Rotjan, R. D. (2019). The Unknown and the Unexplored: Insights Into the Pacific Deep-Sea Following NOAA CAPSTONE Expeditions. *Frontiers in Marine Science, 6*. doi:10.3389/fmars.2019.00480

Kokubu, Y., Rothäusler, E., Filippi, J., Durieux, E. D., & Komatsu, T. (2019). Revealing the deposition of macrophytes transported offshore: Evidence of their long-distance dispersal and seasonal aggregation to the deep sea. *Scientific Reports, 9*(1). doi:10.1038/s41598-019-39982-w

Krause-Jensen, D., & Duarte, C. M. (2016). Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience, 9*(10), 737-742. doi:10.1038/ngeo2790

Lamb, J. (2018, October 24). The great seaweed invasion. *JSTOR Daily*. Retrieved from https://daily.jstor.org/great-seaweed-invasion/

Lee, R. E. (2008). *Phycology* (4th ed.). New York, New York: Cambridge University Press. doi:ISBN:13-978-0-511-38669-5

NOAA. (2019, October 9). What is the Sargasso Sea? National Ocean Service website. Retrieved January 12, 2020, from https://oceanservice.noaa.gov/facts/sargassosea.html

NOAA Ocean Exploration and Research. Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE). Retrieved June 1, 2020 from https://oceanexplorer.noaa.gov/explorations/aspire/welcome.html

NOAA Ocean Exploration and Research. Remotely Operated Vehicle *Seirios*. Retrieved May 20, 2020 from https://oceanexplorer.noaa.gov/technology/subs/seirios/seirios.html. Accessed 5/20/20

Ocean Networks Canada Expedition Management. (n.d.). Retrieved May 2, 2020, from https://data.oceannetworks.ca/ExpeditionManagement

Pérez Ortega, R. (2019, September 4). The complex case of the seaweed that is drowning ecosystems in the Caribbean. *Inside Science*. Retrieved from https://www.insidescience.org/news/complex-case-seaweed-drowning-ecosystems-caribbean

Raven, J. A. (2017). The possible roles of algae in restricting the increase in atmospheric CO2and global temperature. *European Journal of Phycology, 52*(4), 506-522. doi:10.1080/09670262.2017.1362593

Rodríguez-Martínez, R., Medina-Valmaseda, A., Blanchon, P., Monroy-Velázquez, L., Almazán-Becerril, A., Delgado-Pech, B., . . . García-Rivas, M. (2019). Faunal mortality associated with massive beaching and decomposition of pelagic Sargassum. *Marine Pollution Bulletin, 146*, 201-205. doi:10.1016/j.marpolbul.2019.06.015

Peters, C., Coleman, D. F., & Martinez, C. (2019). Expedition support from the inner space center. Raineault, N.A., and Flanders, J., eds., in New Frontiers in Ocean Exploration:

The E/V Nautilus, NOAA Ship *Okeanos Explorer*, and R/V Falkor 2018 Field Season. *Oceanography*, *32*(1) 6–7. doi: 10.5670/oceanog.2019.supplement.01

Sanchez-Rubio, H., Perry, J.S., & Franks, D.R.J. (2018). Occurrence of pelagic *Sargassum* in waters of the US Gulf of Mexico in response to weather-related hydrographic regimes associated with decadal and interannual variability in global climate. *Fishery Bulletin, 116*(1):93- 107. doi: 10.7755/FB.116.1.10

Selig, G., Netburn, A., & Malik, M. (2019). Distributions of the Pelagic Holothurian Pelagothuria in the central Pacific Ocean as observed by remotely-operated vehicle surveys. *Frontiers in Marine Science, 6*. doi:0.3389/fmars.2019.00684.

Schneider, C. W., Searles, R. B., & Child, J. S. (1991). *Seaweeds of the southeastern United States: Cape Hatteras to Cape Canaveral*. Durham: Duke University Press.

Valentini, N., & Balouin, Y. (2020). Assessment of a smartphone-based camera system for coastal image segmentation and Sargassum monitoring. *Journal of Marine Science and Engineering, 8*(1), 23. doi:10.3390/jmse8010023

Volk, T. and Hoffert, M.I. (2013). Ocean Carbon Pumps: Analysis of Relative Strengths and Efficiencies in Ocean-Driven Atmospheric $CO_2$ Changes. Sundquist, E. and Broecker, W., eds., in *The Carbon Cycle and Atmospheric $CO_2$: Natural Variations Archean to Present Geophysical Monograph Series,* pp. 99-110. doi:10.1029/GM032p0099

Wang, M., Hu, C., Barnes, B. B., Mitchum, G., Lapointe, B., & Montoya, J. P. (2019). The great Atlantic Sargassum belt. *Science, 365*(6448), 83-87. doi:10.1126/science.aaw7912