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GEOLOGY AND BIOLOGY OF THE "STICKY GROUNDS," SHELF-MARGIN CARBONATE MOUNDS, AND MESOPHOTIC ECOSYSTEM IN THE EASTERN GULF OF MEXICO

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Abstract

Shelf-margin carbonate mounds in water depths of 116-135 meters in the eastern Gulf of Mexico along the central west Florida shelf were investigated using swath bathymetry, side-scan sonar, sub-bottom imaging, rock dredging, and submersible dives. These enigmatic structures, known to fisherman as the "Sticky Grounds," trend along slope, are 5 to 15 m in relief with base diameters of 5-30 m, and suggest widespread potential for mesophotic reef habitat along the west Florida outer continental shelf. Possible origins are sea-level lowstand coral patch reefs, oyster reefs, or perhaps more recent post-lowstand biohermal development. Rock dredging recovered bioeroded carbonate-rock facies comprised of bored and cemented bioclastics. Rock sample components included calcified worm tubes, pelagic sediment, and oysters normally restricted to brackish nearshore areas. Several reef sites were surveyed at the Sticky Grounds during a cruise in August 2010 with the R/V *Seward Johnson* using the *Johnson-Sea-Link* II submersible to ground truth the swath-sonar maps and to quantify and characterize the benthic habitats, benthic macrofauna, fish populations, and coral/sponge cover. This study characterizes for the first time this mesophotic reef ecosystem and associated fish populations, and analyzes the interrelationships of the fish assemblages, benthic habitats and invertebrate biota. These highly eroded rock mounds provide extensive hard-bottom habitat for reef invertebrate species as well as essential fish habitat for reef fish and commercially/recreationally important fish species. The extent and significance of associated living resources with these bottom types is particularly important in light of the 2010 Deepwater Horizon oil spill in the northeastern Gulf and the proximity of the Loop Current. Mapping the distribution of these mesophotic-depth ecosystems is important for quantifying essential fish habitat and describing benthic resources. These activities can improve ecosystem management and planning of future oil and gas activities in this outer continental shelf region.

Keywords

Mesophotic coral ecosystems; Carbonate mounds; Benthic habitat; Fish assemblages; Sticky Grounds; Gulf of Mexico

1. Introduction

Continental shelves host complex, geomorphic features resulting from repeated sea-level fluctuations and changing depositional environments. Seafloor features include relic structures from past shoreline environments combined with a history of modifications that include ongoing physical (sediment erosion or accumulation) and biological (carbonate production and accretion, bioerosion) processes. The resulting geologic framework is the foundation for present-day benthic habitats that comprise an essential and critical component of marine ecosystems. However, the abundance and character of seafloor benthic habitat is poorly known for marine ecosystems on outer continental shelves. Large portions of the seafloor remain unmapped due to the technical and financial constraints on remote sensing methods.

Several review papers that have focused on shelf-edge, mesophotic coral ecosystems (MCEs) and fish habitat off the southeastern U.S. and Gulf of Mexico (GOM) have illustrated a wide diversity in geomorphology and habitat type (e.g., Coleman et al., 2004a; Brooke and Schroeder, 2007; Hine et al., 2008; Messing et al., 2008; Locker et al., 2010). In the northern and eastern Gulf of Mexico, some well-known settings include the Flower Gardens (Clark et al., 2014), Pinnacles Reef Trend (Sager et al., 1992; Gardner et al., 2000; CSA and Texas A&M, 2001; Weaver et al., 2002, 2007), outer-shelf deltas (Gardner et al., 2005, 2007), Steamboat Lumps (Gardner et al., 2001), Florida Middle Grounds (Hopkins et al., 1977; Coleman et al., 2004b; Reich et al., 2013; Mallinson et al., 2014), Pulley Ridge (Jarrett et al., 2005; Reed et al., 2014; Reed, 2015), and Tortugas mesophotic reefs including Miller's Ledge, Riley's Hump and Sherwood Forrest (Schmidt et al., 1999; Weaver et al., 2006; Ault et al. 2013; Reed et al., 2014), (Fig. 1). These settings provide topographic relief that support Mesophotic Coral Ecosystems (MCEs) - important reef habitat for diverse communities of corals and sponges, and associated critical commercial and recreational fisheries that must be managed for future sustainability. Predominant geomorphic structures are linear paleoshoreline ridges and mounds that tend to occur in along slope trends, and small banks. Except for the Flower Gardens salt structures, these areas primarily reflect past depositional environments and enhanced relic geomorphology constructed in response to Pleistocene sea-level fluctuations and correspondingly changing coastal environments. The widespread occurrence of shelf-edge carbonate mound structures in the GOM indicates this habitat type is underestimated in terms of abundance and associated marine communities.

The generally accepted depth zone for mesophotic reef habitats worldwide is 30-150 m (Hinderstein et al., 2010). The mesophotic zone is generally broken into upper mesophotic (30-50 m depth), mid mesophotic (50-80 m), and lower mesophotic (80-150 m). The lower depth limit is somewhat site and species specific depending in part on water clarity with some mesophotic coral species extending to nearly 150 m in the Indo-Pacific (Khang et al., 2010). The Sticky Grounds occurs at the lower mesophotic depth zone. Since understanding the diversity and interactions of the shelf-edge mesophotic community is critical for managing these deep, dimly lit communities, the mesophotic zone may be considered to include both photosynthetic taxa (30-100 m depth) and inclusive of other reef-associated, non-autotrophic fauna such as azooxanthellate scleractinian corals, octocorals, antipatharians and sponges (30-150 m in depth) (Baker et al., 2016). An analysis of the total area of mesophotic zone depths in U.S. waters indicates that the northern Gulf of Mexico region has an order of magnitude greater area for potential mesophotic depth habitats than either the U.S. Caribbean or main Hawaiian Islands (Locker et al., 2010).

In this paper we report on a previously unstudied shelf-edge environment that is of interest geologically (paleoshorelines, last glacial depositional environments, continental shelf hard grounds) and biologically (essential marine habitat in the Gulf of Mexico). This is the first detailed, quantitative characterization of the Sticky Grounds mesophotic reef habitat, fish populations, and their interrelationships. Currently this site is not a managed area. Sites that are protected and managed in the eastern GOM either as Habitat Areas of Particular Concern (HAPCs) by the Gulf of Mexico Fishery Management Council (GMFMC) or as Marine Protected Areas (MPAs) include Madison Swanson, Steamboat Lumps, the Edges, Florida Middle Grounds, Pulley Ridge, and the Tortugas Ecological Reserves. The long-term goals of this research are to provide baseline data for possible designation as a MPA and/or HAPC by mapping and characterizing the benthic habitat, benthic biota, and fish populations of this unprotected area. These data may then be used as a relative baseline to document changes in these areas and to monitor the efficacy and health of designated managed areas. These data will be of value to the GMFMC, NOAA Fisheries Service, NOAA Office of National Sanctuaries, and perhaps state agencies for management decisions on these habitats and managed key species.

A distinction is made between the term “mounds,” used to refer to the geomorphology, and “reef,” used to refer to the mesophotic reef habitat that covers the mounds. The mounds cannot be considered reefs in a geologic sense because the presence of internal skeletal-framework building organisms is unknown.

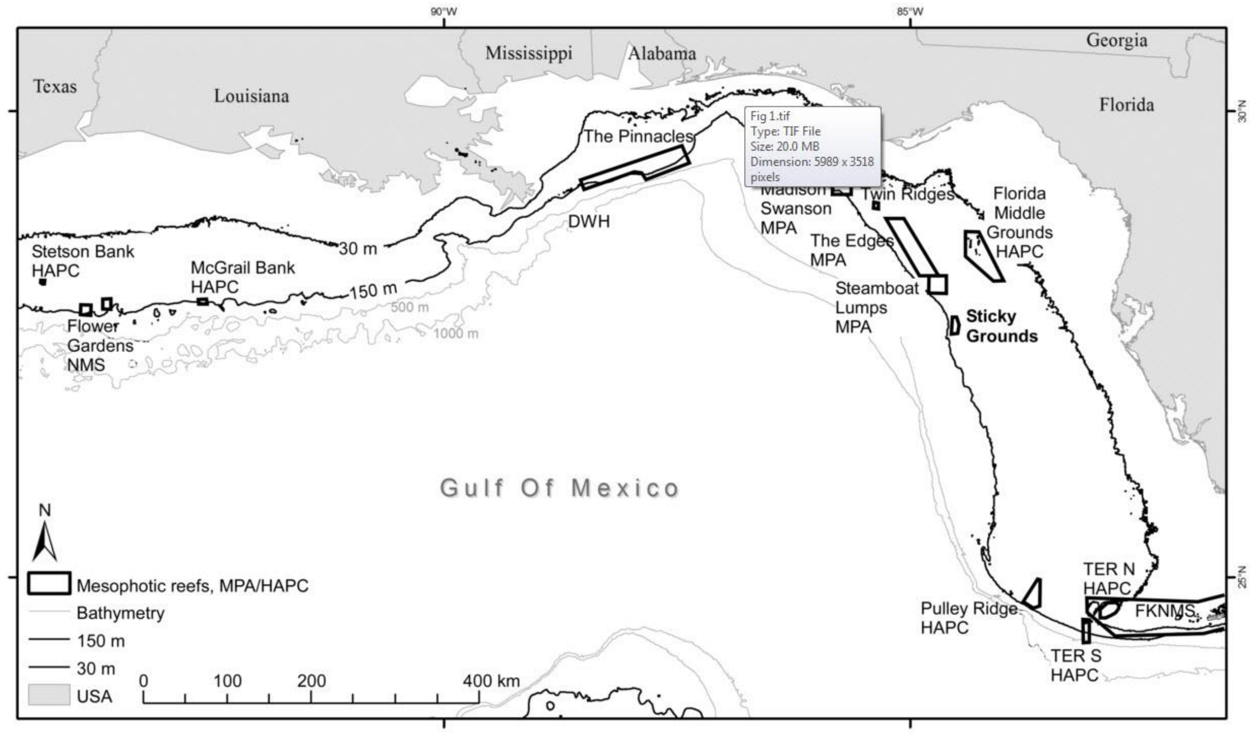

Fig. 1. Map of U.S. Gulf of Mexico showing extent of mesophotic depth habitat (30 m to 150 m depth contours) and major mesophotic reefs (boxes). The Sticky Grounds are located 200 km west of Tampa Bay, Florida. Marine reserves include Marine Protected Areas (MPA), Habitat Areas of Particular Concern (HAPC), and National Marine Sanctuaries (NMS). Deepwater Horizon oil spill site (DWH). North and South Tortugas Ecological Reserves (TER N, TER S). Florida Keys National Marine Sanctuary (FKNMS).

2. Methods

2.1 Geologic Framework

A combination of geophysical surveys, rock dredging, and submersible dives were used to characterize the geologic framework, benthic habitat, benthic biota, and the associated fish populations. The Sticky Grounds site was first discovered in 2005 during reconnaissance geophysical surveys exploring for paleoshoreline structures extending northward from the Pulley Ridge MCE as part of the Sustainable Seas Expedition (Jaap, 2000). A single across-shelf transect survey with a boomer seismic system and Edgetech 272-TD side-scan sonar located a field of mounds trending along slope near the 125 m depth contour due west of Tampa Bay, Florida. In 2007 a 3-day mapping effort revisited the area to conduct swath bathymetry and backscatter mapping, additional sub-bottom imaging, and rock dredging. Sub-bottom single-channel seismic reflection profiles were acquired using a Huntec boomer, 10-element streamer, and Delph Seismic acquisition and processing. Swath bathymetric and side-scan mapping of the seafloor was conducted using a deep-towed 200 kHz Teledyne-Benthos C3D interferometric side-scan sonar. The C3D sonar was a new system that had some limitations - no towfish tracking was available, and cable out was limited to 120 m. The towfish was typically at an altitude of 60-70 m above the seafloor. The C3D towfish included an IXSEA OCTANS motion and heading sensor and a Falmouth Scientific NXIC flow-through conductivity-temperature-depth (CTD) sensor for sound velocity at the transducers. Rock dredging was conducted to recover rock samples. Rocks were cut into slabs and thin sections were prepared to determine composition and digenetic character.

2.2 Submersible Surveys

During the 2010 Deepwater Horizon oil spill in the northern Gulf of Mexico, a four week research cruise was conducted by the Cooperative Institute for Ocean Exploration, Research, and Technology (CIOERT) at Harbor Branch Oceanographic Institute, Florida Atlantic University (HBOI-FAU) in collaboration with NOAA to investigate potential impact of the oil on deep-water and mesophotic reef ecosystems on the west Florida shelf. The HBOI ship R/V *Seward Johnson* with the human-occupied vehicle (HOV) *Johnson-Sea-Link* II submersible were used to survey sites from the Florida Keys to Madison Swanson off the Florida panhandle, and included the Sticky Grounds for the first time (Reed and Rogers, 2011). Submersible photographic and video transects were conducted at the Sticky Grounds to ground-truth the swath sonar maps, and to quantify and characterize the benthic habitats, benthic macrofauna, fish populations, and coral/sponge cover. The submersible carried four people to depths of 914 m. The front acrylic sphere provides 180^{o} field of view to the observers and was equipped with a manipulator arm for collections with a clam-shell grab, jaw, and suction hose; twelve 12.7-L Plexiglas sample buckets; and a CTD data recorder (Seabird SBE 25 Sealogger). The R/V *Seward Johnson* was the support platform for the submersible and was equipped with a SIMRAD EQ50 38/50 kHz video echo sounder that was used for logging acoustic profiles of the bottom. The support ship navigation utilized differential GPS (Magnavox MX 200 Global Positioning System, DGPS), and submersible tracking used Ultrashort Baseline Sonar technology that calculated the submersible's real time DGPS position relative to the ship throughout each dive.

Videotapes recorded the entire submersible dive on digital mini-DV tapes using an external pan and tilt video camera (Sony DX2 3000A) with parallel lasers 25 cm apart for scale. The video transect data were used for the fish analyses. The benthic fauna and substrate analyses used the quantitative photographic images from a digital still camera (Sony DX2 3000A with Canon J8X6B KRS lens) directed straight down (or perpendicular as possible to the substrate) with parallel lasers (25 cm) for scale. In general, 1-2 images were taken per minute. Each photo filename was coded with corresponding UTC time and date code (using Stamp 2.8 by Tempest Solutions©) which was imported into Microsoft Access and linked to the ROV navigation data for site specific data of coordinates and depth and then imported into ArcGIS 10©. Poor and unusable photos (blurred, black, off bottom) or overlapping photos were removed from the analyses.

2.3 Benthic Habitat and Faunal Characterization

Several habitat descriptors were used to characterize and define the benthic habitats. The submersible dive was divided into transects based on the general geological feature (Reef #, On Reef/Off Reef). These categories were used to plot the percent cover of benthic macrobiota, the density of fish, and to plot the transects on the swath sonar maps in ArcGIS 10.0. These classifications were not for any individual photo, but for a zonation within the dive. Images for the benthic transects were analyzed by: 1) species occurrence (presence/absence), and 2) percent cover. Percent cover of substrate type and benthic macrobiota was determined by analyzing the quantitative transect images with Coral Point Count with Excel extensions (CPCe 4.1©, Kohler and Gill, 2006), and following protocols established in part by Vinick et al. (2012) for offshore, deep-water surveys in this region. One hundred random points overlaid on each image were identified as substrate type and benthic taxa. All benthic macrobiota (usually >3 cm) were identified to the lowest taxa level possible. Data are archived at HBOI-FAU, and subsets were archived with NOAA.

2.4 Fish Surveys

Video transects were used for the fish surveys. An On-Screen Display (OSD) video overlay recorded time, date, and depth. The video footage was recorded continuously throughout each dive from surface to surface on hard drives. The color video camera was angled down ~45^{o} and had a pair of parallel lasers (25 cm) for scale. Protocol for the fish analyses was to divide the submersible dive into transects based on the general geological feature as in the benthic surveys (Reef #, On Reef/Off Reef). All fish were identified for each transect down to the lowest taxonomic level and counted. The transect area was then used to calculate the density (# of individuals m^{-2}) of each fish species. Transect area (m^2) was calculated by multiplying the transect width (m) by the transect length (m). Transect length (m) was determined by using the submersible's tracking system. Start and end coordinates for each transect were entered into ArcGIS and the distance between them measured for transect length. Transect width (m) was estimated using the paired lasers on the video camera. Lasers were a known distance of 25 cm apart which was extrapolated to estimate the width of each transect.

2.5 Statistical Analyses

Multivariate analyses were used to determine differences in benthic fauna and fish assemblages among reef sites. All analyses were conducted in PRIMER v6.1.13 and based on guidelines outlined in Clarke and Warwick (2001) and Clarke and Gorley (2006). The benthic transects were classified by the habitat descriptors described above. For the fish analysis, densities (# m^{-2}) of all species (Variables) were entered for each reef (Samples) and then square-root transformed to reduce the effect of common species. For the benthic analyses, the percentage cover data were averaged in PRIMER by site and habitat factors and square root transformed as well. Similarities between reef sites for both fish and benthic biota (separately) were then calculated using S17 Bray-Curtis similarity. A non-metric multidimensional scaling ordination (MDS) plot and a dendrogram with group-average linking were created showing the results of a concurrently run SIMPROF 'similarities profile'. SIMPER (Similarity Percentages) was utilized to determine which species contributed to the dissimilarities among group pairs.

3. Results

3.1 Stratigraphic Framework

Boomer seismic reflection profiles indicate that the Sticky Grounds rest on an unconformity inferred to be the last glacial low-stand sequence boundary formed approximately 20 ka (Fig. 2). The flattening of the basal reflector below the mounds could indicate a narrow coastal bay in this area during the last lowstand of sea level. The mound structures likely formed in the shallow nearshore and have evolved from shallow to deep-water habitat during the Holocene sea-level rise. Mound relief can reach 10-12 m at depths of 116-133 m. The shallow-most elevation of mound tops is approximately 116 m below sea level. The mounds are now partially buried by hemipelagic sediments as well as *in situ* sediment production from calcifying fauna and bioerosion. The Late-Quaternary-Holocene sediment thickness around the mounds is 3-5 m, and overlays a 5-10 m thick section of parallel reflections. Below the parallel reflections is a mixed zone of chaotic and sub-parallel discontinuous reflections. This buried zone of chaotic reflections could represent mounded topography from earlier intervals of mound development during previous sea-level cycles (Fig. 2).

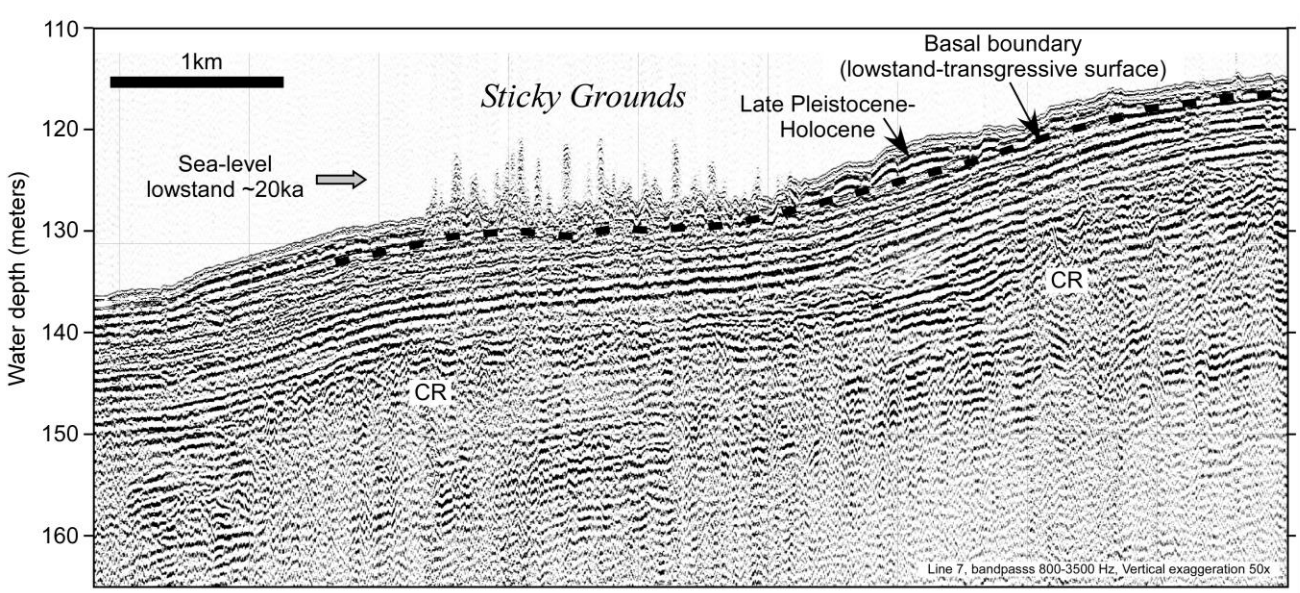

Fig. 2. Boomer seismic profile showing location of carbonate mounds between 120 and 130 m water depth. This dip-orientated profile shows the mounds in this area are restricted to a zone parallel to bottom contours and a flattened slope gradient. Chaotic reflections (CR) may indicate

buried mounds from previous sea-level cycles. The black dashed line marks the lowstand-transgressive surface.

3.2 Geometry and Distribution Patterns

A single across-slope 100 kHz side-scan sonar and boomer sub-bottom survey line in 2005 extending from 50-to-150 m water depth crossing through the study area suggested the mounds were limited to approximately 120-125 m water depth (Fig. 4.39 in Hine et al., 2008). The more comprehensive mapping survey conducted in 2007 using a Teledyne-Benthos C3D for swath bathymetry and side scan was focused on assessing the spatial characteristics of the mound structures.

The 2007 C3D survey mapped an area spanning 20 km N-S and 7 km E-W, and a depth range of 112-143 m water depth (Fig. 3). The occurrence of mounds is remarkably evenly distributed with densities of over 200 mounds km^{-2} (Fig. 4). The along slope trend of the Sticky Grounds is clearly evident, extending past the mapped area in this study. The potential along slope extent is unknown. Recent surveys in 2015 by the Florida Fish and Wildlife Conservation Commission have discovered additional mounds located 36 km south of the Sticky Grounds in similar water depths (Sean Keenan, personal communication).

The boundary between mound areas and adjacent smooth seafloor is distinct. A review of the side-scan backscatter imagery shows some lineation patterns in the backscatter intensity that may reflect some current control on sediment accumulation patterns (Fig. 4). However in general the mounds do not show any clear alignment. In the southern mapped area, the mound habitat bifurcates into two slope-parallel trends (Fig. 5).

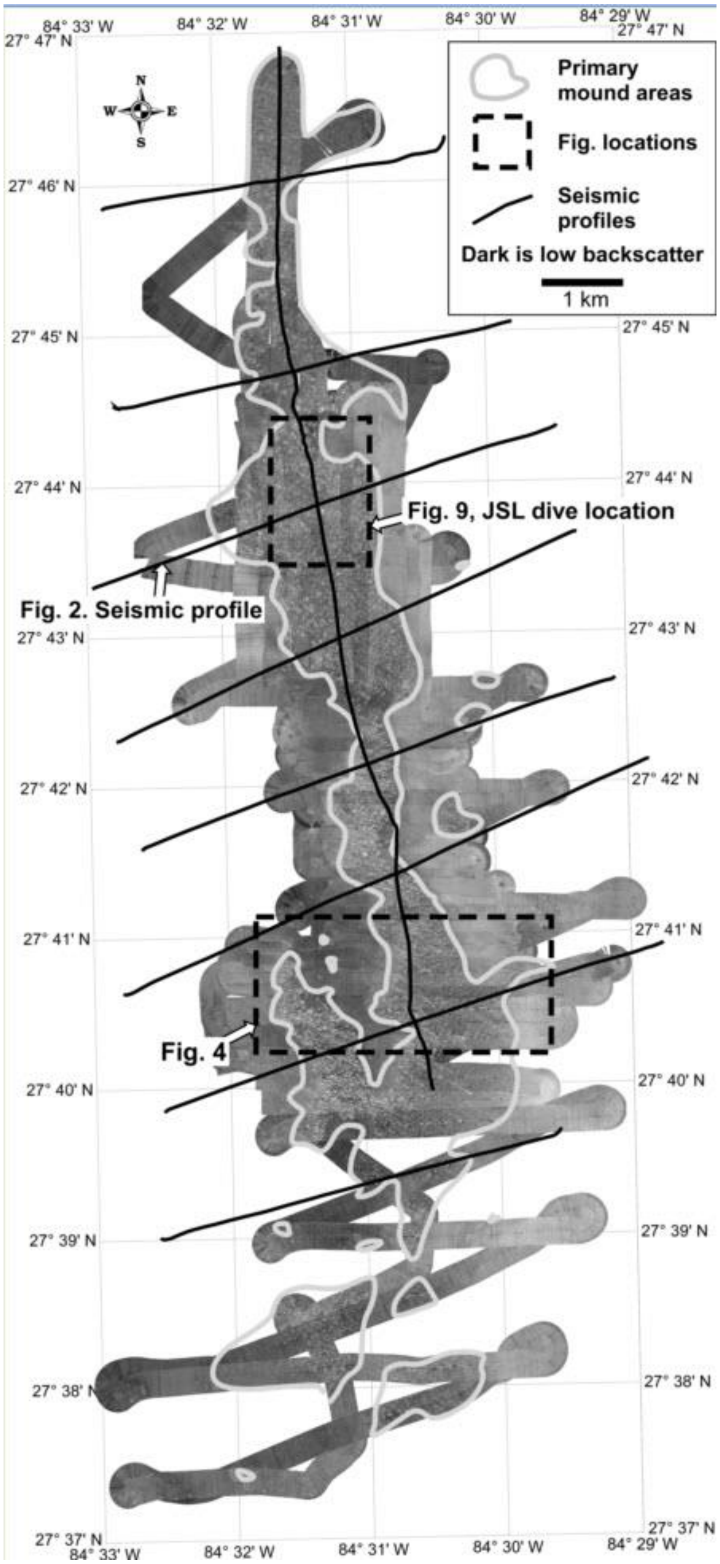

Fig. 3. Side-scan sonar coverage of the Sticky Grounds showing the extent of known mounds. The mounds continue both north and south beyond the current area mapped. Locations of figures in text are shown. Map projection Universal Transverse Mercator, zone 16N, WGS84.

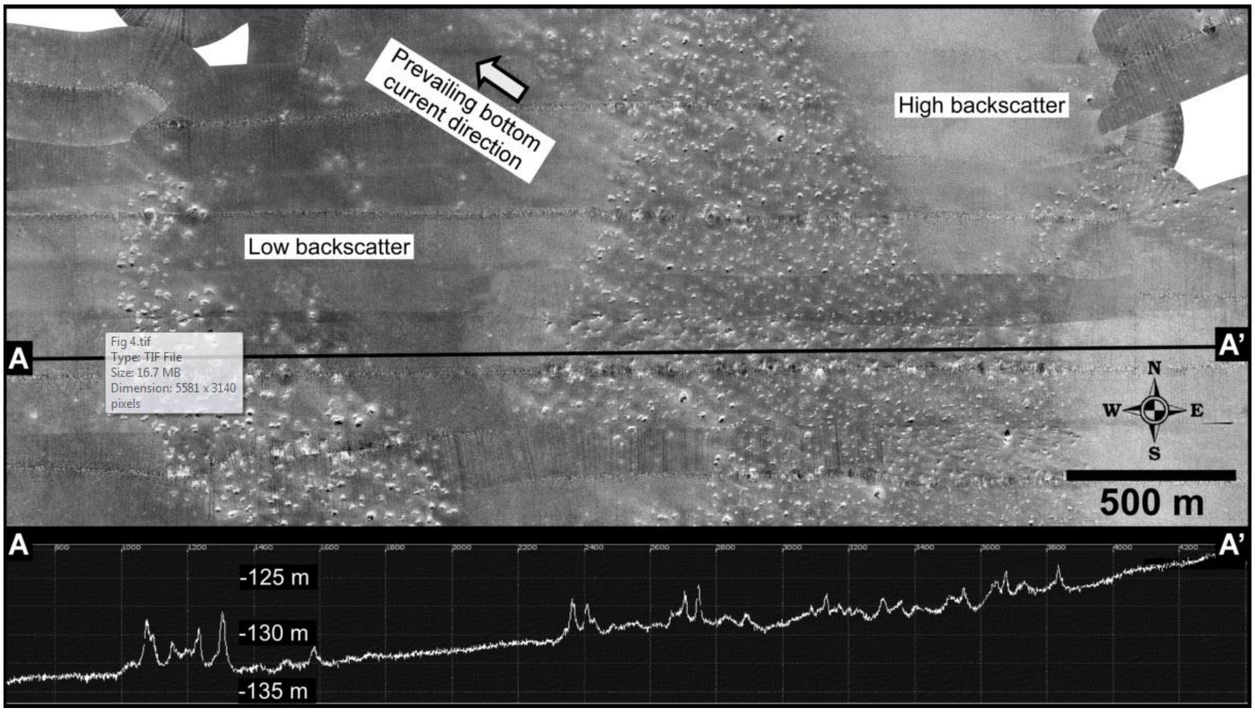

Fig. 4. A closer view of backscatter showing the noticeable variation in intensities attributed to surface sediment grain-size variation. A-A' is a water depth profile from the co-registered swath bathymetry data. Streaks of lighter intensity (coarser sediment) suggest net bottom-current transport of coarse-grained sediment (production and bioerosion) to the NW. Dark shades are lower backscatter and shadows. Location in Fig. 3.

The swath bathymetry shown in Fig. 5 applies shaded relief to highlight mound features that also helped to attenuate along-track artifacts that proved very difficult to remove through processing. Towfish altitude varied from 20-100 m off the seafloor, which made application of a beam pattern correction curve difficult. None-the-less, the basic overall depth trends and mound morphology are well defined.

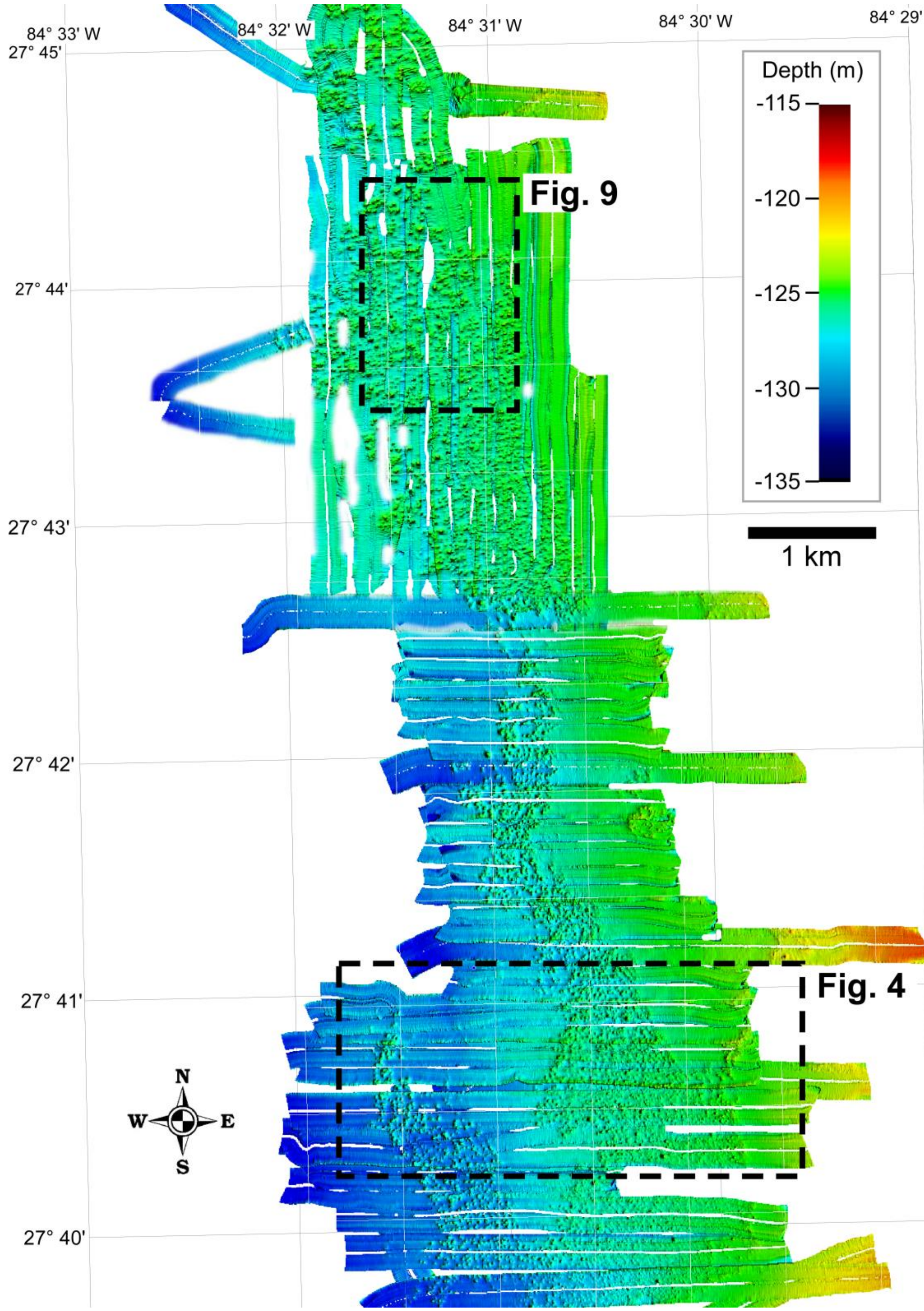

Fig. 5. Shaded relief view of the C3D swath bathymetry shows the organized nature of the mound distribution occurring in distinct trends attributed to a lowstand coastline configuration. Map projection Universal Transverse Mercator, zone 16N, WGS84.

3.3 Mound Origin and Composition

Ten dredge hauls from the northern part of the study area recovered bioeroded rock samples that showed multiple generations of boring and cementation that progressively replaced the original rock composition. Bottom photos all indicate degradation of the carbonate rock structure by bioerosion (Fig. 6). No evidence of shallow-water scleractinian corals was found, although fragments of the present-day deep-water coral fauna are found cemented within the rock matrix (Fig. 7).

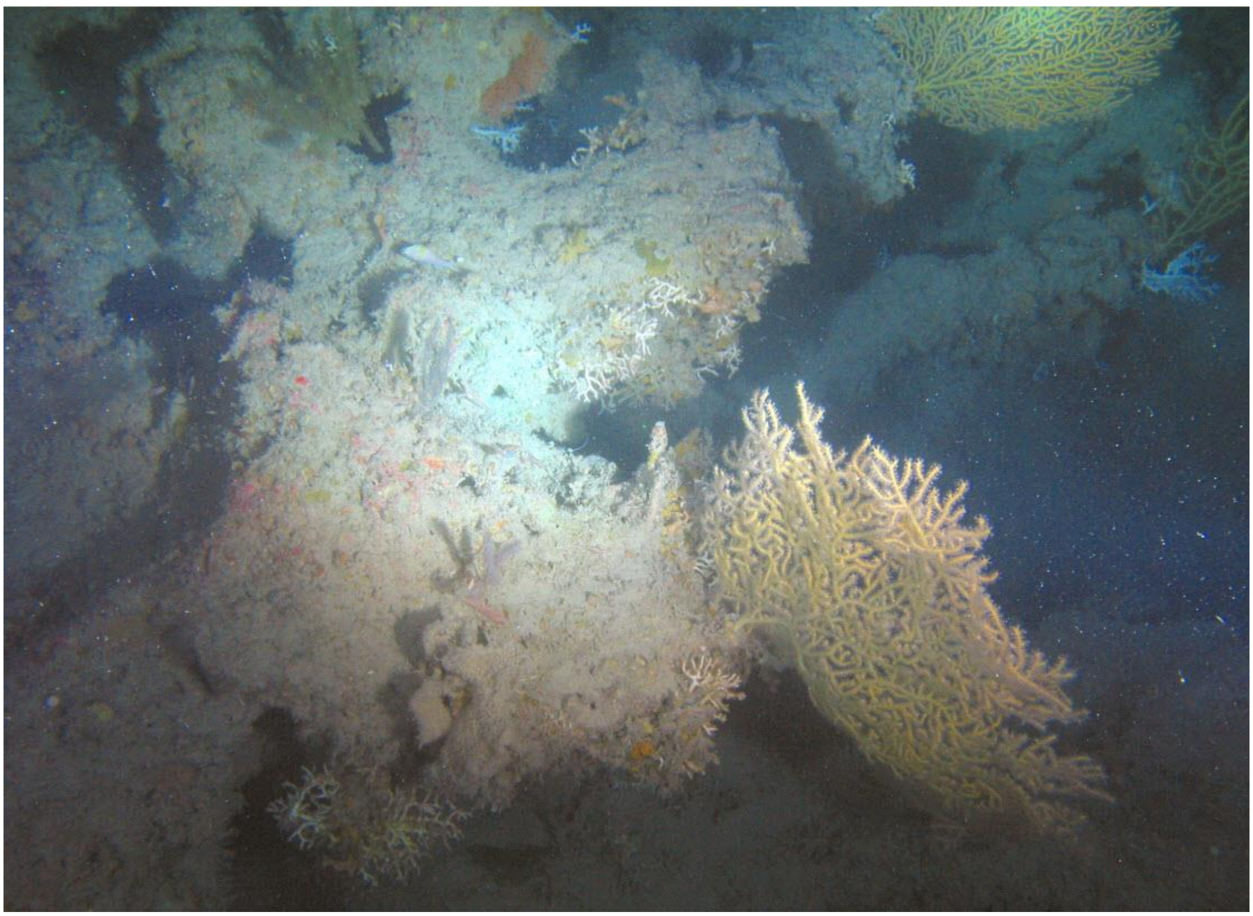

Fig. 6. Video-frame grab from *Johnson-Sea-Link* II submersible showing a heavily bioeroded and encrusted hard bottom that provides habitat for benthic macrofaunal community, essential coral habitat, and essential fish habitat. Reef #12, 128 m depth (see Fig. 9).

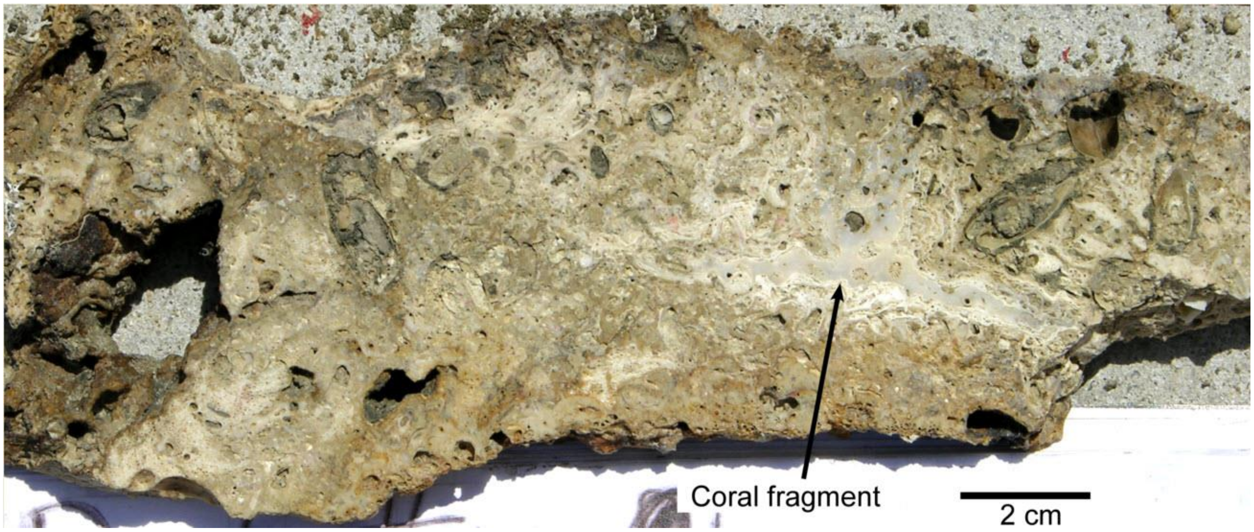

Fig. 7. The typical internal matrix of rocks includes fragments of benthic calcifying organisms (e.g., coral, mollusks) in a bored and multi-generational cemented matrix.

The recovered rocks reflect a multi-generational process of repeated boring, sediment infill and lithification. Some characteristics of the rocks recovered from the Sticky Grounds do resemble reef rock (photo comparisons in Scholle et al., 1983). Sponge and bivalve borings are ubiquitous in nearly all the sectioned slabs. Frequently these borings remain as open voids in the rock, and in some cases the shell of the boring clam is still present. Other borings are completely filled with lithified sediments or may be partially filled with mud. Regardless, the secondary porosity of these rocks is substantial. Fossilized coralline algae are one of the most common constituents of these rocks. These algae may be present as a thick (several centimeters) rind or found in the interior of the slabs, representing a previously exposed surface of the rock. Encrusting foraminifera, bryozoans, worm tubes, and molluscan remains are common throughout these rocks as well (Fig. 7).

A common component making up the rock framework were oyster shells identified as the eastern oyster *Crassostrea virginica* (Hayes and Menzel, 1981; Fig. 8). *Crassostrea virginica* typically lives in shallow water environments of intertidal to 4 m depth (Galtsoff, 1964; Hawaii Biological Survey, 2001), suggesting that an oyster mound habitat may have been responsible for creating an initial mounded landscape.

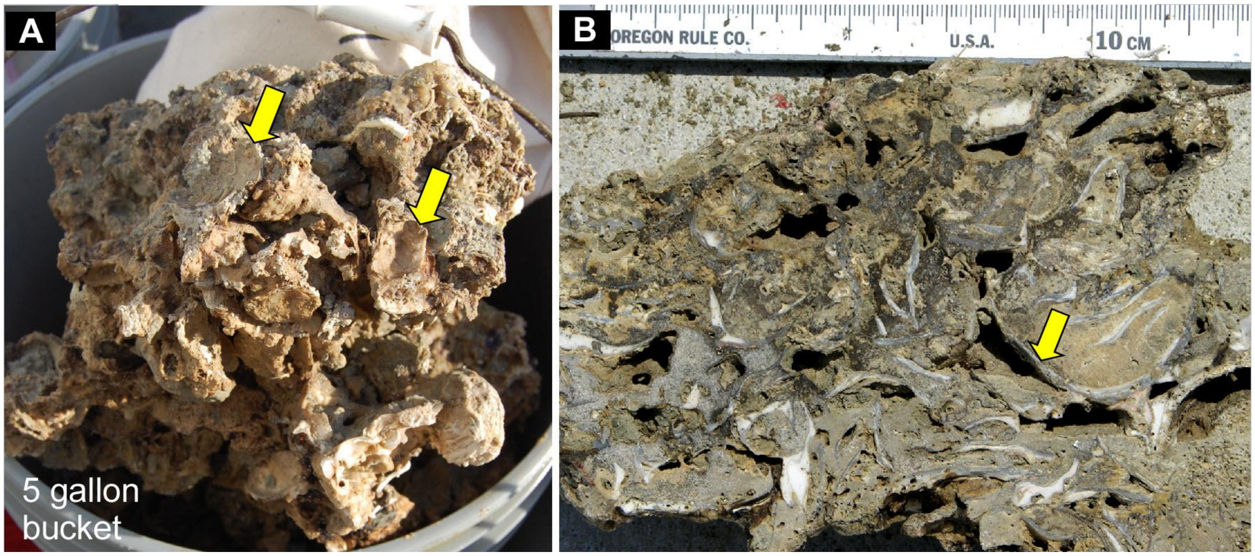

Fig. 8. Rock dredge material dominated by oyster shells (marked with yellow arrows) identified as *Crassostrea virginica* preserved in apparent growth form (A) and cemented within the rock matrix (B).

3.4 Habitat Characterization

The submersible dive track followed a pre-determined path based on the available bathymetry and side-scan sonar maps in a large area of mounds in the northern portion of the study area in order to cross several reef sites (Fig. 9). The total submersible survey covered 2.23 km resulting in a total of 3.25 hours of submersible videotapes, 266 digital photographs, and 16 samples of benthic invertebrates and rock samples.

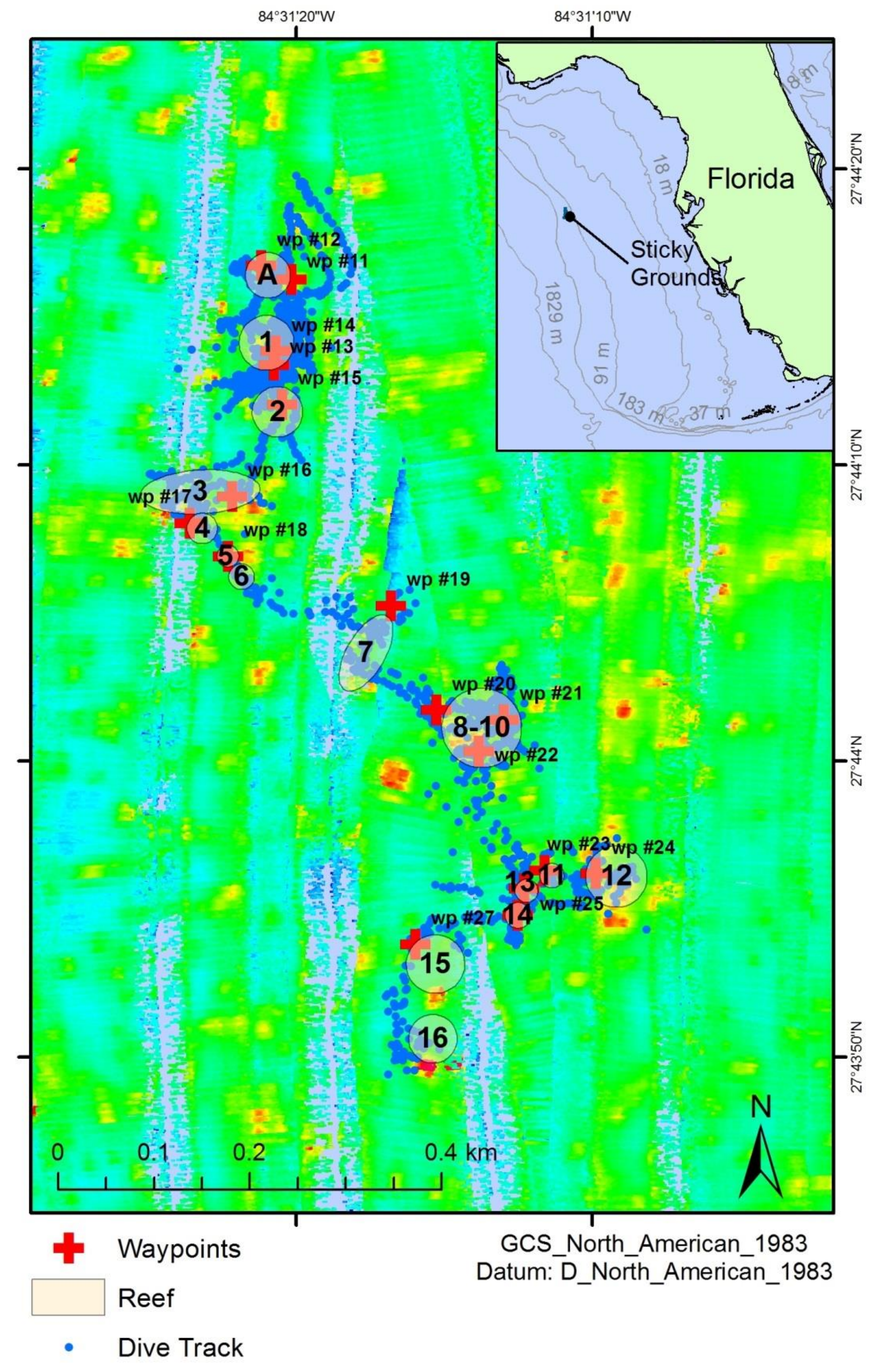

Fig. 9. Track of *Johnson-Sea-Link* II submersible dive (blue points) at the Sticky Grounds Individual reefs are numbered (ovals) on overlay of bathymetry map. Waypoints (red crosses) were taken during the dive.

The submersible transect crossed 17 individual mounds (labeled A, 1-16, “On Reef”). Areas between the mounds (“Off Reef”) was generally flat, soft, silty-sand bottom with no exposed rock and very little fauna. On a shipboard fathometer transect (Fig. 10) from Reef A to Reef 16, mounds averaged 1.90 m in height (range 0.2 to 4.5 m), minimum peak depth was 118.3 m, maximum base depth was 126.5 m, and average width was 3.89 m (maximum 6.6 m). The larger mounds had steep slopes of 10-45^{o} from the flat mud bottom to the rounded peak. The slope and peak consisted of rock outcrops and boulders. The upper slope and crest of the mounds consisted of rock ledges and rugged, eroded outcrops of 0.5 to 1 m relief that provided considerable hard-bottom habitat for benthic fauna and habitat for fish (Fig. 11). CPCe point count of “On Reef” images shows the individual reef areas included bare exposed rock ranging from 37.37% to 98.19% cover (Table 1). Habitat data were not analyzed for Reefs #2, 4, 5 and 11 due to insufficient photographs. Between the reefs was 97.26-100% cover of flat, soft mud bottom. The rock habitat on the mounds consisted of rock pavement, rock pavement with sediment veneer, cobble, boulders and highly eroded rock outcrops. Most of the rock was highly silted over.

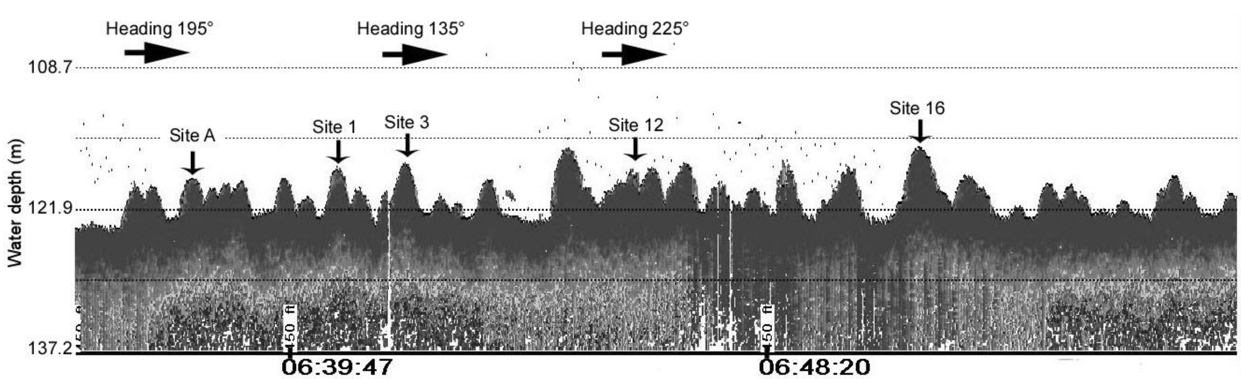

Fig. 10. Shipboard fathometer plot following *Johnson-Sea-Link* II submersible dive track. Select reef sites that were surveyed by submersible are numbered.

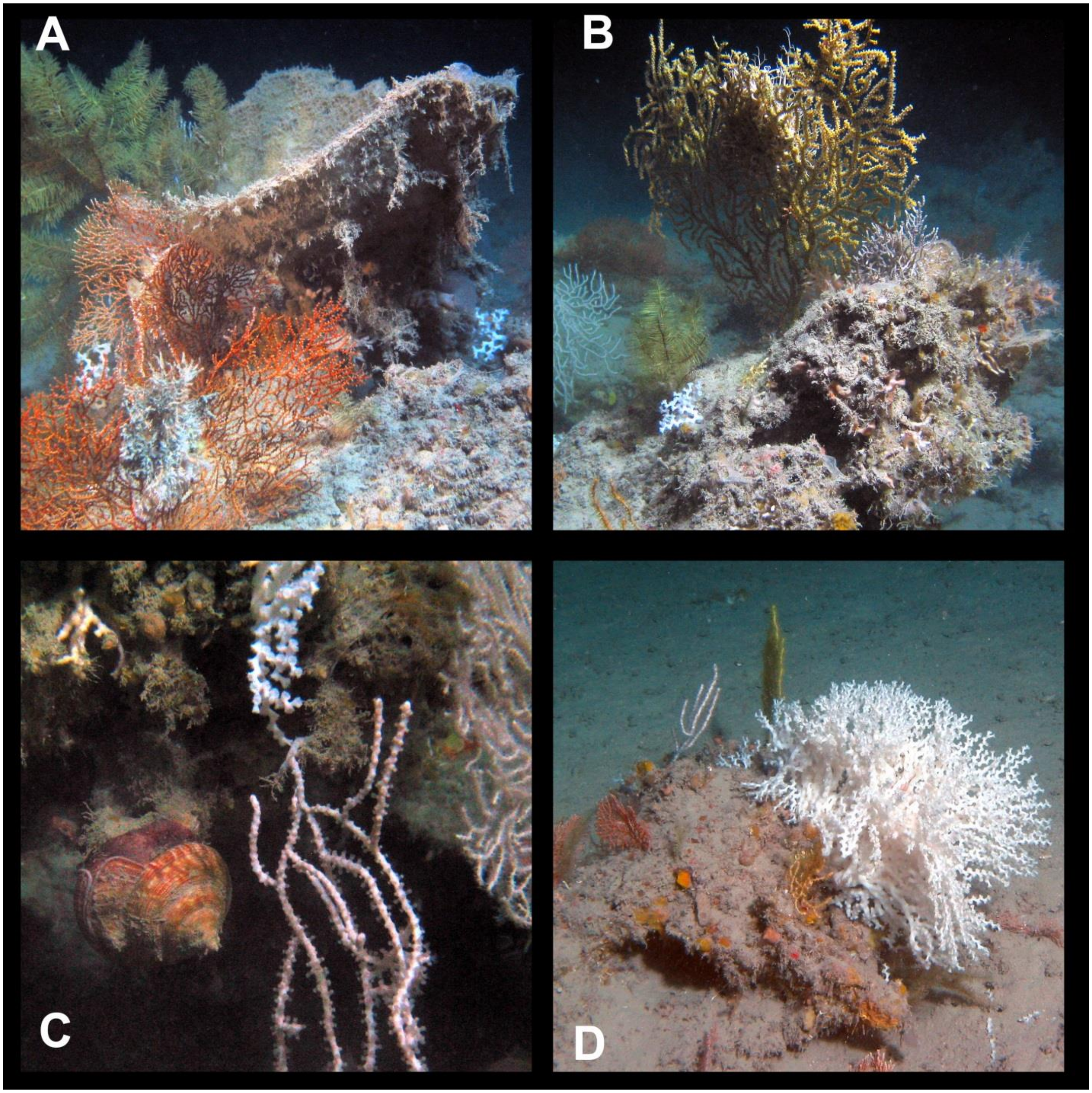

Fig. 11. Images from Reef 1 (depth 123 m): A) Vase sponge *Ircinia campana*; orange sea fan *Nicella guadalupensis;* bushy black coral (upper left) *Elatopathes abietina*; zigzag coral (right) *Madrepora oculata*. B) Yellow plexaurid octocoral, possibly *Placogorgia tenuis*, and hydroids on bioeroded rock outcrop. C) Rock overhang with octocoral (Plexauridae); zigzag coral (top) *Madrepora oculata*; and slit shell gastropod *Perotrochus amabilis*. D) Zigzag coral *Madrepora oculata* (~30 cm diameter).

Table. 1. Transect summary data for 13 reef sites from the *Johnson-Sea-Link* II submersible survey. Percent cover (from CPCe Point Count of submersible photo transects) is shown for 3 substrate types (bare hard, bare soft, and fauna) and benthic macrofauna.

							Percent cover						
Reef	Distance (km)	Depth Range (m)	Latitude Start	Longitude Start	Latitude End	Longitude End	Bare hard bottom	Bare soft bottom	Total fauna cover	Coral	Porifera	Octo-corallia	Anti-patharia
Reef A	0.01	122.5 to 126.5	27.73772	-84.52204	27.73777	-84.52191	98.19	0.00	1.81	0.00	0.00	0.00	1.44
Reef 1	0.07	121.6 to 124.1	27.73708	-84.52240	27.73647	-84.52245	56.47	35.65	7.88	0.77	0.72	3.24	1.58
Reef 3	0.03	122.5 to 124.7	27.73587	-84.52282	27.73576	-84.52314	37.37	50.34	12.29	1.19	0.51	7.34	2.73
Reef 6	0.01	124.4 to 124.4	27.73504	-84.52276	27.73502	-84.52268	70.67	23.00	6.33	0.67	0.00	5.00	0.33
Reef 7	0.01	122.8 to 123.8	27.73415	-84.52148	27.73423	-84.52148	81.82	1.01	17.17	1.01	3.03	3.03	6.06
Reef 8	0.02	124.1 to 124.1	27.73405	-84.52114	27.73387	-84.52098	57.03	38.29	4.68	0.81	0.61	1.63	0.00
Reef 9	0.01	123.8 to 124.4	27.73375	-84.52030	27.73374	-84.52025	89.33	0.33	10.33	2.67	1.33	3.33	1.33
Reef 10	0.13	118.3 to 122.8	27.73372	-84.52027	27.73259	-84.52026	64.80	21.30	13.90	0.58	0.66	1.73	0.16
Reef 12	0.04	119.8 to 122.2	27.73228	-84.51942	27.73219	-84.51980	89.14	0.66	10.19	0.76	0.81	5.03	1.47
Reef 13	0.20	123.4 to 123.4	27.73166	-84.52023	27.73348	-84.51998	93.62	0.00	6.38	0.35	0.35	4.61	1.06
Reef 14	0.02	121.3 to 124.4	27.73181	-84.52076	27.73173	-84.52098	90.24	0.00	9.76	0.76	1.83	0.30	0.61
Reef 15	0.01	125 to 125	27.73089	-84.52122	27.73082	-84.52117	97.97	0.00	2.03	0.00	0.51	1.27	0.25
Reef 16	0.03	122.8 to 125	27.73058	-84.52128	27.73039	-84.52148	78.36	17.83	3.81	0.00	0.56	1.68	1.35

3.5 Benthic Macrobiota

A total of 35 benthic macrobiota were identified from the photographs and samples (Appendix 1). Photographs and specimens were sent to various taxonomists to assist in identifications. A photographic identification album and database was made to identify each species; these were coded for CPCe percent cover analysis. Some common taxa were identified to genus or species level from the images but many could only be identified to a higher taxonomic level such as family, class, order or even phylum. Sponges, octocorals, and black coral in this region are especially difficult to identify without a specimen to inspect. Porifera was the most diverse phylum (12 taxa) and was dominated by the demosponges Astrophorida, Lithistida, Corallistidae, Pachastrellidae, Spirastrellidae, *Placospongia* sp., several unidentified Demospongiae, and a few Hexactinellida. Corals were the next most diverse and included at least five species of non-zooxanthellate Scleractinia (*Madracis myriaster*, *Madrepora oculata*, and various unidentified solitary corals); numerous octocorals (*Bebryce* sp., *Nicella* sp., *N. guadalupensis*, unidentified Plexauridae, *Placogorgia tenuis*, *Paramuricea* sp., and Ellisellidae (*Ellisella* sp.); and antipatharian black corals (*Antipatharia atlantica*, *Elatopathes abietina*, *Tanacetipathes hirta*, *T.*

sp. and *Stichopathes lutkeni*). Non-scleractinian Cnidaria included hydroids, Actiniaria, and Zoanthidea. Other dominant benthic macrofauna included serpulid annelids, Majid crabs, and the basketstar, *Astrogordius cacaoticus* (identification by D. Pawson, USNHM).

Benthic macrofauna cover averaged 8.64% on the On Reef habitat, ranging from 1.81 to 17.17% at each reef (Table 1). The percent cover of fauna was dominated by Cnidaria (5.28% of total bottom cover). Within the Cnidaria, scleractinian hard corals contributed to 0.69% mean cover (maximum cover by reef = 2.67%), Octocorallia (gorgonacea) 3.19% (7.34% maximum cover), and Antipatharia 1.22% (6.06%). Mean cover of sponges was 0.75% ranging from 0% to 3.3% by reef. Removing bare substrate from the analysis, the relative percent composition of all macrobiota was dominated by Octocorallia (35.66% of all fauna), Scleractinia (32.40%), Antipatharia (13.61%), and Porifera (8.44%) (Fig. 12).

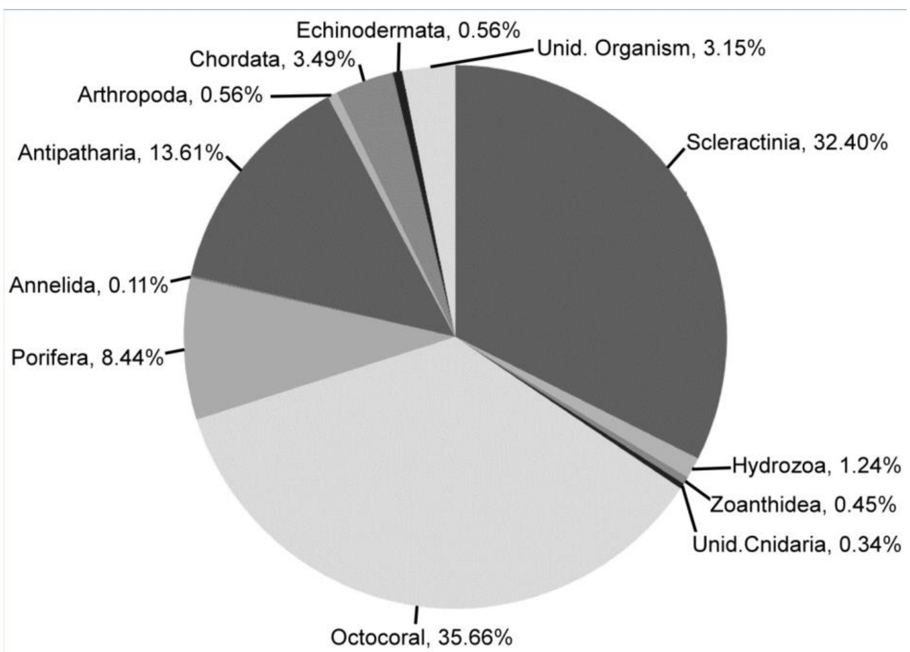

Fig. 12. Relative percent composition (from CPCe Point Count of submersible photo transects) of benthic macrofauna for all Sticky Grounds reef sites.

The relative percent composition of the scleractinian corals was dominated by *Madrepora oculata* (21.38% of all coral), *Madracis myriaster* (21.38%), and unidentified solitary corals (6.92 %). The remaining 56.6% of all coral points were on dead coral that could not be identified, but were likely *Madracis* and/or *Madrepora*. The dominant non-scleractinian corals were dominated by the octocorals *Nicella* sp. (42.01%) and *Placogorgia tenuis* (21.23%); and antipatharians *Tanacetipathes* sp. (13.24%) and *Elatopathes abietina* (10.73%).

3.6 Benthic Macrobiota and Habitat Relationships

The reef sites were compared using a nonmetric, MDS plot in Primer 6.0 of Bray-Curtis similarity for the benthic macrobiota species percent cover averaged by site with square-root transformation (Fig. 13). At this level of resolution and based upon the organisms assessed, the benthic assemblages were very similar among all 17 reef sites; however, Reef A which was on a very small mound, appears as an outlier due to its low cover of biota (1.81% cover) compared to the other reef sites.

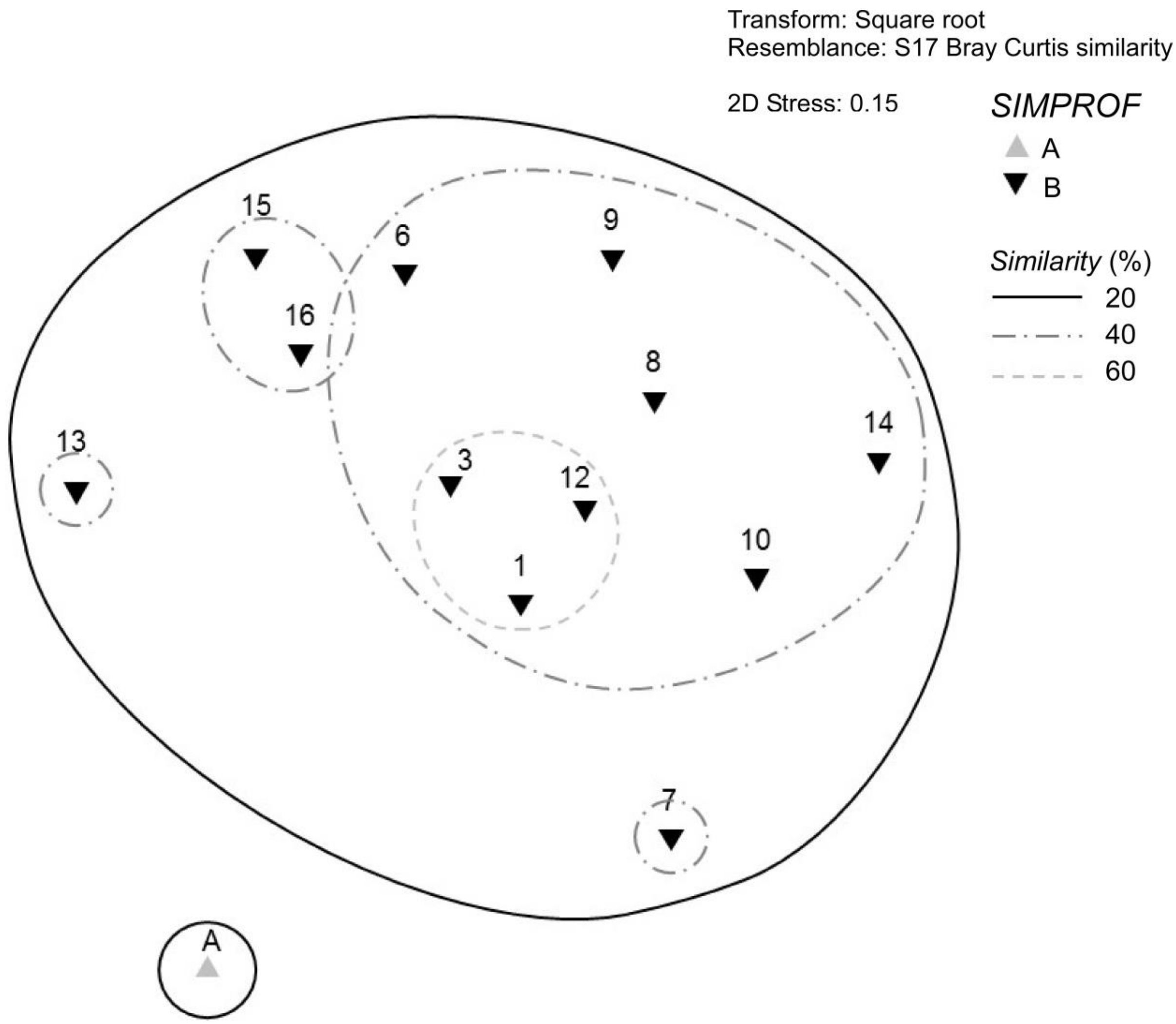

Fig. 13. Similarity of reef sites at Sticky Grounds based on the benthic macrobiota (MDS plot averaged by site with square-root transformation). Assemblage similarities at 20, 40, and 60% are indicated. Reef sites are indicated by numbers (labeled A, 1-16); statistically similar groups (Similarity Profile Analysis [SIMPROF], $p<0.05$) are indicated by the same letters (A and B triangle symbols).

3.7 Fish Analysis

Submersible observations and review of submersible video transects recorded eighteen fish species from On Reef habitat whereas only four species were identified from Off Reef habitat, i.e., mud habitat (Table 2). Four species of grouper were observed on the reefs along with a few large red snapper (*Lutjanus campechanus*). Grouper species included: scamp (*Mycteroperca phenax*), gag (*Mycteroperca microlepis*), snowy grouper (*Hyporthodus niveatus*), and speckled hind (*Epinephelus drummondhayi*).

Table 3 shows the breakdown of fish densities for each individual reef. Anthiids (a mixture of roughtongue bass (*Pronotogrammus martinicensis*) and red barbier (*Hemanthias vivanus*) were observed on all reefs. Scamp were observed on 10 of the 16 analyzed reefs with an average size of 30 cm. Fish diversity was greatest at Reefs 1, 10, 12, 14, and 16, which were all of the largest reefs traversed. Greatest densities of fish were observed at Reefs 1, 12, and 15 with the most abundant fish being anthiids. Greatest densities of grouper (predominantly scamp) were found on Reefs A, 1, and 16. A scamp on Reef 1 was observed changing its color pattern to the greyhead phase in the presence of the other scamp, an indication of spawning behavior (Gilmore and Jones, 1992).

PRIMER was used to analyze differences in fish species composition among reefs. Reef 6 was eliminated because it was only skirted and a direct pass over top was not made. Multi-dimensional scaling ordination was based on the Bray-Curtis similarity matrix calculated from square-root transformed fish densities (Fig. 14). This plot indicated two distinct groups of fish composition for the individual reefs (shown by the two SIMPROF levels). SIMPROF tests confirmed the presence of two statistically different groups (P=0.004) and the 0.10 stress value of the MDS indicated good representation of the relationships in two-dimensional space. Reefs 1, 12, and 15 were significantly different from all other reefs. SIMPER indicated that this was due to a higher density of anthiids and amberjack at these reefs.

Table 2. Fish species identified from submersible video transects for On Reef and Off Reef habitats. Density (# m^{-2}) is given for each species as well as family.

ON REEF

Species Name	Common Name	Density
Serranidae - Small Sea Basses		0.1973
Anthiinae	anthiids	0.1302
Gonioplectrus hispanus	spanish flag	0.0009
Hemanthias vivanus	red barbier	0.0184
Liopropoma eukrines	wrasse bass	0.0009
Plectranthias garrupellus	apricot bass	0.0003
Pronotogrammus martinicensis	roughtongue bass	0.0465
Serranus phoebe	tattler	0.0003
Carangidae		0.0112
Seriola dumerili	greater amberjack	0.0109
Seriola sp.	unidentified amberjack	0.0003
Serranidae - Grouper		0.0095
Epinephelus drummondhayi	speckled hind	0.0006
Hyporthodus niveatus	snowy grouper	0.0006
Epinephelus sp.	unidentified hind	0.0006
Mycteroperca microlepis	gag	0.0009
Mycteroperca phenax	scamp	0.0069
Lutjanidae		0.0011
Lutjanus campechanus	red snapper	0.0009
Lujanus sp.	unidentified snapper	0.0003
Sciaenidae		0.0006
Pareques umbrosus	cubbyu	0.0003
Paraques iwamotoi	blackbar drum	0.0003
Chaetodontidae		0.0017
Prognathodes aya	bank butterflyfish	0.0017
Priacanthidae		0.0003
Pristigenys alta	short bigeye	0.0003
Holocentridae		0.0006
Holocentridae	unidentified soldierfish	0.0003
Ostichthys trachypoma	bigeye soldierfish	0.0003

OFF REEF

Species Name	Common Name	Density
Serranidae - Small Sea Basses		0.0031
Serranus notospilus	saddle bass	0.0020
Serranus phoebe	tattler	0.0011
Carangidae		0.0031
Seriola dumerili	greater amberjack	0.0028
Seriola sp.	unidentified amberjack	0.0003
Synodontidae		0.0008
Synodus intermedius	sand diver	0.0006
Synodus sp.	unidentified lizardfish	0.0003
Unidentified		0.0003
unidentified fish	unidentified fish	0.0003

Table 3. Density (# m^{-2}) of fish species and families at each reef site and total mean density for all sites from submersible video transects (on reef and off reef combined).

Species Name	a	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16	Mean
Serranidae - Small Sea Basses	**0.072**	**0.807**	**0.122**	**0.027**	**0.067**	**0.336**	**0.051**	**0.097**	**0.275**	**0.209**	**0.072**	**1.527**	**0.065**	**0.039**	**0.946**	**0.128**	**0.303**
Anthiinae		0.350	0.122	0.019	0.067	0.336	0.045	0.049	0.110	0.147	0.072	0.889	0.065	0.039	0.595	0.082	**0.199**
Gonioplectrus hispanus										0.002		0.060					**0.031**
Hemanthias vivanus	0.040	0.135								0.037		0.141					**0.088**
Liopropoma eukrines										0.005		0.060					**0.033**
Plectranthias garrupellus								0.007									**0.007**
Pronotogrammus martinicensis	0.031	0.323		0.008			0.006	0.042	0.165	0.017		0.377			0.350	0.046	**0.136**
Serranus phoebe																	
Carangidae		**0.063**												**0.029**	**0.350**		**0.147**
Seriola dumerili		0.054												0.029	0.350		**0.144**
Seriola sp.		0.009															**0.009**
Serranidae - Grouper	**0.040**	**0.054**	**0.003**	**0.011**	**0.012**		**0.006**	**0.007**		**0.012**		**0.011**		**0.004**		**0.035**	**0.018**
Epinephelus drummondhayi		0.018															**0.018**
Epinephelus niveatus										0.002				0.002			**0.002**
Epinephelus sp.			0.003													0.005	**0.004**
Mycteroperca microlepis		0.009														0.010	**0.010**
Mycteroperca phenax	0.004	0.027		0.011	0.012		0.006	0.007		0.010		0.011		0.002		0.020	**0.011**
Lutjanidae		**0.027**														**0.005**	**0.016**
Lutjanus campechanus		0.027															**0.027**
Lujanus sp.																0.005	**0.005**
Sciaenidae							**0.003**							**0.002**			**0.003**
Equetus umbrosus							0.003										**0.003**
Paraques iwamotoi														0.002			**0.002**
Chaetodontidae	**0.004**	**0.018**								**0.002**		**0.006**				**0.005**	**0.007**
Prognathodes aya	0.004	0.018								0.002		0.006				0.005	**0.007**
Priacanthidae									**0.027**								**0.027**
Pristigenys alta									0.027								**0.027**
Holocentridae										**0.002**				**0.002**			**0.002**
Holocentridae										0.002							**0.002**
Ostichthys trachypoma														0.002			**0.002**
Grand Total	**0.116**	**0.969**	**0.125**	**0.038**	**0.079**	**0.336**	**0.060**	**0.104**	**0.302**	**0.225**	**0.072**	**1.544**	**0.065**	**0.076**	**1.296**	**0.173**	**0.522**

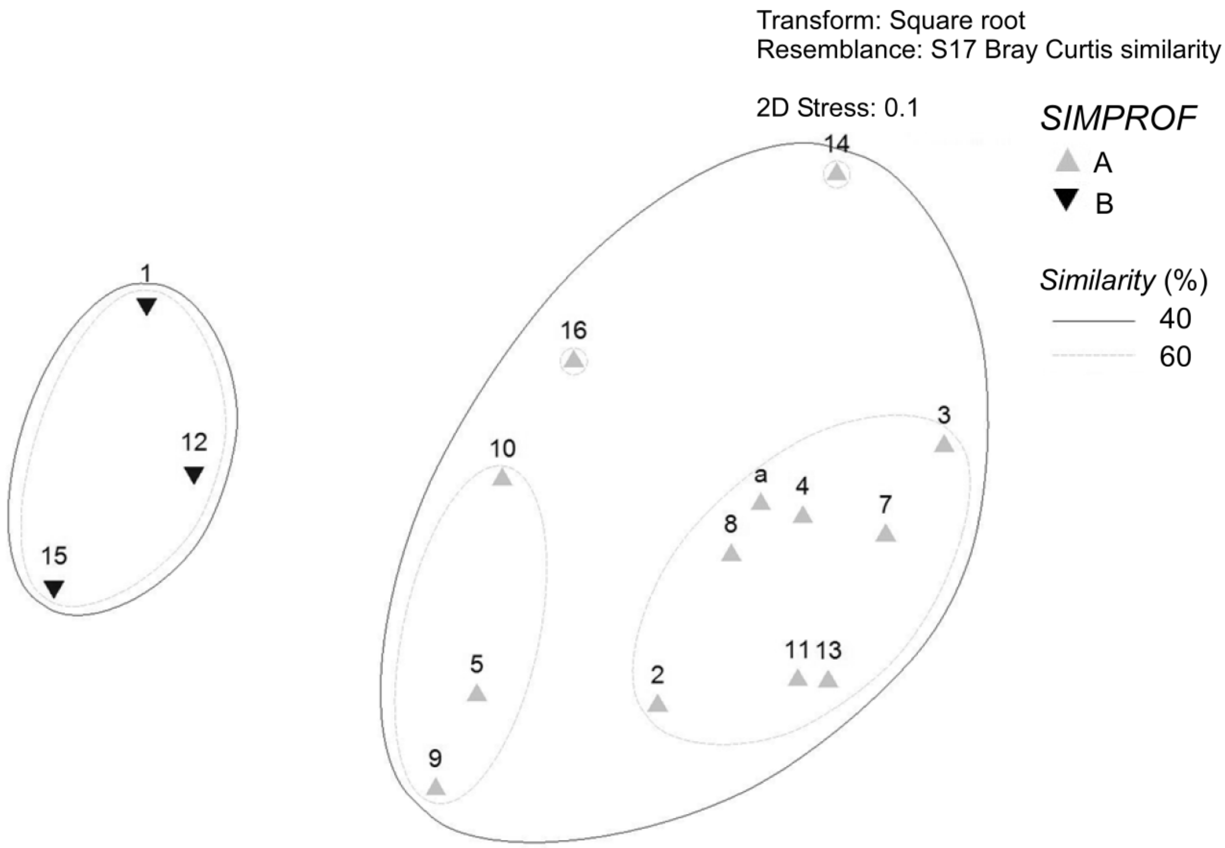

Fig. 14. Multi-dimensional scaling ordination of reef fish communities among reefs (labeled a, 1-5, 7-16) based on the Bray-Curtis similarity matrix calculated from square-root transformed fish densities. Groups resulting from SIMPROF tests are identified by symbols. Clusters are defined at 40% (grey solid line) and 60% (black dashed lines) levels of similarity. Reef 6 was removed from analysis because a direct pass over the reef was not made.

4. Discussion

4.1 Origin of the Carbonate Mounds

The origin of the carbonate mounds that comprise the “Sticky Grounds” remains uncertain as the rocks recovered were too altered by bioerosion and diagenesis to infer original compositions. Similar carbonate mounds have been described elsewhere by Sager and others (1992) off the Mississippi-Alabama shelf, which they termed reef-like mounds (RLM). Similar to the mounds we investigated, the Mississippi-Alabama RLM that are part of the Pinnacles Reef Trend (Gittings et al., 1992), also occur along isobaths probably related to sea-level stillstands and widespread paleoshoreline development in the Gulf of Mexico amid episodic post-glacial sea-level rise (Locker et al., 1996). In support of this, Sionneau et al., (2010) identify evidence for meltwater pulses around the time of paleoshoreline and carbonate mound submergence at these depths.

The Sticky Grounds mounded relief was initially hypothesized to be shallow-water coral patch reefs formed during the last sea-level lowstand (Fig. 4.39 in Hine et al., 2008), that were subsequently drowned during sea-level rise and modified by benthic community bioerosion and cementation processes. We conclude that the uniformly dispersed nature of the carbonate mounds seems more indicative of oyster habitat rather than coral patch-reef habitat. However, an oyster-mound origin is problematic because low-gradient, mixed-salinity, estuarine environments are necessary for oyster growth and survival (Menzel et al., 1966; Wilber, 1992; Livingston et al., 2000). During the last sea-level lowstand, the study area was a coastal shallow-water environment with a steepened slope gradient in this part of the margin that would have limited the possibility for bay or estuarine environments more suitable for oyster habitat. Some of our seismic profiles suggest a flattening of topography below the mounds that could indicate a narrow coastal bay environment (Fig. 2). More importantly however, fresh water input to the coastal zone may have been significant during times of meltwater pulses from the Mississippi River or other fluvial sources such as the Apalachicola River (Leventer et al., 1982; Flower et al., 2004; Sionneau et al., 2010). The fresh meltwater flood to a narrow coastal zone lacking estuaries, combined with alongshore transport, could have created variable salinity conditions suitable for widespread oyster production in a more normal marine coastal setting. Therefore, the existence of the Sticky Grounds and Pinnacles Reef Trend habitats suggests widespread potential for similar mesophotic reef habitat in the Gulf of Mexico linked to this meltwater pulse history and associated isobaths.

4.2 Shelf-Edge Mesophotic Reef Habitat in the Gulf of Mexico

Mesophotic-depth reef habitat is widespread along the west Florida outer continental shelf (Fig.1). Many of these sites were discovered during surveys of the West Florida Shelf (WFS) during 1960s Hourglass cruises (Jaap, 2015), the 1970s Mississippi-Alabama-Florida surveys, and the 1980s Bureau of Land Management surveys (Phillips et al., 1990). These early studies demonstrated the variety and ubiquity of hard-bottom structure on the WFS. The absence of oil and gas exploration on the WFS resulted in little additional research directed to better understand the origin and distribution of these geomorphic structures, along with the associated living resources. The Sticky Grounds, however, missed detection during these early surveys only to be discovered by fishers, and finally examined with a submersible during this study.

Comparison of the Sticky Grounds fauna with other GOM mesophotic-depth reefs shows the variability of these habitats (Fig. 15). Recent ROV surveys were conducted at mid- and shallow-depth mesophotic reefs at Pulley Ridge and Tortugas in 2012-2014 on the southwest Florida shelf using photo and video transects with similar methodology and the same principal investigators conducting the fish and benthic analyses (Fig. 1; Reed et al., 2014, 2015). Pulley Ridge is a submerged 100 km x 5 km barrier island that formed during the last glacial period (~14 ka; Jarrett et al., 2005; Hine et al., 2008). This 5-km wide ridge has about 10 m of relief at depths of 65 to 80 m. Pulley Ridge was designated a Habitat Area of Particular Concern (HAPC) in 2005 and is the deepest known photosynthetic coral reef in continental U.S. waters. It lies 100 miles west of the Dry Tortugas at the far end of the Florida Keys. The ROV dives near the Dry Tortugas were located on shallow-mesophotic reefs just outside the protective boundaries of the Florida Keys National Marine Sanctuary (FKNMS) and the Tortugas Ecological Reserves (TER) at depths of 30 m to 60 m. These sites show little similarity of benthic macrofauna based on MDS plot (Fig. 15). A primary factor to account for the differences in benthic communities is that the benthic community and mesophotic scleractinian corals at Pulley Ridge (Fig. 1) such as *Agaricia* sp. and *Montastraea cavernosa* are supported by the Loop Current, which is the prevailing western boundary current in the Gulf of Mexico that provides warm, clear, low-nutrient waters to Pulley Ridge (Jarrett et al. 2005). Satellite SST and chlorophyll *a* data confirm the influence of the Loop Current on the southwest Florida shelf at Pulley Ridge but less common in the region of Sticky Grounds and northern shelf sites. Although our submersible dives were only at Sticky Grounds one time, the evidence of the highly silted rock and reef substrate and the relatively low visibility at Sticky Grounds (generally <15 m compared to 30+ m at Pulley Ridge) seen during the dives precludes the capability of the typical photosynthetic reef corals to settle and survive. Coral species at Sticky Grounds however included azooxanthellate scleractinians, octocorals and antipatharians.

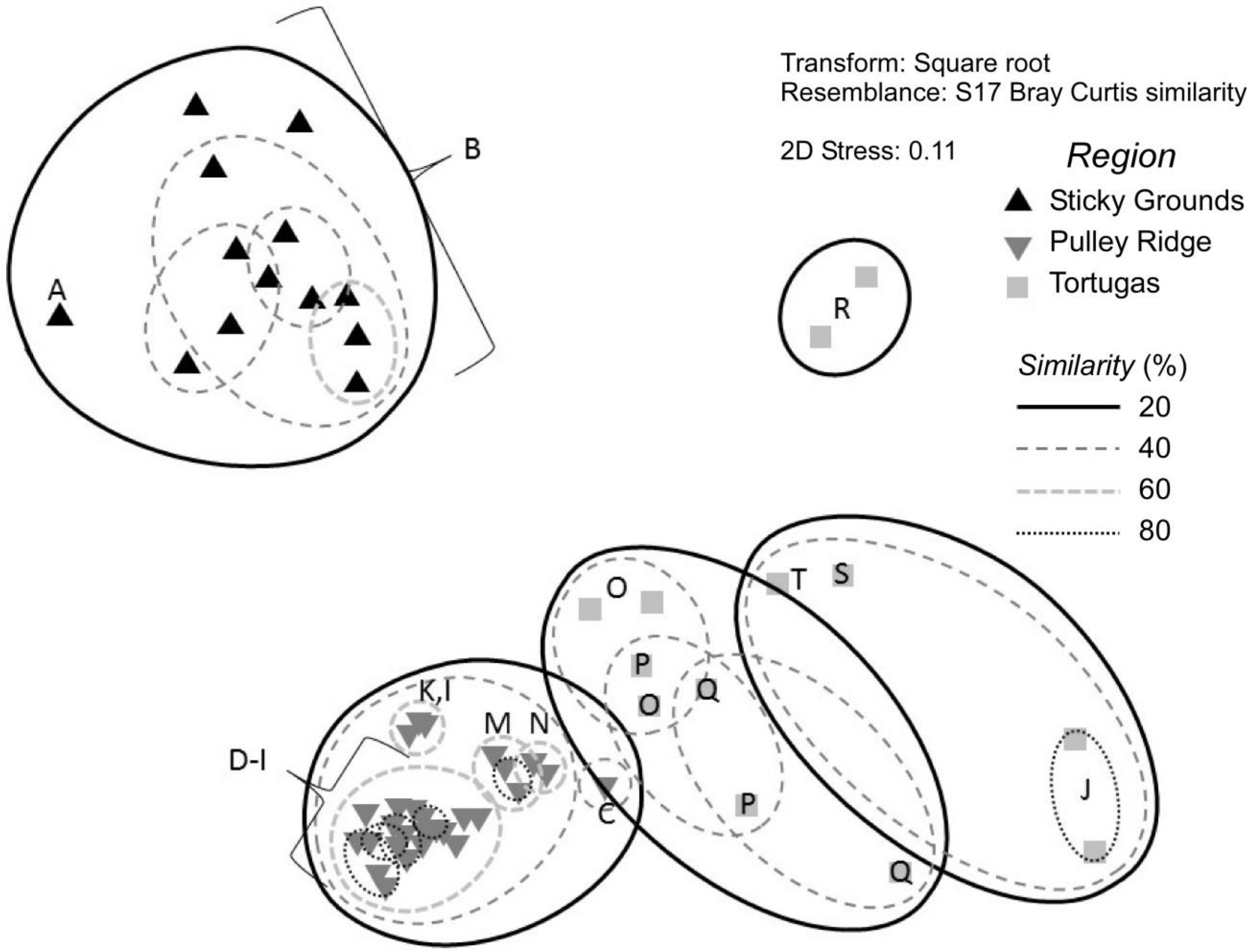

Fig. 15. Similarity of benthic macrofauna at Sticky Grounds compared to Pulley Ridge and Tortugas mesophotic reef sites in the Gulf of Mexico based on non-metric, MDS plot of the Bray-Curtis similarity matrix calculated from benthic biota percentages of cover averaged by site with square root transformation. Assemblage similarities at 20, 40, and 60% are indicated. Reef sites are indicated by symbols; statistically similar groups (SIMPROF, $p<0.05$) are indicated by the same letters (A through T).

Corals found at Sticky Grounds were more similar to those found on the lower mesophotic, deep reef habitat of the Flower Gardens Banks National Marine Sanctuary (FGB) in the western Gulf of Mexico (Fig. 1; Voss et al., 2014). These reefs are far offshore, 180 km off Texas coast and depths of 18 to 150 m. Although the FGB reef cap is shallow, the flanks of the bank provide various mesophotic reef habitats including an upper mesophotic (33-52 m) coral zone, a mid mesophotic (50-82 m) coralline algal and rubble zone, and a deep reef zone (85-152 m). The later depths overlap with the Sticky Grounds. It is similar to Sticky Grounds in that there are no hermatypic corals and is characterized by a diverse assemblage of antipatharians, octocorals, sponges, azooxanthellate branching hard corals, and small, solitary hard corals. Like Sticky Grounds, the FGB deep reefs are also heavily sedimented compared to the upper reef zones which are bathed with clear warmer water like Pulley Ridge. Species similarity between Sticky Grounds and the mesophotic zones of Flower Gardens Banks include the scleractinian corals- *Madracis myriaster* (=*M. mirabilis*), *Madrepora* sp. (likely *M. oculata)*; antipatharian black corals- *Stichopathes lutkeni*, Aphanipathidae (likely *Tanacetipathes*); and octocorals- Ellisellidae (possibly *Nicella guadalupensis*), and various Plexauridae which may be common to both locations.

4.3 Shelf-Edge Mesophotic Reef Fish Communities in the Gulf of Mexico

Comparison of Sticky Grounds fish assemblages with other Gulf of Mexico mesophotic reefs shows the variability of these reefs (Fig. 16). Recent fish surveys were conducted along with the benthic surveys at Pulley Ridge and Dry Tortugas as described above (Reed et al., 2014, 2015), and at Madison-Swanson MPA in 2008 (Harter and David, 2009) using similar ROV methodology. Madison-Swanson is located along the WFS off the Florida panhandle at depths of 65 - 95 m and was designated a MPA in 2000 (Fig. 1). High relief rocky ledges characterize the habitat inside the MPA. Other dives conducted along the WFS, but outside the MPA were in depths of 40 - 85 m with slightly lower relief. The MDS plot shows two distinct groups of fish assemblages at the 20% similarity level with the Sticky Grounds dives separating out from the rest of the regions. At the 40% similarity level, however, dives conducted along the west Florida shelf including those done inside the Madison-Swanson MPA separate into a distinct group. An analysis of similarity (ANOSIM) done on the presence/absence of fish species confirms statistically distinct assemblages among the regions ($R=0.825$). The most dissimilar fish communities were found at Sticky Grounds compared to all other regions ($R \geq 0.904$) and the most similar fish communities were observed between Pulley Ridge and Tortugas ($R = 0.56$).

Differences in fish assemblages among the reefs are most likely explained by habitat type including the benthic fauna along with variation in depth. Distinguishing species for the WFS including Madison-Swanson MPA were scamp (*Mycteroperca phenax*), short bigeye (*Pristigenys alta*), tattler (*Serranus phoebe*), and wrasse bass (*Liopropoma eukrines*). Pulley Ridge had high abundances of greenblotch parrotfish (*Sparisoma atomarium*), lionfish (*Pterois volitans*), and chalkbass (*Serranus tortugarum*). The most distinguishing species for Sticky Grounds were anthiids consisting of roughtongue bass (*Pronotogrammus martinicensis*) and red barbier (*Hemanthias vivanus*). Characteristic species for the Dry Tortugas consisted of bicolor damselfish (*Stegastes partitus*), yellowhead wrasse (*Halichoeres garnoti*), and doctorfish (*Acanthurus* sp.).

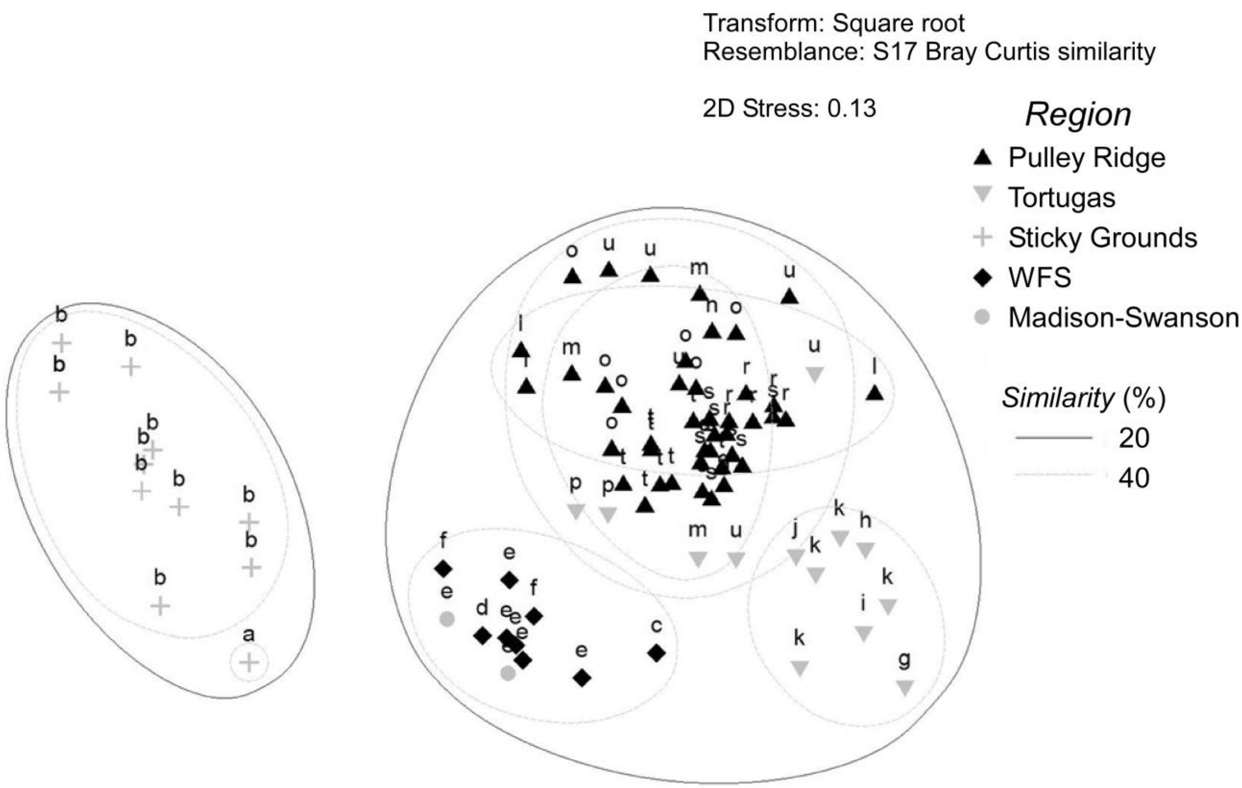

Fig. 16. Similarity of fish species from reef sites at Sticky Grounds compared to ROV dives along the West Florida Shelf at Madison-Swanson MPA, Pulley Ridge HAPC and Dry Tortugas mesophotic reef sites. Non-metric, MDS plot based on the Bray-Curtis similarity matrix calculated from presence/absence of fish species. Assemblage similarities at 20 and 40% are

indicated. Reef sites are indicated by symbols; statistically similar groups (SIMPROF, $p<0.05$) are indicated by the same letters (a through u).

Fish assemblages observed at Sticky Grounds were more similar (qualitatively) to those of the lower mesophotic, deep-reef habitat of the Flower Gardens Banks (FGB) in the western Gulf of Mexico (Clark et al., 2014). The deep reef zone is in depths of 85 – 152 m, similar to that of Sticky Grounds. Both reef areas were dominated by anthiids (*Choranthias tenuis* and *P. martinicensis* at the Flower Gardens and *H. vivanus* and *P. martinicensis* at Sticky Grounds). The dominant apex predators for both reefs were scamp and amberjack (*Seriola* sp.). While the fish species diversity was higher at FGB, scamp was the most abundant grouper in both areas and was observed in similar densities.

Lionfish (*P. volitans)* were not observed on any of the Sticky Grounds reefs, however these data were collected in 2010 and lionfish only first appeared in the Gulf of Mexico that year and have exploded exponentially since then on many of the shelf and mesophotic reefs (Fogg et al., 2013; Nuttall et al., 2014). Presently, there continues to be a strong presence of lionfish in and around Pulley Ridge (Reed et al., 2014, 2015). In the FGB, lionfish densities are currently low but increasing (Clark et al., 2014). Continued monitoring of Sticky Grounds is needed to observe the inevitable invasion of lionfish onto the reefs and the potential for them to impact native fish communities. Lastly, documentation of fishing effort is critically needed to accompany this biological baseline to assess any impacts from fishing on changes in fish densities over time.

4.4 Impacts of Deepwater Horizon Oil Spill and Coral Health

Following the explosion and sinking of the Deepwater Horizon (DWH) drilling rig at the Macondo MC252 well on April 20, 2010, the northern GOM was subjected to the largest offshore crude oil spill ever recorded in the western hemisphere (Fig. 1; Smith et al., 2014). In July 2010, in response to the DWH, HBOI-CIOERT in collaboration with 43 scientists and technicians including various NOAA federal agencies, conducted a 32-day expedition to the south and west Florida shelf to survey shelf-edge mesophotic and deep-water reefs for potential impacts of oil. A total of 121 collection sites were sampled using the *Johnson-Sea-Link* II submersible, CTD rosette, and MOCNESS net. During this expedition, surveys of the Sticky Grounds were made by submersible for the first time. Although no direct evidence of oil was observed on the reefs during submersible dives, we did see evidence of dead coral and sponges at the site. Point count analysis of the photo transects found an average of 0.9% (maximum of 6.0% at Reef 10) of the points were on standing dead colonial coral, likely *Madracis* and *Madrepora*, and a maximum of 5.03% of the points were on unidentified dead coral rubble. In addition many of the sponges, especially the Corallistidae plate sponges which could act as basins to capture sediment and fallout, also appeared dead but it was difficult to determine which were actual or partially dead. How long they had been dead could not be determined from one dive nor whether the cause was from oil or other factors.

Oceanographic conditions during the spill were studied with drifter trajectories, satellite observations, and model simulations that indicated a potential for direct connectivity between the northern Gulf and the Florida Straits via the Loop Current (LC) system (Smith et al., 2014). This pathway could have potentially entrained particles, including northern GOM contaminants related to the oil spill, carrying them directly towards the coastal ecosystems of southwest Florida and northern Cuba. By July 2010 a large Loop Current Ring (LCR) had become separated from the main Loop Current by a cyclonic eddy resulting in the loss of a direct transport mechanism from the northern GOM to the Florida Straits. This cruise sampled the LC, LCR, and frontal eddies to a depth of 2000 m, with the results suggesting that any oil entrained by circulation features in prior months had either been weathered, consumed by bacteria, or dispersed to undetectable levels. However, and more relevant to deep benthic environments, was the potential upwelling onto the West Florida Shelf of contaminants contained in deep water weeks before and after the *Johnson-Sea-Link* II submersible observations in this study (Weisberg et al., 2014). Later in 2011 and 2012, fish with skin lesions were sampled near the Sticky Grounds (Murawski et al., 2014).

4.5 Mesophotic Reef Conservation in the Gulf of Mexico

In 1996 the U.S. Magnuson-Stevens Fishery Management and Conservation Act linked the goals of sustainable fishery production and ecosystem preservation by making habitat a central issue in the management of fisheries. Because the act requires the protection and/or restoration of essential fish habitat, it links preservation of habitat with sustainable production of fishery resources and basically encourages the ecosystem approach to fishery management (Koenig et al., 2000). Regional Fishery Management Councils provide regulation of fisheries in part through the establishment of Habitat Areas of Particular Concern (HAPC) and Marine Protected Areas (MPA). These are identified on the basis of various habitat considerations including: the importance of the ecological function provided by the habitat; the extent to which the habitat is sensitive to human induced environmental degradation; whether and to what extent development activities are or will be stressing the habitat; and the rarity of the habitat type (Cross et al., 2005). Many HAPCs and MPAs are also essential fish habitat. Essential Fish Habitat is defined as those waters and substrate necessary to corals or fish for spawning, breeding, feeding, or growth to maturity. The Gulf of Mexico Fishery Management Council has established several mesophotic depth HAPCs in the northern GOM (Fig. 1). Fishing restrictions within the HAPCs varies among sites and regulatory agency, but typically include prohibition of bottom tending gear such as bottom trawls, bottom longline, buoy gear, pot, or trap and bottom anchoring by fishing vessels (http://www.sefsc.noaa.gov/labs/panama/mp/pulleyridge.htm).

5. Conclusions

Marine spatial planning depends on comprehensive mapping of ocean space, its resources, and its habitats. However the west Florida shelf and slope are inadequately mapped. The Sticky Grounds habitat is potentially widespread in the eastern Gulf of Mexico. It illustrates the important connection between the geological foundations for habitat substrate and the associated living resources. Also the diversity of the various mesophotic depth reefs in the Gulf of Mexico illustrate the importance of establishing a wide variety of marine protected areas to encompass the extent of the species distributions. Widespread exploration of the seafloor, particularly in the eastern Gulf of Mexico, is needed for resource assessment, monitoring, and future stewardship of marine resources. This is more so important in the light of potential oil/gas exploration in the eastern Gulf in the future.

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Highlights

- The Sticky Grounds are bioeroded carbonate mounds on the west Florida shelf at depths of 116-135 m.
- This high-relief mesophotic ecosystem provides habitat for a variety of benthic fauna and fish.
- The benthic community is dominated by sponges, Scleractinia coral, octocorals, and black coral.
- The Sticky Grounds provide extensive essential fish habitat for important fish species.
- The Sticky Grounds habitat is clearly more widespread, but to an unknown extent.

Appendix I. Benthic macrobiota identified from photographs and samples.

Phylum/Scientific Name	**Reef A**	**Reef 1**	**Reef 3**	**Reef 6**	**Reef 7**	**Reef 8**	**Reef 9**	**Reef 10**	**Reef 12**	**Reef 13**	**Reef 14**	**Reef 15**	**Reef 16**
Coral	**0.00%**	**0.77%**	**1.19%**	**0.67%**	**1.01%**	**0.81%**	**2.67%**	**0.58%**	**0.76%**	**0.35%**	**0.76%**	**0.00%**	**0.00%**
Madracis	0.00%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
Madracis myriaster	0.00%	0.30%	0.17%	0.00%	1.01%	0.00%	0.00%	0.25%	0.19%	0.35%	0.30%	0.00%	0.00%
Scleractinia-unid solitary	0.00%	0.34%	0.00%	0.00%	0.00%	0.00%	0.00%	0.08%	0.09%	0.00%	0.00%	0.00%	0.00%
Scleractinia-unid colonial	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.05%	0.00%	0.15%	0.00%	0.00%
Madrepora oculata	0.00%	0.04%	1.02%	0.67%	0.00%	0.81%	2.67%	0.16%	0.43%	0.00%	0.30%	0.00%	0.00%

Octocorallia	**0.00 %**	**3.24 %**	**7.34 %**	**5.00 %**	**3.03 %**	**1.63 %**	**3.33 %**	**1.73 %**	**5.03 %**	**4.61 %**	**0.30 %**	**1.27 %**	**1.68 %**
Bebryce- SG2	0.00 %	0.04 %	0.17 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.19 %	0.00 %	0.00 %	0.00 %	0.00 %
Ellisellidae	0.00 %	0.09 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %
Nicella	0.00 %	1.92 %	4.61 %	4.33 %	1.01 %	0.81 %	3.00 %	1.32 %	1.71 %	4.61 %	0.30 %	1.01 %	1.57 %
Octocorallia	0.00 %	0.60 %	0.17 %	0.33 %	1.01 %	0.41 %	0.33 %	0.08 %	0.38 %	0.00 %	0.00 %	0.25 %	0.11 %
Octocorallia-SG2	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.20 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %
Placogorgia tenuis	0.00 %	0.60 %	2.39 %	0.33 %	1.01 %	0.20 %	0.00 %	0.33 %	2.75 %	0.00 %	0.00 %	0.00 %	0.00 %
Antipatharia	**1.44 %**	**1.58 %**	**2.73 %**	**0.33 %**	**6.06 %**	**0.00 %**	**1.33 %**	**0.16 %**	**1.47 %**	**1.06 %**	**0.61 %**	**0.25 %**	**1.35 %**
Antipatharia	0.36 %	0.21 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.09 %	0.00 %	0.46 %	0.00 %	0.00 %
Antipatharia atlantica	0.00 %	0.13 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.71 %	0.00 %	0.00 %	0.00 %
Elatopathes abietina	0.36 %	0.26 %	0.85 %	0.33 %	0.00 %	0.00 %	1.33 %	0.00 %	0.81 %	0.00 %	0.15 %	0.25 %	1.23 %
Tanacetipathes	0.72 %	0.98 %	1.88 %	0.00 %	6.06 %	0.00 %	0.00 %	0.16 %	0.57 %	0.35 %	0.00 %	0.00 %	0.11 %
Cnidaria Non-Scleractinia	**0.00 %**	**0.43 %**	**0.17 %**	**0.00 %**	**0.00 %**	**0.00 %**	**0.33 %**	**0.08 %**	**0.14 %**	**0.00 %**	**0.30 %**	**0.00 %**	**0.00 %**
Actiniaria	0.00 %	0.04 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %
Hydroidolina	0.00 %	0.34 %	0.17 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.09 %	0.00 %	0.00 %	0.00 %	0.00 %
Unidentified Cnidarian	0.00 %	0.04 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.05 %	0.00 %	0.00 %	0.00 %	0.00 %
Zoanthidea	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.33 %	0.08 %	0.00 %	0.00 %	0.30 %	0.00 %	0.00 %
Porifera	**0.00 %**	**0.72 %**	**0.51 %**	**0.00 %**	**3.03 %**	**0.61 %**	**1.33 %**	**0.66 %**	**0.81 %**	**0.35 %**	**1.83 %**	**0.51 %**	**0.56 %**
Astrophorida	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.09 %	0.00 %	0.00 %	0.00 %	0.00 %
Demospongiae	0.00 %	0.38 %	0.34 %	0.00 %	0.00 %	0.20 %	0.33 %	0.49 %	0.47 %	0.00 %	0.76 %	0.25 %	0.56 %
Demospongiae-SG2	0.00 %	0.04 %	0.00 %	0.00 %	0.00 %	0.00 %	0.33 %	0.00 %	0.00 %	0.00 %	0.15 %	0.00 %	0.00 %
Demospongiae-SG3	0.00 %	0.00 %	0.17 %	0.00 %	3.03 %	0.41 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %
Demospongiae-SG4	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.67 %	0.00 %	0.00 %	0.00 %	0.76 %	0.00 %	0.00 %
Demospongiae-SG5	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.09 %	0.00 %	0.00 %	0.00 %	0.00 %
Hexactinellida	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.15 %	0.00 %	0.00 %
Lithistida- SG1	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.35 %	0.00 %	0.25 %	0.00 %
Pachastrellidae	0.00 %	0.17 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.05 %	0.00 %	0.00 %	0.00 %	0.00 %
Pachastrellidae-SG1	0.00 %	0.13 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.08 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %
Placospongia	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.08 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %

Spirastrellidae	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.09%	0.00%	0.00%	0.00%	0.00%
Annelida	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**1.01%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**
Serpulidae	0.00%	0.00%	0.00%	0.00%	1.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Arthropoda	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.41%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**
Majidae	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.41%	0.00%	0.00%	0.00%	0.00%	0.00%
Chordata	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.14%**	**0.00%**	**0.00%**	**0.00%**	**0.22%**
Fish	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.14%	0.00%	0.00%	0.00%	0.22%
Echinodermata	**0.00%**	**0.09%**	**0.17%**	**0.33%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.05%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**
Astrogordius cacaoticus	0.00%	0.09%	0.17%	0.33%	0.00%	0.00%	0.00%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%
Unidentified Organism	**0.36%**	**0.55%**	**0.17%**	**0.00%**	**0.00%**	**0.61%**	**0.00%**	**0.16%**	**0.19%**	**0.00%**	**0.15%**	**0.00%**	**0.00%**
Natural detritus	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.05%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**
Bare hard bottom	**98.19%**	**56.98%**	**37.37%**	**70.67%**	**84.85%**	**58.04%**	**90.67%**	**74.92%**	**90.71%**	**93.62%**	**96.04%**	**97.97%**	**78.36%**
Bare rock	97.83%	34.16%	19.28%	19.00%	31.31%	45.82%	32.00%	44.41%	71.27%	93.62%	71.04%	54.94%	73.54%
Bare rubble/cobble	0.36%	2.39%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.95%	0.00%	0.46%	0.76%	0.45%
Colonial dead coral	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.67%	6.00%	0.47%	0.00%	0.76%	0.00%	0.00%
Coral rubble	0.00%	0.51%	0.00%	0.00%	3.03%	1.02%	0.67%	4.11%	1.09%	0.00%	5.03%	0.00%	0.00%
Pavement	0.00%	0.81%	0.00%	0.33%	0.00%	0.00%	0.00%	0.00%	0.57%	0.00%	0.00%	0.00%	0.00%
Sediment veneer pavement	0.00%	19.12%	18.09%	51.33%	50.51%	11.20%	57.33%	20.39%	16.36%	0.00%	18.75%	42.28%	4.37%
Bare soft bottom	**0.00%**	**35.65%**	**50.34%**	**23.00%**	**1.01%**	**38.29%**	**0.33%**	**21.30%**	**0.66%**	**0.00%**	**0.00%**	**0.00%**	**17.83%**