Continental shelf seafloor mapping, benthic habitat surveys, and reef fish assessments in the eastern Gulf of Mexico, 2015 – 2019

Technical Report
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Continental Shelf Characterization, Assessment, and Mapping Project (C-SCAMP)
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Introduction

In April 2010, The *Deepwater Horizon* (DWH) oil spill originated in the deep sea 1,500 m below the ocean surface at the edge of the continental shelf off Louisiana. Surface and sub-surface dispersal of the oil eventually encompassed an area of over 200,000 km^2. Impacts of DWH on biota of the Gulf of Mexico were severe, wide-spread, and are ongoing even a decade after the spill. Because of its offshore origin, the spill caused injury to many resources on the continental shelf, including important reef fish species (e.g., snappers and groupers, etc.) and protected species including sea turtles. Habitats which these species occupy were oiled which resulted in the loss of key supporting plant and animal species. Because so little of the offshore habitat of reef fish species and sea turtles was mapped and characterized prior to the spill, restoration efforts aimed at improving degraded habitats and strengthening species populations proved difficult.

This project was specifically developed to discover additional, high conservation value, habitats of reef fishes and sea turtles on the continental shelf of the Gulf of Mexico off Florida (the West Florida Shelf, WFS). The goal of the project was to map such habitats and quantify the density and biodiversity of species occupying them, and to facilitate additional conservation management decisions to enhance their long-term sustainability. The project resulted in mapping and classifying and characterizing 2,350 km^2 of heretofore unmapped habitats, the development of new methods to extrapolate habitat types from a sub-sample from video surveys, and new technologies to automate the counting and identification of fish species and habitat features using artificial intelligence. Project personnel have presented these materials to the competent management authorities responsible for fish and sea turtle management. Here we provide technical detail on the methods, procedures and findings from this project.

Project Overview

The execution of this program included fusing a number of technologies and data processing steps to accomplish the ultimate goals of the study (Figure 1). Three field sampling technologies – namely multibeam bathymetric mapping, the use of towed video cameras and the use of water column fish sonars provided the basic building blocks for habitat mapping and characterization of habitat attributes and fish/turtle densities in the mapped areas. From the data sets generated by these technologies, researchers generated a series of intermediate products, including mapping benthic habitat characteristics over the bathymetry and related bottom backscatter, developing fish-habitat relationships (which species were associated with which habitats, and combining species identification and abundance (numbers of individuals) with derived biomasses from water column sonar. Finally, important end-user relevant products including species habitat maps and habitat-stratified absolute estimates of population size were delivered to managers to be considered in conservation planning and management (Figure 1). These steps ate detailed in the sections to follow.

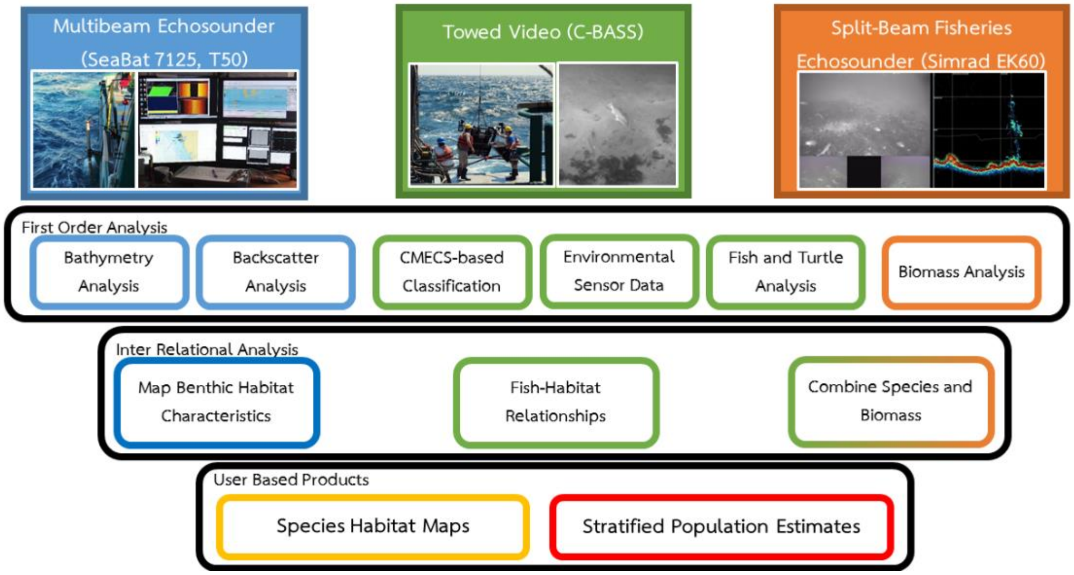


Figure 1. Information collection and data processing steps leading to natural resource management-relevant products.

Fieldwork Overview

During each year of the project, we averaged 30 sea days dedicated to mapping or ground-truthing operations. All field efforts are summarized in Figure 2. This program could only be accomplished by combining the expertise of a number of engineering and scientific disciplines including hydrographic surveying, advanced electronic instrumentation fabrication, artificial intelligence research, ship operations, ecology and population dynamics, to name but a few. This required assembling and training a rather large group (up to 14 people at one point) in key positions supporting this project. Assembling this expertise was not easy (finding the right people) nor was is accomplished quickly. By the end of the project, the through-put to final products was efficient and productivity was high.

One of the first tasks undertaken was to determine the status and availability of previously collected multibeam bathymetry coverage available for the West Florida Shelf as well as to evaluate the quality of the identified datasets. To be of optimum utility to resource managers, bathymetry maps need to have precision ≤ 10m x 10m grid sizes. This was determined to be the minimum resolution sufficient for useful habitat maps to be consistent with higher-resolution habitat map products to be derived from combining the project's many datasets.

One of the strategies of this task was to establish an independent Oversight Committee and to elicit their input prior to commencing fieldwork and to efficiently manage the overall project. It was envisioned that this Oversight Committee would persist to provide ongoing oversight and input over the life of the project. What came to be known as our *Steering Committee* was formed in early 2015 and met four times during the active life of the project (2015, 2016, 2017, and 2019), generally prior to the initiation of each field season. The committee was comprised of individuals knowledgeable in habitat mapping products and their use, and representing the following organizations: the National Atmospheric and Administration's National Marine Fisheries Service (NOAA-NMFS; Matthew D. Campbell, Brandi Noble, Steve Giordano), NOAA's National Ocean Service (NOAA-NOS; Ashley Chappell, Paul Turner), NOAA's National Centers for Environmental Information (NOAA-NCEI; Angela Salis), the United States Geological Survey (USGS; Stan Locker, Lisa Robbins), the Florida Fish and Wildlife Research Institute (FWRI; Luiz Barbieri, Ted Switzer, Sean Keenan), the National Fish and Wildlife Foundation (Eric Schwaab, Jon Porthouse, David Reeves), the Gulf of Mexico Coastal Ocean Observing System (GCOOS; Barb Kirkpatrick), the Bureau of Ocean Energy Management (BOEM; Rebecca Greene), SRI International (Michael Piacentino), the Ocean Conservancy (Christopher Robbins), the University of New Hampshire's Center for Coastal and Ocean Mapping (UNH-CCOM)/NOAA-UNH Joint Hydrographic Center (Larry Mayer), the Florida Institute of Oceanography (FIO; Bill Hogarth, Elizabeth Fetherston-Resch, Philip Kramer) as well as fishermen from Madeira Beach Seafood (Robert Spaeth) and Light Tackle Charters (Edward Walker).

Before meeting with the Steering Committee initially in 2015, the project enlisted a Ph.D. student at the University of South Florida (Dr. Marcy Cockrell) who was then working with data from the vessel monitoring (VMS) and logbook data systems maintained for the Gulf of Mexico by NOAA/NMFS. Under the assumption that the locations of where reef fish fishers fished would indicate obligate habitats, she constructed a "heat map" of reef fish fishing effort to help guide our project's priorities of where mapping efforts should be focused in the eastern Gulf of Mexico (Cockrell et al. 2019). She filtered the VMS and logbook data (to eliminate steaming lanes and other observations not associated with actual fishing) for the reef fish species of interest (e.g. snappers, groupers, amberjacks, porgy) and comm. To supplement the VMS data, the Committee also evaluated sea turtle satellite-tag tracking data obtained via the OBIS-SEAMAP database (http://seamap.env.duke.edu/) maintained by Duke University to use in prioritization discussions. In the proposal, we stated that another source of data for prioritization we planned to use was SEAMAP trawl survey data. However, after working with the VMS and sea turtle tracking datasets, we determined that there were clearly-defined areas of priority to be mapped and that the trawl survey data would not have helped further refine our prioritization decisions. During subsequent meetings with the Steering Committee, the project personnel presented the results of the previous field season's mapping efforts which would be the basis for refining priorities for the upcoming year. The committee's guidance was also helpful in suggesting how the data would fit into management priorities of various agencies and organizations and encouraged project staff to reach out to these organizations. These discussions resulted in numerous 'action items' that the C-SCAMP team would address in subsequent Steering Committee meetings.

MULTIBEAM BATHYMETRY SURVEYS

This project completed twelve multibeam mapping cruises and seven cruises on which multibeam mapping was a secondary/ancillary activity (Table 1). At the conclusion of principal field work for C- SCAMP, approximately 2,350 km^2 of bathymetry and co-registered backscatter data had been added to the cumulative map of publicly accessible data for the West Florida Shelf, almost doubling what was previously available (Figure 2). Many different bedforms and other seafloor features were encountered during our multibeam surveys. Among those ostensibly linked to key fish and sea turtle populations were ridges, troughs, sand waves, and sinkholes. Anthropogenic features included the Gulfstream natural gas pipeline and several shipwrecks. Pits and holes excavated by red grouper, some as deep as 2m below the seafloor, were also mapped.

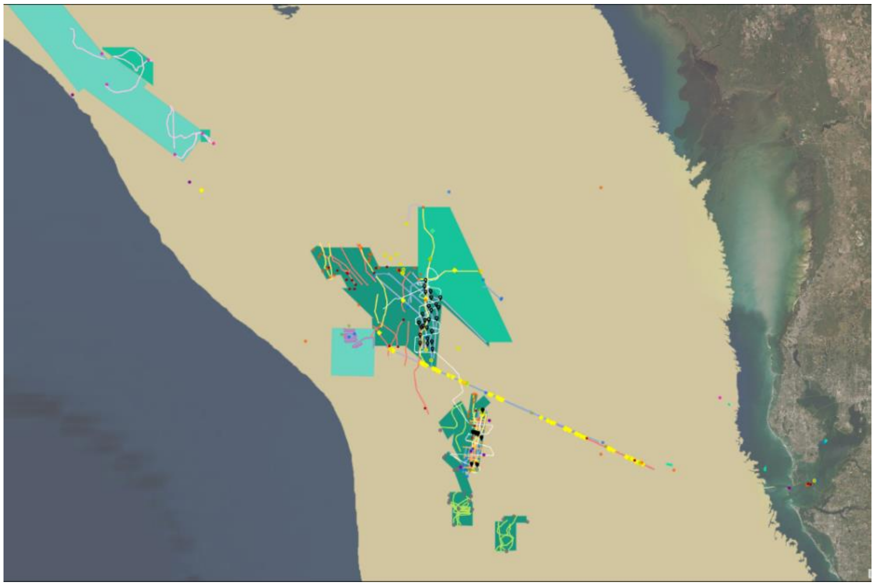


Fig. 2. Overview map of fieldwork completed in the eastern Gulf of Mexico between 2015 and 2019 by the C-SCAMP group. The lines indicate C-BASS tows (excluding the white line which shows the footprint of where the sub-bottom imaging system was towed), the multi-color points are where CTD/SVP casts were taken, the black pins are grab sample locations, the darker teal polygons are where we collected multibeam bathymetry, and the lighter teal is where there was already existing multibeam bathymetry information prior to the start of this project.

Cruise	Sea Days	Operations	Area Mapped (km^2)	Transect Length Surveyed with CBASS (km)	Hours of Video Collected
December 2015	5	MB	108	---	---
February 2016	6	CBASS	---	430	56
April 2016	6	CBASS/MB	13.5	158	26
May 2016	6	MB	68.5	---	---
June 2016	9	MB	250	---	---
July 2016	7	MB	215	---	---
August 2016	3	MB	10	---	---
September 2016	4	MB	50	---	---
October 2016	7	CBASS/MB	35	422	53
April 2017	7	CBASS/MB	55	470	59
July 2017A	8	MB	200	---	---
July 2017B	8	MB	230	---	---
October 2017	7	CBASS/MB	80	363	48
April 2018	2	CBASS/MB	---	110	13
July 2018	5	MB	120	---	---
August 2018	6	MB/SB	215	---	---
September 2018	6	CBASS/MB	125	324	38
October 2018	8	MB	220	---	---
April 2019A	7	MB	185	---	---
April 2019B	5	CBASS/MB	170	242	34

Table 1. All cruises undertaken as part of C-SCAMP between 2015 and 2019. Operations were either or both multibeam mapping (MB) and seafloor imaging (CBASS). In August 2018, a sub-bottom profiler (SB) was also used to collect data which were used to supplement bathymetric and habitat map development and interpretation.

BENTHIC FISH AND HABITAT SURVEYS WITH C-BASS

Upon bathymetry survey cruises returning to port, we had processed bathymetry surface files in-hand that could be used to plan companion fish and habitat cruises using the C-BASS video system. The planned transects along which C-BASS was to be towed were mostly concentrated on hard bottom features, however soft and low-relief bottom was also sampled to ensure coverage over as many different potential habitat types as possible. The C-BASS was typically towed at 3 - 4 knots and at 3 - 5 meters above the seafloor which provided imagery from which we could make fish and habitat classifications.

Analysis of the imagery collected with C-BASS began with reading the videos for fish abundance. These data were recorded using freely available, open-source annotation software from CVision AI (https://github.com/cvisionai/tator) which allowed us to directly count each individual fish observed on one of the forward-facing HD video cameras (chosen based on which had the best quality). The individuals we observed were enumerated and identified to the lowest taxonomic level possible and grouped in continuous, 15-second bins. Using the C-BASS altitude, the amount of tow cable line out, and inherent camera parameters, the amount of area covered for each 15-sec bin could then be calculated (e.g., average width of the visible area multiplied by the distance traveled in 15 sec.). This facilitated converting the count data into density (number of fish per m2) which a critical metric for comparing fish abundance in different habitats and allows for total abundance estimates for an area by multiplying average density time the physical area mapped with sonar.

Findings

DEVELOPING WEST FLORIDA SHELF HABITAT MAPS

The first-order habitat classification of fish and turtle habitats on the West Florida Shelf (WFS) is the distinction between rocky reef habitats and sediment (sand), as these rocky reefs serve as preferred reef fish habitat based upon the relative densities of fish found there. Knowing the location of these reef habitats is important for designing fisheries independent monitoring surveys for managed reef fish (Smith et al., 2011; Switzer et al., 2014) as well as for designating Marine Protected Areas (Andersen et al., 2018). Likewise, previous evaluations of where large swaths of hard-bottom habitat were located led to their designations as “Habitats of Particular Concern” as defined in the Magnuson Stevens Fishery Conservation and Management Act (e.g., the Florida Middle grounds, Madison-Swanson and Pulley Ridge along the West Florida Shelf).The WFS is an economically important fishing area (to both commercial and recreational fishers) in which many species of reef fish have historically been overfished (Chen, 2017). This led to stricter management regulations which helped the populations of many of these species rebuild, but landings restrictions reduced the utility of catch-based monitoring methods (Bryan & McCarthy, 2015; Smith et al., 2015; SEDAR, 2018; Switzer, 2020). As a result, fisheries-independent monitoring has become more important to assessing these species.

Traditionally, habitat maps have been created through manual delineation of boundaries by expert interpretation of acoustic data sets (Brown et al., 2011). This method, although effective in some scenarios, is subjective and can be time consuming, and is less reliable when contrast is more subtle which can occur for example when trying to identify flat hard bottom areas (Riggs et al., 1996; Cochrane, 2008). With the increasing volume of data and the desire to use these maps for management, there has been increased interest in developing semi-automated statistical classifiers that can create habitat maps in a more objective and repeatable manner (Cochrane, 2008; Brown et al., 2011; Brown et al., 2012; Diesing et al., 2014; Lecours, 2017). Although there are several different types of acoustic technologies, C-SCAMP utilized multibeam echosounders as these can rapidly and accurately map large portions of the seafloor in terms of both bathymetry and backscatter (Brown et al., 2011; Lamarche et al., 2016). Collection of bathymetry provides a topographic map of the seafloor. Backscatter, on the other hand, relates to how strong the echo returns, which can be a good predictor of sediment grain-size, composition, and substrate type (Goff et al., 2000; Collier & Brown, 2005; Brown et al., 2011; McGonigle & Collier, 2014; Lamarche et al., 2016; Brizzolara, 2017). Therefore, bathymetry and backscatter both provide different but complementary information describing the potential habitat of an area (Brown et al., 2011; Hasan et al., 2014).

Bathymetry and backscatter both can be used to delineate habitat types on the seafloor and including both bathymetry and backscatter as well as their derivatives increase the accuracy of habitat maps over using either one of them alone (Ierodiaconou et al., 2007). From bathymetry various informative derivative features can be calculated that describe the habitat including the slope, rugosity, and curvature of the seafloor (Wilson et al., 2007). Moreover, several texture metrics can be calculated from the backscatter mosaic which can be useful predictors of benthic habitat (Haralick & Shanmugam, 1973; Hasan et al., 2014; Porskamp et al., 2018). In addition to the collection of bathymetry and backscatter, it is critical to collect some form of ground-truth information (Brown et al., 2011; Lamarche et al., 2016) for which C-SCAMP used the Camera-Based Assessment Survey System (C-BASS). These ground-truth data points are then used to train a machine-learning model using a random forest algorithm (Breiman, 2001) which predicts habitat to the extent of the multibeam survey based on the multibeam bathymetry, backscatter, and their derivative features. Overall, the C-BASS camera system obtained video data for about 1% of the area subject to multibeam coverage. Extrapolating the 1% coverage to reliable full habitat maps required constructing and validating a robust statistical model.

A full explanation of the process by which C-SCAMP's habitat maps were generated can be found in Ilich (2018). The ultimate result of this work is a shelf-wide habitat map delineating reef from non-reef habitats for all publicly available high resolution multibeam data on the WFS (Figure 3). This totals to about 11,000 km^2 of classified benthic habitat, and includes multibeam data collected by the C-SCAMP group as well as previously existing data with approximately 10 m grid-cell resolution, although one area of previously collected multibeam data on the northern end known as "the Pinnacles" was at 16 m resolution. The final map is presented at 10 m resolution and was found to be 96% accurate with $\kappa = 0.74$ based on a random subset of ground-truth observations that was withheld to validate the model, indicating "substantial agreement" between predictions and observations. (Cohen, 1960; Landis & Koch, 1977).

The habitat map shown in Fig. 3 for all available data did not utilize backscatter information as multibeam backscatter is uncalibrated and difficult to use when making predictions across surveys (Lamarche & Lurton, 2018; Misiuk, 2020). Some work was done to normalize backscatter across several adjoining surveys that would be expected to have similar statistical properties using z-score normalization. In Figure 4, the range of drastically different values between surveys is well depicted. But this can be adjusted via a normalization, the results of which are depicted on the right-hand side of Fig. 4. Though useful, this approach is limited to adjoining surfaces that would be expected to have similar environments and were surveyed using the same frequency sonar. Much work is being done to improve the collection and processing of multibeam backscatter (Lamarche & Lurton, 2018), and recently a method was developed to calibrate backscatter to a reference surface based on survey overlap (Misiuk, 2020), which may help integrate backscatter habitat classification models used to predict across several different surveys. Further, while the inclusion of backscatter information can provide a benefit, the backscatter mosaic and its derivatives were less important predictors of habitat than bathymetry and its derivatives, a result that has been demonstrated by several others as well (Hasan et al., 2014; Ilich, 2018; Porskamp et al., 2018; Ilich, 2019).

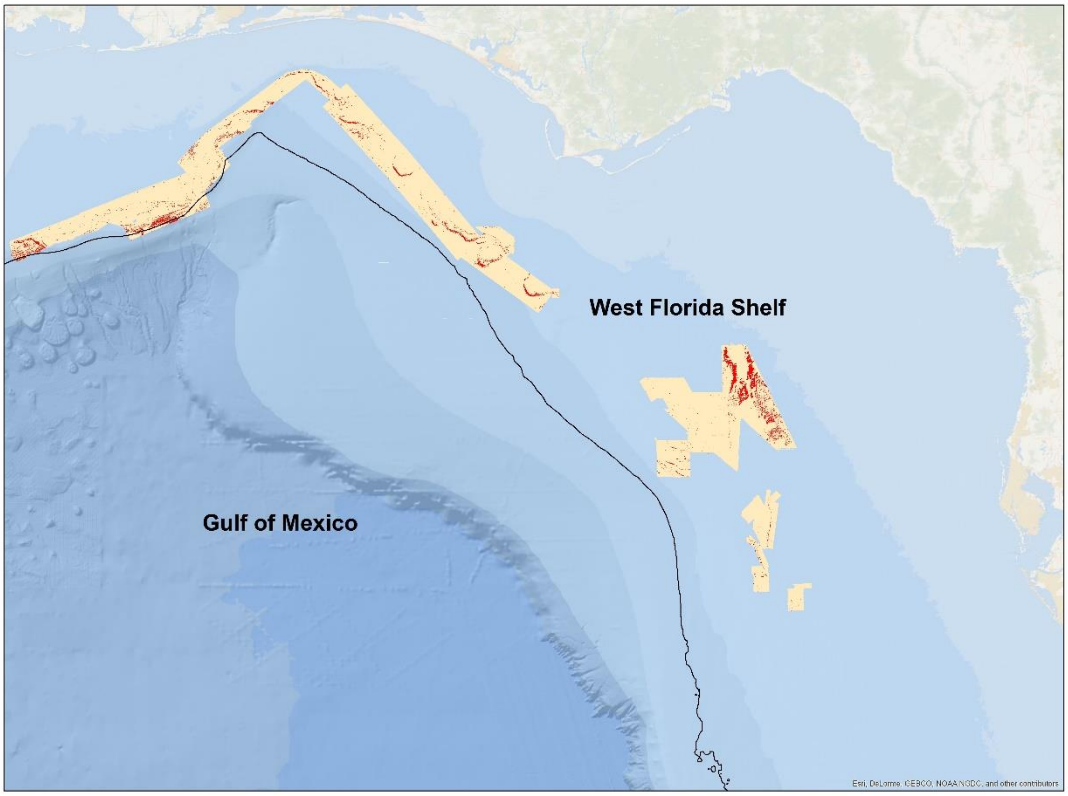


Fig. 3. Unified map of substrate at 10 m resolution delineating rocky reef (red) from sandy habitats across all available high resolution multibeam for the north eastern West Florida Shelf created using a semi-automated statistical classifier that was trained using multibeam bathymetry and C-BASS ground-truth observations.

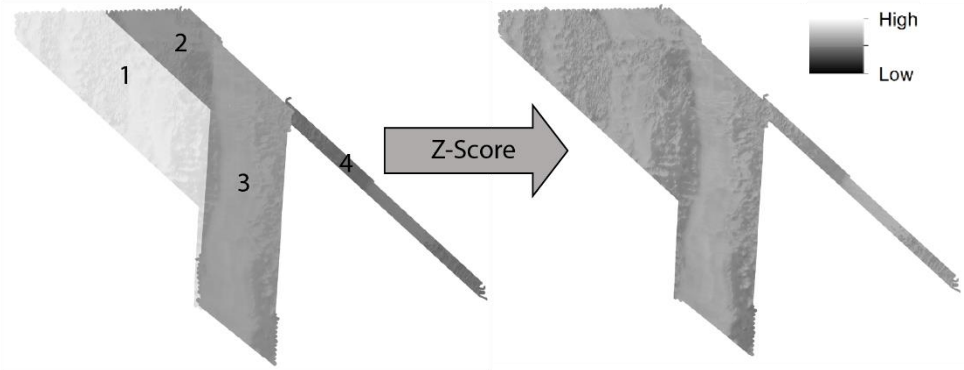


Fig. 4. Backscatter surface of the Southwest Florida Middle Grounds from four surveys. On the left you can see the backscatter surfaces before normalization do not match up well, which is due to the nature of multibeam backscatter being an uncalibrated measure that can vary from survey to survey. To account for this and merge backscatter surfaces across surveys, the surface for each survey was normalized using a z-score transformation, creating a single normalized surface which is shown on the right. This method however is limited to adjoining surfaces that would be expected to have similar environments and were surveyed using the same frequency sonar.

REEF FISH DENSITIES OBSERVED AMONG SURVEY AREAS

The video collected with the C-BASS was analyzed for fish abundance and species identification using the imagery from highest-quality forward-facing HD camera. Counts were acccumulated into continuous 15-second bins and analysis encompassed the entire recording for a transect from recording start to finish. These counts were then converted to densities based on the area viewed for each 15-second bin. Habitat classifications, following NOAA's CMECS scheme, were then linked to each 15-second bin by viewing the first frame of each bin. All fish and habitat analyses were then sorted by area and tagged with a general habitat classification: Mixed/Fragmented Hard Bottom, Soft, Hard. The average densities of all observed species were then calculated, stratified by the general habitat classification, following methods in Grasty (2014) which utilizes the following equations, adapted from those used by the Food and Agriculture Organization of the UN for bottom trawl surveys (FAO 1982) and by Smith et al. (2011) for reef fish visual surveys, were used, viz;

Equation 1

$$\gamma_{bs}=c_s/A_m$$

γ_{bs} = Density of species s per 15-sec bin
s = Species
c_s = Species count for 15-sec bin, b
A_b = Area covered during 15-sec bin, m (km^2)
b = 15-sec bin

Equation 2

$$\bar{\gamma}_{hs}=\sum_{1..n}^{h}\gamma_{bs}*\frac{1}{n_h}$$

$\bar{\gamma}_{hs}$= Average density of species (s) per habitat, h ($\#/km^2$)
n_h = Number of 15-sec bins sampled in habitat, h
h = habitat classification

Over the course of the three years in which the C-BASS was used to collect seafloor imagery (2016 – 2019). A total of 327 hours of video was collected over 2,519 km of transect. This equates to approximately 25 km^2 of area imaged via camera. Within this video collection, we observed 124 unique species along with diverse habitat types, from flat sand to hardbottom pinnacles that were several meters tall. One of the most important takeaways from the video analysis was the importance of relatively small (<100 m^2 in area) patches of low-relief hardbottom which are present throughout the WFS in discontinuous patches, particularly in the South-West Florida Middle Grounds (Fig. 5). Though small and lacking in extreme vertical relief, these patches still tended to hold considerable quantities of fishes and additively were an important habitat class in the eastern Gulf of Mexico. The Gulfstream Natural Gas Pipeline was, by far, the densest structure surveyed in terms of fish abundance – particularly along the pipeline itself and especially when there were parallel piles of dredged rock on either side of the pipeline (Fig. 5). Prior work done in assembling vessel monitoring system and observer data by Cockerell et al. (2019) indicated that this area may experience considerable commercial grouper fishing activity. Combining this with our observations of wide-spread, low-relief hardbottom, this certainly warrants discussion about possible management implications. Because of its size, it would not be practical to necessarily designate this region as an HAPC or MPA, however it may warrant some level of protection or management as Red Grouper populations continue to struggle in the eastern Gulf of Mexico. Additional data collection and collaboration with other fisheries independent sampling groups (i.e. NOAA Southeast Fisheries Science Center and Florida Fish and Wildlife's Fisheries Independent Monitoring Group) should be consulted during next steps for input and to determine if their data also supports the observations of this project.

The results of average densities observed by species, by area for the Mixed/Fragmented Hardbottom habitat type is presented in Table 2. A notable takeaway from these results is the comparatively high densities observed in the Elbow (EL), West (WFMG) & South-West Florida Middle Grounds (SWFMG) study areas vs. the Florida Middle Grounds (FMG) and Madison-Swanson (MS) areas (Table 3), both of which have varying levels of protections. Further, the top 5 highest species densities observed in the non-protected survey areas (EL, WFMG, SWFMG), excluding Lionfish, are all managed species. In looking at the snapper family, in particular, Gray Snapper dominated the C-BASS datasets for most of the study areas with average densities that were an order of magnitude greater in the Elbow, SWFMG, and WFMG than in MS, SMS/NMS, and the FMG (Fig. 6). In the grouper family, the Atlantic Creolefish was observed in the overall highest densities, followed by Scamp, Gag, and Red Grouper (Fig. 6).

The only species observed in all transects completed during this project was Lionfish (*Pterois miles/volitans*). This underscores now ubiquitous the species has become on the West Florida Shelf over a wide depth range as our surveys were as shallow as 25 m (Florida Middle Grounds) and as deep as ~185 meters (Madison-Swanson MPA). This species was also widely distributed across all habitat types we surveyed and was consistently within the top three highest average densities among the six survey areas and for four out of the six areas, this species was observed as having the highest densities (Table 3). Further elaboration on C-SCAMP's findings regarding Lionfish is provided below.

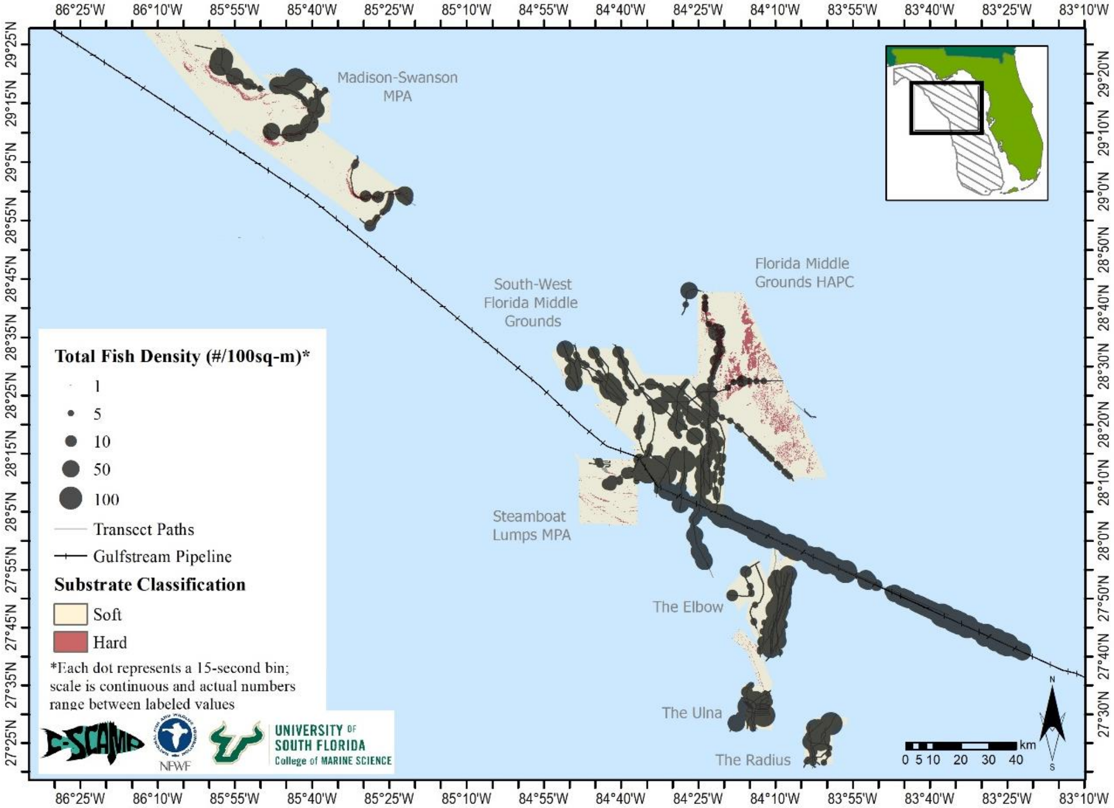


Figure 5. Total fish densities observed with the C-BASS throughout several areas on the WFS. Densities include all observed fish excluding small (<6 in), unidentifiable individuals but does include all identified and unidentified large (≥6 in) individuals.

ELBOW	Average Fish Density (#/sq-km)	MS	Average Fish Density (#/sq-km)	SMS/NMS	Average Fish Density (#/sq-km)	SWFMG	Average Fish Density (#/sq-km)	FMG	Average Fish Density (#/sq-km)	WFMG	Average Fish Density (#/sq-km)
snapper_gray	**7040**	**lionfish_spp**	**972**	**lionfish_spp**	**1434**	**lionfish_spp**	**4854**	**drum_jacknifefish**	**126**	**lionfish_spp**	**3658**
lionfish_spp	**4824**	**grouper_creolefish atlantic**	**766**	**snapper_gray**	**288**	**snapper_gray**	**3948**	**snapper_gray**	**72**	**snapper_gray**	**1054**
grunt_spp	**2557**	**grouper_scamp**	**172**	**Jack_spp**	**94**	**snapper_spp**	**276**	**lionfish_spp**	**72**	**grouper_scamp**	**355**
grouper_creolefish atlantic	**1850**	**grouper_spp**	**171**	**jack_amberjack spp**	**84**	**triggerfish_gray**	**215**	**filefish_spp**	**23**	**snapper_red**	**244**
porgy_spp	**502**	**grouper_gag**	**121**	**grouper_spp**	**69**	**filefish_spp**	**202**	**snapper_spp**	**20**	**Jack_spp**	**239**
grouper_scamp	472	snapper_spp	106	porgy_spp	67	grouper_scamp	197	grouper_red	15	triggerfish_gray	157
snapper_spp	378	porgy_spp	58	grouper_scamp	58	jack_amberjack spp	195	grouper_gag	11	grouper_creolefish atlantic	114
snapper_vermilion	373	jack_amberjack spp	50	snapper_red	55	grouper_spp	148	grouper_scamp	5	grouper_red	96
jack_bluerunner	329	grouper_red	48	snapper_vermilion	55	grouper_creolefish atlantic	141	triggerfish_gray	5	porgy_spp	81
triggerfish_gray	308	snapper_red	36	grouper_gag	49	snapper_red	131	grouper_spp	4	snapper_spp	79
porgy_jolthead	209	porgy_jolthead	20	snapper_spp	42	seabass_bank	127	triggerfish_spp	2	jack_amberjack spp	68
grouper_red	176	grouper_yellowfin	19	grouper_red	30	porgy_spp	115	Jack_spp	2	grouper_gag	63
jack_amberjack spp	152	triggerfish_gray	12	flounder_spp	28	porgy_jolthead	110			grouper_spp	58
herring_spp	149	drum_jacknifefish	9	filefish_spp	27	drum_jacknifefish	108			drum_jacknifefish	44
grouper_spp	147	jack_amberjack greater	9	grouper_creolefish atlantic	16	grouper_red	104			triggerfish_spp	31
grouper_gag	143	porgy_red	8	seabass_spp	12	grouper_gag	101			grouper_black	13
jack_almaco	92	seabass_spp	8	seabass_bank	9	triggerfish_spp	73			jack_banded rudderfish	13
Jack_spp	91	Jack_spp	6	jack_almaco	8	wrasse_hogfish	51			porgy_jolthead	12
jack_pilotfish	84	snapper_vermilion	5	wrasse_hogfish	6	Jack_spp	49			seabass_spp	6
drum_jacknifefish	76	grunt_porkfish	4	triggerfish_gray	6	seabass_spp	40			jack_almaco	3
snapper_red	63	jack_almaco	4	jack_banded rudderfish	4	flounder_spp	22				
filefish_spp	57	snapper_gray	1	trumpetfish_spp	3	grouper_nassau	17				
wrasse_hogfish	49	trumpetfish_spp	0	jack_crevalle	2	porgy_sheepshead	17				
jack_banded rudderfish	45					jack_almaco	14				
trumpetfish_spp	40					mackerel_spp	10				
triggerfish_spp	40					grunt_white margate	9				
jack_amberjack greater	31					filefish_orange	9				
seabass_spp	30					cobia_cobia	6				
filefish_unicorn	27					jack_crevalle	5				
snapper_yellowtail	26					grouper_black	5				
porgy_sheepshead	26					seaturtle_spp	4				
seabass_bank	18					jack_banded rudderfish	4				
flounder_spp	11					snapper_vermilion	3				
grouper_goliath	10					snapper_mutton	3				
jack_rainbowrunner	10					grouper_goliath	2				
jack_bluntnose	10										
triggerfish_ocean	9										
seaturtle_spp	7										
grouper_black	6										
porgy_red	4										
cobia_cobia	3										

Table 3. Average densities by area ranked from largest to smallest for the Mixed/Fragmented Hardbottom habitat.

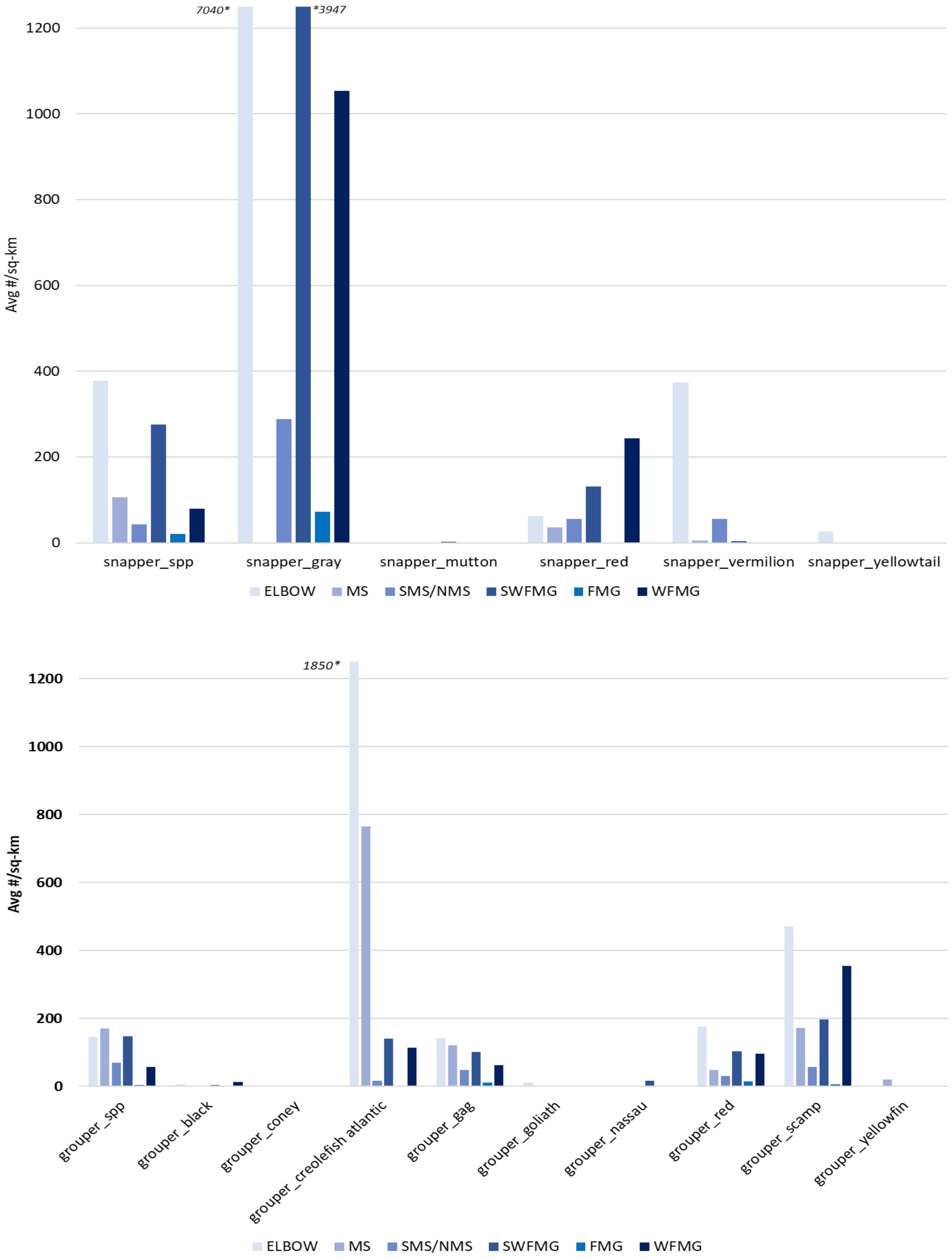


Fig. 6. Average densities (per square-km) of snapper (top) and grouper (bottom) in C-SCAMP's study areas for Mixed and Fragmented Hard Bottom Habitat.

Have MPAs been successful in increasing fish densities? (from Grasty et al. 2019 and edited for clarity/brevity)

The Red Grouper (*Epinephelus morio)* is an ecologically and economically important Gulf of Mexico reef fish species and their well-documented excavation behavior generates several-meter-wide depressions (‘holes’) that serve as habitat in otherwise featureless areas. These mesohabitats are notably dense within the Steamboat Lumps (SL) Marine Protected Area (MPA) in the eastern Gulf of Mexico. Previous work in the SL-MPA used high-resolution multibeam bathymetry to analyze changes in hole density and structure (width, height, and slope) between 2006 and 2009. The current project was able to collect additional multibeam data in 2017 to assess change in population status over time (Fig. 7). The previously-collected data as well as the full data analysis from the Wall et al. (2011) publication were obtained directly from Dr. Wall. These data included the bathymetry surfaces used for analysis as well as all georeferenced, individual grouper hole data (i.e., latitude/longitude, depth, etc.). Average hole depths, widths, and heights throughout the comparison region were measured and calculated. These attributes were compared to the hole depths and widths measured by Wall et al. (2011) with the purpose of determining whether the holes were being actively maintained (same depth or deeper) or were abandoned (shallower). Only holes from the 2017 data set that could be directly linked to holes present in 2009 within the comparison area were measured.

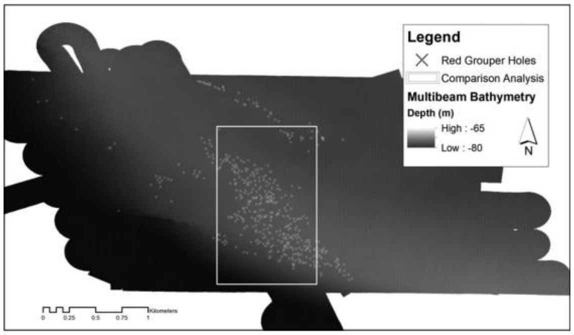


Fig. 7. The full extent of multibeam bathymetry collected in 2017 where 456 Red Grouper holes (white x-marks) were identified. The comparison area with Wall et al. (2011) is indicated by the white bounding box.

In the Wall et al. (2011) study, 181 holes were detected in 2006 and 231 holes in 2009 from the multibeam bathymetry data within the area of overlap with the current study. Using the 2017 multibeam bathymetry data with the 3-x3-m grid, a total of 317 grouper holes were detected within the comparison area which equates to a density of 193 holes/km^2. These results indicate a trend of increasing hole density from 2006 to 2017 (Table 4).

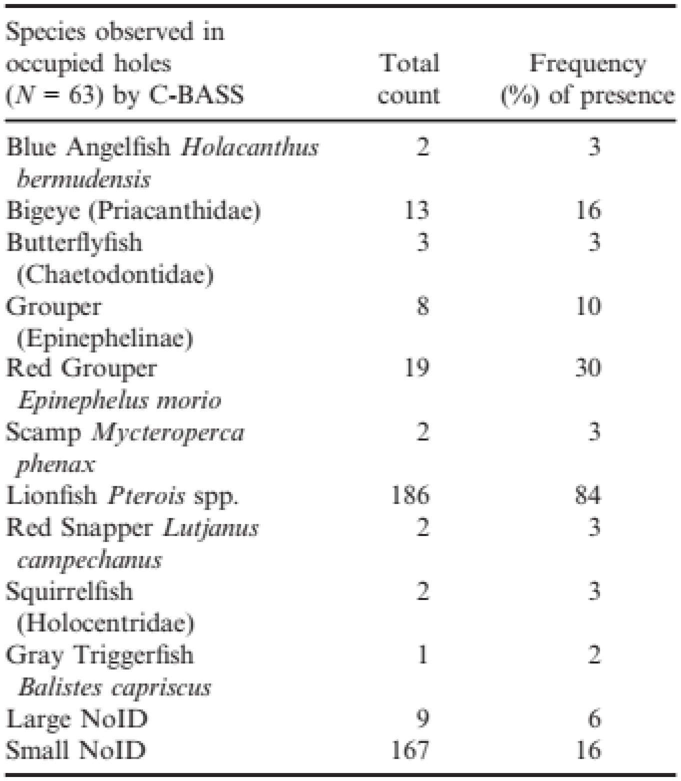
Table 4. Number of grouper holes observed within the comparison area based on 2006 and 2009 data (Wall et al. 2011) and in 2017 (C-SCAMP). Next to the data set name is the grid size used to identify grouper holes.

Data set	Number of holes	Density (holes/km^2)
2006 (3 × 3 m)	181	110
2009 (3 × 3 m)	231	141
2017 (3 × 3 m)	317	193
2017 (0.5 × 0.5 m)	340	207

In total, 188 holes within the comparison area could be linked to holes that were measured in 2006 and 2009. Based on this subset, the average hole height in 2017 was comparable to measurements from 2006, but less than that estimated from the 2009 data. The average widths of the holes decreased in 2009 relative to 2006, but then increased in size by 2017. The slopes of the holes increased from 2006 to 2009 but then decreased in 2017 and were more comparable to the 2006 average value. A t-test was used to evaluate statistically significant differences in the average height, width, and slopes between the 2006 and 2009 data sets and between the 2009 and 2017 data sets. All six pairs of average values were found to be significantly different within each category (P < 0.05). When examining the individual changes in widths for each of the 188 holes from 2009 to 2017, we found that a majority experienced growth of approximately 2–39% relative to their width in 2009. For those that decreased in size, most shrank by 70–90%. The number of holes that were present in 2009 but not 2017 and vice versa were also counted (filled in or newly formed). Overall, there was a greater number of newly formed holes (61) than filled-in holes (31) by 2017.

The C-BASS was used to collect four hours of imagery over the 2017 mapped area within which a total of 95 holes were captured on film. Of these, 63 holes (~66%) had fish present, and no fish were detected in the remaining 32 (note that smaller-bodied fishes were likely present in most of the holes but could not always be observed from the towed platform). Of the 63 holes where the towed system imagery detected fish, 19 holes were observed to have Red Grouper present, and 7 holes had an unidentified grouper (Epinephelinae) individual present, meaning just over 40% of the observed holes had an individual grouper present (Table 5). Lastly, of the 63 holes in which fish were detected, 84% (53 holes) had at least one lionfish (*Pterois spp.*) individual in or near the hole, and approximately 35% (22 holes) had two or more lionfish individuals present. The maximum number of lionfish observed within and near a single Red Grouper hole was 24 individuals. Other than groupers and lionfish, bigeyes (Priacanthidae) were the next most frequently encountered species, with approximately 16% of the 63 occupied holes having at least one individual present. The other species of larger reef fishes (i.e., angelfishes [Pomacanthidae], butterflyfishes [Chaetodontidae], Red Snapper, and triggerfishes [Balistidae]) tended to be rarely observed on the C-BASS imagery, with only 1–4% of the 63 holes having any detectable individuals.

Table 5. Total number of individuals observed by species that were detected within the occupied grouper holes (N = 63). Also shown is the frequency (%) with which each species or family group was observed along the transect.



Species observed in occupied holes (*N* = 63) by C-BASS	Total count	Frequency (%) of presence
Blue Angelfish *Holacanthus bermudensis*	2	3
Bigeye (Priacanthidae)	13	16
Butterflyfish (Chaetodontidae)	3	3
Grouper (Epinephelinae)	8	10
Red Grouper *Epinephelus morio*	19	30
Scamp *Mycteroperca phenax*	2	3
Lionfish *Pterois* spp.	186	84
Red Snapper *Lutjanus campechanus*	2	3
Squirrelfish (Holocentridae)	2	3
Gray Triggerfish *Balistes capriscus*	1	2
Large NoID	9	6
Small NoID	167	16

Although the detection ability of the C-BASS for most reef fishes is likely affected by reactive behavior, as is the case for visual surveys in general (Stoner et al. 2008), it’s likely that lionfish are an exception to this condition. Previous studies on this species have reported how minimally reactive Lionfish are toward divers and that they can in fact be fairly aggressive (Whitfield et al. 2007). Based on this information, and the hundreds of hours of C-BASS imagery that have been collected over the past 5 years where lionfish are frequently observed, Lionfish appear to be very minimally reactive toward the C-BASS. It is important to note that lionfish commonly reside in crevices and under overhanging rocks, where towed video imagery cannot sample effectively. Therefore, the observations of lionfish on C-BASS imagery are likely underestimates, but determining the degree to which they are underestimated requires further habitat-specific surveys. Nonetheless, the lionfish observations were a notable part of the towed camera work, as approximately 84% of the 95 holes observed with the C-BASS had at least one lionfish individual present in or near the hole.

The spread of invasive lionfish began along the east coast of Florida in the early 1980s (Morris and Whitfield 2009), but lionfish were not detected in the Pulley Ridge MPA (an area ~400 km south of the SL-MPA) until 2010 (Harter et al. 2017). The last published study using a visual-based survey to evaluate the reef fishes present in the SL-MPA was completed in 2002—that is, 15 years prior to our 2017 survey (Gledhill and David 2004). The area was scheduled to be resurveyed in 2010, but due to funding issues, the SL-MPA was removed from the cruise plan (David and Gledhill 2012). However, lionfish were observed in 2013 from C-BASS video data collected in the SL-MPA grouper hole area (S. E. Grasty, unpublished raw data). It is therefore likely that lionfish did not start colonizing the SL-MPA until after 2010 but took less than 4 years to populate the grouper holes. Additional visual survey work in tandem with diet studies could assess whether there is a negative effect of Lionfish colonization for the grouper hole habitat in the SLMPA.

Our work does not present an exhaustive study of the efficacy of Steamboat Lumps as an MPA. However, the results of this research, in tandem with the work done by Wall et al. (2011), show that over the last 11 years, the density of Red Grouper holes has continued to increase within the boundaries of the MPA. Although the SL-MPA was intended to protect spawning aggregations of Gags (*Mycteroperca microlepis;* Coleman et al. 2004), this work documents that there are likely positive side benefits for the local Red Grouper population. As the Red Grouper population in the Gulf of Mexico continues to recover from past exploitation (SEDAR 2015), this can serve as an example of the importance of properly implemented MPAs. To truly comment on the efficacy of the SL-MPA for supporting a growing local population, data on Red Grouper populations and hole habitat outside of the MPA are necessary. A subsequent analysis to assess the level of illegal fishing that occurs within the SL-MPA (Gledhill and David 2004) could also help to determine whether the increase in holes is in fact due to the effective protection of this habitat.

SEA TURTLE OBSERVATIONS (FROM BROADBENT ET AL. 2020 AND EDITED FOR CLARITY/BREVITY)

This portion of the project demonstrated that towed camera systems have a unique ability to document sea turtle presence over wide swaths of area in offshore (>25 m to approximately 200 m) environments at the sea bottom as opposed to the sea surface where they spend varying amounts of time. In addition to recording species presence, each observed sea turtle can be evaluated for behavior, the surrounding habitat can be classified, and various environmental parameters can be measured to provide a more complete characterization of sea turtle habitat use. With the appropriate setup, these systems can also facilitate size estimates to then estimate life stage, data which are imperative to better understand sea turtle population dynamics. Though the refinement of CBASS's stereo setup was in progress during the timeframe in which these data were collected, the data nonetheless demonstrate that it is possible to observe a range of life stages with this approach. In addition to collecting data on various life stages, towed camera systems such as the C-BASS offer the ability to observe sea turtle behavior. This may be of particular utility considering the need for improved data on where foraging habitats for sea turtles are located (Hamann et al. 2010).

A total of nine C-BASS survey cruises were conducted from 2014 to 2018 which resulted in a total of 97 transects (2750 km) which were analyzed for sea turtle abundance, identification, behavior, and habitat usage. A total of 79 sea turtles were sighted (Fig. 8): 69 loggerheads, 4 Kemp's Ridleys, 1 green turtle, 5 hardshelled turtles that were unidentifiable to species, and 1 possible turtle (Fig. 9). Most sea turtles (91%) were observed on the GSPL, where a total of 70 turtles were sighted: 63 loggerheads, 3 Kemp's ridleys, 3 unidentified hard-shelled turtles, and 1 possible turtle. Several sea turtles (n = 6) were observed in the FMG: 4 loggerheads, 1 Kemp's Ridley, and 1 green turtle and only two were observed in the EL, both loggerheads. No sea turtles were observed in the MS or SL MPA areas during the surveys. Two of the GSPL loggerheads were identified as males based on the tail appearing to extend well beyond the posterior edge of the carapace (approx. >10 cm).

After analyzing the C-BASS footage for sea turtle presence and identification, the individuals observed were then measured. For the 2016 sightings, stereo vision had not yet been properly calibrated, but measurements could be estimated for 16 sea turtles using the ratio of known pipeline width to standard carapace length; all were identified as *Caretta caretta*. Due to occluded views of the individuals spotted, as well as their orientation relative to the camera, only an additional 5 measurements could be made using the stereo vision capability from the 2017 and 2018 datasets. All of these were identified as *C. caretta*. Most of the measurements were from sea turtles spotted along the GSPL (n = 19); only 2 individuals that resided on natural features could be measured. Loggerheads were grouped into life stages based on the following breaks (Eaton et al. 2008): oceanic-stage juvenile (<30 cm), neritic-stage juvenile (30–69 cm), sub-adult (70–79 cm), and adult (≥80 cm). Based on the length analysis for these 21 loggerheads, the C-BASS was able to observe individuals from all 4 life stages (oceanic-stage juvenile, neritic-stage juvenile, sub-adult, adult) within anthropogenic and natural habitats. The most frequently observed life stage was neritic-stage juveniles (n = 15), followed by sub-adults (n = 4), oceanic-stage juvenile (n = 1), and adult stage (n = 1).

Sea turtles were observed in both natural and anthropogenic benthic habitats (Fig. 8) but most were observed adjacent to or near an anthropogenic structure (n = 71), namely the GSPL (n = 70). The most utilized benthic substrate was pipe with dredge (n = 35), with 23 seen near bare pipe and 12 observed where the pipe was buried. One turtle in the EL was sighted near an unknown anthropogenic structure which consisted of metal debris. Only 9 sea turtles were observed in a natural benthic habitat, including both hard and soft substrates which consisted of rock outcrops (n = 4), sand (n = 3), and a ledge (n = 1)

In addition to identification, measurement, and habitat usage, behavior of the sea turtles could also be analyzed from the C-BASS data. Of the 79 observed sea turtles, 58 were classified as resting, 12 were swimming, and 6 were seen crawling. Loggerheads were observed exhibiting all 6 of the classified behaviors, including surfacing and diving which were observed when C-BASS was either ascending or descending during deployment. Three of the Kemp's ridleys were seen resting on the seafloor and one was crawling along the bottom. The green turtle was seen swimming along the seafloor.

Sea turtles may use artificial structures for foraging (Rosman et al. 1987), resting (Lohoefener et al. 1990), self-cleaning (Schofield et al. 2006), or predator avoidance (Barnette 2017). The C-BASS data observed most sea turtles utilizing the GSPL as a resting area, whereas the turtles observed in the natural habitats were mostly seen performing active behaviors such as swimming, crawling, and foraging. Use of tracking technology has allowed researchers to identify offshore benthic hot spots for sea turtles (Walcott et al. 2012, Hardy et al. 2014, Hart et al. 2014, 2018). However, little is known about the specific features of these habitat areas. A better understanding of the fine-scale characteristics of these features is needed so similar habitats in the GoM can be identified and conserved. Loggerheads use patches within their overall home ranges; to fully understand the environmental and habitat characteristics required for loggerhead foraging, fine-scale habitat use data are needed (Dujon et al. 2018).

The key takeaway from this work was the apparent high use of artificial structure (i.e. the GSPL) by a large majority of the sea turtles sighted (Table 6). It is therefore worth further discussion and study as these results indicate that the GSPL serves as essential habitat for Threatened and Endangered sea turtle species in the GoM. Sea turtles have long been known to use natural and artificial reefs (Stoneburner 1982, Witzell 1982, Steimle & Zetlin 2000), including oil and gas platforms (Gitschlag & Herczeg 1994). However, few studies have quantified use of these structures, particularly pipelines, by sea turtles. The GSPL transects were only 17% of the total distance surveyed, but contained 89% of the sea turtles observed. Close associations between neritic sea turtles and benthic anthropogenic structures is not without risk. For example, anthropogenic structures pose entanglement risks (Barnette 2017) as well as potential to oil or chemical spills (Wallace et al. 2017). As more anthropogenic structures are installed in marine offshore environments (Dance et al. 2018), understanding how sea turtles use different artificial structures is necessary, both from the perspective of habitat requirements and injury risk.

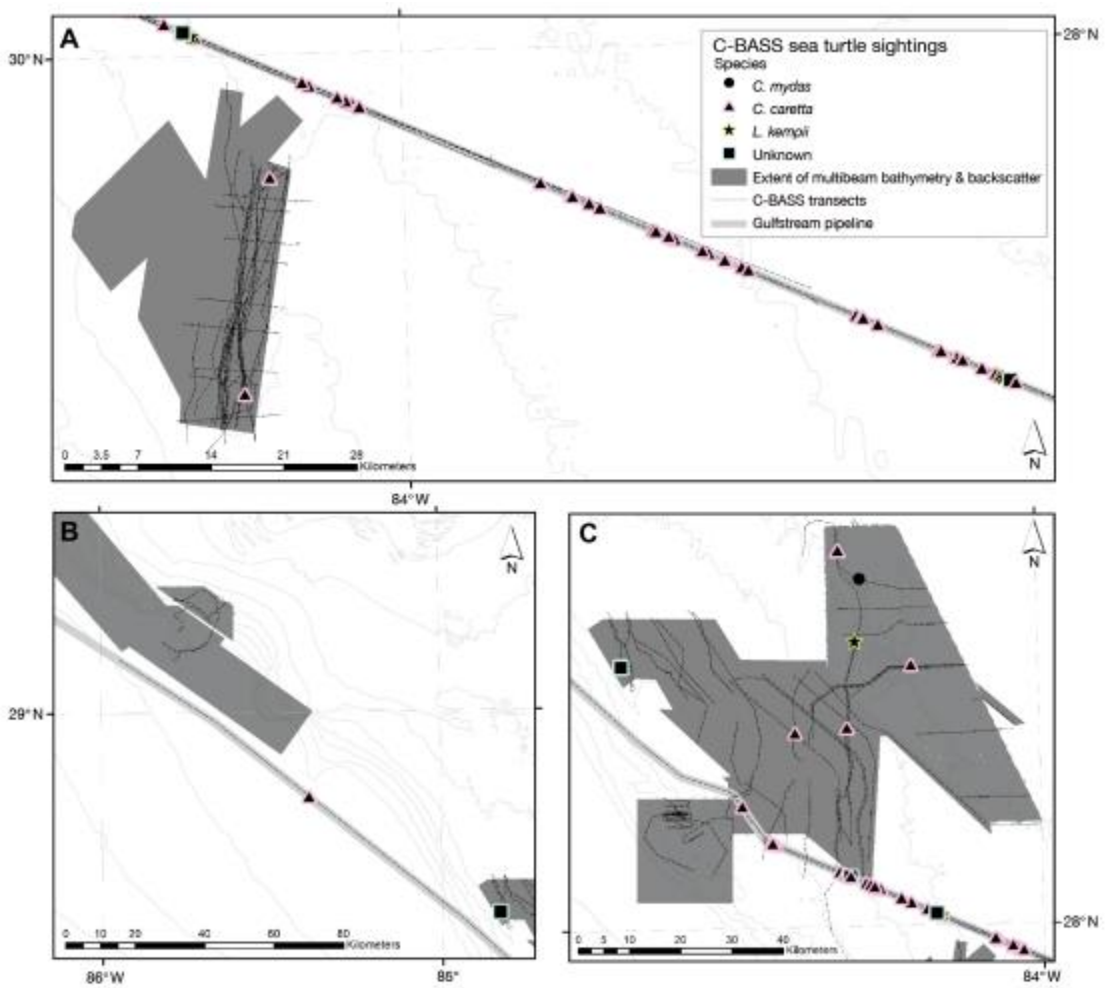
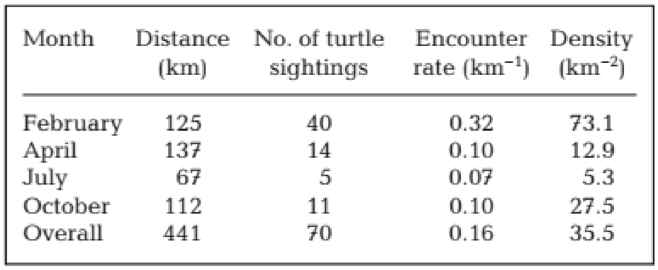


Fig. 8. Maps of the areas where sea turtles were observed along C-BASS transects (black lines). The area footprints (gray polygons) are equivalent to the extent of multibeam bathymetry available. (A) the Elbow and southern portion of the Gulfstream Natural Gas Pipeline (GSPL); (B) Madison-Swanson MPA and northern GSPL; (C) Florida Middle Grounds HAPC and central GSPL)

Table 6. Estimated sea turtle density along the GSPL based on C-BASS data from 10 transects during 6 separate cruises.



Month	Distance (km)	No. of turtle sightings	Encounter rate (km^{-1})	Density (km^{-2})
February	125	40	0.32	73.1
April	137	14	0.10	12.9
July	67	5	0.07	5.3
October	112	11	0.10	27.5
Overall	441	70	0.16	35.5

The apparent disproportionate use of the GSPL by sea turtles may be a consequence of detectability. While larger areas of other sections of the WFS (FMG and EL) were surveyed, the same section of the GSPL was examined multiple times. Since the GSPL region is a relatively flat linear area that is easy to follow and capture with the C-BASS cameras, the higher sea turtle abundance observed on the pipeline could be a function of easier detectability over this habitat compared to more complex, natural hardbottom. In the natural regions, the area of suitable benthic habitat was usually larger than the C-BASS field of view, thus preventing us from recording its entirety within a single transect. Also, several areas in the natural habitats were characterized by steep ridges and other topographic features that hindered the benthic viewing range of the C-BASS (e.g. pinnacles in MS MPA), thus quite possibly preventing observations of present sea turtles. Additionally, sea turtles have been known to exhibit diel behavior patterns, such as longer dives and lower activity levels during night hours (Hays et al. 2000, Christiansen et al. 2017), which suggests that sea turtles rest at depth during those hours. Most of the C-BASS transects were conducted during daylight hours, thus potentially preventing observations of benthic sea turtles due to diel activity patterns.

Characterizing the benthic habitat and developing methods to improve sub-surface sea turtle surveys is highly important to understanding sea turtle ecology. Work done by C-SCAMP researchers is the first example of towed camera system data being used to characterize and study sea turtles in the GoM at depths greater than 30 m (Zawada et al. 2008). The importance of this work is underscored by how data-deficient the GoM is for sea turtles (Valverde & Holzwart 2017); though the C-BASS cannot fill all of the knowledge gaps which currently exist for GoM sea turtle populations, it demonstrated valuable utility for studying offshore occurrences of several life stages, namely for *C. caretta* individuals. Additionally, it does what few other types of observation platforms can, by associating an individual within a small and large-scale habitat context while also providing a description of behavior at the time of observation.

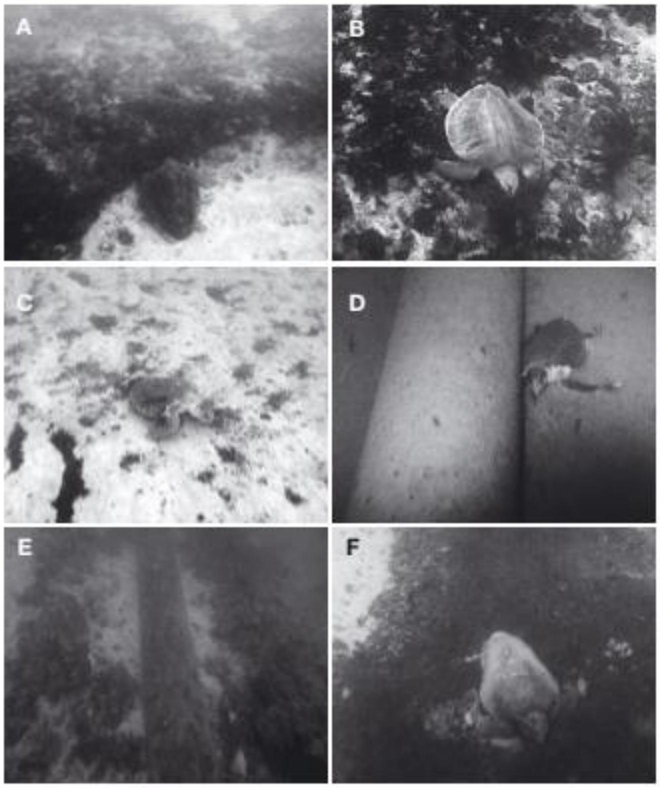


Fig. 9. Example images of sea turtles observed on C-BASS imagery over different benthic habitat types: (A) *Caretta caretta* on natural ledge; (B) *Lepidochelys kempii* on natural rock outcrop; (C) *C.caretta* on natural soft (sand) bottom; (D) *C.caretta* on bare pipeline; (E) *C.caretta* on pipeline with dredge spoils on either side; (F) *C.caretta* on buried pipeline.

PAIRING ACOUSTIC AND VISUAL FISH DATASETS

NOTE: The following data presented are preliminary and subject to change slightly, however overall trends are expected to remain the same as analyses continue and are refined. Results NOT for wide distribution.

The use of joint remote technologies (active acoustic and video technologies) to characterize different aspects of reef fish populations and their habitat continues to evolve and expand in reef environments (Stanley and Wilson, 2000; Boswell et al., 2010a; Kracker et al., 2011; Jones et al., 2012; Campanella and Taylor, 2016; Gastauer et al., 2017; Zenone et al., 2017; Egerton et al., 2018). Video can provide great detail about the fish species present and in what quantities, the associated habitat, and information on the size classes of observed fish pending proper stereo measurement set-up. Acoustics provides a rapid alternative method to collecting spatially-explicit, high-resolution synoptic data across large areas (Zenone et al., 2017). A primary goal of using acoustics in fisheries management is to provide accurate abundance estimates while preserving the spatial distribution of fish densities and sizes within the survey data (Jech and Horne, 2001). Both video and acoustic techniques are non-invasive and non-destructive to the fish, but each has its own biases and limitations which is what this work sought to address. To do this, the densities of reef fishes determined from vessel-borne echosounder and towed video surveys based on data collected almost concurrently (<2 min apart) over four transects with varying habitat conditions (e.g., substrate, rugosity, relief) were compared (Fig. 10; Table 7).

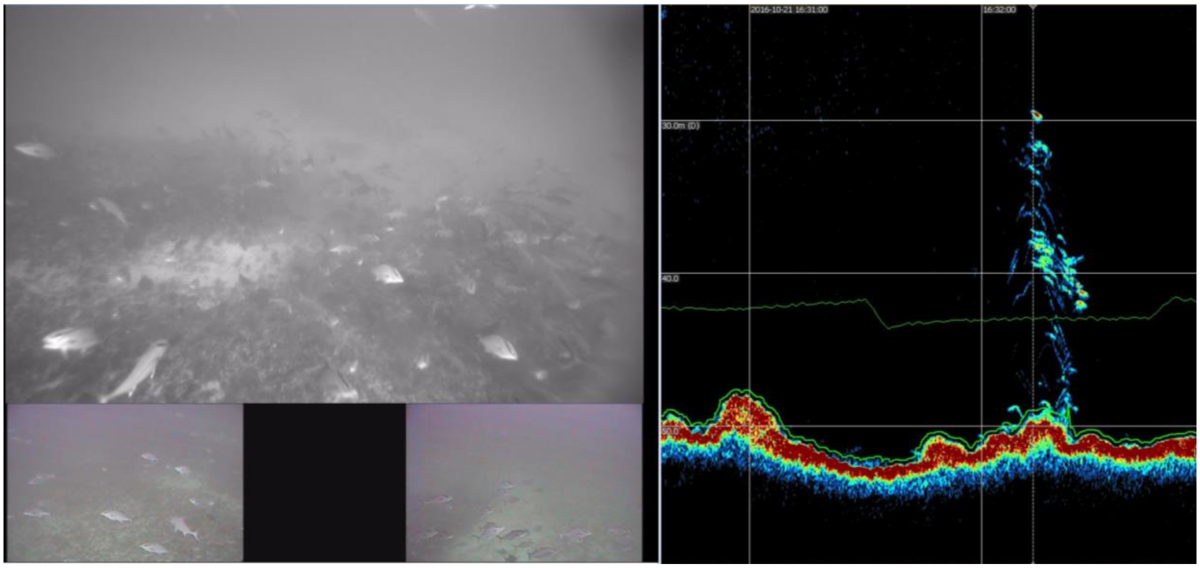


Figure 10. A example of a side-by-side multi-video frame grab (left) from the C-BASS and echogram (right) that have been synced in time and space. A school of greater amberjack (*Seriola dumerili*) were encountered along the transect and have an increased vertical distribution in the water column over relief features. Note, the upper green line on the echogram shows the approximate altitude path of the towed camera.

The advantages of using split beam echosounders include the ability to capture a synoptic view of the water column, its application is non-destructive, results can be seen immediately from a permanent record, and with proper technique and calibration, it can provide independent assessments of abundance. Active acoustics facilitates the survey of large areas relatively quickly. One of the main disadvantages of active acoustics, particularly in the fishery echosounder frequency range, is taxonomic ambiguity–fish species cannot be identified by an acoustic approach alone (Simmonds and MacLennan, 2005; Johnston et al., 2006; Murphy and Jenkins, 2006). Seafloor proximity is another disadvantage (the acoustic "dead zone") where acoustic targets of fish located close to the seafloor will not be discernable due to the strong acoustic return from the seafloor itself (Ona and Mitson, 1996). Further, fish with gas bladders have a higher TS than fish that lack them, which can bias subsequent length and biomass estimates (Murphy and Jenkins, 2010).

In the context of this project's work, the main advantages of video are its ability to enumerate, identify, and measure individual fishes. Camera systems can also be used in areas where more traditional fish capture gears cannot be used due to depth, selectivity, seafloor rugosity, or fish behavior (Cappo et al., 2006). Disadvantages of this approach includes behavioral responses to the camera systems, a limited field of view, and a detection ability that is difficult to quantify as fish near the seafloor may camouflage or hide under crevices and within other structure.

For this initial study, four transects were chosen that varied in seafloor relief which included, from lowest to highest, the following study areas: Steamboat Lumps MPA (SL), the Gulfstream Natural Gas Pipeline (GSPL), the Elbow (EL), and Madison-Swanson MPA (MS). Semi-concurrent data were collected along these four transects and the fish densities were calculated in one-minute intervals based on both the acoustic and video datasets then compared. Densities were generally within the same order of magnitude along the transects. However, as relief increased (i.e., in EL and MS) higher densities and greater variability were observed using the acoustic technology. This is likely attributable to the wider vertical distribution of reef and reef-associated fishes over regions of greater relief and the echosounder having a greater field of view than the video camera, essentially "seeing" more of the fish present in the water column as the C-BASS cannot easily navigate over areas of sharp depth change.

Table 7. Summary Data of Four Video/Acoustic Transects Along the West Florida Shelf.

Region	Survey Date	Transect Length (km)	Tow Duration (hours:minutes)	Depth Range (m)	Maximum Relief (m)
Steamboat Lumps (SL-T1)	April 26, 2017	27.13	4:00	70–83	<1
Gulfstream Pipeline (GSPL-T1-D1)	April 21, 2017	52.67	6:21	37–52	~ 1–2*
The Elbow (EL-T6)	October 21, 2016	26.0	3:41	40–80	4–6
Madison-Swanson (MS-T1)	April 9, 2016	43.1	6:25	54–120	Up to 12

*Note, the pipeline has a diameter of 36" plus additional armoring, so it is likely just over a meter tall in some areas along its length. Occasional sections of excavated spoil associated with attempted pipeline burial also contribute to local relief.

Areal densities derived from the acoustic and video datasets were statistically compared by normalized cross-correlation calculations (Table 8). A 60-sec lag was used between the acoustic and video data as this was generally the lag time experienced between the two technologies passing over the same location (hull-mounted echosounder followed by towed video camera). In the Steamboat Lumps MPA, average fish density was comparable between the acoustics-based and video-based methods; 0.0007 fish per m2 ± 0.0001 standard error (SE). A normalized cross-correlation of 0.16 was calculated which was the weakest correlation observed in this study.

For the Gulfstream Natural Gas Pipeline comparisons, average acoustic-based density was lower than corresponding video-based estimates at 0.0069 fish per m^2 ± 0.0012 SE compared to 0.019 fish per m^2 ± 0.0021. Average acoustic-based density ranged between 0–0.274 fish per m^2 and concurrent video-based density ranged between 0–0.330 fish per m^2. A normalized cross-correlation of 0.48 was calculated for the acoustic and video-based densities which was the strongest cross correlation observed in the study. A weak positive correlation was observed between the two technologies when a linear regression model was applied. The coefficient of determination (r2) was the strongest observed for the four transects examined.

Table 8. PRELIMINARY Acoustic and Video-Based Densities and Normalized Cross Correlations.

Transect	**Depth Range (m)**	**Acoustic-Based Density Mean, Standard Error, and Range (fish m^{-2})**	**Video-Based Density[1] Mean, Standard Error, and Range (fish m^{-2})**	**Normalized cross correlation[2] Acoustics vs. Video-Based Density**
Steamboat Lumps	70–83	0.0006 SE = 0.0001 0–0.018	0.001 SE = 0.0002 0–0.032	0.16
Gulfstream Pipeline	37–52	0.0069 SE = 0.0012 0–0.274	0.0191 SE = 0.0021 0–0.330	0.48
The Elbow	28–51	0.0045 SE = 0.0013 0-0.238	0.0027 SE = 0.0009 0–0.170	0.35
Madison Swanson	54–120	0.0088 SE = 0.0014 0–0.305	0.0029 SE = 0.0004 0–0.052	0.35

[1] Schools of small fish were excluded in density estimation.

[2] Normalized cross correlations were based on a 60-sec lag of the video-based density against the acoustics-based densities.

In the Elbow, average fish density was similar for acoustics-based and video-based methods; average acoustic-based density was slightly higher at 0.0044 fish per m^2 ± 0.0013 SE compared to 0.0027 fish per m^2 ± 0.0009 SE for the video-based method. A normalized cross-correlation of 0.35 was calculated for the acoustic and video-based densities and a very weak positive correlation was observed between the two technologies when a linear regression model was applied.

For the Madison-Swanson MPA, acoustics-based densities were roughly 3 times higher than the video-based density, averaging 0.0088 fish per m^2 ± 0.0014 SE with a range of 0–0.3052 fish per m^2. A normalized cross-correlation of 0.35 was calculated for the acoustic and video-based densities with a lag interval of 60 sec. A very weak positive correlation was observed between the two technologies when a linear regression model was applied.

The vertical distribution of acoustic backscatter within the water column increased with increasing seafloor relief (Fig. 11). Starting with the SL transect which had the least relief, all acoustic backscatter was located within 10 m of the seafloor and 80% was within 3 m of the seafloor. The GSPL transect had limited relief and all backscatter was within 12–14 m of the seafloor and 80% of the backscatter within 3 m of the seafloor. The EL transect had relief changes as high as 4–6 m and the acoustic backscatter range increased to within 26 m of the seafloor with 80% was within 10 m of the seafloor. Finally, the MS transect which had the greatest relief changes (up to 12 m) possessed backscatter observed as high as 46 m above the seafloor and 80% of total backscatter was within 10 m of the seafloor.

The GSPL transect had the highest normalized cross correlation score between the acoustic and video-based densities (0.48). The pipeline itself has a 1 m internal diameter and adjacent areas of spoil sometimes >1 m in height increases the amount of relief present. The pipe is also completely buried in some sections. It was apparent from the towed video that some fish, in particular groupers, tended to be observed near the seafloor adjacent to exposed pipe, and their acoustic return would have been masked by the pipe itself (Figure 16). Fish returns were also often seen above the flight path of the towed C-BASS, which made them unobservable to the video cameras, but they were ensonified by the EK60. These fishes were identified as pelagic species (e.g., amberjacks) based on other towed camera work that occurred higher in the water column on later cruises. This greater fish presence increased the level of cross correlation between the two technologies. It may be that the exposed segments of the Gulf Stream pipeline acts as an artificial reef, aggregating fish along a linear corridor at a relatively shallow height. This also suggests that areas of moderate relief are better suited for directly comparing acoustic and video-based density estimates.

There are some biases associated with the comparisons that are imperative to note. There were likely spatial and temporal inconsistencies in the sampling volume. Additionally, fish are motile and the video system lag time can miss fish that were ensonified by the echosounder. Conversely, fish may be observed by the towed camera that were not previously ensonified, either by actively swimming into the field of view or if the camera tow direction was affected by cross currents, which positions the camera to varying degrees outside of the ensonified swath. Additionally, it was noted that that the densities within the 60-sec segment bins can be zero-inflated. If the actual real time lag exceeded 60-sec, the binning could cause values to “just miss”, which could decrease the values of the cross-correlation where the relationships were in fact stronger. A potential future remedy would be to increase binning to 90 or even 120 sec, which would result in more accurate comparisons of density relationships.

Another noted potential bias is associated with fish located close to the bottom (i.e., within the acoustic “dead zone”). This results in their backscatter being aliased by the seafloor backscatter and they are unobserved acoustically. This particular bias was evident along the SL transect; this region had the lowest density of fish observed and the lowest normalized cross correlation score between the acoustic and video-based densities (0.16). This was not entirely unexpected; the SL MPA is a comparatively flat region primarily composed of unconsolidated sand-mud seafloor pockmarked with shallow depressions created and commonly occupied by red grouper (Grasty et al. 2019; Wall et al. 2011) and sometimes other fishes, particularly lionfish *(Pterois volitans*). Due to the deeper-than-grade depression, fish occupying the holes would be visible to the passing camera but unlikely to be acoustically discernable in the “dead zone”.

Based on the results of this study, when these two remote technologies are used together and (reasonably) concurrently, there are notable advantages over the use of a single technology. Video technology can reduce taxonomic ambiguity of the acoustic data, particularly when there is tighter overlap in fish distribution. The video technology can certainly provide additional information about benthic substrate and bottom features that could affect comparisons (e.g., fish residing in holes/depressions). Both technologies together also provide greater confidence in “matching” schools observed acoustically and through video, particularly when monospecific schools are present. The acoustic technology provides an indication of vertical distribution and potentially provides an estimate of what fish are “missed” from video. Since both systems are mobile, the chance of counting the same fish twice is reduced, which diminishes the overestimation of abundance estimates.

In summary, this study examined two remote technologies used concurrently to estimate fish densities. They can both be utilized for a rapid and non-invasive assessment of the characterization and distribution of reef fishes, and provides further evidence that both technologies used concurrently has value for reef fish surveys, particularly in regions where traditional assessment methods may be unsuitable or time consuming. In previous efforts, such observational methods have proved to be an effective means of reducing inherent biases in each technology, increasing the range and detail of data obtained from spatial surveys of management areas (e.g., Zeller and Russ 1998; Boswell et al., 2010a), and this study adds to that body of work.

Moving forward, more conventional fisheries acoustic surveys (Simmonds and MacLennan, 2005) versus long linear transects are recommended. They should be conducted over additional habitat regions in a more balanced survey approach and a subsequent comparison between these paired technologies to improve our understanding of the relationship between the two approaches should be made. The addition of one or more echosounder frequencies would also assist in acoustic discernment capabilities (i.e., better removal of non-fish acoustic targets). This would allow more rigorous statistical analyses and identify what additional factors affect the strength of correlation of the two technologies and to what degree.

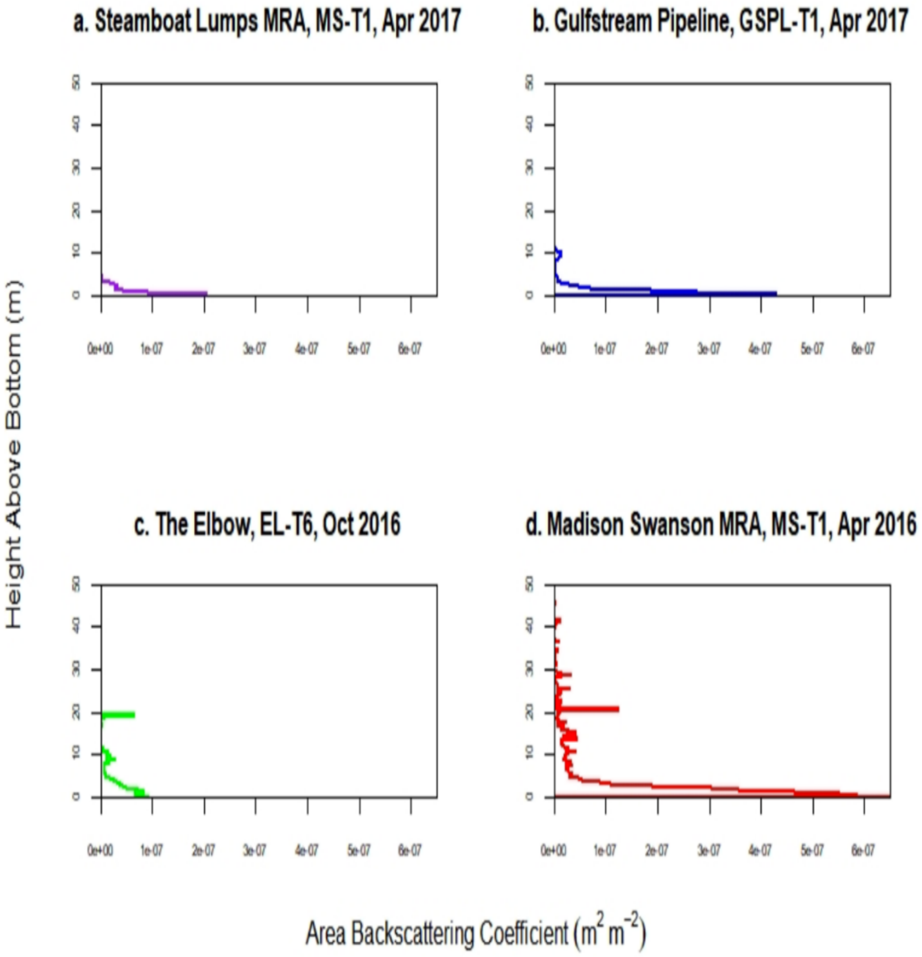


Figure 11. Area Backscatter Coefficients (ABC) plotted against height above the bottom. a) Steamboat Lumps Marine Protected Area (MPA), b) the Gulfstream Pipeline, c) The Elbow, and d) Madison-Swanson MPA. The region sequence follows from regions of lesser to greater relief.

Management Implications

MAPPED AREAS AS CANDIDATES FOR ADDITIONAL HAPCS OR OTHER SPATIAL MANAGEMENT AREAS

The 2,350 km^2 of habitats mapped in this project were intentionally prioritized to connect existing Habitat Areas of Particular Concern (HAPCs; e.g., Florida Middle Grounds and Steamboat Lumps) and to map other features known to be important fishing regions. In the region identified as the South-West Florida Middle Grounds (SWFMG; Figure 12), the rock feature extending north-south from similar features in the Florida Middle Grounds (FMG) represents a drowned sea level sand (barrier beach) probably formed 10-12,000 years B.P. (Dr. Stanley Locker, *pers. comm.)*. Our observations of fishes on this feature indicate relatively high densities of reef fishes and associated species similar those found within the FMG HAPC. The hard ridge area extending southward from the FMG is an obvious candidate to consider for an extension of the current HAPC

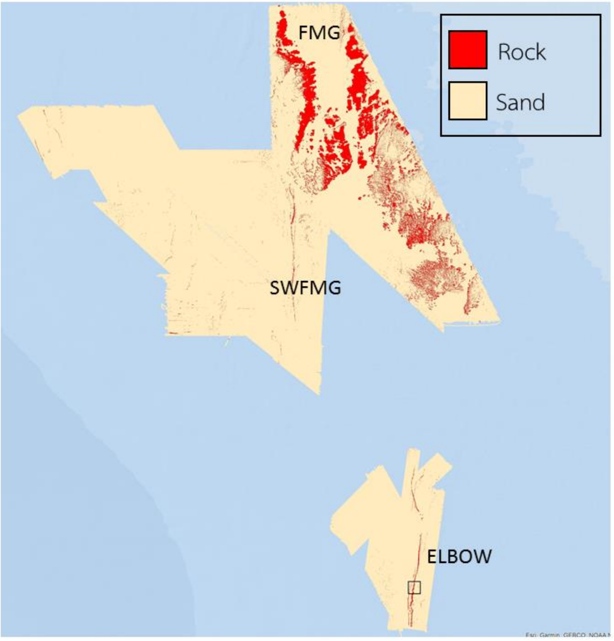


Figure 12. Classified habitats (rock vs. sand) in three mapped regions off the west coast of Florida.

The Elbow region also includes a hard rock north-south spine serving as high-quality habitat for reef fish communities. Our video evidence there indicates that 50% of the fish numbers occurring in the Elbow region were located over just 4% of the available habitat comprised of rock reef. Because the reef here is low stand, it may be subjected to periodic trawl activity (although we have no information on trawling history in this region) in addition to recreational and commercial reef fishing activity. This region should also be considered for additional protections.

THE GULFSTREAM PIPELINE AS AN IMPORTANT SEA TURTLE HABITAT

Published research from our project (Broadbent et al. 2020) demonstrates that the density of sea turtles (Fig. 13) on or near the Gulfstream Gas Pipeline was more than 30x greater compared to natural habitats observed using towed underwater video in the Florida Middle Grounds, SW Florida Middle Grounds, the Elbow, Steamboat Lumps, and Madison-Swanson regions. This pipeline extends northwest from the mouth of Tampa Bay in Florida and terminates in Mobile Bay, Alabama. Large portions of the pipeline are exposed and along a considerable length of it, there are dredge spoils which essentially function as artificial hardbottom habitat.

Our interactions with both the recreational and commercial industries indicate considerable fishing activity occurs in the vicinity of the pipeline, particularly in depths shallower than approximately 40 m. Because of the high level of rod and reel activity directly on the pipeline co-located with such high densities of turtles, the probability of accidentally hooking turtles is likely greater than over other natural habitats (although we did not document any recreational fishing takes of turtles near the pipeline). The Gulf of Mexico Fishery Management Council and NOAA National Marine Fisheries Service should consider soft-governance approaches to heighten awareness of the possibility of hooking turtles associated with the pipeline and advise on required safe de-hooking and reporting requirements of such encounters. Similarly, while bottom longlining inside of 20 fathoms (~40 m) is prohibited between June and August, there is the possibility that longline encounters in this region would similarly result in elevated accidental takes. Longline observer data could be queried to see if encounters are elevated in the vicinity of the pipeline. If so, appropriate additional regulations could be considered.

Figure 13. Loggerhead sea turtle partially under the Gulfstream Natural Gas Pipeline which runs along the seafloor from Tampa Bay, FL to Mobile Bay, AL.

USE OF DIRECT ESTIMATES OF POPULATION SIZE IN STOCK ASSESSMENTS AND HABITAT PROTECTION

The combination of multibeam bathymetry and video observations of fish and turtle densities allow for habitat-stratified population estimates (absolute vs. relative) by multiplying the average numbers observed per sampled area times the physical areas of each habitat, and summing (for extensive detail of this method, refer to Ilich 2018). This method does require inherent assumptions regarding the avoidance/attraction of fishes to the camera sled and the detectability of target species, but nevertheless results in quantification of the absolute abundance of animals. These same procedures were used as part of the *Great Red Snapper Count* (Harte Research Institute, Texas A&M University – Corpus Christi) specifically focusing on abundance over pipelines and naturally-occurring bottom substrates in the Central and Western Gulf of Mexico. Given the success of this method in this project and the extension Gulf-wide for the *Great Red Snapper Count*, managers might consider greater application of these procedures for estimating the abundance of various target and protected species and, as well, for identifying additional areas for protection of benthic fauna such as shallow-water sponge fields, mesophotic reefs and cold-water corals. Current work is also underway in collaboration with the Fisheries Independent Monitoring Group at the Florida Fish and Wildlife Research Institute to better elucidate the sighting and detection biases of both towed and stationary cameras. We expect the results to make this approach all the more robust in the near future.

Priority areas for additional mapping and fish density estimates

This project has extended the quantity of habitat mapped along the west Florida shelf by over 60% from what was mapped with high precision sonar before our project began. We also identified key geologic features associated with the areas we mapped. Because so much of the West Florida Shelf remains to be mapped, we can target efforts by extrapolating our findings to identify other key areas that we consider priorities for future extended mapping activities (Figure 14). We are also in frequent communication with the Florida Coastal Mapping Group (FCMaP; Hapke et al. 2019) who has worked with several other agencies, groups, and natural resource management bodies throughout Florida to prioritize inshore and offshore areas for mapping. As of November 2020, we have begun mapping in one such priority area in the offshore region of the Big Bend via a grant from NOAA's Office of Coast Survey.

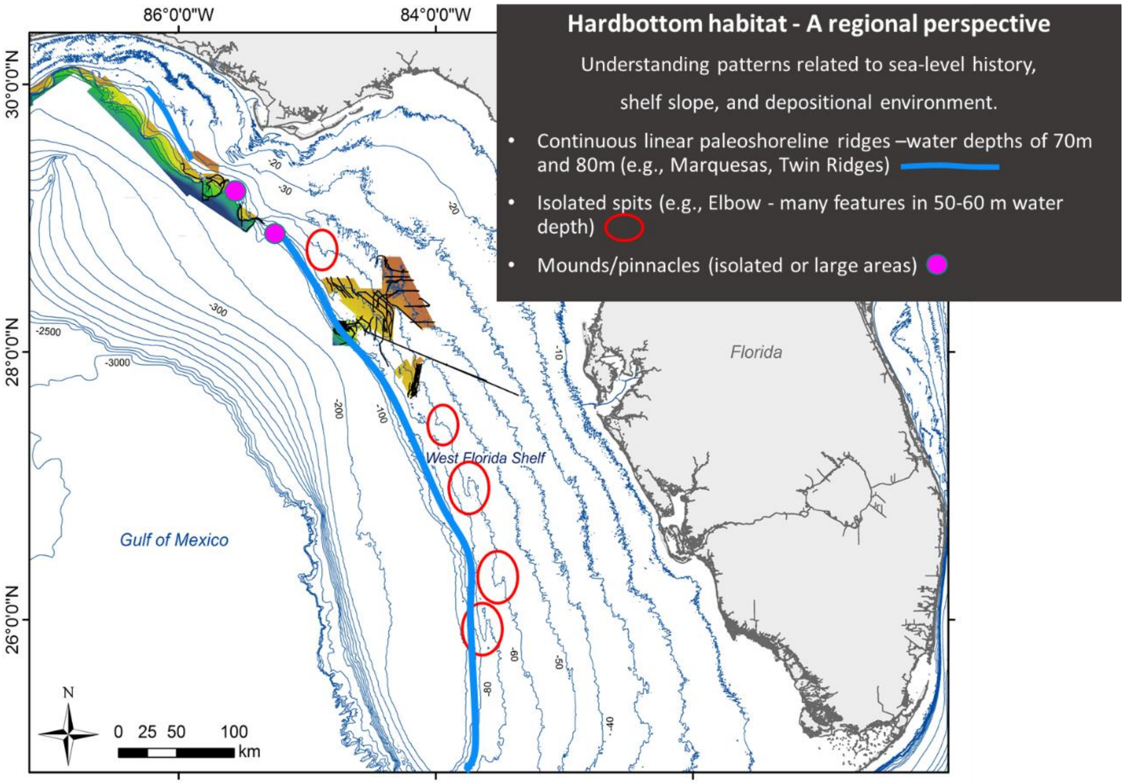


Figure 14. Geologic and bathymetric features likely containing high priority habitat features and thus should be targeted for mapping in future field campaigns.

These features include additional semi-continuous linear paleo-shoreline features (such as in the Elbow and SWFMG areas) as well as isolated spits (indicating previous barrier islands), banks, and various mounds and pinnacles identified in low-resolution bathymetry (Figure xx). Based on the areas currently mapped and a broad understanding of the geological context under which these features have formed over time, we estimate that an additional ~15,000 km^2 of high priority habitat exist on the WFS, primarily between 50m and 80m of depth, that could be similarly mapped with a combination of multibeam sonar and towed video to provide a prioritized inventory for fisheries, habitat and protected species management. We recommend that management agencies consider supporting additional seafloor mapping (e.g. multibeam bathymetry) in tandem with ground-truthing/habitat analyses to close this gap.

Outcomes and Key Takeaways

This project resulted in several important outcomes and long-term benefits for the management of living marine resources on the West Florida Shelf, including:

- Discovering, documenting and accumulating all relevant bathymetric data available for projects completed prior to the project, and providing a "one-stop-shop" of availability of these data for resource managers and scientists
- The collection and processing of 2,519 km^2 of precision bathymetry and associated backscatter information for important reef fish and sea turtle habitats on the west Florida Shelf, nearly doubling the quantity of such data over previous efforts,
- Integrating towed video with bathymetric sonar data and developing methods to objectively classify bottom habitats (e.g., sand, mixed bottom and rock habitats) using a sub-sample of 1% of area subject to video validation,
- Developing and testing a method for autoclassification of fish and habitat data from towed video surveys that will result in faster and more reproducible results (as compared to human-read videos) from similar surveys on the west Florida Shelf and elsewhere,
- Calculation of habitat-stratified abundance estimates for fishes occupying large sections of the west Florida Shelf. These analyses indicate that over 50% of fish ≥ 15 cm long occur in less than 4% of the total shelf area (high relief habitats),
- Identifying the Elbow, South-West Florida Middle Grounds, and Gulfstream Natural Gas Pipeline areas as candidates for inclusion in existing marine protected areas (MPAs), as additional standalone MPAs, or for some level of appropriate management/protections,
- Documenting specific benthic habitats for species of marine turtles that may deserve additional protections, especially from fishing gear that may encounter them resulting in "takes" of these species regulated under the Endangered Species Act, and,
- Identification of the geologic processes giving rise to critical hard bottom habitats along the west Florida Shelf. Using these geological indicators, project personnel have identified an additional ~15,000 km^2 of likely high valued habitat to be mapped along the shelf.

With respect to the stated goals of the project proposal, we were able to complete all anticipated aspects of this project. Project outcomes have focused research and management interest on critical habitats of the West Florida Shelf. Given our interactions with the management community, the information we have developed will be used as managers consider additional protections to resources injured as a result of the *Deepwater Horizon* accident.

Based on the investments made by NFWF and the GBEF in this habitat mapping program we have been able to leverage additional grants to continue and expand habitat mapping on the west Florida Shelf. This includes the Big Bend Bathymetric Mapping Demonstration project, funded by the NOAA Office of Coast Survey. Additionally, we were funded by the MARFIN program to continue video technology calibration studies between C-BASS and the S-BRUV camera systems operated by FWRI and NOAA/NMFS to aid in the sustainable management of reef fishes. As a result of this project, USF researchers were able to participate in a project during 2018-2020 termed the "Great Red Snapper Count" using bathymetric imagery and towed video to directly assess population size for red snapper throughout the Gulf of Mexico. Last, two major efforts informed by this project have the potential to support sustained mapping in the future: the FCMaP program (Florida Coastal Mapping Program initiative) as well as the newly-awarded (as of October 2020) Center for Ocean Mapping and Integrated Technologies (COMIT; www.marine.usf.edu/comit) to be housed at the USF College of Marine Science.

In addition to the outcomes described above, there were several unanticipated, but nonetheless important, aspects of the project that NFWF leadership should be aware of: First, this program could only be accomplished by combining the expertise of a number of engineering and scientific disciplines including hydrographic surveying, advanced electronic instrumentation fabrication, artificial intelligence research, ship operations, ecology and population dynamics, to name but a few. This required assembling and training a rather large group (up to 14 people at one point) in key positions supporting this project. Assembling this expertise was not easy (finding the right people) nor was is accomplished quickly. By the end of the project, the through-put to final products was efficient and productivity was high. Assembling an outstanding cadre of people to perform this project for NFWF was difficult but necessary, and very rewarding. Such expertise is difficult to assemble but easy to lose without continuity of funding and resources. Mapping of critical Gulf resources must continue as most of the continental shelf area within the Gulf of Mexico has not been mapped. We encourage NFWF and its collaborators to continue supporting such projects in the future as they will provide an enduring and uniquely valuable environmental legacy from the Deepwater Horizon accident.

While we did not initially consider commercial partners to disseminate the results of our mapping work, we were approached by several commercial vendors including businesses that provide fishing guidance to recreational fishers and general ocean mapping, to include our results in their product lines. These data were, of course, provided free of charge, but the interactions with the commercial sector attest to the value of such products and services derived from carefully collected and curated bathymetry and habitat data. Such collaborations should be a hallmark of similar projects in the future.

As we wrap up the project *Restoring Fish and Sea Turtle Habitat on the West Florida Continental Shelf: Benthic Habitat Mapping, Characterization and Assessment*, funded by the National Fish and Wildlife Foundation, it is appropriate to consider what has been accomplished and the “next steps” in bathymetric and habitat mapping in the Eastern Gulf of Mexico and beyond. Using the assets of the University of South Florida’s College of Marine Science, and especially the staff of the Ocean Technology Group, C-SCAMP was able scale up from what was a research and “proof of concept” stage to a fully integrated mapping program that has vastly expanded our knowledge of essential habitats on the West Florida Continental Shelf. Doing so would not have been possible without the strategic partnerships forged with our collaborating institutions including the Florida Fish and Wildlife Research Institute, the National Oceanic and Atmospheric Administration (including the National Ocean Service, the National Marine Fisheries Service and the National Centers for Environmental Information), the Florida Institute of Oceanography, the National Fish and Wildlife Foundation and our talented and insightful external steering committee.

While much has been accomplished in developing operational end-to-end approaches to bathymetric mapping and fusing these data with in-situ habitat surveys, much remains to be done. Large swaths of the continental shelf of the eastern Gulf of Mexico have yet to be comprehensively mapped. We estimate that about 15,000 km^2 of the over 200,000^2 km of the west Florida shelf contain hard-bottom habitat features of critical importance to fisheries and protected species. Delineating these areas is a requisite for effective ecosystem management agencies to effectively do their jobs in protecting and enhancing critical habitats sustaining the region’s valuable living marine resources. Our project has established a strategy for prospecting for these habitats based on the geology of the shelf.

Working with relevant agencies, the C-SCAMP program will seek to identify funding opportunities and additional strategic partnerships with government, academic and private entities to continue comprehensive mapping activities initiated under this program.

The need to comprehensively map the bathymetric and habitat resources of the United States Exclusive Economic Zone (EEZ) has long been recognized as a scientific and management gap that has been recently emphasized by federal government Executive Order, viz: "*To improve our Nation's understanding of our vast ocean resources and to advance the economic, security, and environmental interests of the United States, it is the policy of the United States to support the conservation, management, and balanced use of America's oceans by exploring, mapping, and characterizing the U.S. EEZ*" (The White House, November, 2019).

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