Office of National Marine Sanctuaries
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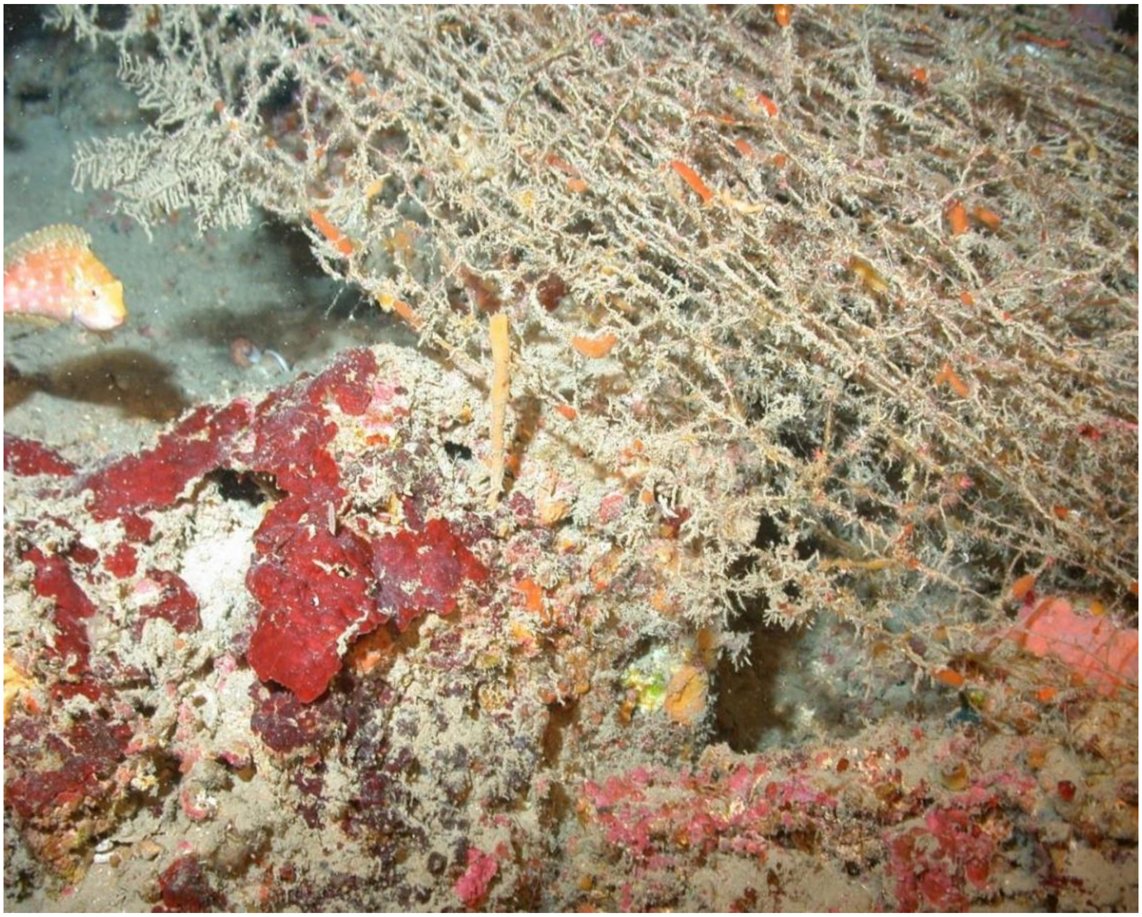
NATIONAL MARINE SANCTUARIES CONSERVATION SERIES

Marine Debris on Reefs and Banks in the Vicinity of Flower Garden Banks National Marine Sanctuary



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Cover photo: A greenblotch parrotfish (*Sparisoma atomarium*) near a derelict fishing net at a depth of 83 meters on West Flower Garden Bank. Photo: NOAA/University of North Carolina at Wilmington Underwater Vehicle Program

About the National Marine Sanctuaries Conservation Series

The Office of National Marine Sanctuaries, part of the National Oceanic and Atmospheric Administration, serves as the trustee for a system of underwater parks encompassing more than 620,000 square miles of ocean and Great Lakes waters. The 15 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our nation's maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sites range in size from less than one square mile to almost 583,000 square miles. They serve as natural classrooms and cherished recreational spots, and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each national marine sanctuary has a tailored management plan. Conservation, education, research, monitoring, and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The National Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the National Marine Sanctuary System. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and cultural sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate. All publications are available on the Office of National Marine Sanctuaries website.

Disclaimer

Report Availability

Electronic copies of this report may be downloaded from the Office of National Marine Sanctuaries website.

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Abstract

This report assesses marine debris in and around the recently expanded Flower Garden Banks National Marine Sanctuary by determining the spatial distribution, abundance, and composition of litter. Data were primarily compiled from exploratory dives in mesophotic depths (34–150 m) carried out by a remotely operated vehicle over the course of two decades. A total of 485 debris items were identified and binned into categories based on type. The composition of benthic marine debris reflected the heavy influence of local fishing activities, with derelict fishing gear the predominant debris type in the study area, comprising 63.7% of all litter. Anchoring produced the second largest contribution of benthic debris, representing 18.2% of observations. Marine debris in sensitive benthic habitats contributes to the vulnerability of these ecosystems via ingestion by and entanglement of motile species, and smothering and physical damage to sessile organisms. This report serves as a baseline evaluation of benthic marine debris in the sanctuary and provides a spatial and quantitative assessment that can be used in future efforts to target debris removal and research.

Key Words

marine debris, Flower Garden Banks National Marine Sanctuary, Gulf of Mexico, expansion, mesophotic

Chapter 1:
Introduction

An admiralty-style 19th century anchor covered in crustose coralline algae lays next to a live colony of *Stephanocoenia intersepta* at 50 m depth at McGrail Bank. Photo: NOAA/University of North Carolina at Wilmington Underwater Vehicle Program

Background

Marine debris is a growing issue worldwide. It is one of the most incessant global threats to the health of the world’s coastal areas and ocean ecosystems (Bergmann et al., 2015). Marine debris is defined as “any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or Great Lakes” (33 U.S.C. 1951 *et seq*., as amended in 2012 by Title VI of Pub. L. 112-213 and in 2018 by Pub. L. 115-265). Typically introduced to the marine environment by natural disasters, improper disposal, or accidental loss, debris often accumulates on the seafloor and has the ability to be transported long distances by ocean currents and tides. The increasing use of single-use products, disposal of litter with inadequate waste management, and poor recycling practices are the principal reasons for the accumulation of litter in the sea (Bergmann et al., 2015). In 2014 alone, Eriksen et al. (2014) estimated a minimum of 5.25 trillion plastic particles weighing 268,940 tons were afloat in the ocean. This is a major concern for resource managers because the debris can injure marine life, interfere with navigation safety, pollute beaches, damage and degrade habitats, and pose a threat to human health. While land-based pollution is a considerable source of marine debris, the discard and loss of synthetic material and plastics by the maritime industry is also a significant burden (NOAA Marine Debris Program, 2014).

Anthropogenic litter causes harm to a wide range of marine biota. Marine debris research has emphasized two fundamental types of biological interactions: (1) ingestion, whereby debris items are intentionally or accidentally eaten and enter the organism’s digestive tract; and (2) entanglement, whereby the loops and openings of various types of debris entangle animal appendages or entrap animals (Laist, 1997). Plastic ingestion leads to loss of nutrition, internal injury, intestinal blockage, starvation, and often death in wildlife (Kühn & Andries van Franeker, 2020). However, the detection of ingestion effects is difficult and typically requires necropsy. The implications of abandoned fishing nets, often referred to as “ghost nets,” are far reaching, as they create increased fishing pressure through entanglement of already-exploited populations. Such information is not captured in commercial and recreational fishing landings data, reducing the accuracy and utility of stock assessments (Macfadyen et al., 2009).

Although floating debris is a primary focus in marine debris research, litter accumulating on the seafloor can significantly impact benthic habitats and organisms. Surveys using drop cameras and more advanced technology, such as remotely and autonomously operated vehicles, have revealed that marine debris began accumulating in the deep sea long before the era of science exploration, illustrating how the seafloor serves as the ultimate sink for marine litter (Pham et al., 2014). But its accumulation and movement make these habitats vulnerable to physical damage and smothering, resulting in economic losses to fishing and disrupting ecological interactions in seafloor communities.

As part of the National Oceanic and Atmospheric Administration (NOAA), the Office of National Marine Sanctuaries serves as the trustee for 14 national marine sanctuaries and two marine national monuments, all of special national significance in the United States. Flower Garden Banks National Marine Sanctuary (FGBNMS) was designated in 1992 under the authority of the National Marine Sanctuaries Act (56 Fed. Reg. 63634) to protect East and West Flower Garden

Banks. A third bank, Stetson Bank, was added to the sanctuary in 1996. In 2021, the sanctuary expanded again to include 14 additional features, primarily mesophotic in nature (86 Fed. Reg. 4937). This report serves as a baseline for estimates of marine debris in the sanctuary, and will enable future assessments of resource status and trends.

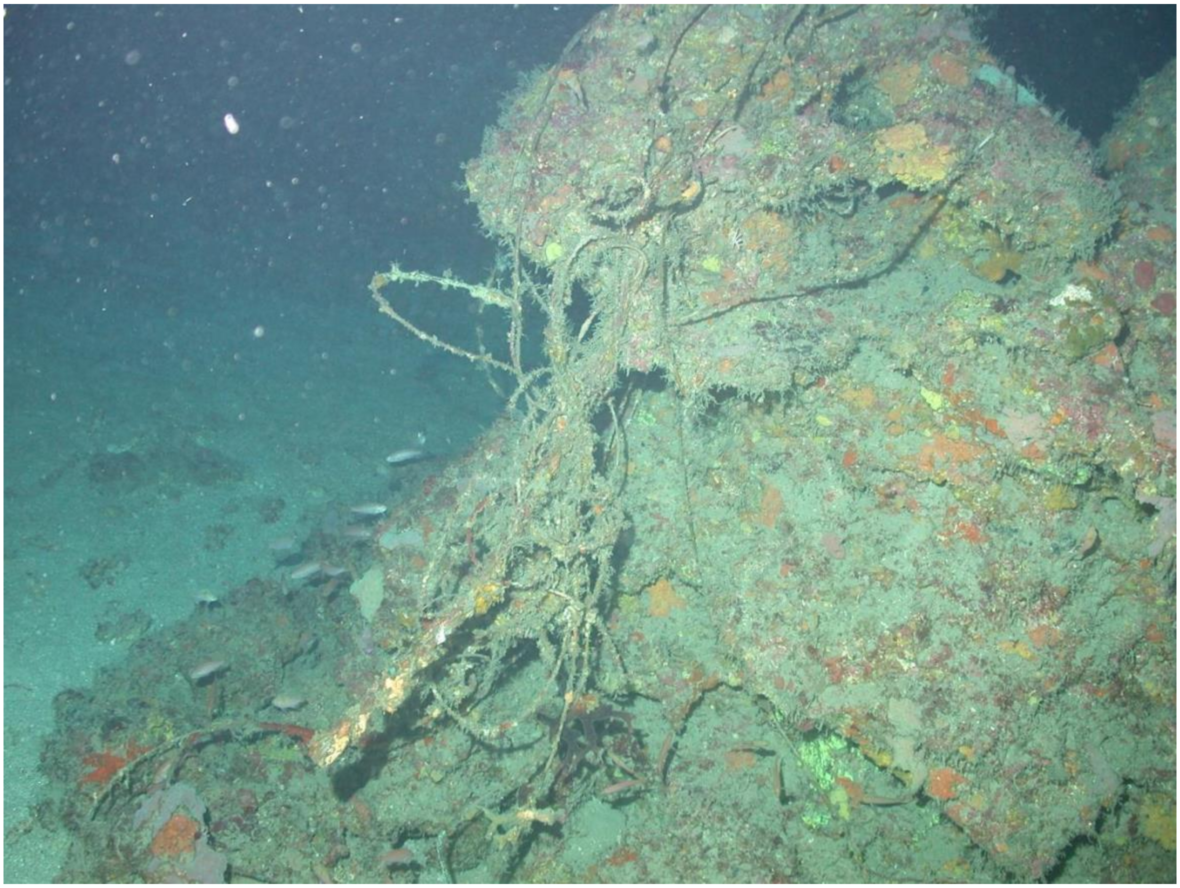


Figure 1. Fishing line entangled on an East Flower Garden Bank mesophotic feature at 81 meters. Photo: NOAA/University of North Carolina at Wilmington Underwater Vehicle Program

Study Area

Located in the Gulf of Mexico, 70 to 190 miles (110 to 304 km) from Galveston, Texas. FGBNMS encompasses 160 square miles and includes 17 underwater features, or banks. These banks are part of a discontinuous arc of reef environments along the outer continental shelf in the northwestern Gulf of Mexico (Bright et al., 1985; Figure 2). The majority of the reefs are built upon salt domes and contain several distinct habitats ranging in depth from 16–220 m (Bright & Rezak, 1976; Schmahl et al., 2008). The reefs and banks provide a wide range of habitats that support distinct biological communities, including the northernmost coral reefs in the continental United States (Schmahl et al., 2008) and much more extensive mesophotic and deep-sea coral habitats. They provide important habitat for recreationally and commercially important fish, as well as threatened and endangered corals and sea turtles, whale sharks, and manta rays.

FGBNMS recently finalized a boundary expansion that increased the number of protected areas from three to 17 banks and expanded the size of sanctuary from 56 square miles to approximately 160 square miles. The expansion extended protections to these new boundaries and aims to limit the impact of activities related to fishing with bottom-tending gear, ship anchoring, and salvaging. Additional protections are designed to limit future marine debris in these locations and protect sensitive biological resources.

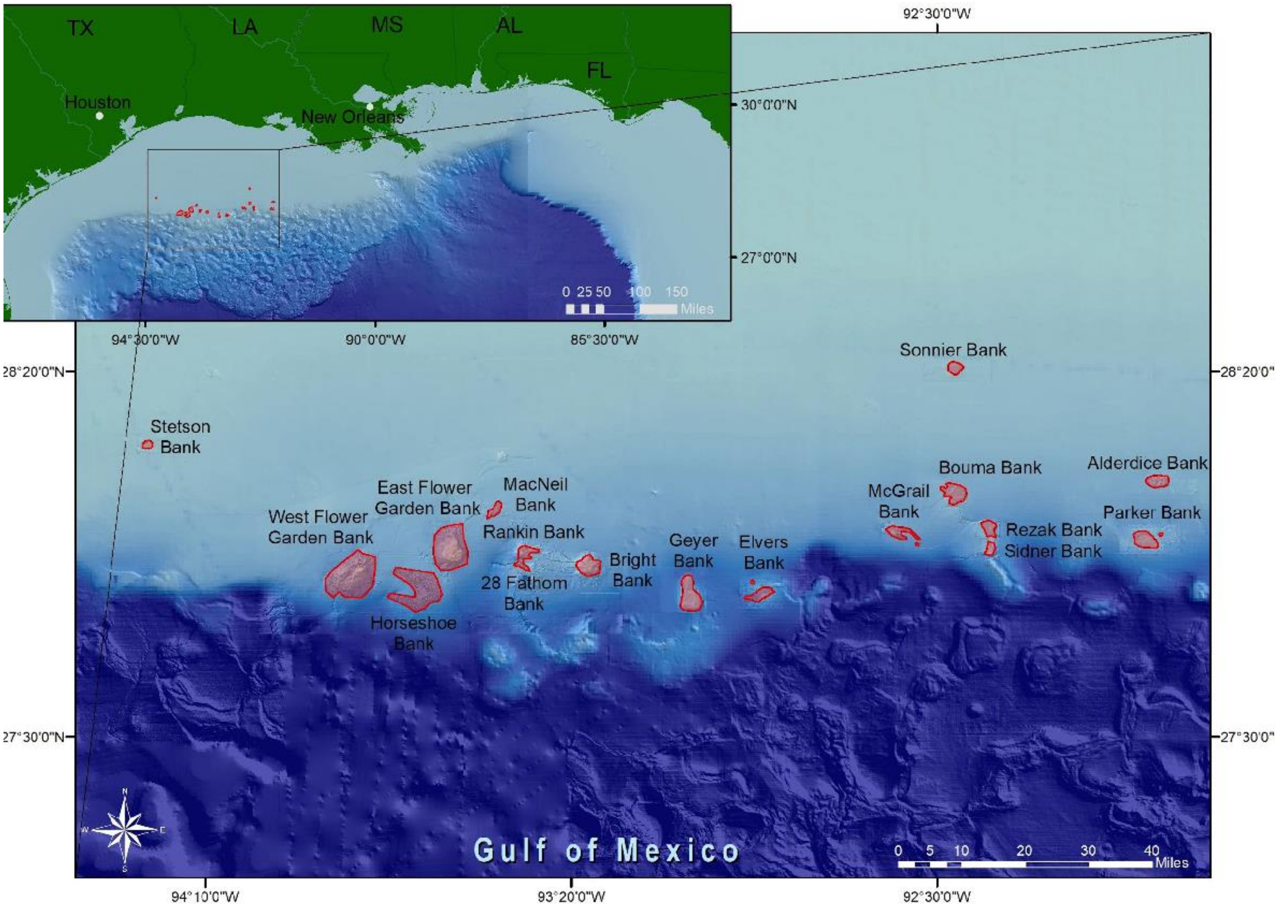
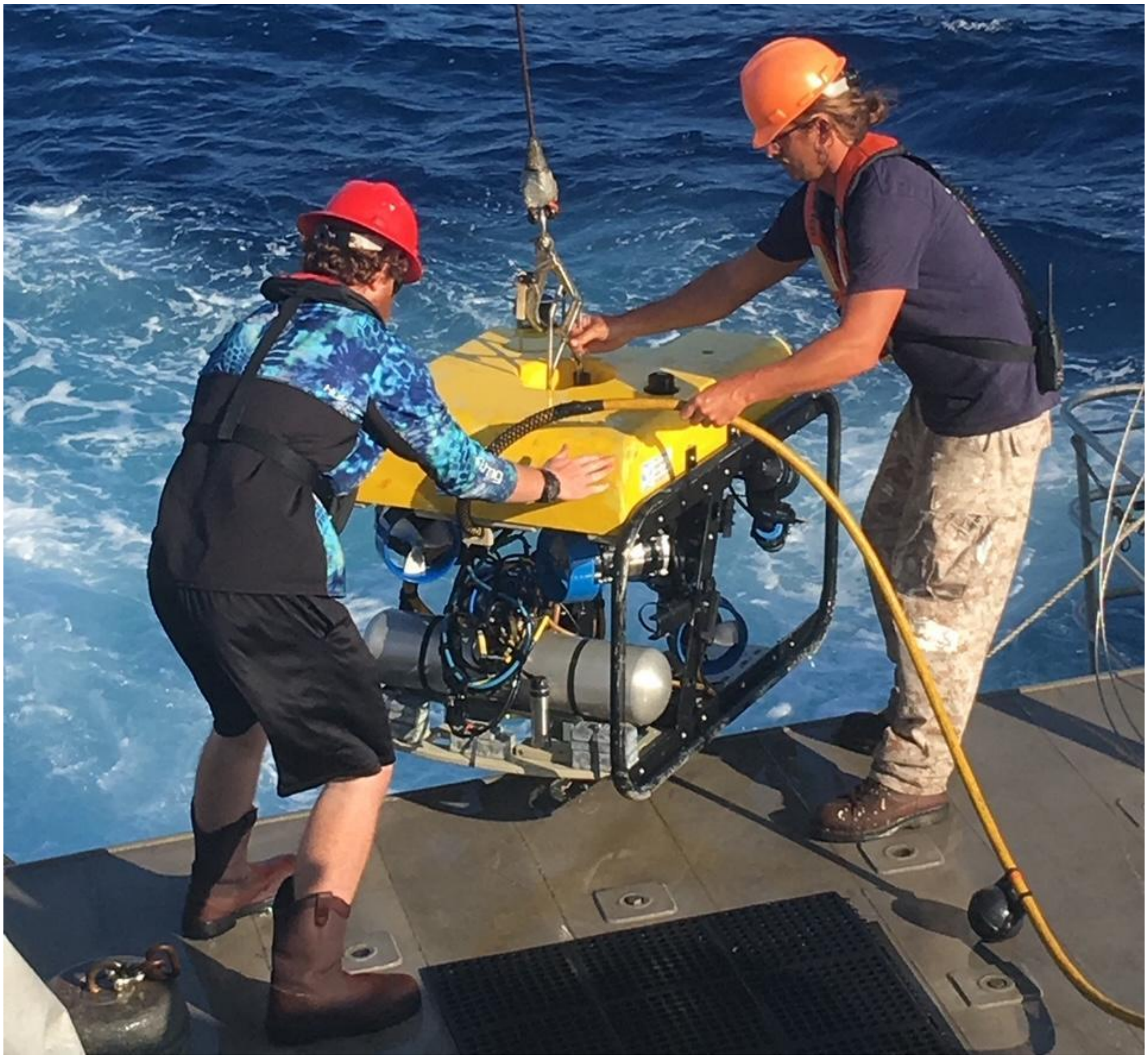


Figure 2. FGBNMS boundaries following the 2021 sanctuary expansion. Image: NOAA

As anthropogenic stressors (e.g., shipping activity, oil and gas exploration) continue to increase along the outer continental shelf of the U.S. in the Gulf of Mexico, the hazards of increased marine debris from both marine and land-based operations become more severe (Katsanevakis & Maravelias, 2008). Because of the growing concern regarding marine debris in the sanctuary, this analysis assessed the extent and composition of benthic debris located in and near sanctuary boundaries, as well as on Bryant Bank, an area considered but ultimately not selected for expansion. The objectives of this report were to identify marine debris items and their likely source, as well as describe the spatial distribution and abundance of debris among mesophotic and deep benthic habitats. These data, collected along remotely operated vehicle (ROV) tracks, provide a snapshot of the seafloor conditions and serve as a baseline for benthic marine debris in newly protected areas of the sanctuary.

Chapter 2:
Methods



University of North Carolina at Wilmington Underwater Vehicle Program ROV pilot Jason White and FGBNMS volunteer Hawkins Williams, launch the Mohawk ROV aboard FGBNMS's R/V *Manta*. Photo: Kelly O'Connell/NOAA

Field Methods

Marine debris data were gathered opportunistically during research cruises and surveys. ROV surveys were conducted primarily aboard R/V *Manta*, an 82-foot catamaran dedicated to research and monitoring in the northwestern Gulf of Mexico. The vessel is equipped with an A-frame and winch configured for ROV operations. Debris items were recorded and annotated during exploration and characterization surveys. FGBNMS collected marine debris data alongside biological data during 38 research cruises and over 570 ROV dives since 2001. Depth within the survey area ranged from 22 to 150 meters. These data were part of a larger annotated dataset collected throughout the entirety of each dive to document time, location, events, fish and benthic biological occurrence with relative abundance, habitat type, and items of note. Time codes synced to georeferenced dive tracks, still and video imagery, and annotations were reviewed to characterize debris type and location. The ability to identify and access debris depended on visibility, degree of seafloor relief, and condition of the items (e.g., degree of degradation and overgrowth).

Surveys between 2001 and 2013 were completed using the ROV *Phantom S2*, owned and operated by the University of North Carolina at Wilmington Underwater Vehicle Program. This system was equipped with a Pacific Scorpio digital still camera, a TrackPoint II navigation system, and two parallel spot lasers set at 10 centimeters in both the video and the still camera frames for scale. Surveys after 2013 utilized the SubAtlantic ROV *Mohawk 18*, owned by the National Marine Sanctuary Foundation and operated and maintained by the University of North Carolina at Wilmington Underwater Vehicle Program. The ROV was equipped with an Insite Pacific Mini Zeus II HD video camera with two Deep Sea Power and Light 3100 LED lights, a tool skid with an ECA Robotics five-function all-electric manipulator, two parallel spot lasers set at 10 centimeters in both the video and the still camera frames for scale, and a LinkQuest Tracklink navigation system.

Data Analysis

ROV cruise data were analyzed to determine the date, time, location, and depth of marine debris. By common practice, debris items were photographed during field operations for archiving. Notes on the date and time of marine debris encounters were used to locate still images captured from video footage to determine the composition, type, and likely source of each item.

Debris items were identified on video and still images and binned into seven categories based on their likely source: anchoring, fishing, human, oil and gas, research, salvage, and vessel. Marine debris was recorded at 28 Fathom, Alderdice, Bouma, Bryant, Elvers, Geyer, Horseshoe, MacNeil, McGrail, Parker, Rankin, Rezak, Sidner, Sonnier, and Stetson banks, as well as East Flower Garden Bank (EFGB) and West Flower Garden Bank (WFGB). Debris was not collected, and the selection of categories reflects FGBNMS's ultimate goal of managing littering behavior rather than fully documenting specific objects based on criteria such as composition or size. In addition to its practical utility, classification by source is an approach considered feasible and appropriate when debris is documented remotely (Intergovernmental Oceanographic Commission, 2009). Using this approach, miscellaneous human-made items such as aluminum cans or bottles are lumped together regardless of composition. Rope with an associated chain was assumed to result from anchoring. Although salvage activities occur exclusively on Bright Bank, this category was included to bring awareness to the destruction of habitat that may result from treasure hunting activities. The impact of this activity on the marine environment is limited in scale compared to other sources of debris. Table 1 provides more examples of common debris in each category.

Table 1. Marine debris source categories with examples of common types of debris that fall within each category.

Category	Common Examples
Anchoring	Ropes, anchors, dragline, cables
Fishing	Line, tackle, nets, longlines, trawling gear, turtle exclusion devices
Human	Bottles, cans, plastic, tires, miscellaneous human-made debris
Oil and gas	Pipeline, seismic cable
Research	Weather buoys, materials from old research stations
Salvage	Scaffolding gear, rigging tools
Vessel	Batteries, ship materials, ladders, fire hoses, flanges

Some observations lend themselves to further investigation. Photos containing anchors, for example, were analyzed by a historian to determine their style and age, and could reveal insights about historical use of the sanctuary (H. Van Tilburg/NOAA, personal communication, 2021).

The number of items observed was calculated by category and bank. To standardize for differences in sampling effort on each bank (Table 2), item encounter rate was calculated by dividing the number of items by the number of ROV dives performed on each bank. Category encounter rate was calculated by dividing the total number of items per category by the total number of ROV dives. Depth was recorded from annotations when available and obtained from the ROV navigation file when absent.

It should be noted that standardization by number of dives does not fully adjust for effort, as surveys differed in length and covered different distances across various habitats. Average bottom distance traveled was 2,480 meters, but ranged from 50 to 96,500 meters. Time and distance were not used in this analysis to adjust for effort.

Table 2. Survey details describing the years marine debris were surveyed and the number of dives completed at each bank.

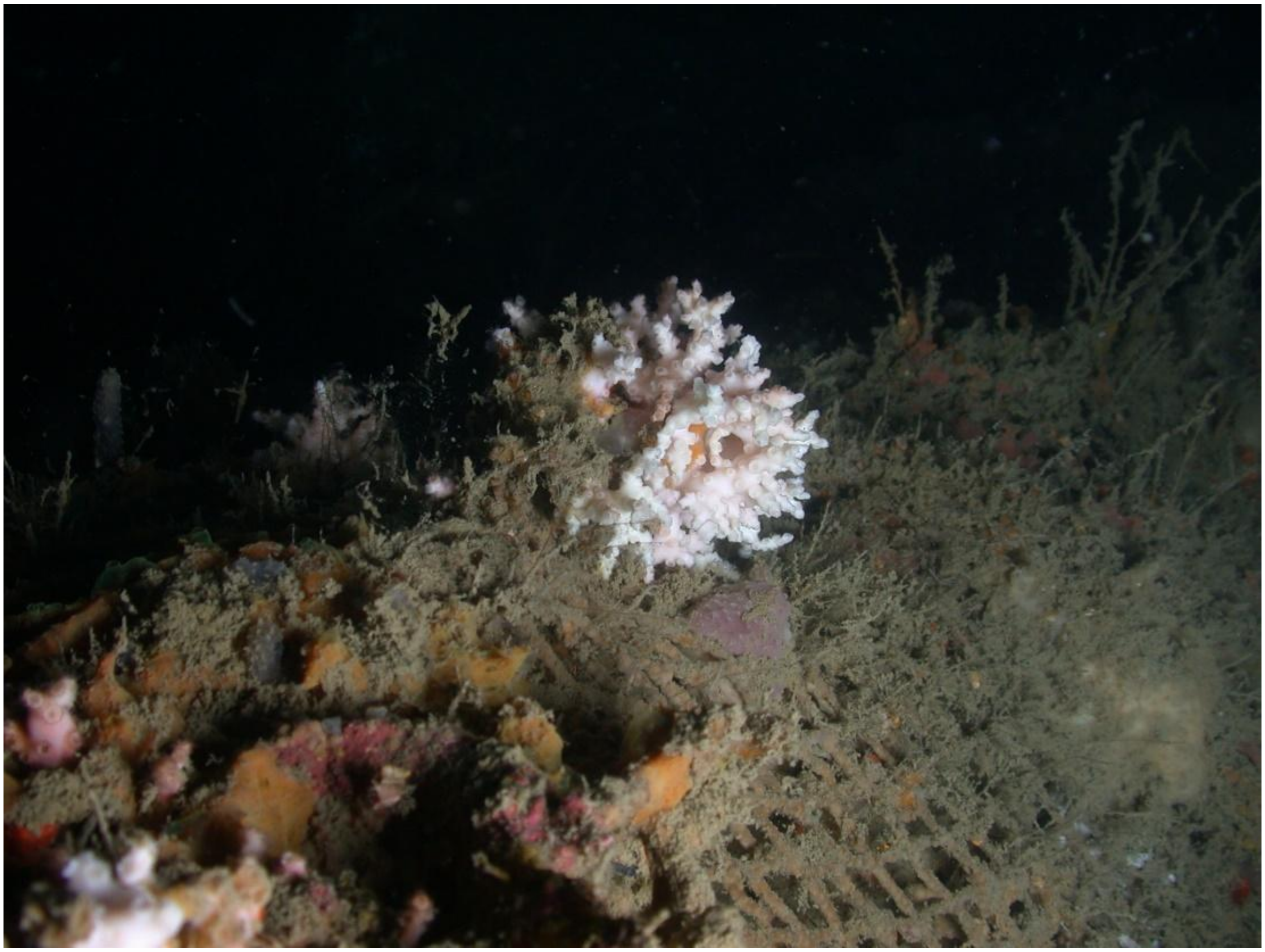
Bank	Years Surveyed	Number of Dives
28 Fathom	2003, 2012, 2017, 2018	14
Alderdice	2002, 2003, 2013, 2015, 2017, 2018	25
Bouma	2013, 2015, 2016, 2018	15
Bright	2003, 2012, 2015, 2017, 2018	21
Bryant	2015, 2016	7
EFGB	2002, 2003, 2004, 2005 2010, 2011, 2013, 2015, 2016, 2018, 2019	105
Elvers	2013, 2015, 2016, 2017, 2018	32
Geyer	2004, 2012, 2018	15
Horseshoe	2004, 2005, 2011, 2015	14
MacNeil	2009, 2017	8
McGrail	2002, 2003, 2004, 2009, 2013, 2017	42
Parker	2013, 2015, 2016, 2017, 2018	39
Rankin	2012, 2015	15
Rezak	2013, 2015, 2016, 2018	18
Sidner	2013, 2015, 2016, 2018	15
Sonnier	2002, 2013, 2017	13
Stetson	2003, 2004, 2005, 2009, 2013, 2015, 2016, 2017, 2018, 2019	73
WFGB	2002, 2003, 2004, 2005, 2010, 2011, 2012	99

ANOVA assumptions of normality and homogeneity of variance were assessed with the Kolmogorov test. Because data failed the assumptions of normal distribution, nonparametric tests were used for the statistical analyses of the two types of data, count and encounter rate. Debris data were examined to evaluate how the presence and abundance of debris varied among debris types and banks.

Due to the frequency of zero counts (i.e., no debris observed) and overdispersion in variance, count data were analyzed using a zero-altered negative binomial (hurdle) model that is often used for zero-inflated data and does not follow a Poisson distribution (Cunningham & Lindenmayer, 2005). The Vuong test for non-nested models confirmed that the excess of zeros resulted in the rejection of a standard negative binomial model (in favor of a zero-altered model; $z = 3.43$, $p < 0.01$). The zero-inflated model was a better fit for debris count data because it separately calculated the probability of being in a “perfect state” (zero marine debris) and in a “disturbed state” (non-zero values). In the first step, the debris was scored as present or absent, and the presence/absence data were modeled using a binomial distribution and a log link. At sites where debris was present, the number of debris items was modeled with a truncated negative binomial model with log link.

Marine debris encounter rate was compared among sites using the Kruskal–Wallis test. A pairwise post-hoc Dunn test was then performed to determine which debris categories were driving differences. The statistical analyses were performed using R Version 4.1.1 (R Core Team, 2021) and R software package ‘pscl’ (Zeileis et al., 2010).

Chapter 3:
Results



A branching *Oculina* spp. coral growing on top of a derelict fishing net on Stetson Bank at a depth of 41 m. Photo: NOAA/University of North Carolina at Wilmington Underwater Vehicle Program

A total of 485 marine debris items were documented during ROV surveys, with 478 items found on or near protected banks (Table 3). The most common category was fishing debris (303 items, representing 63.4% of all observations). Fishing debris included monofilament line, longline, trawling gear, nets, turtle exclusion devices, and miscellaneous items used for commercial or recreational fishing. The second most common type of debris was from anchoring (87 items, representing 18.2% of observations). This included dragline, rope, chain, and anchors. The remaining categories, in decreasing order, were human, oil and gas, vessel, research, and salvage. The total number of items and percent composition of each debris category is displayed in Table 3.

Table 3: Number of debris items by bank and category and percent composition by category.

Bank	Anchoring	Fishing	Human	Oil and Gas	Research	Salvage	Vessel	Total (by Bank)
28 Fathom	0	3	1	0	0	0	0	4
Alderdice	3	2	1	0	0	0	0	6
Bouma	2	1	1	0	0	0	1	5
Bright	4	14	1	2	0	3	0	24
Bryant	1	3	1	0	0	0	0	5
EFGB	14	21	11	4	1	0	4	55
Elvers	3	6	1	0	0	0	1	11
Geyer	0	4	1	0	0	0	0	5
Horseshoe	1	18	2	0	0	0	0	21
MacNeil	0	0	0	0	0	0	0	0
McGrail	6	11	19	1	0	0	0	37
Parker	3	12	1	1	0	0	0	17
Rankin	3	10	0	0	0	0	0	13
Rezak	1	7	0	0	0	0	0	8
Sidner	4	13	3	1	0	0	0	21
Sonnier	2	18	0	0	2	0	0	22
Stetson	25	110	9	3	1	0	3	151
WFGB	15	50	2	6	0	0	0	73
Total (by Category)	87	303	54	18	4	3	9	478
Percent of All Debris	18.2	63.4	11.3	3.8	0.8	0.6	1.9	

To adjust for differing dive effort at each bank, results are presented as encounter rate ± standard error. Fishing debris had the highest encounter rate, with 0.53 ± 0.11 items observed per dive. Anchoring debris was second, with 0.15 ± 0.02 items per dive. Results for these and other categories are shown in Figure 3.

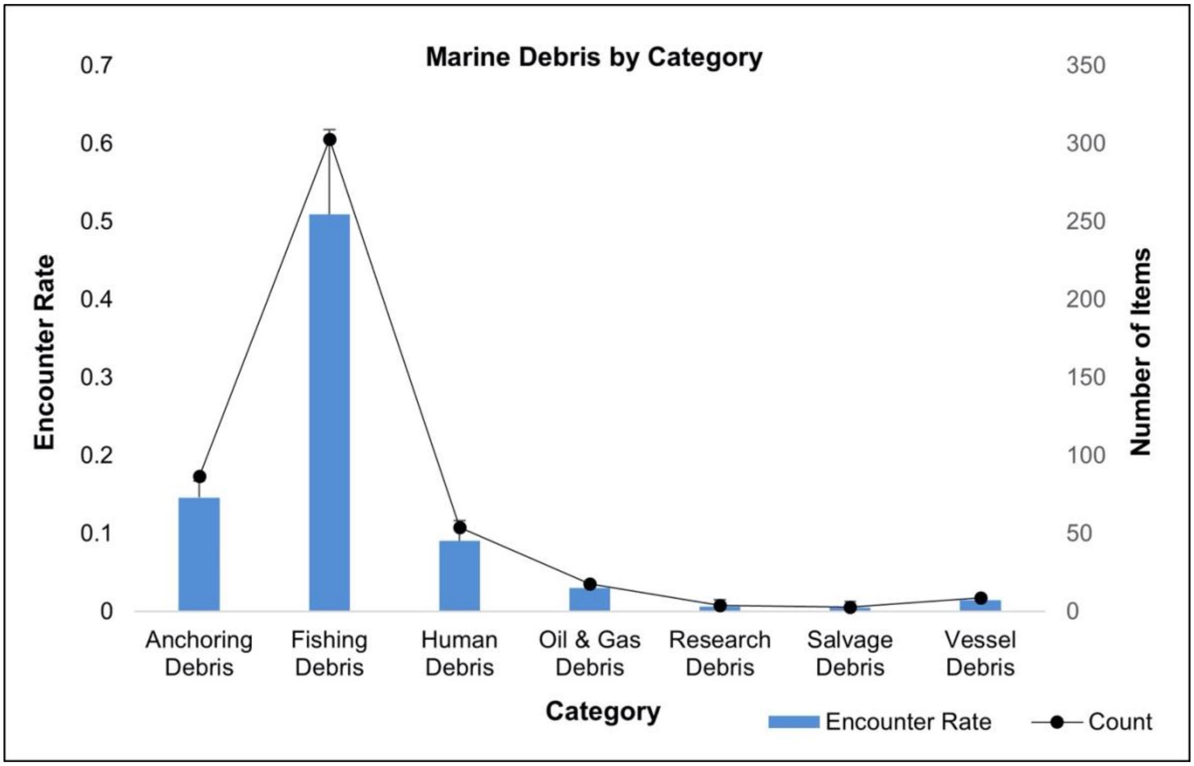


Figure 3. Encounter rate and debris count in each debris category found in the study area.

Stetson Bank had the highest marine debris encounter rate at 2.1 items per dive. Sonnier and Horseshoe banks had the second and third highest rates, with 1.7 and 1.5 items encountered per dive, respectively. Encounter rates are shown for each bank in Figure 4.

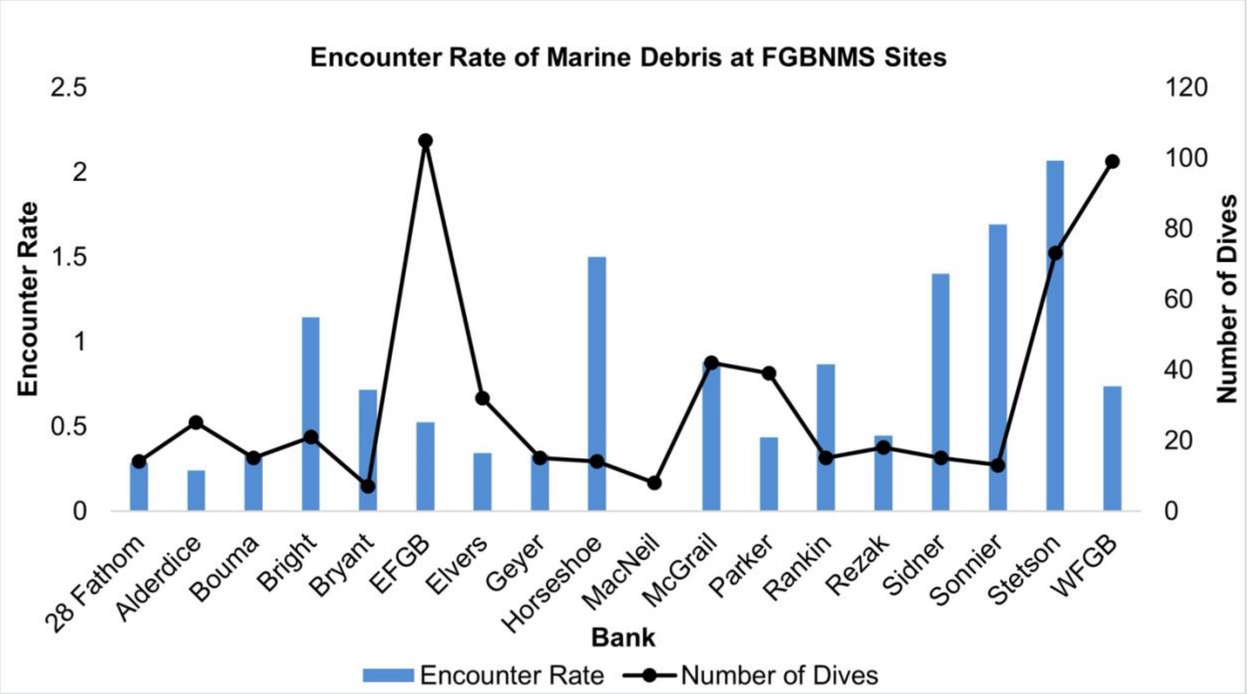


Figure 4. Encounter rate of marine debris in surveys at each bank.

When marine debris was categorized by type and by bank (Figure 5), it was apparent that the majority of marine debris found among the reefs and banks was fishing gear. Stetson Bank had the highest occurrence rate with 1.5 fishing items per dive followed by Sonnier Bank and Horseshoe Bank with 1.4 and 1.3 items per dive, respectively. Next was anchoring, with 0.3 items per dive at Stetson Bank and 0.3 and 0.2 items per dive at Sidner Bank and Rankin Bank, respectively. Tables with more detailed information can be found in Appendix B.

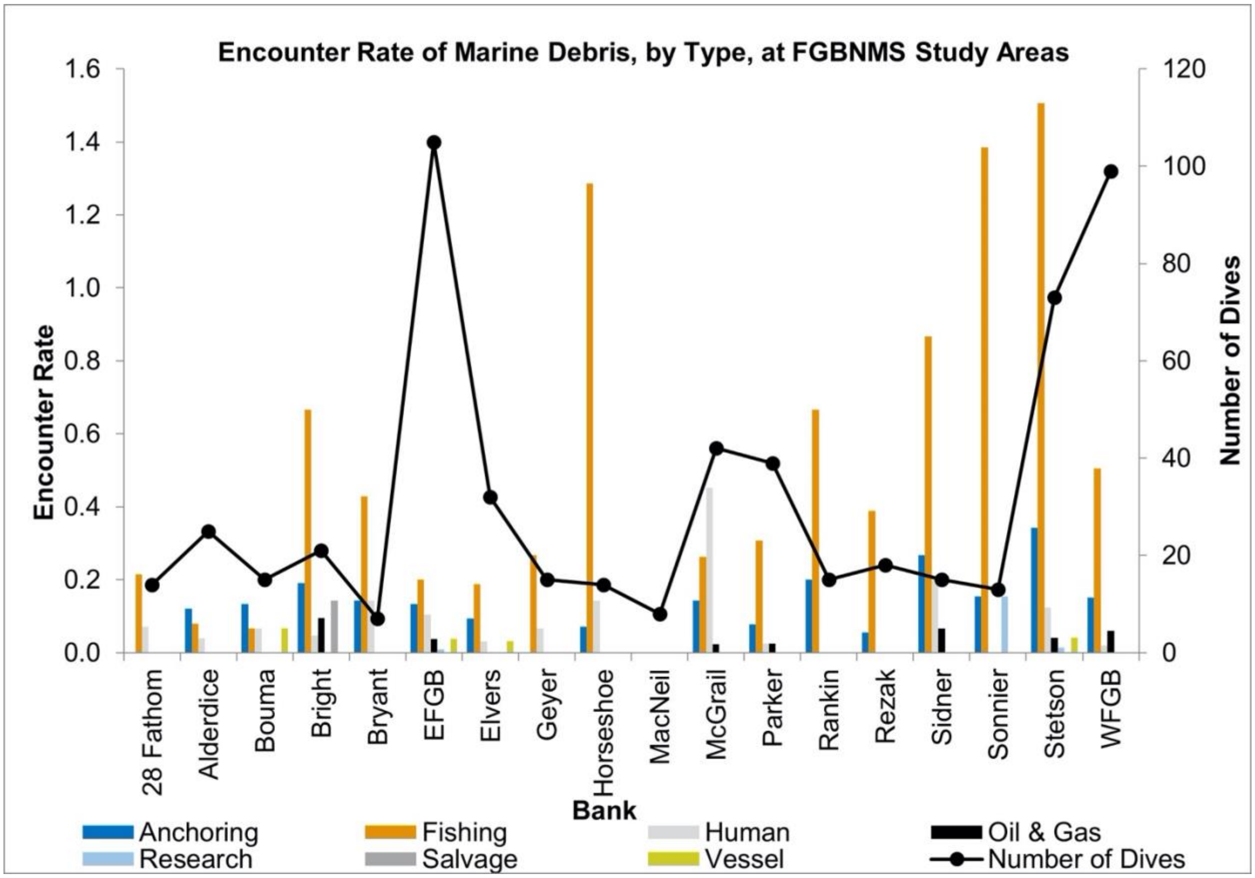


Figure 5. Number of items observed per dive at individual banks for each category of marine debris.

Debris count data were assessed with the hurdle model in two parts. The results from the zero-distribution model indicated that the debris count varied significantly by bank and debris type. Debris was more likely to be present at Bouma, Bright, EFGB, Elvers, McGrail, Parker, Stetson, and WFGB. Oil and gas, research, and vessel debris were statistically less likely to be encountered within the study sites (Table 4).

Results from the positive count distribution model indicate that bank and debris type significantly influence the abundance of debris when present. Debris was more likely to be abundant at Bright, EFGB, Horseshoe, McGrail, Sidner, Sonnier, Stetson, and WFGB. Fishing debris was significantly more likely to be abundant than any other type of debris and oil and gas, research, and vessel debris were significantly less likely to be abundant than other types of debris (Table 5).

Table 4. Part one of the zero hurdle binomial model with logit link, modeling presence/absence of debris. Significant values are presented with asterisks (**p* = 0.05, ***p*=0.01, ****p* < 0.001).

Factor Type	Category	Coefficient	P-value
Overall	Intercept	0.32	0.847
Bank	Alderdice	2.33	0.310
Bank	Bouma	4.55	0.046*
Bank	Bright	6.05	0.008**
Bank	Bryant	2.33	0.311
Bank	EFGB	7.63	0.002**

Factor Type	Category	Coefficient	P-value
Bank	Elvers	4.56	0.045*
Bank	Geyer	3.64e-09	1.000
Bank	Horseshoe	2.33	0.311
Bank	McGrail	4.56	0.046*
Bank	Parker	4.56	0.046*
Bank	Rankin	3.64e-09	1.000
Bank	Rezak	3.64e-09	1.000
Bank	Sidner	4.56	0.046*
Bank	Sonnier	2.33	0.311
Bank	Stetson	7.63	0.002**
Bank	WFGB	4.56	0.046*
Debris type	Fishing	17.51	0.996
Debris type	Human	-0.72	0.556
Debris type	Oil and gas	-4.49	0.004**
Debris type	Research	-6.62	0.000***
Debris type	Salvage	-8.51	0.000***
Debris type	Vessel	-5.98	0.001***

Table 5. Part two, truncated negative binomial model with log link, modeling debris abundance. Significant values are presented with asterisks (*p = 0.05, **p = 0.01, ***p < 0.001).

Factor Type	Category	Coefficient	P-value
Overall	Intercept	-0.47	0.549
Bank	Alderdice	0.31	0.751
Bank	Bouma	-0.72	0.566
Bank	Bright	1.69	0.041*
Bank	Bryant	-0.18	0.865
Bank	EFGB	2.98	0.000***
Bank	Elvers	0.93	0.289
Bank	Geyer	0.34	0.729
Bank	Horseshoe	1.66	0.045*
Bank	McGrail	2.73	0.001***
Bank	Parker	1.39	0.097
Bank	Rankin	1.45	0.092
Bank	Rezak	0.85	0.347
Bank	Sidner	1.72	0.038*
Bank	Sonnier	1.92	0.023*
Bank	Stetson	3.50	0.000***
Bank	WFGB	3.03	0.000***
Debris type	Fishing	1.32	0.000***
Debris type	Human	-0.45	0.113
Debris type	Oil & Gas	-1.48	0.000***
Debris type	Research	-3.08	0.003**
Debris type	Salvage	-0.23	0.788
Debris type	Vessel	-1.65	0.002**
Overall	Log (theta)	1.96	0.000***

Conversely, marine debris encounter rate did not differ significantly among the banks, suggesting that the differences found in the count data were likely an artifact of effort (Kruskal-Wallis test; χ^2 = 9.732, df = 16, p = 0.88). However, the encounter rate of different types of debris differed significantly (χ^2 = 77.947, df = 6, p < 0.001). A pairwise post-hoc Dunn test showed significant differences between some categories, with fishing debris driving most of those differences; fishing debris encounter rates were significantly greater than all other categories (Table 6).

Table 6. Results of a pairwise post-hoc Dunn test. Significant values are presented with asterisks (*p = 0.05, **p = 0.01, ***p < 0.001).

	Anchoring	Fishing	Human	Oil and Gas	Research	Salvage
Fishing	Z = -1.9881 p = 0.0234*	N/A	N/A	N/A	N/A	N/A
Human	Z = 1.1289 p = 0.1295	Z = 3.1170 p = 0.0009	N/A	N/A	N/A	N/A
Oil and Gas	Z = 3.4210 p = 0.0003*	Z = 5.4091 p = 0.0000*	Z = 2.2921 p = 0.0109*	N/A	N/A	N/A
Research	Z = 4.2934 p = 0.0000*	Z = 6.2815 p = 0.0000*	Z = 3.1646 p = 0.0008*	Z = 0.8724 p = 0.1915	N/A	N/A
Vessel	Z = 4.1110 p = 0.0000*	Z = 6.0991 p = 0.0000*	Z = 2.9821 p = 0.0014*	Z = 0.6900 p = 0.2451	Z = -0.1824 p = 0.4276	Z = -0.5235 p = 0.3003

Marine Debris Maps

Maps were generated to show location and type of marine debris encountered at each bank explored in the study area. Additionally, images are included on each map to provide an example of the debris observed at that location. ROV survey tracks are included to show the locations at which marine debris was not observed. The caption on each map includes a description of the dominant forms of marine debris observed.

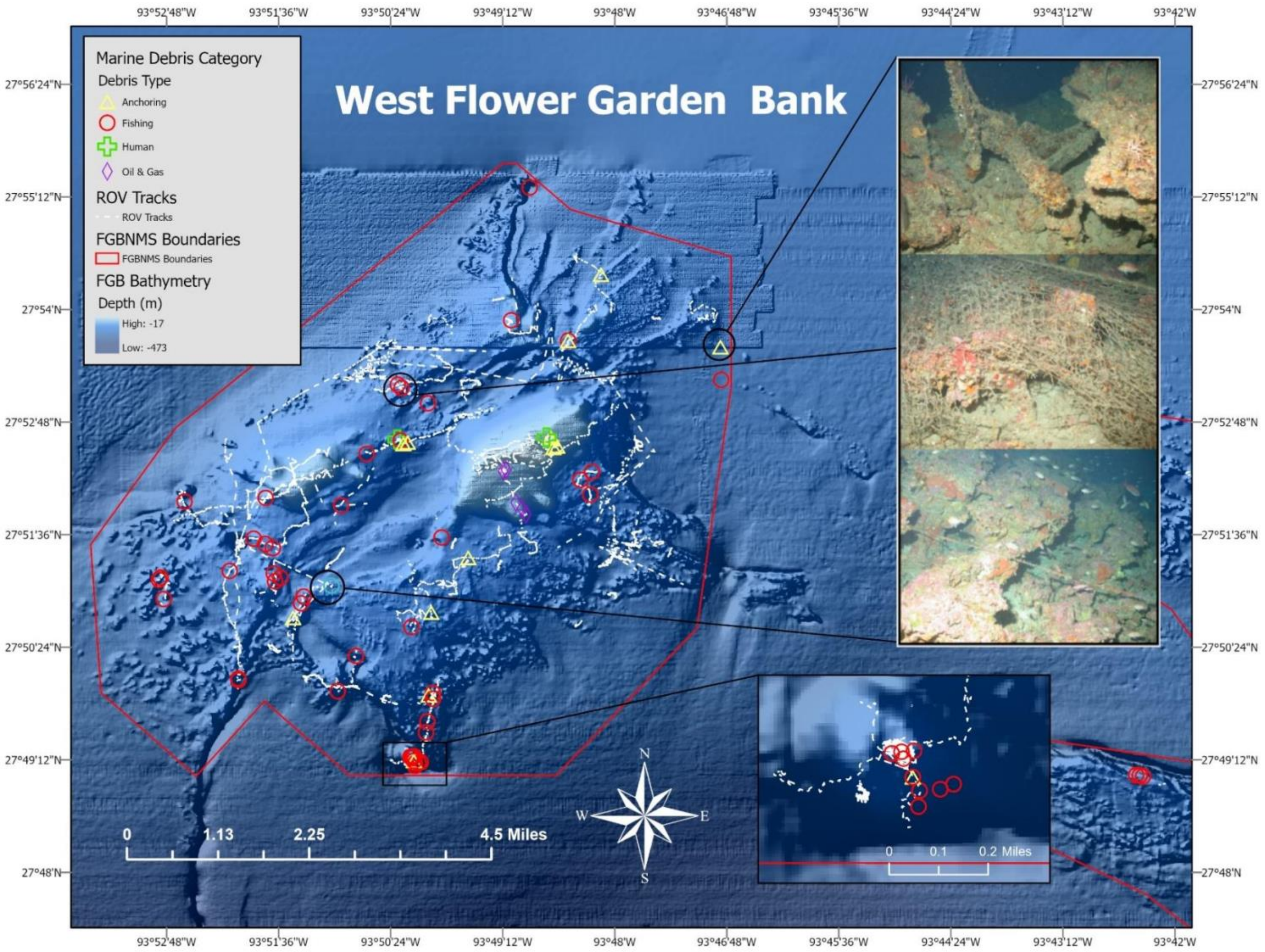


Figure 6. Marine debris at WFGB. Fishing debris, primarily monofilament line and fishing nets, accounted for 69% of marine litter recorded at WFGB. The majority of debris was in areas of higher topography, with fewer items in deeper regions and on soft bottom. Image: Kelly O'Connell/NOAA

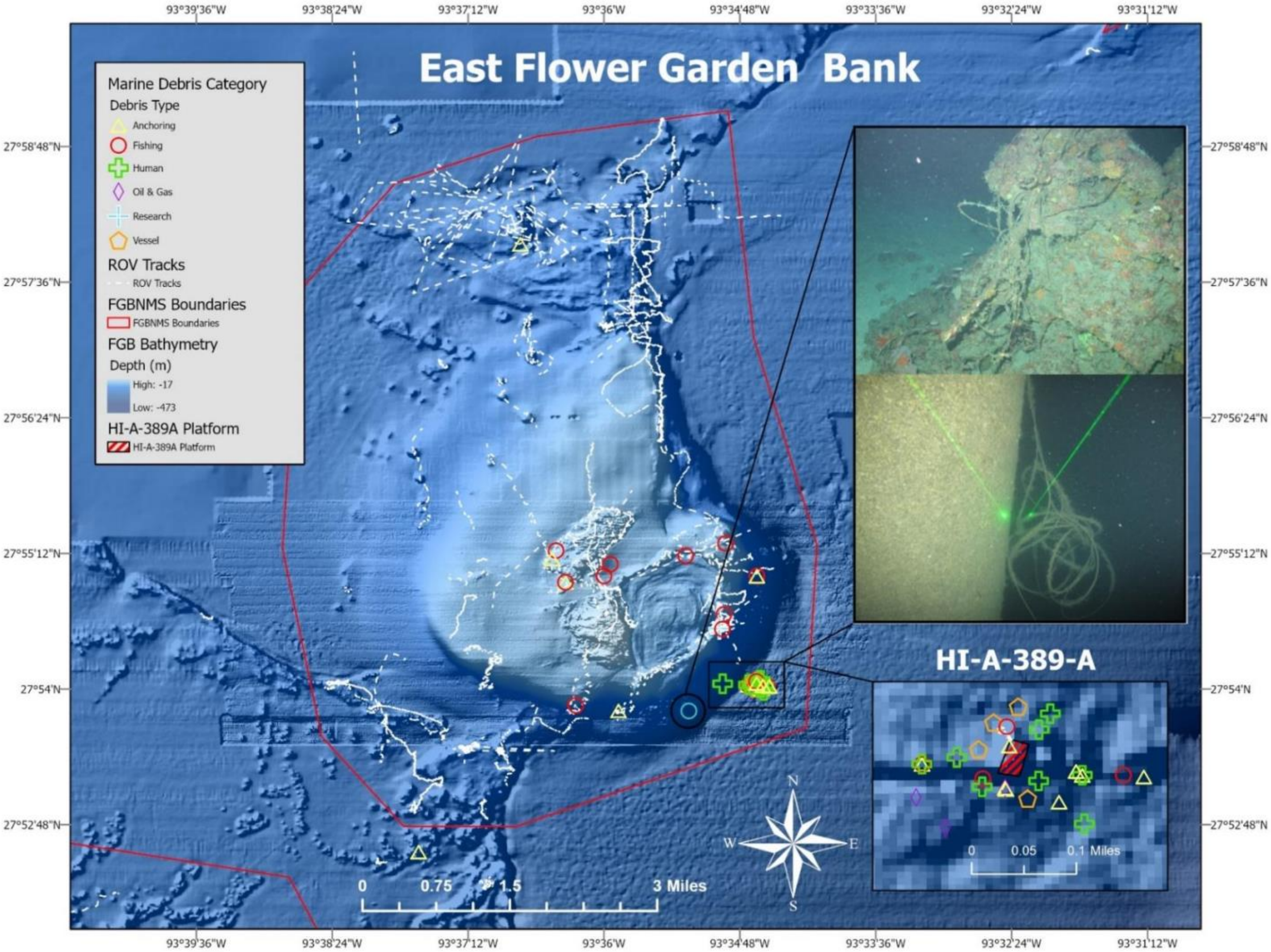


Figure 7. Marine debris at EFGB. Anchoring and fishing debris accounted for 25% and 38% of marine litter recorded at EFGB, respectively. The majority of fishing debris appeared to be in areas of higher topography on the southeastern edge of the bank. The debris near the oil and gas platform HI-A-389-A had higher concentrations of human, oil and gas, and vessel debris than those observed on the shallower features. Image: Kelly O'Connell/NOAA

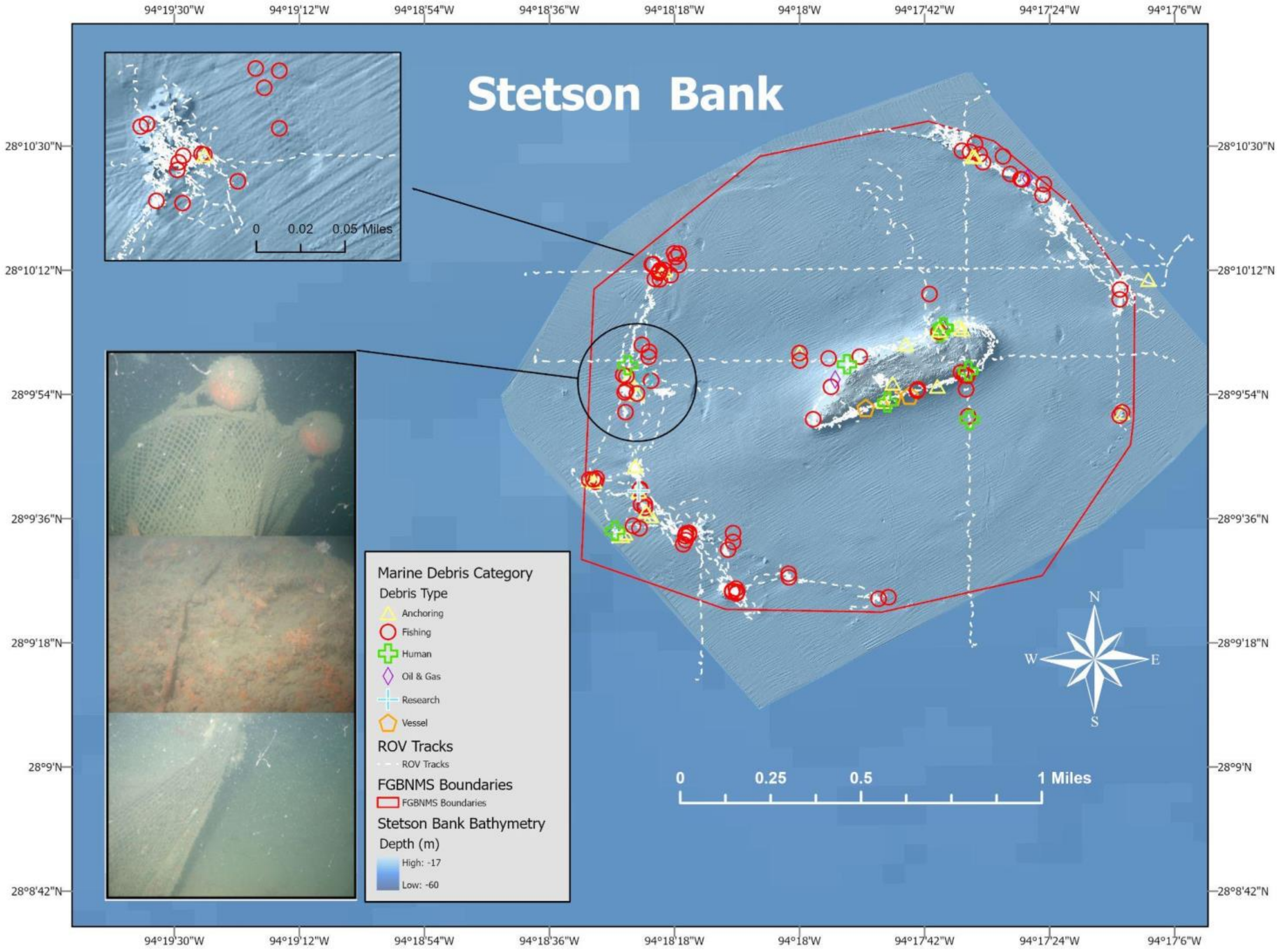


Figure 8. Marine debris at Stetson Bank, which had the highest debris encounter rate of any bank. Fishing debris made up 73% of items found at this mid-shelf bank. The majority was concentrated along the edge of the central feature and along the outer ring surrounding the bank, where the majority of survey effort occurred. Image: Kelly O’Connell/NOAA

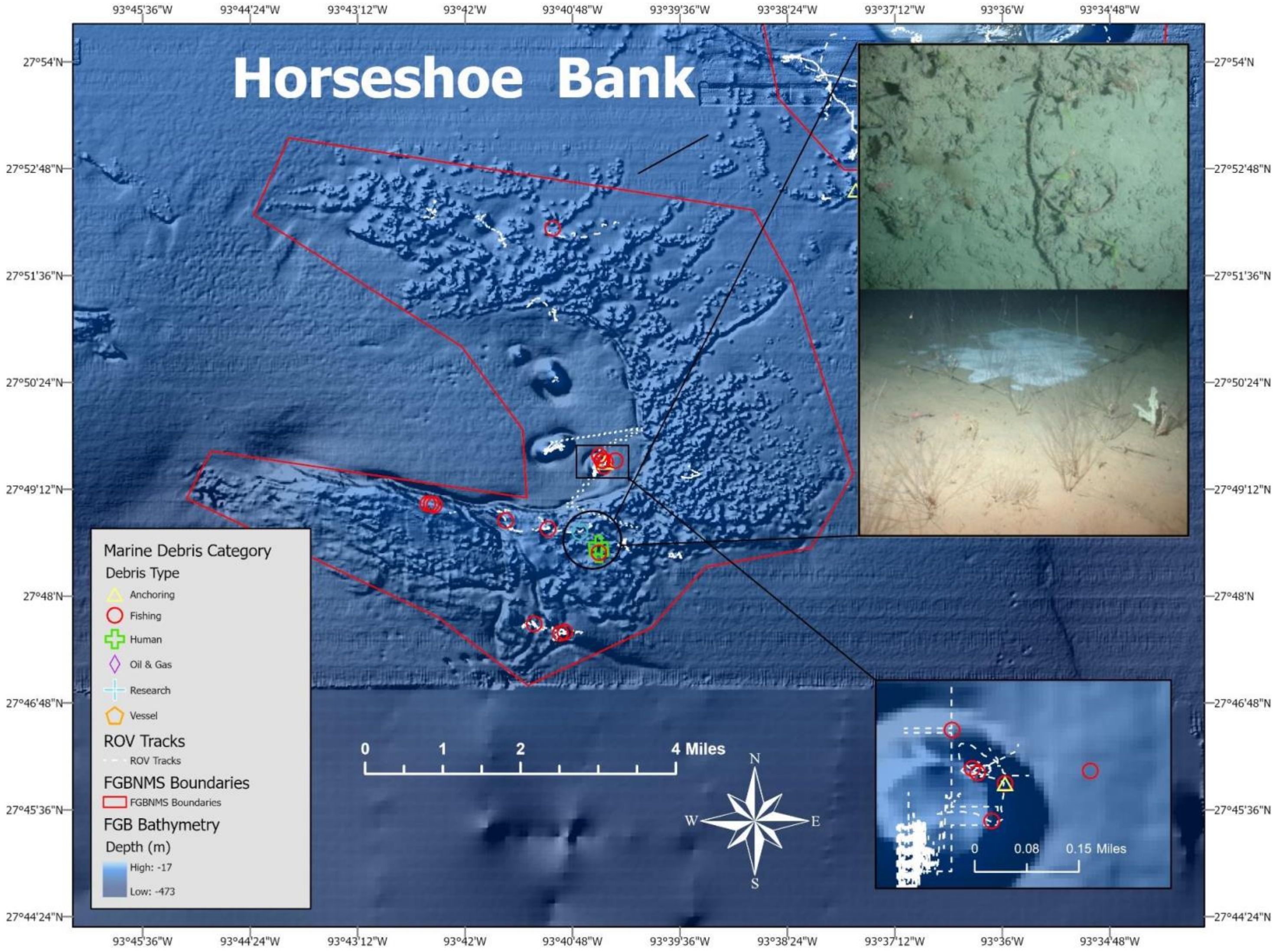


Figure 9. Marine debris at Horseshoe Bank, which had the third highest encounter among the banks surveyed. Fishing debris made up 86% of items at Horseshoe Bank, and all items were found within sanctuary boundaries. The majority of items were concentrated along topographical ledges in the center of the bank; however, human debris was concentrated in one area rather than spread across the bank. Image: Kelly O'Connell/NOAA

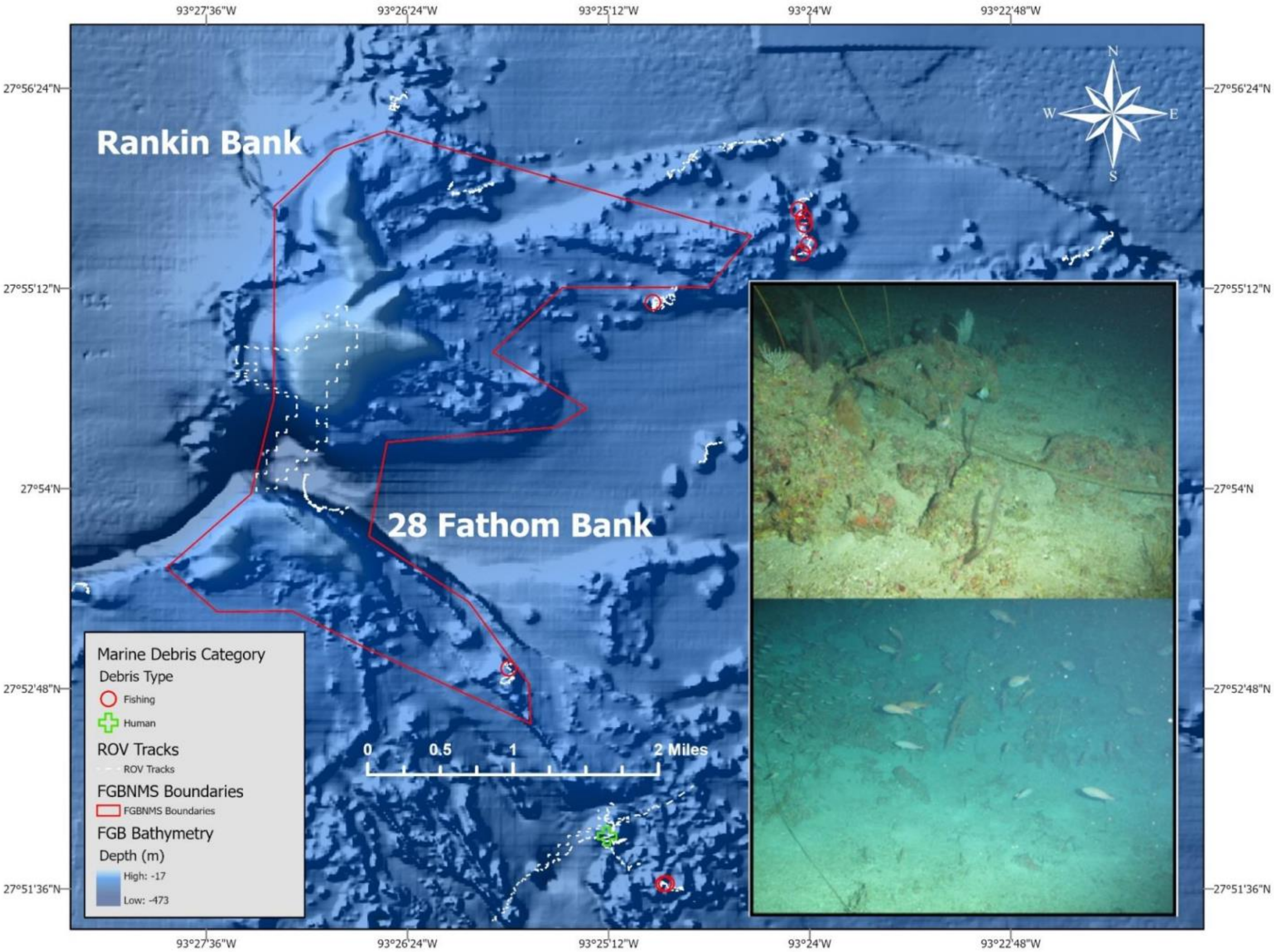


Figure 10. Marine debris at Rankin Bank and 28 Fathom Bank. All but one debris item was located outside the sanctuary boundaries at Rankin and 28 Fathom banks. This was not due to a lack of surveys, as ROV dives were conducted within sanctuary boundaries. Some items are not pictured as they were scattered in the deep reefs surrounding the banks. The majority of debris was related to fishing and anchoring, but encounter rates were comparatively low. Image: Kelly O'Connell/NOAA

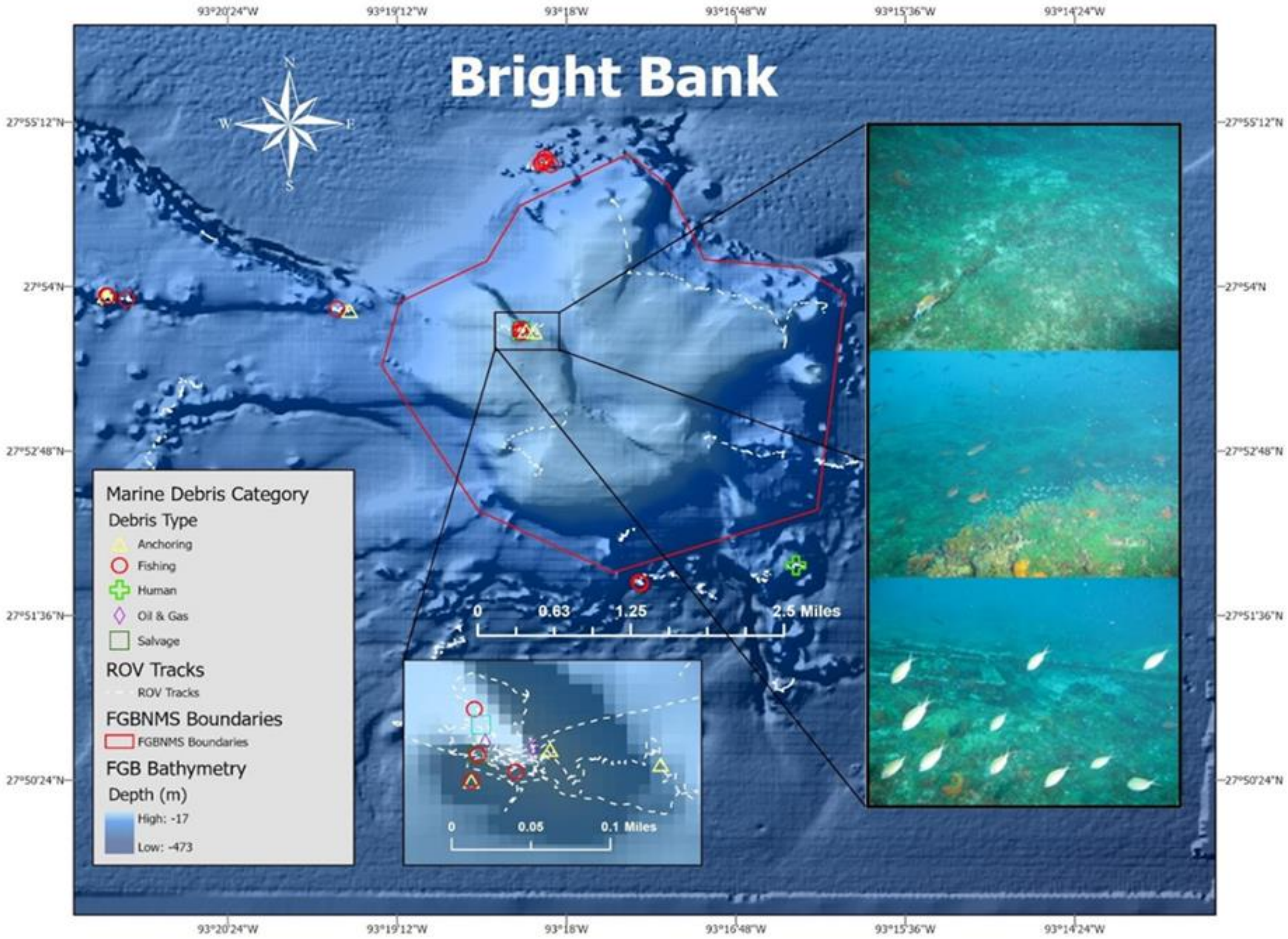


Figure 11. Marine debris at Bright Bank. Items were scattered both within and outside sanctuary boundaries. There were higher concentrations in clusters in higher topographical areas and along ridgelines. Anchoring and fishing debris tended to be clustered together, suggesting that fishing on the bank may be conducted from anchored vessels. Image: Kelly O'Connell/NOAA

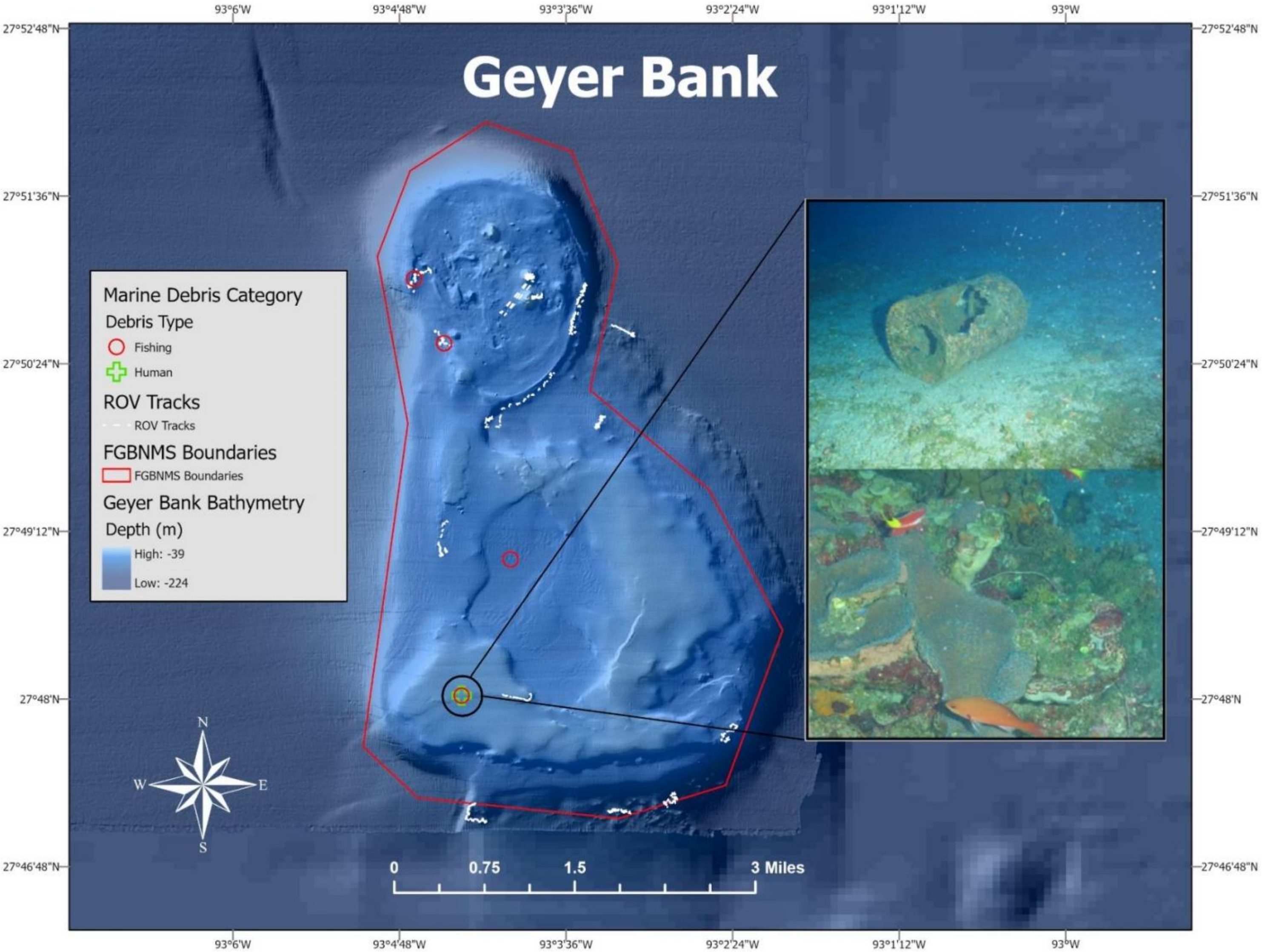


Figure 12. Marine debris at Geyer Bank. The only debris found at Geyer Bank was within sanctuary boundaries and consisted of fishing and human debris. Debris was concentrated on the highest topographical features near areas of the bank with stony corals. Image: Kelly O’Connell/NOAA

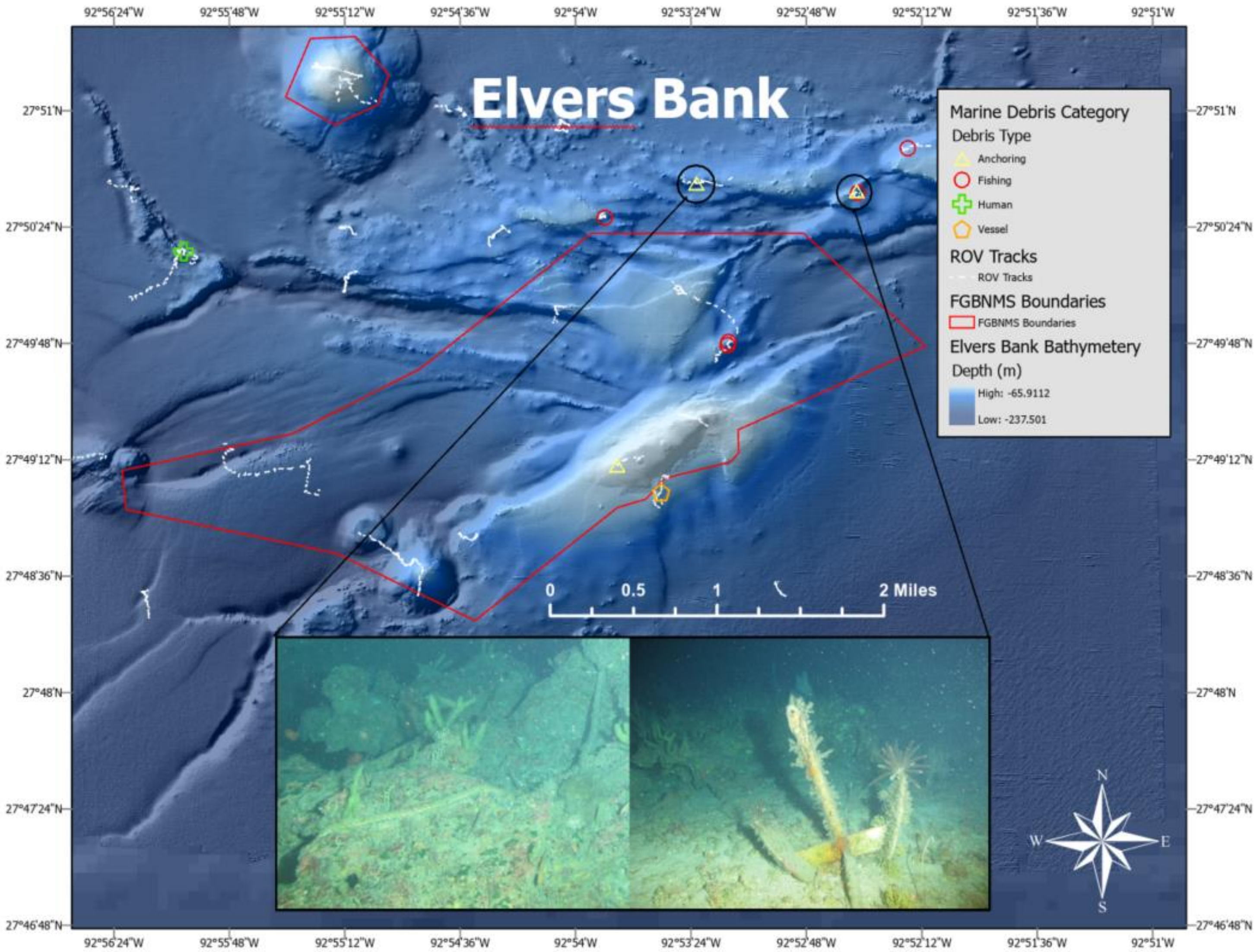


Figure 13. Marine debris at Elvers Bank. The bank had debris scattered within sanctuary boundaries and outside sanctuary boundaries, on surrounding features. Unlike many other banks, few items were found on the shallowest part of the reef. The anchors found on Elvers Bank were of modern design. Image: Kelly O'Connell/NOAA

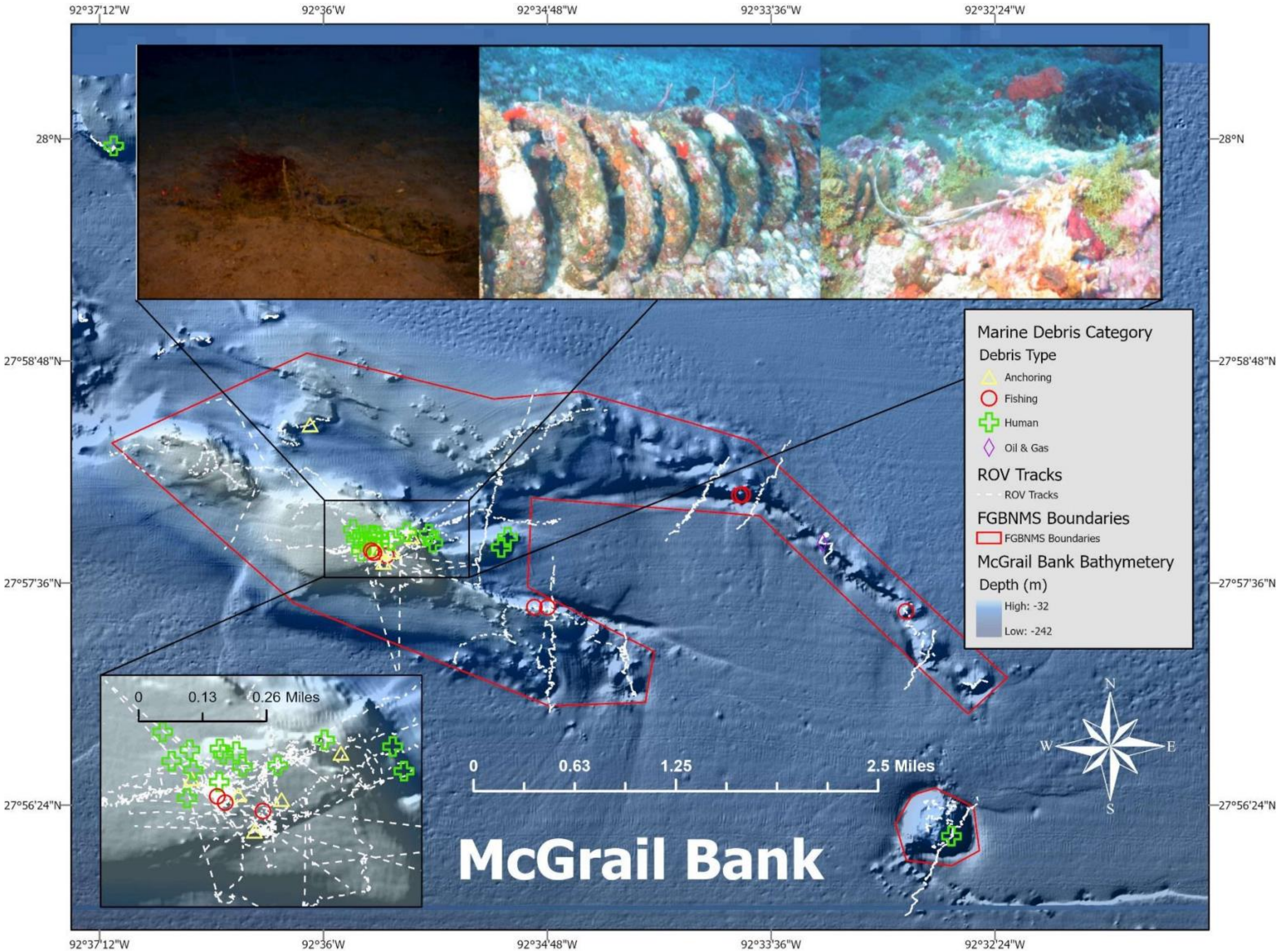


Figure 14. Marine debris at McGrail Bank. McGrail Bank had the largest proportion of observations of human debris (38%) of all banks. It was primarily concentrated in one area on the bank. Few items were found outside of sanctuary boundaries. Image: Kelly O'Connell/NOAA

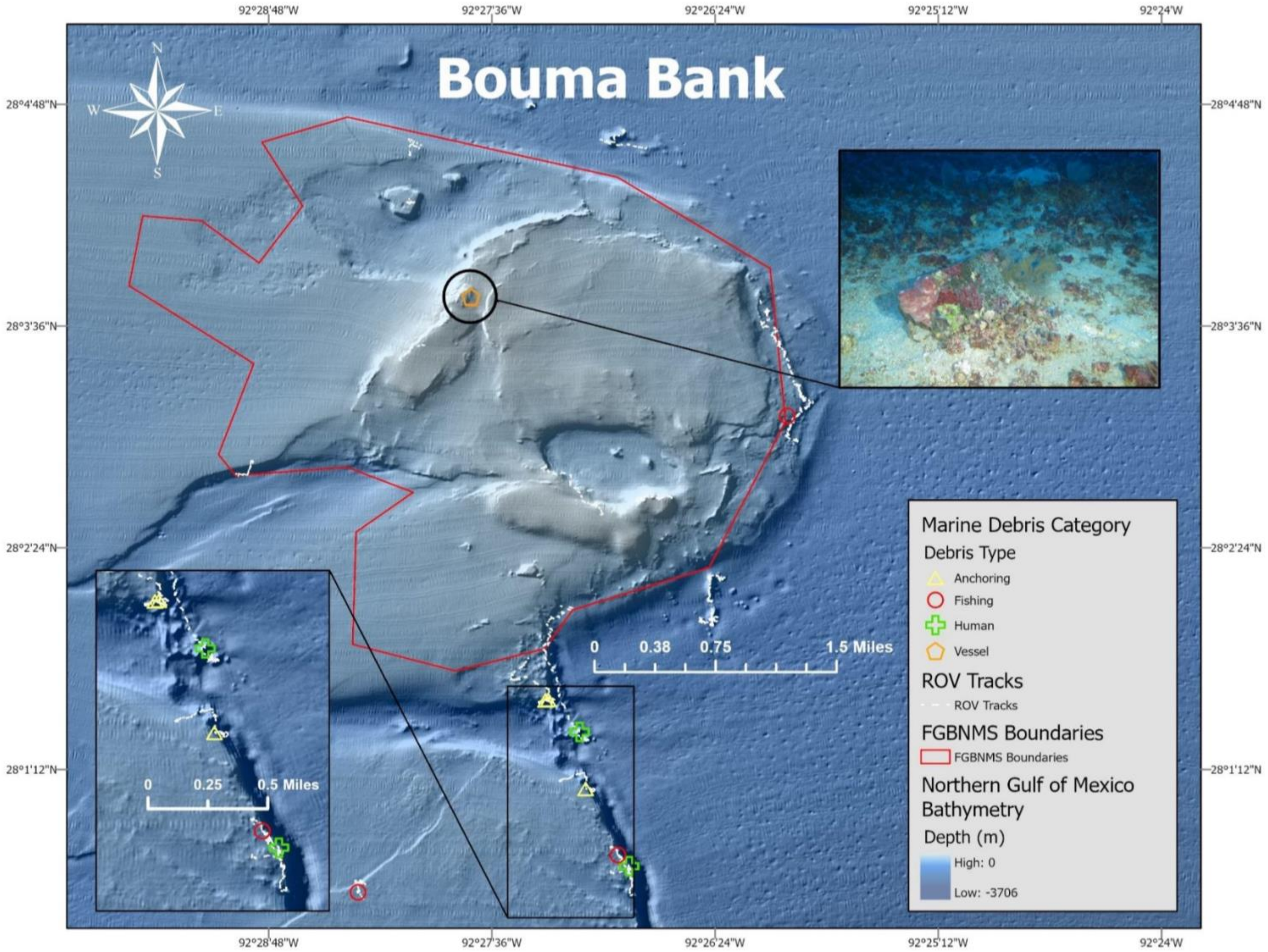


Figure 15. Marine debris at Bouma Bank, which had the third lowest debris encounter rate of all banks. The majority of debris was found south of the sanctuary boundary. Very few items were found in the coral habitats on the shallowest portion of Bouma Bank. Image: Kelly O'Connell/NOAA

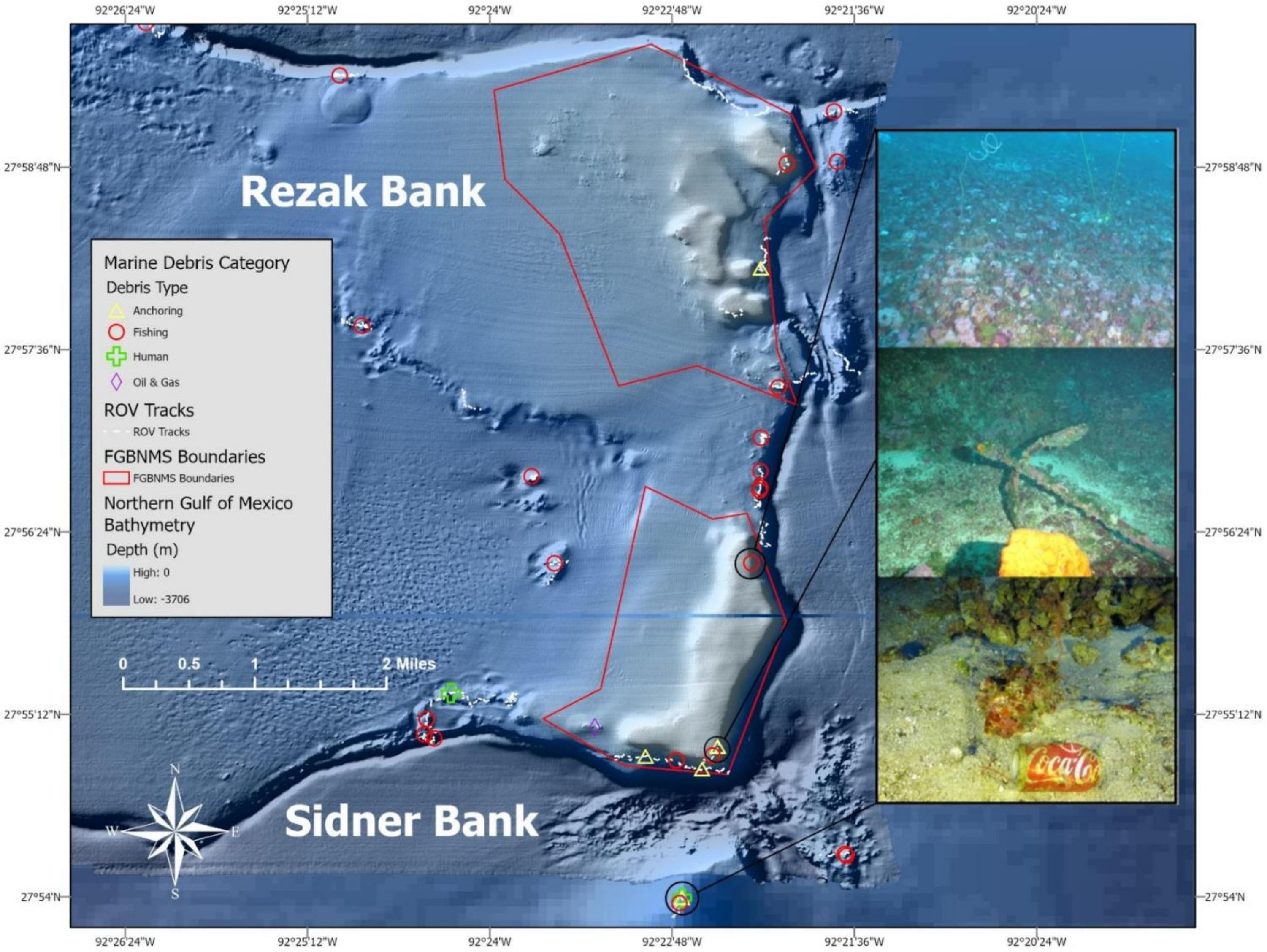


Figure 16. Marine debris at Rezak Bank and Sidner Bank. Debris appeared to accumulate along the eastern ridgeline of the banks. Fishing debris made up 88% and 62% of items observed at the banks, respectively. Image: Kelly O'Connell/NOAA

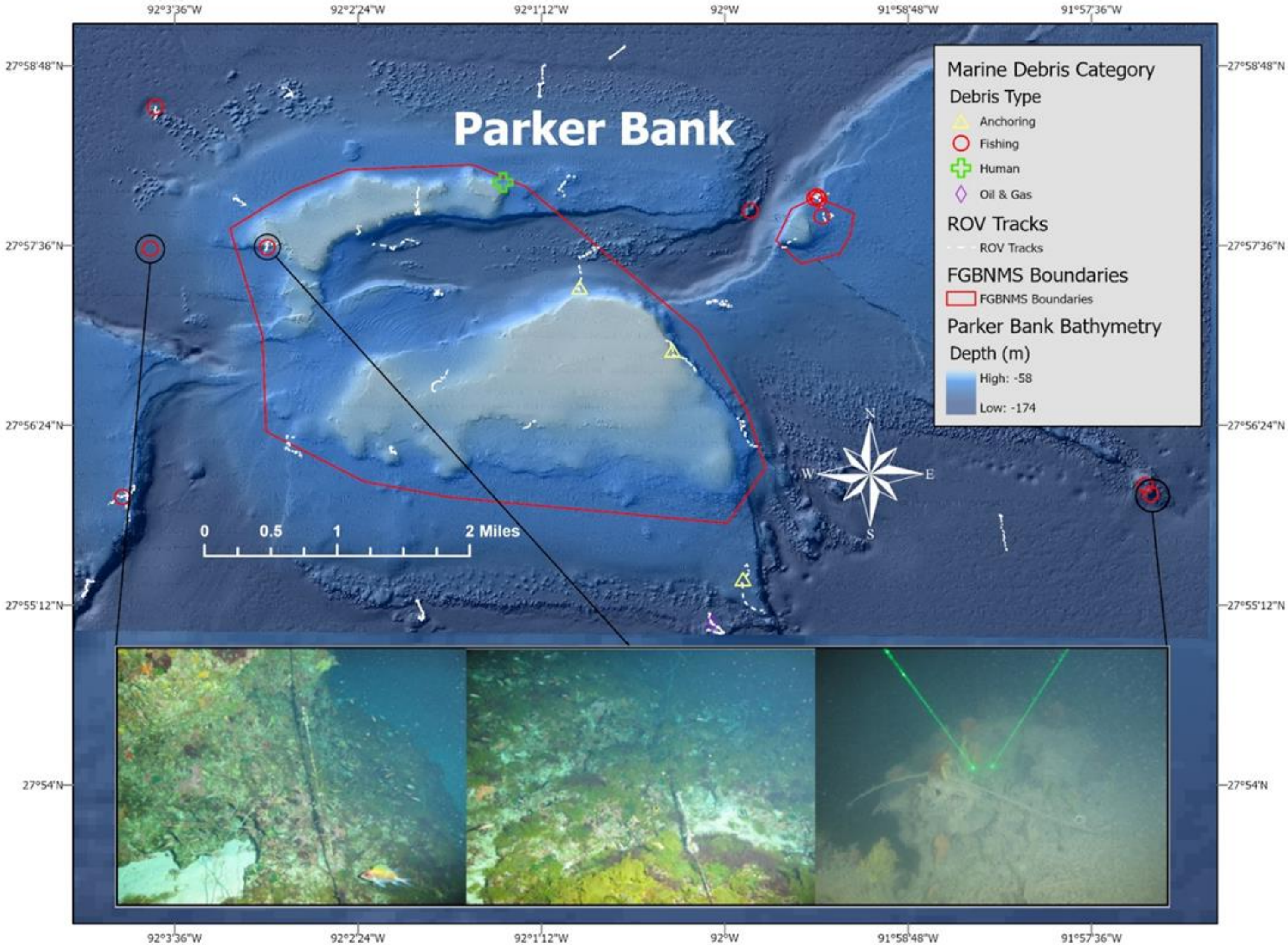


Figure 17. Marine debris at Parker Bank. Debris accumulation at Parker Bank did not exhibit clear patterns of distribution or concentration. It appeared to be scattered along the corners of the bank, throughout deeper water outside sanctuary boundaries and along ridges. Fishing was the most common debris type at 71% of all items observed, but with comparatively low encounter rates compared to most other banks. Image: Kelly O'Connell/NOAA

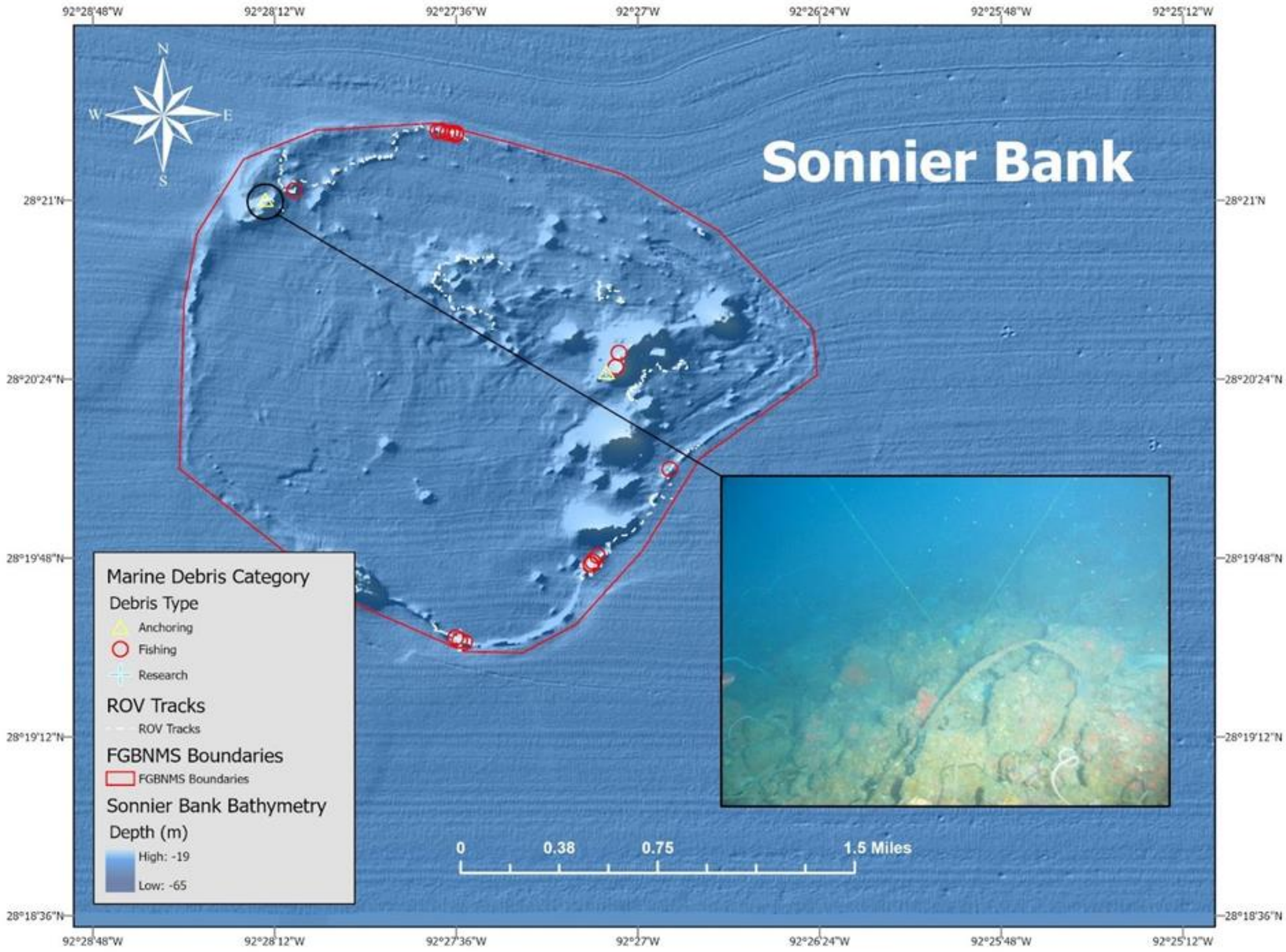


Figure 18. Marine debris at Sonnier Bank. Debris at this mid-shelf bank was concentrated along the outer ridge ring near the sanctuary boundary. With the second highest encounter rate of all banks, fishing contributed 73% of debris, and debris was concentrated around areas of high topographic relief. Image: Kelly O'Connell/NOAA

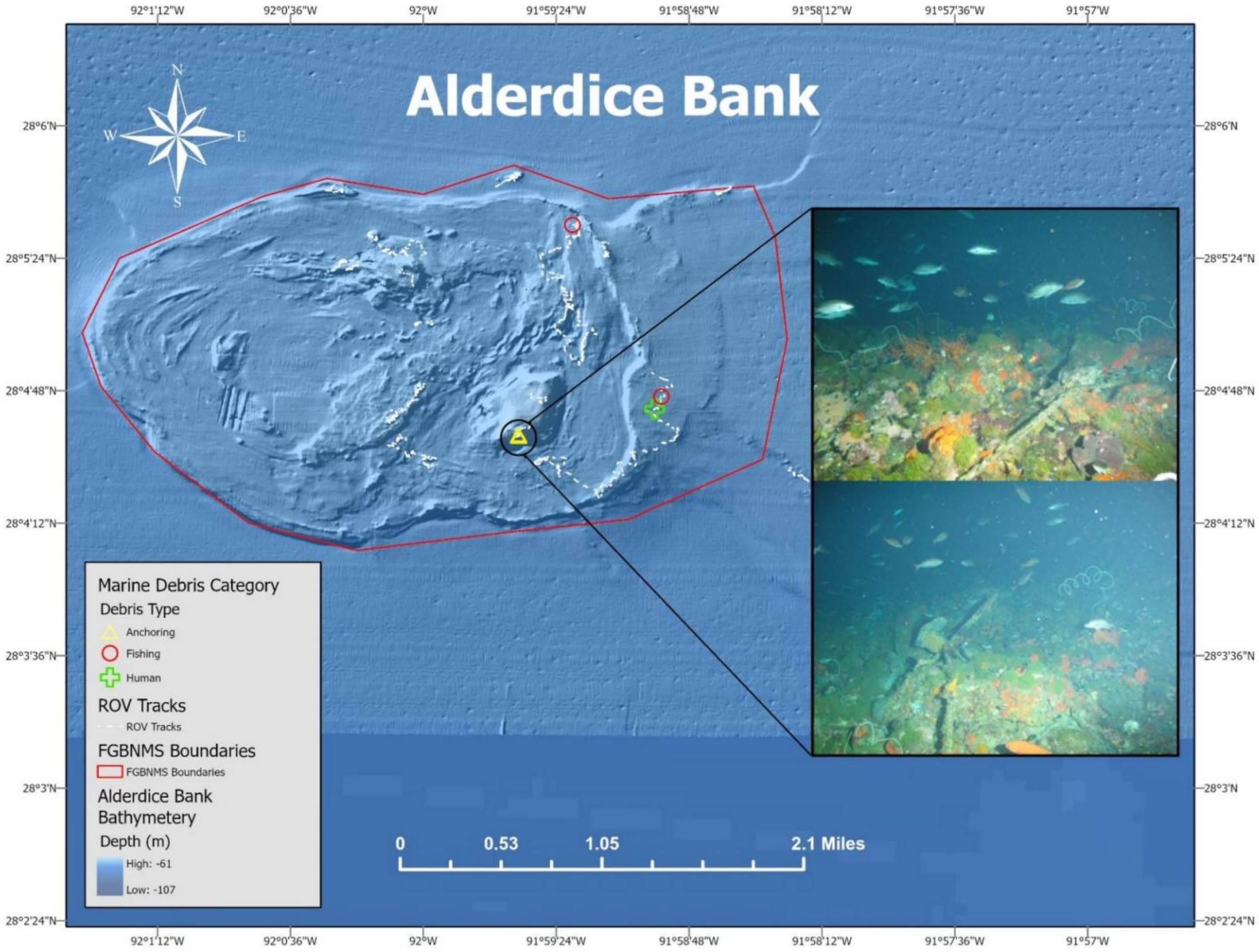
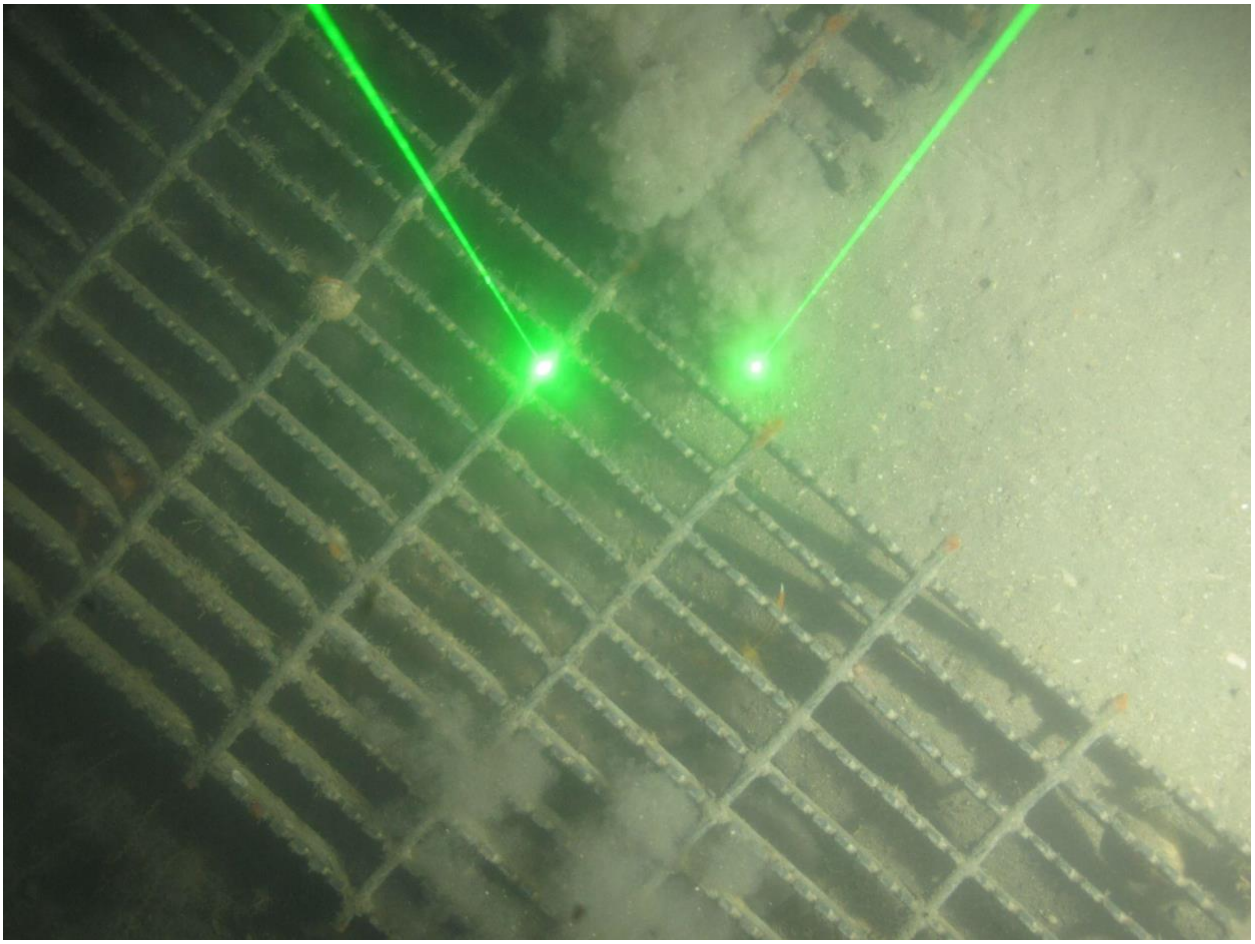


Figure 19. Marine debris at Alderdice Bank, which had one of the lowest debris encounter rates of all banks. All debris observed at Alderdice Bank was within sanctuary boundaries. Anchoring debris accounted for half the items and was concentrated in one area on the bank. Image: Kelly O’Connell/NOAA

Chapter 4:
Discussion



Metal grating found at WFGB. This type of grating is typically used on oil and gas platforms. Photo: NOAA/University of North Carolina at Wilmington Underwater Vehicle Program

The ocean floor is an accumulation site for marine debris. Debris can physically and chemically alter benthic habitats; kill organisms through smothering, entanglement, or ingestion; and affect community structure and ecosystem integrity. Most debris observed in this study in and around FGBNMS appeared to have been present for some time, with evidence of encrusting algae, sponges, and other invertebrates growing on debris items or using them for shelter. Although there are many short-term studies on the effects of marine debris (Chiappone et al., 2005; Watters et al., 2010; Amon et al., 2020), a long-term monitoring approach is necessary to determine the full range of impacts to ecosystems in the northwestern Gulf of Mexico and prioritize response actions for the resource management community.

Our observations were consistent with those of other studies in the region, finding that marine debris consisted mostly of lost fishing gear, anchors, ground tackle, and discarded trash, with some debris associated with oil and gas activities (Miller et al., 1995; Ribic et al., 2011). By comparison, debris in the U.S. Caribbean (waters around Puerto Rico, U.S. Virgin Islands, Navassa Island, and Guantanamo Bay Naval Base) is dominated by miscellaneous human-made items (Ribic et al., 2011). Debris was widespread in and around FGBNMS, with concentrations in areas of heaviest use or areas with high relief. Concentrations of small debris items related to oil and gas activities (e.g., tools) were typically near platforms, such as the former production platform at EFGB. Geophysical and exploratory survey cables were more concentrated in areas of relief, where they may have inadvertently snagged on the bottom during surveys. Furthermore, unlike others who generate debris, when leases or pipeline right-of-ways are abandoned, oil and gas operators are required to clear the seafloor of all obstructions, including debris created, used, deposited, or accumulated (Bureau of Safety and Environmental Enforcement, 2019).

In this report, debris count varied significantly by bank, but much of the variation was due to differences in sampling effort. When adjusted for effort, there was no statistical difference in the encounter rates for debris (all categories combined) among the banks. There were, however, differences in encounter rates among banks for particular types of debris, which reflected hotspots of certain activities, particularly fishing.

Georeferenced information on marine debris maps suggests debris items are more likely to be found along ledges and shallow peaks. This may reflect concentrations of effort by recreational or commercial fishers, and the higher likelihood of fishing gear becoming caught on structurally complex habitats (Watters et al., 2010). It also suggests that unsurveyed areas of the banks with similar habitats may have comparable concentrations of debris.

While some debris may drift from other locations (Hess et al., 1999) before catching on bottom features of the banks, our impression based on observations of human activities on some banks is that most items originated from localized activities. This could enable strategic selection of sites for future surveys and removal efforts by FGBNMS staff.

Marine debris photographed during this study included derelict fishing lines, nets, and salvage gear covering structurally complex biota such as sponges, branching stony corals, octocorals, and antipatharians. Nets cause entanglement problems in the water column, and, when they accumulate on a reef, can smother organisms or, in the case of corals, block sunlight needed by symbiotic algae for photosynthesis (Pastorok & Bilyard, 1985). Injured organisms become susceptible to infections and may eventually die, as shown in shallow-water hard and soft corals and deep octocorals (Bavestrello et al., 1997; Schleyer & Tomalin, 2000; Asoh et al., 2004; Yoshikawa & Asoh, 2004; Chiappone et al., 2005; Bergmann et al., 2015). Additionally, constant or repeated contact with soft plastic litter, such as miscellaneous wrappers, bottles, and other human-made debris, can cause necrosis, as observed in the cold-water coral *Lophelia pertusa* (Fabri et al., 2014). However, necrosis was not observed in the present study.

Most physical damage to habitats and living resources caused by fishing gear, anchors, and other human-made items occurs either during their use or when they initially become tangled or settle to the bottom. When lost, these items often become immobile, which may prevent further damage, and the affected resources may even recover. The longer the gear remains in place, the harder it is to determine its impacts.

An iron admiralty style anchor without a stock (Figure 20) was found at a depth of 88 meters on WFGB. It is a 19th-century design, and may have been used into the early 20th century (H. Van Tilburg/NOAA, personal communication, 2021). The anchor illustrates the fact that damage to mesophotic habitats from anchors and chains has been a reality for many years on these banks, as it has been elsewhere (Goenaga, 1991). But the lack of evidence of recent nearby damage from this and other anchors shows that heavy objects that become immobile on the bottom can become virtually harmless over time. Some have questioned the need for removal of such objects because they pose no continuing threat, and because the removal can cause unnecessary damage.

Figure 20. An anchor found at a depth of 88 m on WFGB, with details that suggest it was designed in the 19th century. Photo: NOAA/University of North Carolina at Wilmington Underwater Vehicle Program

Fishing-related activities contributed more to marine debris abundance in the study area than any other category. The specific items, which were primarily fishing line and lost nets, originate from the active hook-and-line, longline, and shrimp fisheries in the region. Similar observations have been made in other parts of the world (Walker et al., 1997; Cunningham & Wilson, 2003; Ribic et al., 2010; Ribic et al., 2011). But unlike anchors, lost nets often remain unstable when entangled on a reef, and can move with currents and surge. Thus, impacts can continue for a longer period of time. Sites impacted by nets often exhibit higher cover of abraded substrate, sand, and crustose coralline algae, as well as low coral and macroalgae cover (Suka et al., 2020).

Stetson Bank in particular has a large amount of shrimp nets and associated gear among the features of the siltstone/claystone ring surrounding the bank. Some of the nets are recent, others older, and they have directly impacted the biology of these sensitive habitats. Though there was no obvious decrease in fishing debris with distance from Galveston, the high encounter rate at Stetson Bank may be attributed to its accessibility to the fishing community. It is only about 130 kilometers from shore; most other banks are at least 175 kilometers from the nearest ports.

Figure 21. An abandoned shrimp net found among sponges on a feature at a depth of 59 m at Stetson Bank. Photo: NOAA/University of North Carolina at Wilmington Underwater Vehicle Program

Mortality from fishing gear has been well documented for mammals and marine birds (Majluf et al., 2002; Read et al., 2006; Good et al., 2009, 2010; Jacobsen et al., 2010; Senko et al., 2020), but no estimates are available for the number of animals affected (Bergmann et al., 2015). Fish can also die from entanglement, as they are prevented from eating, taking up oxygen, and avoiding predators. Though FGBNMS staff did not witness entanglement during ROV surveys, it may have been because the animals had already been preyed on (Laist, 1997; Ryan et al., 2009; Allen et al., 2012). Observations of entangled animals are typically opportunistic.

While the impacts of lost nets are fairly well documented, impacts from other gear are less well understood. Chiappone et al. (2005) found that less than 0.2% of invertebrates were affected by lost hook-and-line fishing gear. However, this gear caused 84% of the documented impacts (primarily tissue abrasion) to sponges and cnidarians, leading to partial or complete mortality. Amon et al. (2020) found that deep-sea fauna directly interacted with over a third of the debris observed (e.g., via sheltering, encrustation, entanglement). Edward et al. (2020) found that corals in contact with derelict fishing gear exhibited a high prevalence of tissue loss (34%) and fragmentation (48%). Further investigations are needed to determine what other impacts may occur, such as increased susceptibility to predation, competitive overgrowth, and disease.

Human-sourced debris, primarily plastic wrappers, plastic bottles, cans, and tires, was an important contributor to the marine debris on the seafloor, making up 11.3% of all observations. Finding a large quantity of household items was not unexpected, as these are the primary components of the well-known and worldwide problem of trash accumulation in the global ocean (Goldberg, 1997; Derraik, 2002; Moore, 2008; Barnes et al., 2009; Gregory, 2009; Andrady, 2011). While solar radiation and thermal oxidation often degrade floating plastics and other materials, they don't affect sunken debris, making the rate of degradation in deep ocean environments extremely low (Watters et al., 2010; Andrady, 2011). Within this category, plastic debris poses a demonstrable and substantial threat to wildlife. It can cause choking, clogging, and starvation; act as a vector for exotic or invasive species; expose animals to toxic chemicals; and break down to smaller and smaller pieces, exposing ever-smaller animals to its impacts (Barnes et al., 2009). Studies have shown that plastic items of all sizes are reaching some of the most remote and deepest parts of the globe (Chiba et al., 2018). Unfortunately, the difficulty of sampling mesophotic and deep-sea ecosystems make it difficult to understand their full threats and impacts.

In the 1980s, dynamite was used for excavation on the crest of Bright Bank in a failed hunt for a purported treasure-laden galleon. The salvage activities created deep holes and destroyed corals on the bank, damage that remains evident four decades later, along with scattered equipment and tools from the operation. It was the only bank at which salvage debris was observed.

Debris from oil and gas activities was observed at seven of the 18 banks. It included lost seismic cables used during exploration as well as discarded equipment such as pipes. The cables tended to accumulate near the edges of the banks, where rapid depth changes and high relief snagged cables as survey ships approached the banks in the years before operators became familiar with the terrain. In recent decades, much loose debris has been removed from dive sites at the Flower Garden Banks. What remains is embedded in the coral reef around the flanks of EFGB and WFGB (Figure 22) and in deeper habitats.

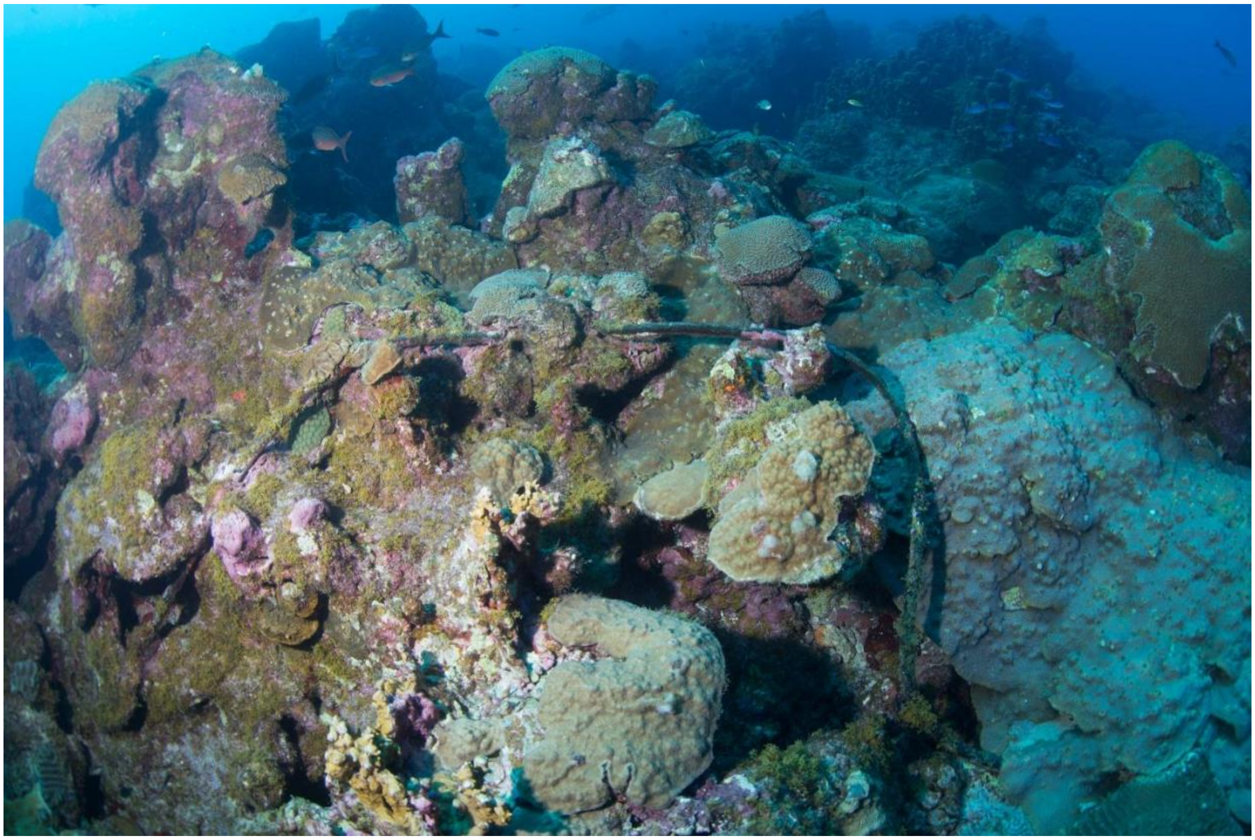


Figure 22. Diver observation of abandoned seismic cables on the coral reef cap. Photo: G.P. Schmahl/NOAA

Extreme weather, such as hurricanes, often damages monitoring and research equipment on the seafloor and detaches data buoys, resulting in loss of data, gaps in time series, interruptions in activities, and considerable expenses. An ocean acidification station deployed at EFGB was extensively damaged during the 2020 hurricane season, the most active storm season in the history of FGBNMS (Figure 23). Although the instrument package was recovered near its installation site, the associated science buoy was lost and was not found until it reached the coast near Louisiana in 2022. FGBNMS staff often see evidence of impacts from various hurricanes and other storms in which substantial sediment movement in the sand patches buries moored instruments and affects data collection. Storm activity is likely the cause of many lost research debris items in the northwestern Gulf of Mexico.

Additionally, 12 sanctuary mooring and marker buoys, which facilitate access to research and monitoring sites, were lost between 2020 and 2021. These seldom become debris in the sanctuary because they drift away. Thus, these were not included in the categories described in this report.

Figure 23. Ocean acidification benthic instrument package just after installation in 2019 (left) and in pieces after 2020 hurricanes passed through the area (right). Photo: G.P. Schmahl/NOAA

Despite the many known negative impacts of marine debris, the objects themselves can be useful to deep-sea fauna such as corals, hydroids, crinoids, sponges, and anemones. Though debris inevitably alters the seafloor, it acts as artificial habitat that provides shelter for motile organisms and attachment surfaces for sessile organisms (Watters et al., 2010; Miyake et al., 2011; Schlining et al., 2013; Amon et al., 2020). But such ecological benefits are frequently debated, both philosophically (no alteration is desirable) and because artificial habitats are typically unstable and transitory. They are prone to movement during storms, likely to degrade, can enable the proliferation of nuisance and non-native species, and continue to entangle more debris. Even in relatively deep water, artificial habitats can be affected by storm energy, which can reach over 90 meters (National Oceanic and Atmospheric Administration [NOAA], 2017). The generally preferred action in national marine sanctuaries is to remove debris when the removal is unlikely to cause more harm than it prevents.

Understanding the sources and impacts of marine debris is crucial to guide mitigation policies and management practices (NOAA Marine Debris Program, 2014). Based on knowledge about fishing and debris impacts, many recommendations have been made to understand and mitigate the problem including: document and monitor entanglement rates; recover lost or abandoned gear; urge or incentivize fishers to report lost or abandoned gear; keep marine debris on board if brought up during fishing operations; develop new technology for fishing gear, such as float releases to aid retrieval and degradable gear; gear marking; inspection of gear by port authorities; onshore collection/recycling facilities and payment incentives for old/retrieved gear; reduction in fishing effort; spatial management of fishing; and awareness programs (Laist, 1997; Laist et al., 1999; MacFadyen et al., 2009).

The problem of human debris is a much more complex one to address. A large component of this category consists of plastic, which is an immense and growing global issue. A range of new solutions are needed to reduce plastic waste, remove all sizes of plastic debris, including microplastics, and improve waste management and recycling practices, particularly in coastal areas. Incentives are needed for producers of consumer products to minimize the unnecessary use of plastic, promote recycling and reusable packaging (Moore, 2008), explore biodegradable options, and develop reusable packaging. Both products and packaging contribute significantly to the problem. Some European countries are benefiting from initiatives that support packaging reductions and place direct responsibility for waste reduction on manufacturers, importers, and distributors.

While trends in technology and human activities will largely determine the future of marine debris accumulation on the seafloor, protected marine areas like FGBNMS are focal points for protection, response, and awareness about marine debris. They often conduct removals and cleanups, characterize and monitor debris, and engage in public education and outreach efforts to spread awareness. Some, like FGBNMS, also install mooring buoys not only to protect habitats but to reduce the loss of anchors.

This report demonstrates the utility of archived survey records to produce baseline information on marine debris and the status of resources affected by it. Future monitoring will enable assessments of the effectiveness of management actions and changing levels of lost gear and trash debris as human activity levels change. Of course, other stressors are also affecting shallow and mesophotic reef ecosystems, including many related to human activities, such as climate change, pollution, overuse, invasive species, and coral disease, in addition to natural events like hurricanes activity (NOAA Marine Debris Program, 2014). Monitoring and research in marine protected areas enable comparison of the relative impacts of marine debris amid these many other factors that affect ecosystem integrity.

Acknowledgements

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Appendix A:
Photo Gallery

Fishing debris found throughout study areas in the northwestern Gulf of Mexico.

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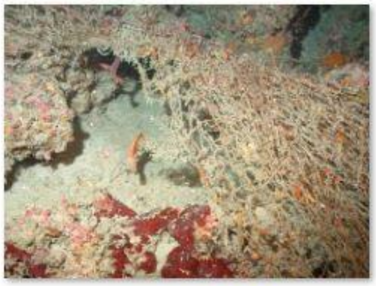

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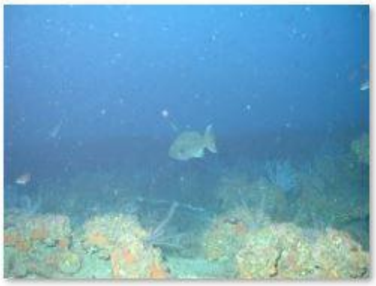

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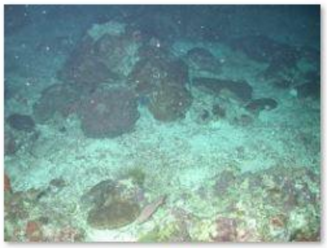
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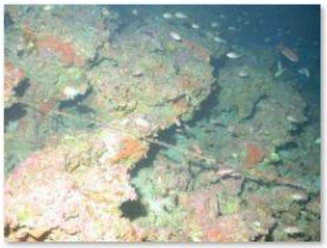
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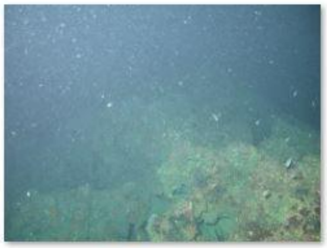
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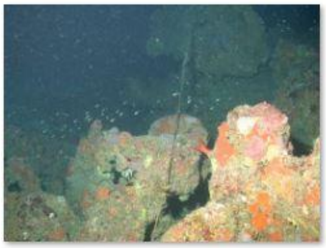
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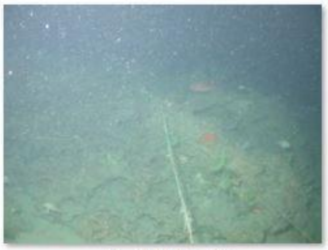
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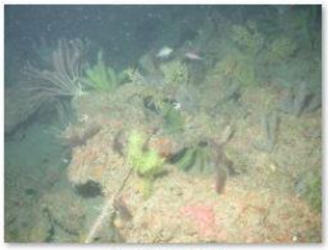
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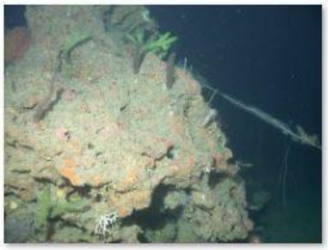
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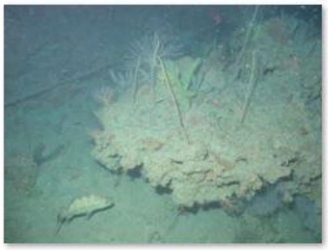
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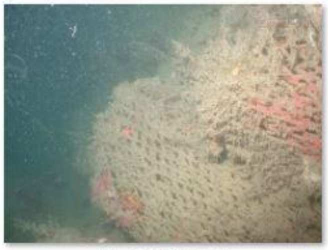
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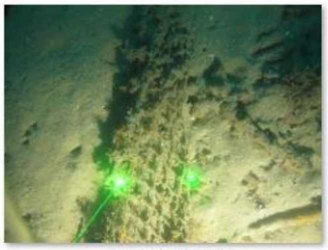
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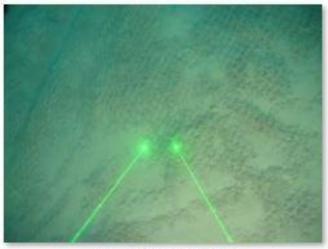
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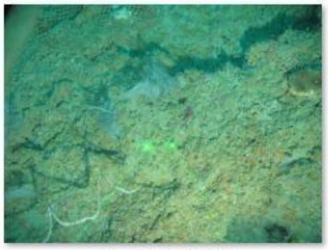
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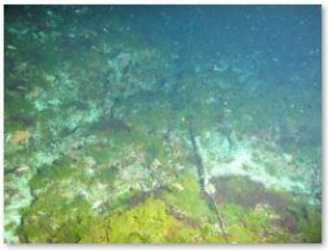
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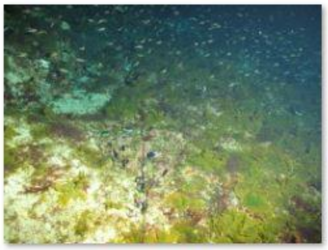
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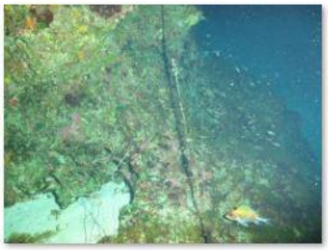
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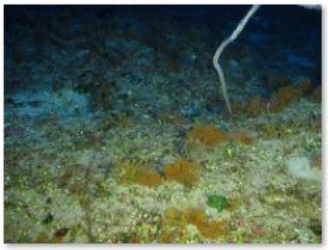
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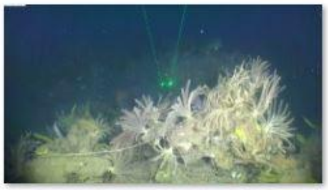
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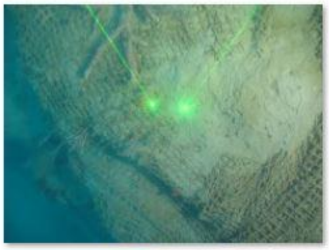
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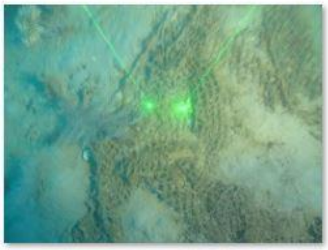
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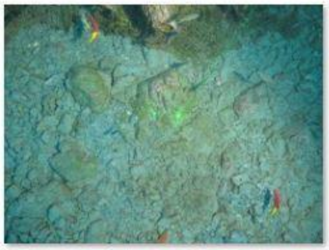
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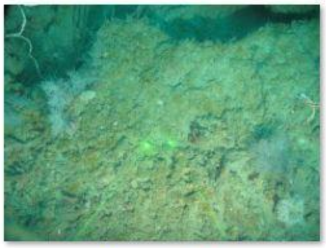

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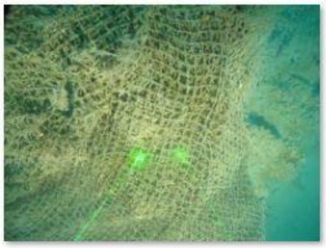

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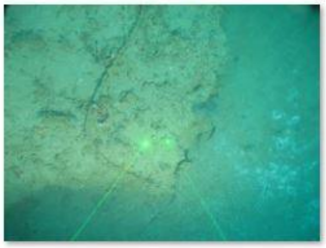

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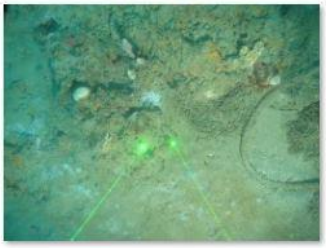

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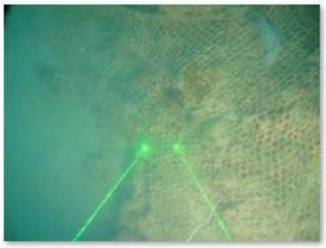

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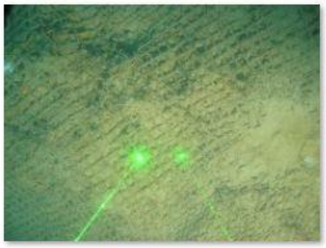

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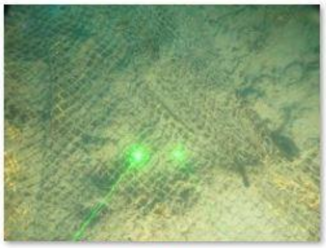

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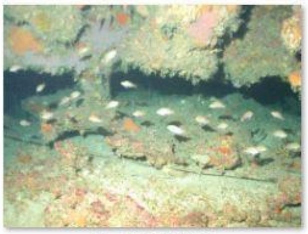
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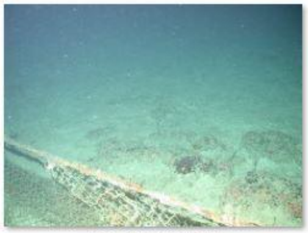
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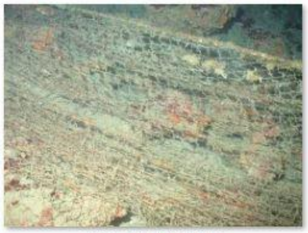
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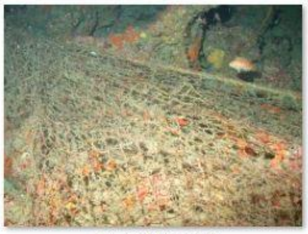
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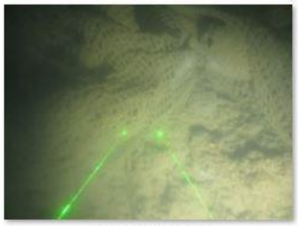
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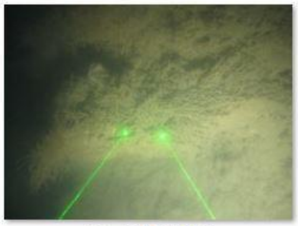
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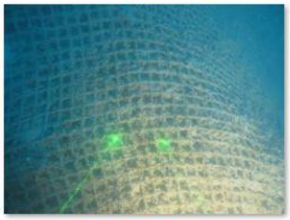
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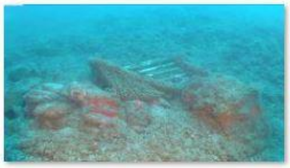
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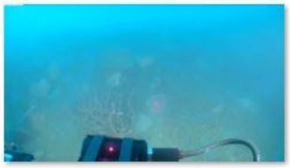
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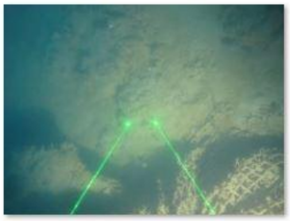
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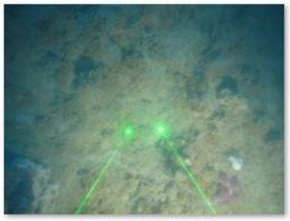
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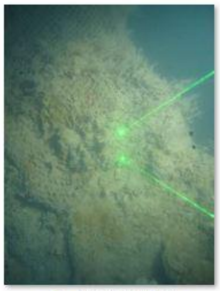
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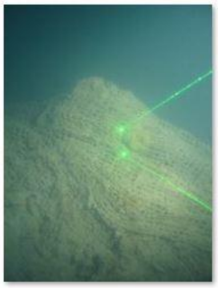
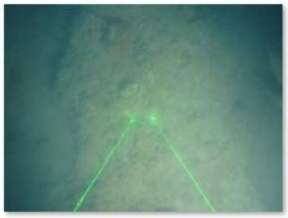
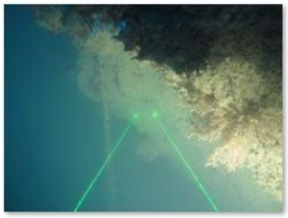
Dive 643_0100_172943


Dive 643_0101_173017

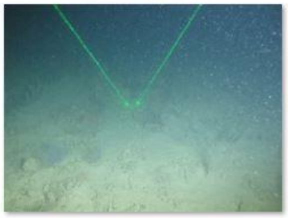

Dive 644 0034 085629

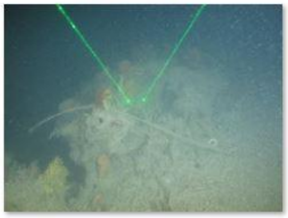

Dive 644 0064 093923


Dive 648_0051_152306


Dive 648_0052_152333

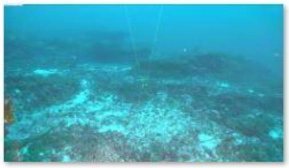

Dive 657_0273_095054


Dive 660_0068_143431

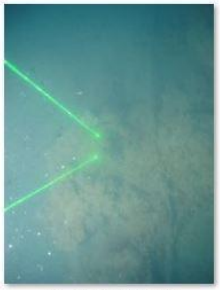

Dive 660_0116_145811

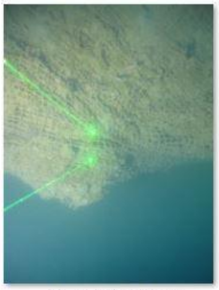

Dive 664_0232_110107

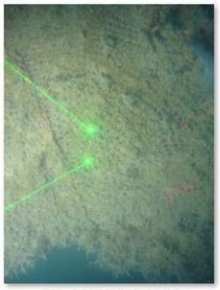

Dive 664_0233_110110


Dive 665_0113_115408

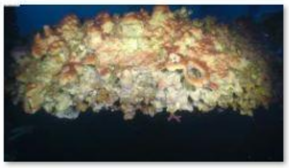

Dive 791_0024_100655


Dive 794_0124_102212

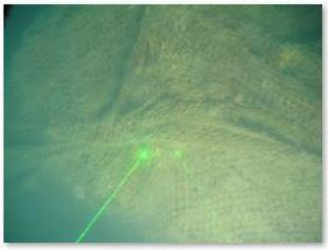

Dive 794_0128_102407

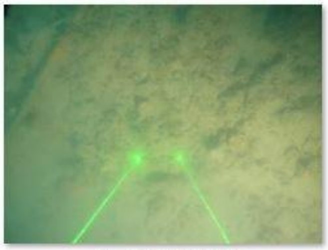

Dive 794_0129_102439

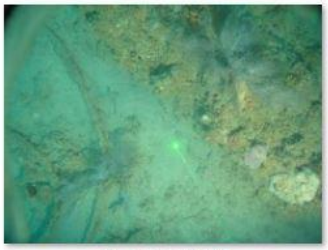

Dive 794_0130_102507


Dive 798_0011_090710

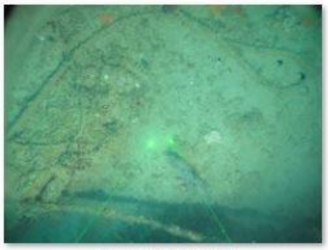

Dive 798_0012_090736

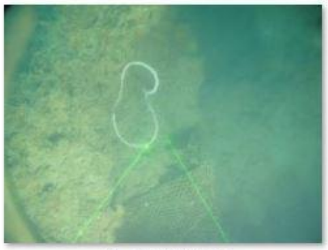

Dive209190 15 50 20


Dive209192 15 54 33


Dive209202 15 59 32

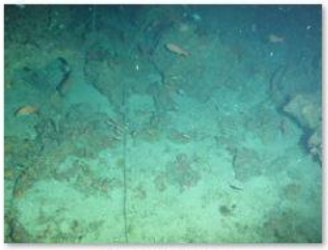

Dive209203 16 00 02


Dive209205 16 01 03


Dive209211 16 04 02


Dive232043 16 50 53


Dive232044 16 50 59


Dive232045 16 51 13

Anchoring debris found throughout study areas in the northwestern Gulf of Mexico.

Dive 13109 10 37 16

Dive 16070 11 07 00

Dive 16071 11 07 04

Dive 16072 11 07 12

Dive 248056 12 17 27

Dive 535012 11 41 21

Dive29 004 18 21 18

Dive01043 11 11 10

Dive01044 11 11 25


Dive01045 11 11 39


Dive03031 10 50 42


Dive232031 16 48 41


Dive232033 16 48 59


Dive239006 11 24 04

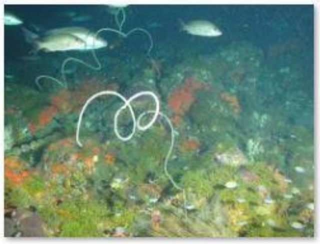

Dive239015 11 25 48


Dive239016 11 25 54


Dive239017 11 26 02


Dive239018 11 26 19


Dive239019 11 26 30


Dive239022 11 26 58


Dive239024 11 27 22


Dive239027 11 46 39


Dive239028 11 46 47


Dive377163 14 09 45

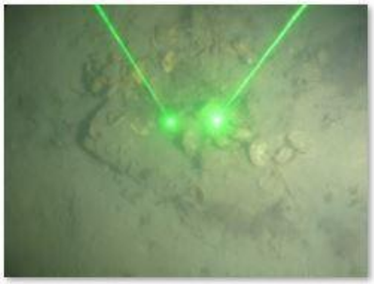

Dive377164 14 09 52


Dive377165 14 10 00

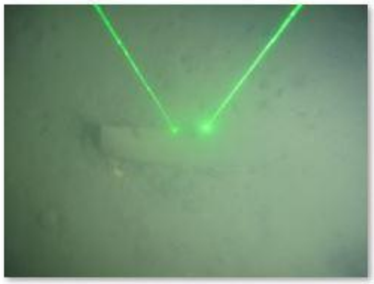

Dive529047 14 57 23

Likely oil and gas debris found throughout study areas in the northwestern Gulf of Mexico.

Dive 256001 16 46 27

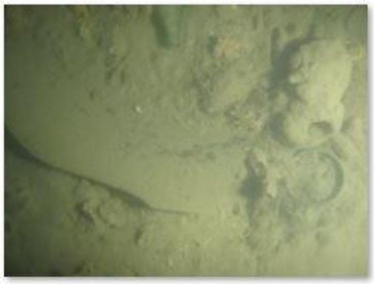


Dive 259001 16 44 52

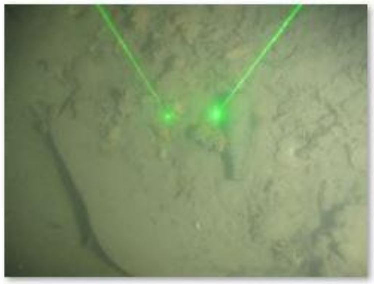


Dive 259003 16 44 52

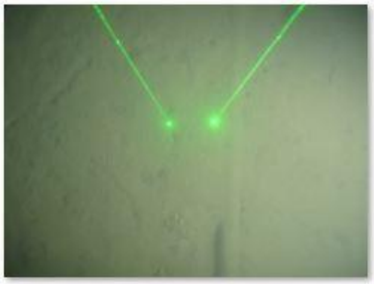
Dive 259007 16 44 46



Dive 259037 16 44 46



Dive 259039 16 44 46

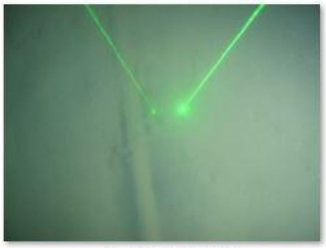


Dive 259040 16 44 46

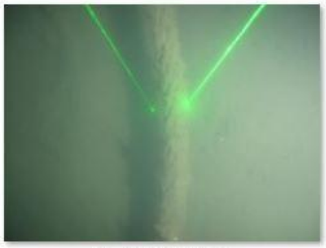
Dive 259041 16 44 46

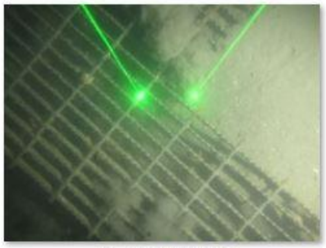
Dive 259042 16 44 46

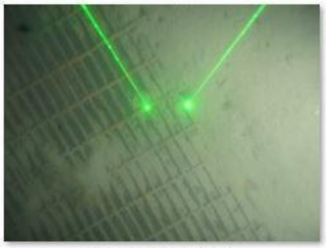

Dive 259044 16 44 46

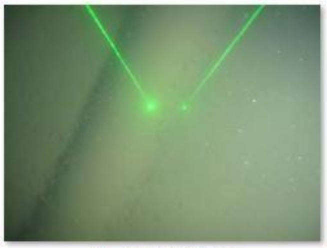

Dive 259045 16 44 46


Dive 259046 16 44 46

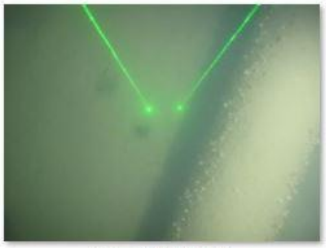

Dive 259047 16 44 46


Dive 259117 16 44 48

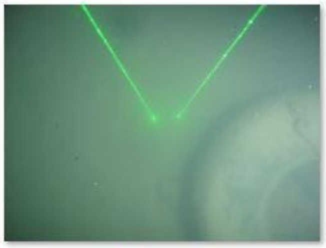

Dive 259118 16 44 48


Dive 259167 16 44 49


Dive 259168 16 44 49

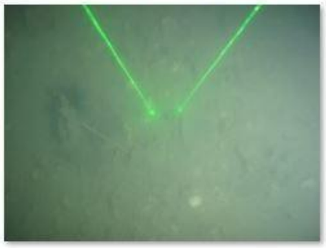

Dive 259171 16 44 49


Dive 259173 16 44 49


Dive 259176 16 44 50

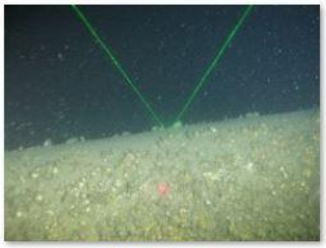

Dive 259177 16 44 50


Dive 259197 16 44 50

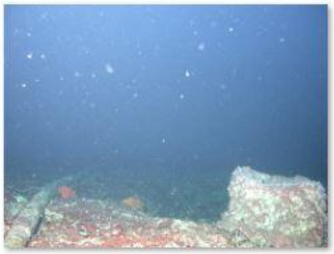

Dive 259199 16 44 50


Dive 259203 16 44 50


Dive 259236 16 44 51


Dive 516034 08 02 10


Dive22008 17 45 37


Dive22009 17 47 07


Dive22010 17 47 18


Dive22011 17 52 48


Dive22012 17 53 21


Dive22013 17 53 41


Dive22014 17 54 15


Dive22015 17 54 45


Dive22022 18 11 56


Dive22023 18 12 27


Dive22024 18 12 55


Dive22025 18 13 10


Dive22026 18 13 32


Dive22027 18 13 53


Dive22031 18 17 41


Dive22032 18 18 20

Salvage debris found throughout study areas in the northwestern Gulf of Mexico.


Dive254002 09 53 10


Dive254039 10 00 06


Dive254086 10 13 46


Dive254098 10 15 58

Research debris found throughout study areas in the northwestern Gulf of Mexico.

Dive02001 15 42 27

Dive02002 15 43 57

Dive02003 15 45 22

Dive02007 15 49 19

Dive02009 15 50 55

Dive02010 15 52 25

Dive02011 15 52 33

Dive02012 15 52 53

Dive02013 15 53 00

Dive02014 15 53 21

Dive02015 15 53 29

Dive02016 15 53 51

Shipwreck debris found outside of FGBNMS in the northwestern Gulf of Mexico


Dive237034 08 44 29


Dive237041 08 45 19


Dive237076 08 56 43

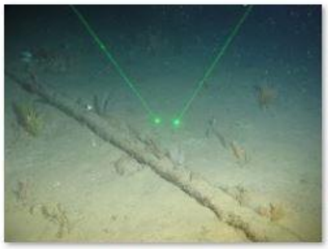

Dive237079 08 57 02

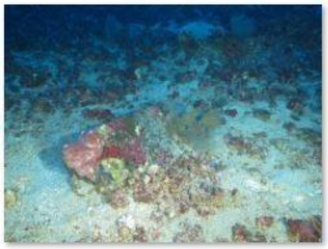

Dive237080 08 57 10


Dive237084 08 57 39


Dive237087 08 58 04

Miscellaneous debris found throughout study areas in the northwestern Gulf of Mexico


Dive 545 022 141030


Dive 671_0042_102637


Dive 797_0004_143944


Dive 797_0018_154716


Dive 798_0001_082948


Dive 798_0022_092655

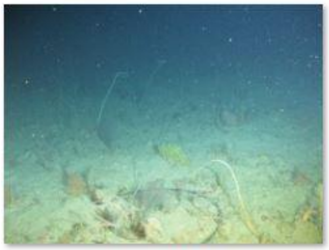

Dive 4047 09 30 02

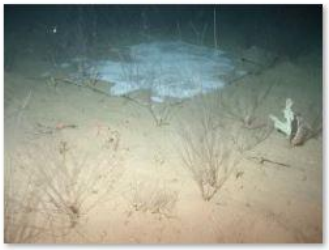

Dive 4120 09 56 28


Dive 9150 13 45 50


Dive 9151 13 45 58


Dive 504043 09 49 58


Dive 523199 17 33 43


Dive33 097 21 00 43


Dive33 098 21 00 59


Dive01074 11 40 42


Dive01078 11 45 55


Dive01080 11 46 46

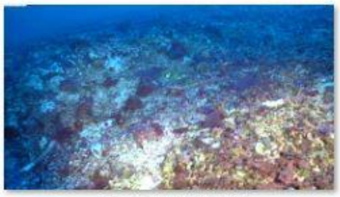

Dive02001 12 57 05

Dive02002 12 57 14

Dive02119 16 46 05

Dive02144 17 04 15

Dive02197 18 08 13



Dive356002 16 59 45

Dive377162 14 08 12

Dive380022 17 48 22

Dive380023 17 48 27

Dive406227 11 49 57

Dive 633_0147_180516

Dive 633_0148_180531

Dive 633_0149_180543

Appendix B:
Supplementary Tables

Table App.1. Total number of debris items found at each location in the study area.

Bank	Anchoring	Fishing	Human	Oil and Gas	Research	Salvage	Vessel	Total	Number of Dives
28 Fathom	0	3	1	0	0	0	0	4	14
Alderdice	3	2	1	0	0	0	0	6	25
Bouma	2	1	1	0	0	0	1	5	15
Bright	4	14	1	2	0	3	0	24	21
Bryant	1	3	1	0	0	0	0	5	7
EFGB	14	21	11	4	1	0	4	55	105
Elvers	3	6	1	0	0	0	1	11	32
Geyer	0	4	1	0	0	0	0	5	15
Horseshoe	1	18	2	0	0	0	0	21	14
MacNeil	0	0	0	0	0	0	0	0	8
McGrail	6	11	19	1	0	0	0	37	42
Parker	3	12	1	1	0	0	0	17	39
Rankin	3	10	0	0	0	0	0	13	15
Rezak	1	7	0	0	0	0	0	8	18
Sidner	4	13	3	1	0	0	0	21	15
Sonnier	2	18	0	0	2	0	0	22	13
Stetson	25	110	9	3	1	0	3	151	73
WFGB	15	50	2	6	0	0	0	73	99
Total	87	303	54	18	4	3	9	478	570

Table App.2. Items per dive for each bank and each debris category.

Bank	Anchoring	Fishing	Human	Oil and Gas	Research	Salvage	Vessel	Occurrence Rate by Bank
28 Fathom	0.00	0.21	0.07	0.00	0.00	0.00	0.00	0.29
Alderdice	0.12	0.08	0.04	0.00	0.00	0.00	0.00	0.24
Bouma	0.13	0.07	0.07	0.00	0.00	0.00	0.07	0.33
Bright	0.19	0.67	0.05	0.10	0.00	0.14	0.00	1.14
Bryant	0.14	0.43	0.14	0.00	0.00	0.00	0.00	0.71
EFGB	0.13	0.20	0.10	0.04	0.01	0.00	0.04	0.52
Elvers	0.09	0.19	0.03	0.00	0.00	0.00	0.03	0.34
Geyer	0.00	0.27	0.07	0.00	0.00	0.00	0.00	0.33
Horseshoe	0.07	1.29	0.14	0.00	0.00	0.00	0.00	1.50
MacNeil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
McGrail	0.14	0.26	0.45	0.02	0.00	0.00	0.00	0.88
Parker	0.08	0.31	0.03	0.03	0.00	0.00	0.00	0.44
Rankin	0.20	0.67	0.00	0.00	0.00	0.00	0.00	0.87
Rezak	0.06	0.39	0.00	0.00	0.00	0.00	0.00	0.44
Sidner	0.27	0.87	0.20	0.07	0.00	0.00	0.00	1.40
Sonnier	0.15	1.38	0.00	0.00	0.15	0.00	0.00	1.69
Stetson	0.34	1.51	0.12	0.04	0.01	0.00	0.04	2.07
WFGB	0.15	0.51	0.02	0.06	0.00	0.00	0.00	0.74
Occurrence Rate by Category	0.15	0.53	0.10	0.03	0.01	0.01	0.02	N/A

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