Comparison of Reef-Fish Assemblages between Artificial and Geologic Habitats in the Northeastern Gulf of Mexico: Implications for Fishery-Independent Surveys

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Comparison of Reef-Fish Assemblages between Artificial and Geologic Habitats in the Northeastern Gulf of Mexico: Implications for Fishery-Independent Surveys

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Abstract.—Reef-fish assemblage structure was compared among multiple artificial and geologic (i.e., naturally occurring hard bottom) habitats in the northeastern Gulf of Mexico during 2014–2016 as part of a larger fishery-independent survey. Baited remote underwater video systems equipped with stereo cameras were deployed (n = 348) on 11 habitat types, classified through interpretation of side-scan sonar imagery. In the video samples, 11,801 fish were enumerated. Nonparametric analysis of reef-fish assemblages detected four clusters related to habitat; assemblages associated with geologic habitats were distinct, whereas the remaining three clusters represented groupings of artificial habitats of different size, scale, and complexity. While many species, including Vermilion Snapper *Rhomboplites aurorubens* and Red Snapper *Lutjanus campechanus*, were observed in greater numbers on artificial reef habitats, most species were observed in all habitats sampled. Among artificial reef habitats, the habitat cluster consisting of unidentified depressions, unidentified artificial reefs, construction materials, and reef modules was similar to geologic habitats in supporting larger individuals, specifically Gray Triggerfish *Balistes capriscus* and Red Snapper. In contrast, the habitat cluster consisting of smaller, generally solitary chicken-transport cages was inhabited by smaller individuals, including smaller Red Snapper. Although geologic reefs are the predominant reef habitat throughout much of the eastern Gulf, artificial reefs are important locally, especially in the Florida Panhandle. Accordingly, continued incorporation of artificial reef

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habitats within large-scale fishery-independent monitoring efforts is critical to the accurate assessment of the status of reef-fish stocks on broad spatial scales.

Introduction

Reef fishes in the southeastern United States have supported extensive commercial and recreational fisheries for decades, contributing US$30 million to $60 million in annual landings revenue and $3 × 10^9$ to $8 × 10^9$ in annual economic impact in the Gulf of Mexico region (Keithly and Roberts 2017). In particular, species such as Red Snapper *Lutjanus campechanus*, Gag *Mycteroperca microlepis*, Vermilion Snapper *Rhomboplites aurorubens*, Gray Triggerfish *Balistes capriscus*, and Greater Amberjack *Seriola dumerili* are targeted by both commercial and recreational fisheries (NMFS 2017). In recent decades, many reef fishes have been assessed as overfished or undergoing overfishing, necessitating increasingly restrictive management regulations to end overfishing and rebuild overfished stocks. Such measures include individual fishing quotas, changes in size or bag limits, and seasonal fishing closures. These management strategies often indirectly modify behavior in fishery sectors and make it more difficult to use fishery-dependent data to evaluate changes in relative abundance and size/age composition of managed fish populations. There is, therefore, an increasing need for fishery-independent data that accurately characterize the entire population of managed reef fishes, not just that portion sampled by the fishery (Rotherham et al. 2007).

Although expanding the fishery-independent survey effort has long been a high priority in the southeastern United States, implementing new or expanding existing surveys has been challenging. A significant impediment to broad-scale surveys of reef fishes, particularly in the Gulf of Mexico, is an incomplete understanding of the quantity and distribution of reef habitat upon which reef-fish populations rely. The identification and characterization of critical reef habitat in the eastern Gulf is complicated because (1) the area containing potential reef habitat is extremely large and (2) reef habitat is widely distributed throughout much of the region. Overall, the west Florida continental shelf extends for ~900 km along the 75-m isobath that varies between 25 and 250 km in width, encompassing approximately 125,000 km^2 (Hine and Locker 2011). In addition, the region's geologic history contributes to significant variability in the quantity, quality, and distribution of benthic habitat throughout the region. The west-central Florida shelf is characterized as a sediment-starved, gently sloping surface with a sediment veneer overlaying a lithified carbonate surface (Brooks et al. 2003; Obrochta et al. 2003). In contrast, the near-shelf off the Florida Panhandle (USA) contains relatively thick quartz sediments originating from the Apalachicola River and smaller rivers to the west (Davis 2017). Hard-bottom habitats on the west-central Florida shelf are widely distributed across the shelf and include ledges and large areas of low-relief hard-bottom habitat covered with encrusting infauna such as gorgonians and macroalgae. Drowned shorelines comprise the majority of hard-bottom habitats off the Florida Panhandle and are often concentrated between 90- and 120-m isobaths (Davis 2017). Because of its large areal extent, mapping the entire eastern Gulf in support of fishery-independent monitoring activities is cost-prohibitive. Moreover, focused mapping efforts within regions (e.g., Madison-Swanson, Florida Middle Grounds, and Pulley Ridge; Mallinson et al. 2014) of ecological or fisheries importance do not encompass the full range of habitats important to all species and life history stages of managed reef fishes. Accordingly, an alternative approach (e.g., stratified random, systematic) to mapping the eastern Gulf may be required to identify representative reef habitats in support of fishery-independent monitoring surveys.

Broad-scale surveys of reef-fish populations in the southeastern United States have relied on either diver-based, point-count methods in the Florida Keys reef tract (Ault et al. 2005) or baited remote underwater video (BRUV) systems off the southeastern United States in the Atlantic Ocean and the Gulf of Mexico (Campbell et al. 2015; Thompson et al. 2017a). Although these surveys provide valuable data for the assessment of managed reef fishes, most focus entirely on geologic reef habitats (defined here as naturally occurring hard-bottom habitat—not biogenic, reef-building coral) and exclude artificial reef structures. Over recent decades, deployments of artificial reefs have increased worldwide (Stone et al. 1991) with objectives as varied as the materials used to create them, including mitigating loss of bottom habitat (Dupont 2008), creating diving and fishing opportunities (Adams et al. 2011), and enhancing angling opportunities (Lindberg 1997; Baine 2001; Leeworthy et al. 2006). In general, the focus of scientific studies has evolved from the attraction-versus-production hypothesis to evaluating the ecological function of artificial reefs (Bohnsack and Sutherland 1985; Lindberg 1997). Improved technologies that foster research into specific aspects of artificial (and geologic) reef ecology include remotely operated vehicles (ROVs) and BRUVs (Rooker et al. 1997; Patterson et al. 2014; Streich et al. 2017), acoustic telemetry (Lindberg et al. 2006; Topping and Szedlmayer 2011; Biesinger et al. 2013), stable isotopes (Simonsen et al. 2015), and active and passive acoustics (Stanley and Wilson 2000; Wall 2012).

We conducted a 3-year pilot study to determine whether artificial reefs could appropriately be incorporated into ongoing surveys of geologic reefs in the eastern Gulf. Data on reef habitats and reef-associated fish populations were analyzed to (1) assess the distribution of different artificial and geologic reef habitats and (2) determine whether reef-fish assemblages differed between artificial and geologic reef habitats. Based on the outcomes of this study, we determined whether ongoing surveys of geologic reef habitats may be improved upon through the incorporation of artificial reef habitats and discussed implications that such improvements may have on the assessment and management of reef-fish populations.

Methods

Study Area

This study was conducted in nearshore (10–37 m) waters of the northeastern Gulf of Mexico off the Florida Panhandle (Figure 1), a region within which the state of Florida's fishery-independent survey of reef fishes is currently conducted (Thompson et al. 2017b). Numerous artificial reefs and geologic reef habitats exist within this region. This region is of particular interest because approximately 3,000 additional artificial reefs are planned to be deployed through Natural Resource Damage Assessment oil spill recovery efforts (Keith Mille, Florida Fish and Wildlife Conservation Commission, personal communication).

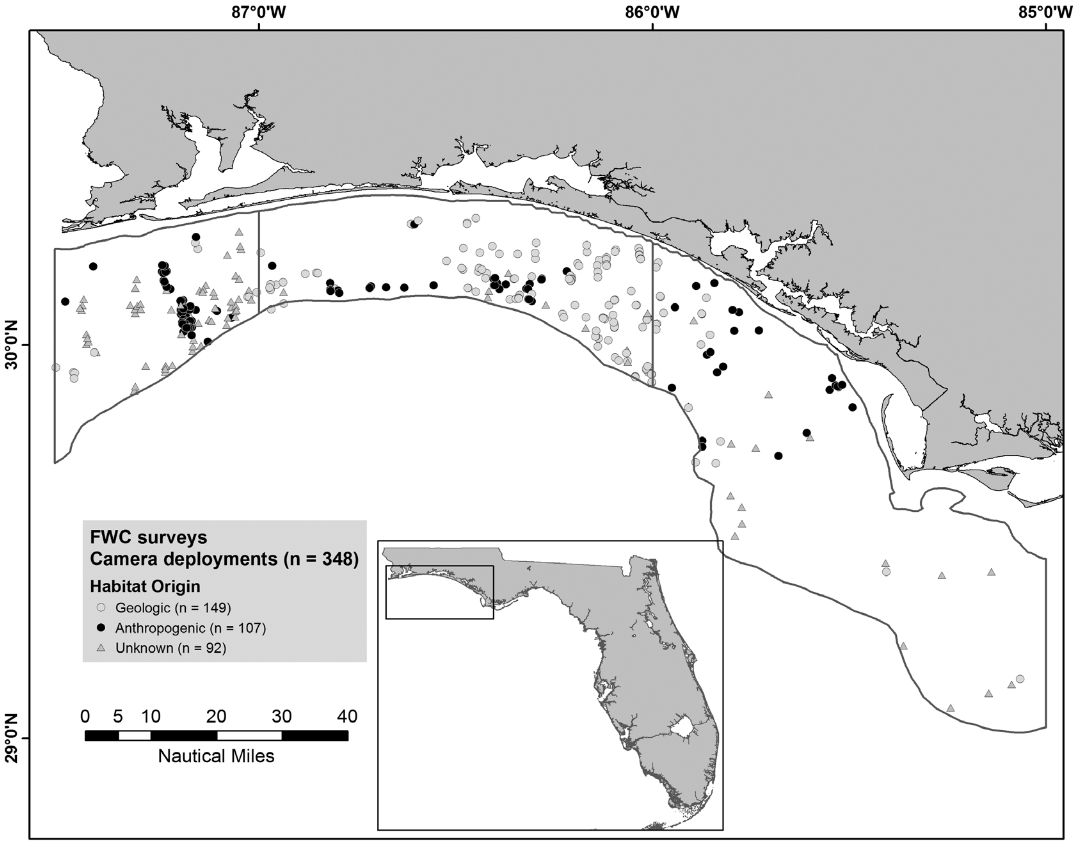

Figure 1. Sampling sites (2014–2016) within the Florida Panhandle study area in the Gulf of Mexico. The three National Marine Fisheries Service statistical zones are indicated within the 50-m isobaths, and sampling sites are characterized as geologic (gray circles), anthropogenic/artificial (black circles), or unidentified depressions (gray triangles).

Habitat Classification and Site Selection

Annual sampling (2014, 2015, and 2016) was allocated between both spatial (longitudinal grids corresponding to National Marine Fisheries Service [NMFS] statistical zones) and habitat strata (artificial reefs and geologic reefs). High-resolution, benthic-mapping data on the distribution of reef habitat are unavailable for much of the study area. To identify and delineate all geologic and artificial reef habitats prior to conducting fishery-independent surveys, spatially randomized habitat-mapping surveys (each covering an area of 2.1 km^2) were completed using a side-scan sonar (L3-Klein 3900) operating at 445 kHz. Each survey location was randomly selected from a gridded universe within the study area via ArcGIS 10.3 and Geospatial Modeling Environment procedures. A standardized survey for geologic habitats covered an area 0.55 km E–W and 3.89 km N–S, running perpendicular to the coast to increase the probability of locating habitats. A standardized survey for artificial reefs covered an area 1.30 km E–W and 1.67 km N–S, with the randomly selected artificial reef centered in the surveyed area. This format provided mapping data on the artificial reef (locations presumably known) and the surrounding area while covering the same area as the geologic surveys. Surveys were processed to correct for time-varied gain and navigational errors using Chesapeake Technologies SonarWiz software to produce a geotiff with 0.25 m resolution. Geotiffs were imported into an ArcGIS 10.3 project in which habitats were identified and manually delineated using a polygon-drawing tool and the Habitat Digitizer extension. The habitat classification scheme was a derivative of the geoform and surface geological component of the Coastal and Marine Ecological Classification Standard developed by the National Oceanic and Atmospheric Administration's Office for Coastal Management (www.fgdc.gov/standards/projects/cmecs-folder) and consisted of a series of distinct geologic and artificial reef habitats (Table 1). Another habitat identified and sampled was termed "unidentified depressions," which may represent either an artificial or a natural habitat.

A routine was created within ArcGIS 10.3 to randomly select specific deployment locations from identified habitats within the geologic and artificial reef surveys. For the geologic surveys, any identified geologic habitat was equally eligible to be sampled, and

Table 1. Habitats occurring in the study area as identified through interpretation of side-scan sonar imagery and criteria used to delineate habitat types.

Habitat class	Definition
Flat hard bottom (HB)	Flat or nearly flat areas (<0.1-m relief) of hard bottom generally colonized by benthic biota
Fragmented hard bottom (FB)	Areas dominated by exposed rock or coral that may be separated by narrow channels of finer sediment that has been eroded leaving the rock elevated above the seafloor with relief of >0.1 m
Mixed hard bottom (MB)	Mainly flat areas of hard bottom containing some features that have relief of >0.1 m
Ledge (LD)	A linear change in elevation of the seafloor that is associated with a rocky outcrop or underwater ridge of rocks. Ledges are defined spatially as the area within 5 m of the identified ledge
Unidentified artificial reef (UR)	Any artificial material >2 m in size that cannot be identified
Construction material (CM)	Any material deposited on the seafloor that was originally intended for construction purposes
Chicken-transport cages (CP)	A wire cage used for transporting poultry
Vessel (VL)	A vessel that was either intentionally or unintentionally sunk
Military tank (MT)	Decommissioned tanks that were deposited as a part of an artificial reef
Reef module (RM)	Prefabricated structures that have been constructed for the purpose of being deployed as reef-fish habitat (reef balls, pyramids, etc.)
Unidentified depression (PH)	Small (2–10 m in diameter) indentations or depressions lower than the surrounding surface usually occurring in unconsolidated sediments. This feature could be naturally made such as a pothole excavated by groupers or created by current scour.

one or two BRUVs were deployed in each geologic survey. Sites in artificial reef surveys focused on the initially selected central reef, but if no artificial reef habitat was identified, other artificial structures in a survey area were randomly selected. Any identified artificial habitat was eligible for inclusion as a sampling point, but geologic habitats identified in artificial reef surveys were not sampled; similarly, artificial habitats were not sampled from geologic reef surveys. All randomly selected sampling locations were spaced at least 100 m apart.

Collection and Processing of Video Data

Sampling was conducted using a BRUV consisting of two independent stereo-video recorders mounted opposite each other inside a 0.6 × 0.6 × 0.6 m aluminum frame. Each stereo-video recorder consisted of two digital video cameras set to record 10 images per second. Additionally, GoPro cameras were mounted orthogonal to the stereo-video recorders to provide habitat view in all directions. Baited remote underwater videos were baited with four cut mackerel *Scomber* spp. halves and deployed for 35 min.

For deployments for which at least 20 min of video was available, MaxN was determined for each species (i.e., the maximum number of individuals of the species observed in one of the screen shots for that deployment). Viewing of each video began at the point approximately 10 min after the gear reached the bottom. Only fishes identified to species were retained in the database for analyses. Because it is so difficult to count individuals in large schools, MaxN was assigned at 300 individuals in such cases. Stereo-video cameras allow measurement of individuals that are viewed by both lenses. Measurements were generated for selected species and examined as fork length (FL in mm) or total length (TL in mm) if the fish did not have a forked tail (e.g., Gray Triggerfish and lionfishes *Pterois* spp.). Only measurements from individuals less than 5 m from the camera were included in analyses.

Analytical Methods

Reef-fish assemblage structure in association with habitat type was compared using a Bray–Curtis similarity matrix calculated using fourth-root-transformed MaxN to reduce the influence of highly abundant taxa. Species-specific MaxN were first averaged by habitat type (flat hard bottom, ledge, fragmented hard bottom, mixed hard bottom, unknown artificial reef, construction materials, chicken-transport cages, vessels, military tanks, artificial reef modules, and unidentified depressions; see Table 1 for descriptions). Rare species (i.e., those occurring in five or fewer samples) were removed from the analyses. All analyses were conducted using the PRIMER v7 computer program (Clarke and Gorley 2015). To visualize the patterns of assemblage structure among habitats, we constructed a nonmetric multidimensional scaling (nMDS) ordination. To identify habitat clusters with statistically distinct fish assemblages, a similarity profile (SIMPROF) test was conducted using group averaging, and statistically significant clusters were then overlaid on the nMDS ordination. Species that contributed to 80% of the dissimilarity in assemblage structure between habitat clusters were identified via similarity percentages analyses (SIMPER). Length-frequency distribution of selected species contributing to the differences among habitat clusters were generated to qualitatively evaluate trends in size among clusters.

To explore the presumption of whether artificial reef habitats deployed within permit areas were properly documented by or reported to the Florida Fish and Wildlife Conservation Commission (FWC), the number of habitat polygons and area coverage of identified habitats were examined. Habitat data were evaluated within the FWC artificial reef permit areas, as well as the FWC data set of artificial reef coordinates. Area of habitat reported within a permit area was defined as any habitat located within 100 m of a documented artificial reef inside the permit area; unreported artificial reefs inside a permit area were more than 100 m from any coordinate in the database. Also summarized were artificial reef habitats identified outside of permit boundaries and interpreted as private reefs.

Results

Baited remote underwater videos were deployed 348 times in 2014–2016, 149 times on geologic habitats, 107 times on artificial habitats, and 92 times on unidentified depressions (Figure 1). Most deployments on geologic habitats occurred on flat hard bottom (n = 117); most deployments on artificial habitats occurred on unidentified artificial reefs (n = 34). Although not explicitly delineated as a sampling stratum within our design, many deployments were made on unidentified depressions (n = 92), which initially appeared similar to grouper potholes (sensu Coleman et al. 2010) when viewed using side-scan sonar imagery. Based on examination of video from earlier surveys and this study, we could not determine whether these depressions originated from active excavations by fish or from current-induced scouring. Because these features could include artificial or natural reef habitats, they were treated as a separate habitat class for analyses.

A total of 11,801 individual fish from 75 species were identified from BRUV deployments (Table 2), but 25 of the 75 species were represented by only one or two individuals. The most commonly observed species were Vermilion Snapper (n = 4,212), Tomtate *Haemulon aurolineatum* (n = 2,011), and Red Snapper (n = 1,058); more than 60% of observed individuals represented these valuable fishery and forage species (Table 2). The five most abundant species were observed in all 11 habitat classes. But individuals of 14 species were viewed solely from geologic habitats (e.g., Short Bigeye *Pristigenys alta* and Banded Rudderfish *Seriola zonata*), those of 10 species were viewed solely from artificial habitats (e.g., Hardhead Catfish *Ariopsis felis* and Bigeye *Priacanthus arenatus*), and those of 9 species were observed only on unidentified depressions (e.g., Blackwing Searobin [also known as Blackfin Searobin] *Prionotus rubio* and Goliath Grouper *Epinephelus itajara*), and in most instances (n = 30), only one individual of the species was seen.

Reef-fish assemblage structure differed significantly among habitat classes (Figure 2). The SIMPROF identified four significant habitat groups: group A (habitat classes: vessel, military tank) comprised artificial habitats with a high degree of vertical relief, group B (chicken-transport cages) represented chicken-transport cages, group C (flat hard bottom, ledge, mixed hard bottom, fragmented hard bottom) consisted of all geologic habitats, and group D (construction material, reef module, unidentified depression, unidentified artificial reef) comprised artificial habitats with less vertical relief and unidentified reefs or depressions. There were 20 species that, in combination, contributed nearly 80% of the dissimilarity between at least one pair of habitat groups (Figure 3). While many species were more abundant in artificial habitats, Red Porgy *Pagrus pagrus*, Blue Angelfish *Holacanthus bermudensis*, Bank Sea Bass *Centropristis ocyurus*, Spotfin Butterflyfish *Chaetodon ocellatus*, and Yellowtail

Table 2. Species observed in each habitat class within each reef type (i.e., geologic or artificial) where values represent the sum of MaxN for each identifiable species by habitat class. Species are ranked by increasing total number observed. The number of deployments is the number of camera deployments on each habitat. See Table 1 for habitat class abbreviations.

		Geologic				Artificial						Unknown	
		HB	FB	MB	LD	UR	CM	CP	VL	MT	RM	PH	Total
	Number of deployments	117	19	7	6	34	29	7	11	4	22	92	348
Scientific name	Common name												
Rhomboplites aurorubens	Vermilion Snapper	712	437	44	82	596	433	66	135	28	639	1,040	4,212
Haemulon aurolineatum	Tomtate	304	387	35	8	162	81	392	21	17	277	327	2,011
Lutjanus campechanus	Red Snapper	182	54	14	10	168	156	44	35	28	57	310	1,058
Pagrus pagrus	Red Porgy	384	50	30	26	24	23	11	2	4	32	162	748
Seriola dumerili	Greater Amberjack	96	11	7	2	163	30	5	21	8	31	31	405
Balistes capriscus	Gray Triggerfish	132	19	3	8	35	40	9	4	9	66	69	394
Caranx crysos	Blue Runner	206	1	3	49	13	2	0	0	89	9	20	392
Lutjanus griseus	Gray Snapper	26	13	2	2	95	43	0	4	30	63	66	344
Chromis enchrysura	Yellowtail Reeffish	258	5	20	14	0	0	0	0	0	8	0	305
Centropristis ocyurus	Bank Sea Bass	132	8	5	5	16	0	1	0	0	3	105	275
Lutjanus synagris	Lane Snapper	47	5	1	0	86	18	11	2	2	7	61	240
Pterois spp.	Lionfishes	33	15	4	5	26	12	9	0	0	32	73	209
Holacanthus bermudensis	Blue Angelfish	80	30	11	5	21	27	2	3	3	12	7	201
Equetus lanceolatus	Jackknife-fish	63	1	1	3	37	0	7	0	0	3	22	137
Chaetodon ocellatus	Spotfin Butterflyfish	52	8	1	3	4	13	1	2	0	10	6	100
Seriola rivoliana	Almaco Jack	7	5	2	0	24	11	5	4	4	14	10	86
Serranus phoebe	Tattler	55	2	5	3	2	1	0	1	0	1	11	81
Mycteroperca phenax	Scamp	13	16	3	2	7	10	0	2	2	0	5	60
Xyrichtys novacula	Pearly Razorfish	8	0	2	0	6	0	2	1	0	4	30	53
Chaetodon sedentarius	Reef Butterflyfish	22	11	4	4	1	0	0	0	0	0	0	42
Aluterus monoceros	Unicorn Filefish	4	0	0	0	17	0	0	0	0	10	8	39
Calamus proridens	Littlehead Porgy	21	3	0	0	5	4	0	0	0	3	2	38
Halichoeres bathyphilus	Greenband Wrasse	14	0	1	0	3	1	0	0	0	2	11	32

Table 2. Continued.

		Geologic				Artificial					Unknown		
Scientific name	Common name	HB	FB	MB	LD	UR	CM	CP	VL	MT	RM	PH	Total
Pristigenys alta	Short Bigeye	20	7	0	3	0	0	0	0	0	0	0	30
Sphoeroides spengleri	Bandtail Puffer	8	0	1	3	2	0	0	0	0	3	7	24
Canthigaster rostrata	Sharpnose Puffer	12	0	1	2	1	7	0	0	0	0	0	23
Gymnothorax saxicola	Honeycomb Moray	16	1	0	1	1	0	0	0	0	0	4	23
Epinephelus morio	Red Grouper	14	3	1	2	1	0	1	0	0	0	0	22
Mycteroperca microlepis	Gag	0	0	0	1	2	2	2	0	1	1	10	19
Rypticus maculatus	Whitespotted Soapfish	4	1	0	0	0	7	0	4	0	0	3	19
Seriola zonata	Banded Rudderfish	11	0	0	4	0	0	0	0	0	0	0	15
Archosargus probatocephalus	Sheepshead	1	0	0	0	1	3	0	5	2	2	0	14
Serranus subligarius	Belted Sandfish	7	1	3	0	1	1	0	0	0	0	0	13
Muraena retifera	Reticulate Moray	4	3	0	1	0	1	1	0	0	0	0	10
Ophichthus puncticeps	Palespotted Eel	2	0	1	0	0	1	0	0	0	0	6	10
Cephalopholis cruentata	Graysby	3	4	0	0	0	1	0	0	0	1	0	9
Priacanthus arenatus	Bigeye	0	0	0	0	0	0	0	8	0	0	0	8
Holacanthus ciliaris	Queen Angelfish	5	1	0	0	0	0	1	0	0	0	0	7
Aluterus schoepfii	Orange Filefish	3	1	0	0	0	0	0	1	0	0	1	6
Ariopsis felis	Hardhead Catfish	0	0	0	0	0	6	0	0	0	0	0	6
Lagocephalus laevigatus	Smooth Puffer	4	0	0	0	1	0	0	0	0	0	1	6
Stegastes partitus	Bicolor Damselfish	2	3	0	0	0	0	0	0	0	1	0	6
Bodianus pulchellus	Spotfin Hogfish	0	2	0	3	0	0	0	0	0	0	0	5
Sphyraena barracuda	Great Barracuda	0	0	0	0	1	1	1	1	0	0	1	5
Carcharhinus plumbeus	Sandbar Shark	1	0	0	0	0	0	0	0	1	0	2	4
Halichoeres bivittatus	Slippery Dick	4	0	0	0	0	0	0	0	0	0	0	4
Lagodon rhomboides	Pinfish	2	0	0	0	0	0	0	0	0	1	1	4
Stegastes variabilis	Cocoa Damselfish	3	0	0	0	0	1	0	0	0	0	0	4
Chaetodipterus faber	Atlantic Spadefish	0	0	0	0	0	0	0	0	0	3	0	3
Prognathodes aya	Bank Butterflyfish	1	0	0	2	0	0	0	0	0	0	0	3
Rachycentron canadum	Cobia	2	1	0	0	0	0	0	0	0	0	0	3

Table 2. Continued.

		Geologic				Artificial						Unknown	
Scienitific name	Common name	HB	FB	MB	LD	UR	CM	CP	VL	MT	RM	PH	Total
Bodianus rufus	Spanish Hogfish	0	0	0	0	0	1	0	0	1	0	0	2
Calamus bajonado	Jolthead Porgy	0	0	0	0	0	0	0	2	0	0	0	2
Canthigaster jamestyleri	Goldface Toby	0	0	0	0	0	1	0	1	0	0	0	2
Caranx hippos	Crevalle Jack	0	0	0	0	0	1	0	0	0	0	1	2
Carcharhinus leucas	Bull Shark	0	0	0	0	1	0	0	0	0	0	1	2
Ginglymostoma cirratum	Nurse Shark	0	0	0	0	0	1	1	0	0	0	0	2
Parablennius marmoreus	Seaweed Blenny	2	0	0	0	0	0	0	0	0	0	0	2
Paranthias furcifer	Atlatnic Creolefish	0	0	0	2	0	0	0	0	0	0	0	2
Prionotus rubio	Blackwing Searobin	0	0	0	0	0	0	0	0	0	0	2	2
Seriola fasciata	Lesser Amberjack	0	0	0	0	0	0	0	0	0	2	0	2
Acanthostracion polygonius	Honeycomb Cowfish	1	0	0	0	0	0	0	0	0	0	0	1
Epinephelus itajara	Goliath Grouper	0	0	0	0	0	0	0	0	0	0	1	1
Gonioplectrus hispanus	Spanish Flag	0	0	0	1	0	0	0	0	0	0	0	1
Gymnothorax moringa	Spotted Moray	0	0	0	1	0	0	0	0	0	0	0	1
Haemulon plumierii	White Grunt	0	0	0	0	0	0	0	0	0	1	0	1
Hyporthodus niveatus	Snowy Grouper	0	0	0	0	0	0	0	0	0	0	1	1
Liopropoma eukrines	Wrasse Basslet	0	0	0	1	0	0	0	0	0	0	0	1
Orthopristis chrysoptera	Pigfish	0	0	0	0	1	0	0	0	0	0	0	1
Paradiplogrammus bairdi	Lancer Dragonet	0	0	0	0	0	0	0	0	0	0	1	1
Pronotogrammus martinicensis	Roughtongue Bass	0	0	0	1	0	0	0	0	0	0	0	1
Serranus annularis	Orangeback Bass	1	0	0	0	0	0	0	0	0	0	0	1
Serranus notospilus	Saddle Bass	0	0	0	0	0	0	0	0	0	0	1	1
Sphyrna lewini	Scalloped Hammerhead	0	0	0	0	0	1	0	0	0	0	0	1
Sphyrna mokarran	Great Hammerhead	0	0	0	0	0	0	0	0	0	0	1	1
	Total	2,984	1,109	205	259	1,524	941	572	259	229	1,298	2,421	11,801

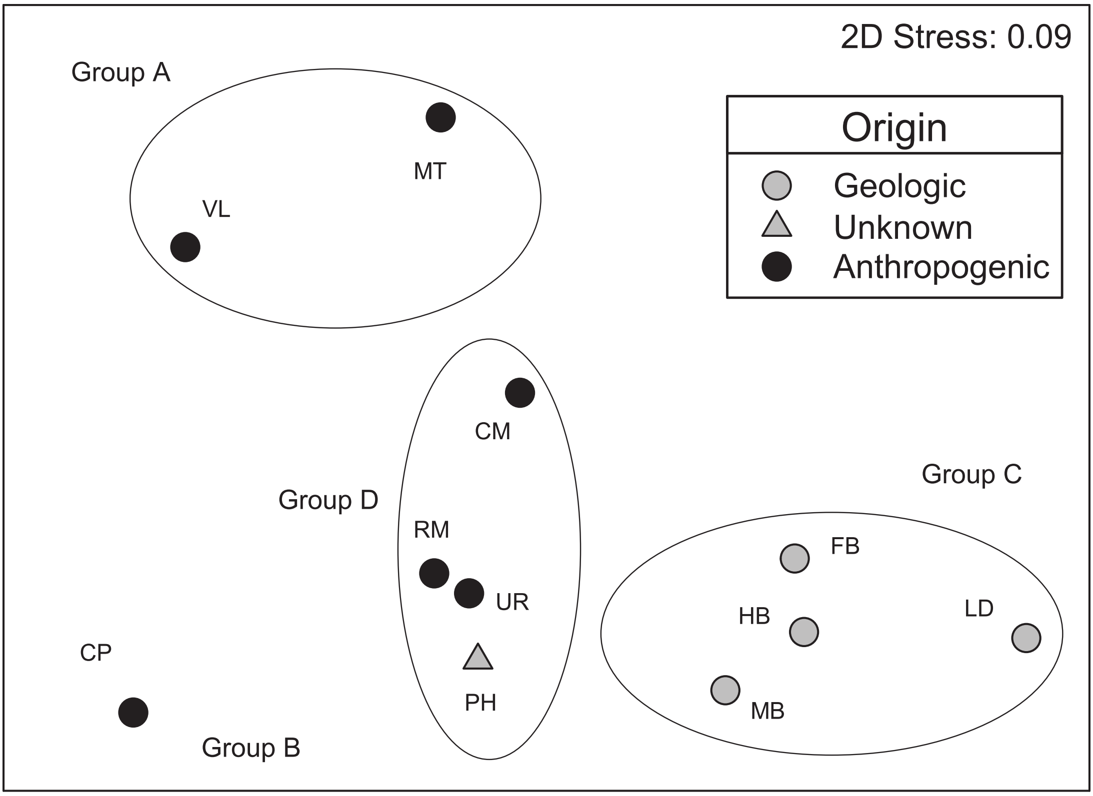

Figure 2. Nonmetric multidimensional ordination of reef-fish assemblage species abundance by habitat class representing geologic, anthropogenic, and unknown habitats. Lines represent significant clusters as identified via SIMPROF analyses. See Table 1 for habitat class abbreviations.

Reeffish *Chromis enchrysura* were more abundant in geologic habitats. Economically important Red Snapper and Vermilion Snapper were abundant in all habitats, with greatest abundance from chicken-transport cages, while Greater Amberjack and Gray Snapper *Lutjanus griseus* were more abundant from vessels and military tanks. Lionfishes were also observed in all habitats, with greatest abundances observed on chicken-transport cages.

While not quantitatively assessed, fishes contributing to differences in reef-fish community structure among habitat groups also exhibited marked variability in size distribution among habitat groups. These results should be interpreted cautiously due to substantially greater sampling effort and subsequently greater number of overall length measurements coming from group C (geologic habitats) and group D (reef modules, construction material, and unidentified depressions). The largest Red Snapper were observed in association with habitat groups C and D while the smallest Red Snapper were associated with group B (Figure 4). Habitat-related size composition of Gray Snapper was not as distinct, but larger individuals were observed in habitat group C (Figure 4). Vermilion Snapper length distributions overlapped among habitats, but small individuals (≤100 mm fork length) were observed only

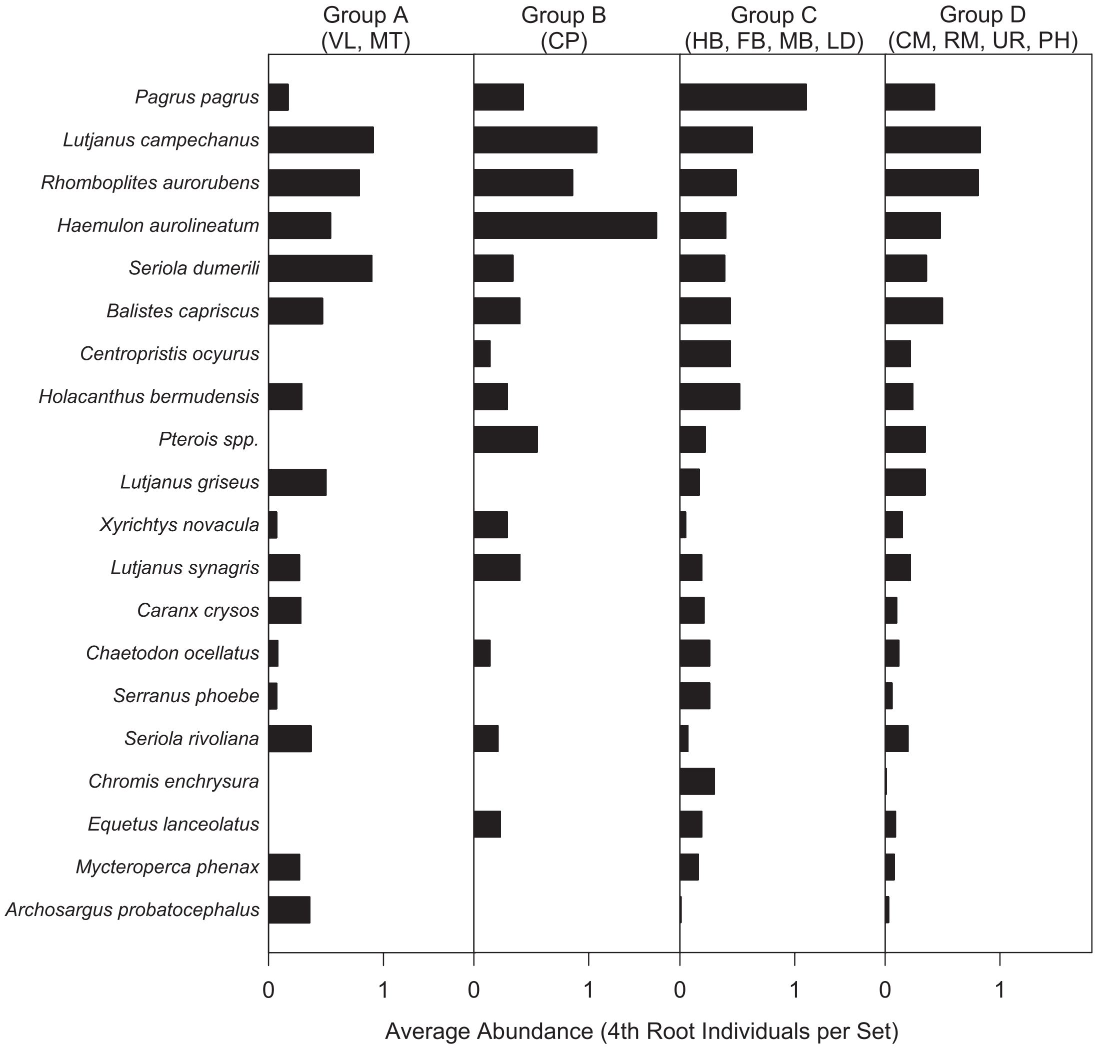

Figure 3. Fourth-root transformed abundance data for species that contributed up to 80% of differences among habitat groups. See Table 1 for habitat class abbreviations.

in association with habitat group D (Figure 5). This pattern was similar in Red Porgy, with the smaller individuals observed in habitat group D and larger individuals observed from geologic habitats in group C (Figure 5). The largest Gray Triggerfish were observed in group C and D habitats, whereas the smaller lionfishes were associated with habitat group D (Figure 6).

In the study region, 601.108 km^2 of the ocean bottom was scanned in support of reef-fish survey efforts, including areas in and outside Florida artificial reef permit areas. Of this total, approximately 1.2% of the area (7.155 km^2), represented by 5,755 individual polygons, was coded as reef habitat (Table 3). Flat hard bottom (5.577 km^2) comprised the greatest area of geologic habitat; construction materials (0.136 km^2) comprised the greatest area of artificial habitat. Unidentified depressions accounted for 373 polygons, totaling 0.025 km^2. In the scanned

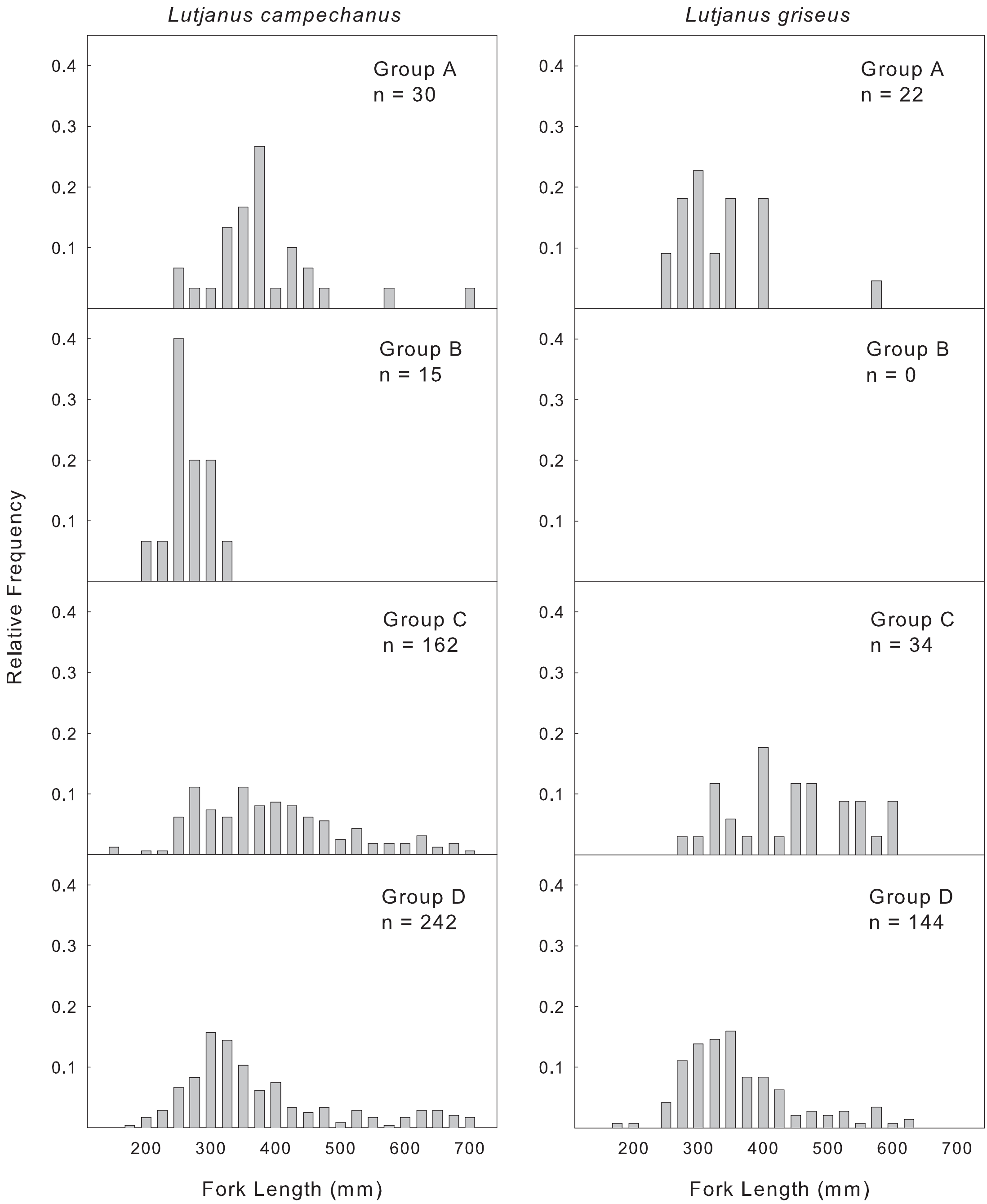

Figure 4. Length-frequency (mm fork length) histograms for Red Snapper and Gray Snapper separated by habitat groups. Habitat groups included group A—VL, MT; group B—CP; group C—HB, FB, MB, LD; and group D—CM, RM, PH, UR. See Table 1 for habitat class abbreviations.

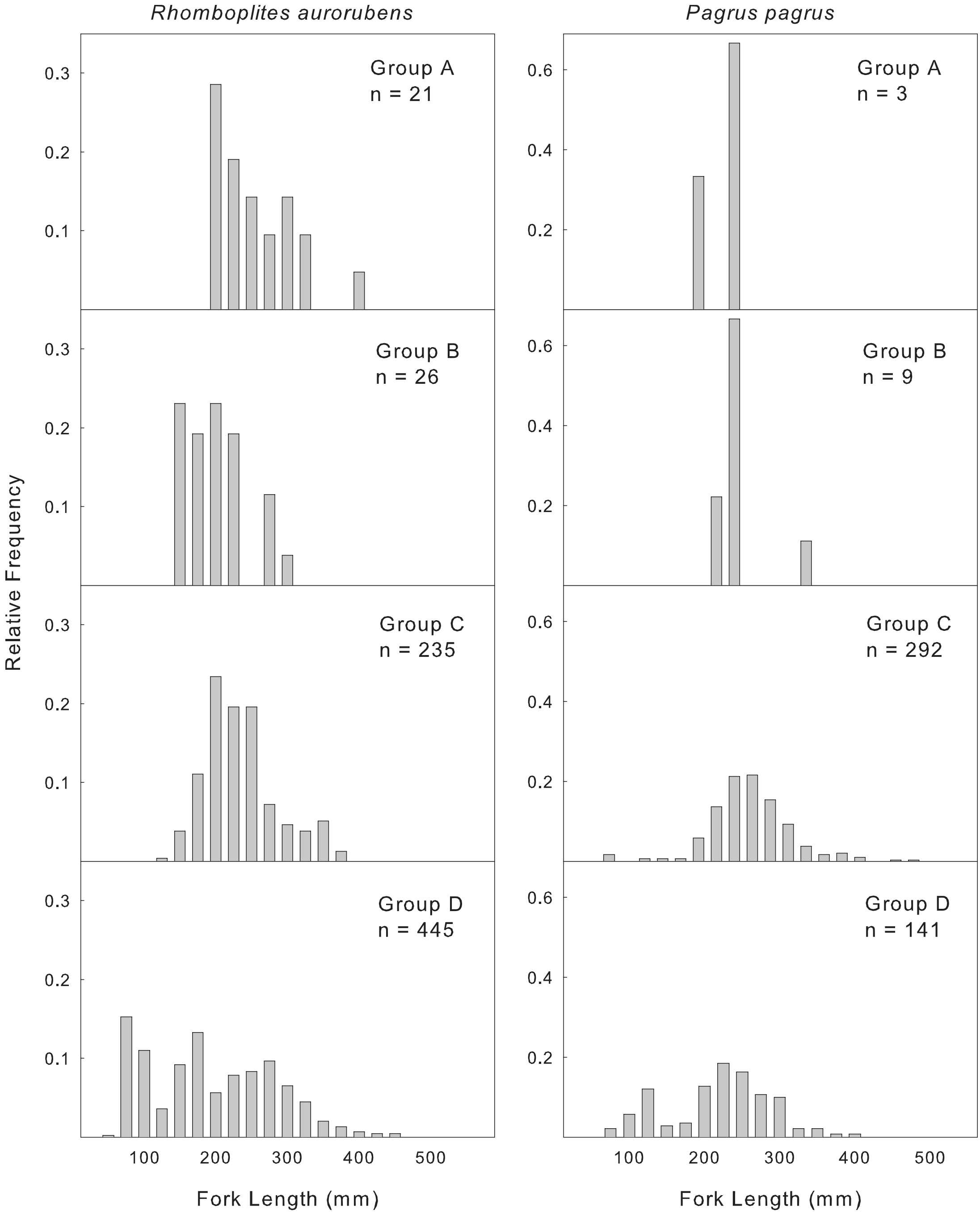

Figure 5. Length-frequency (mm fork length) histograms for Vermilion Snapper and Red Porgy separated by habitat groups. Habitat groups included group A—VL, MT; group B—CP; group C—HB, FB, MB, LD; and group D—CM, RM, PH, UR. See Table 1 for habitat class abbreviations.

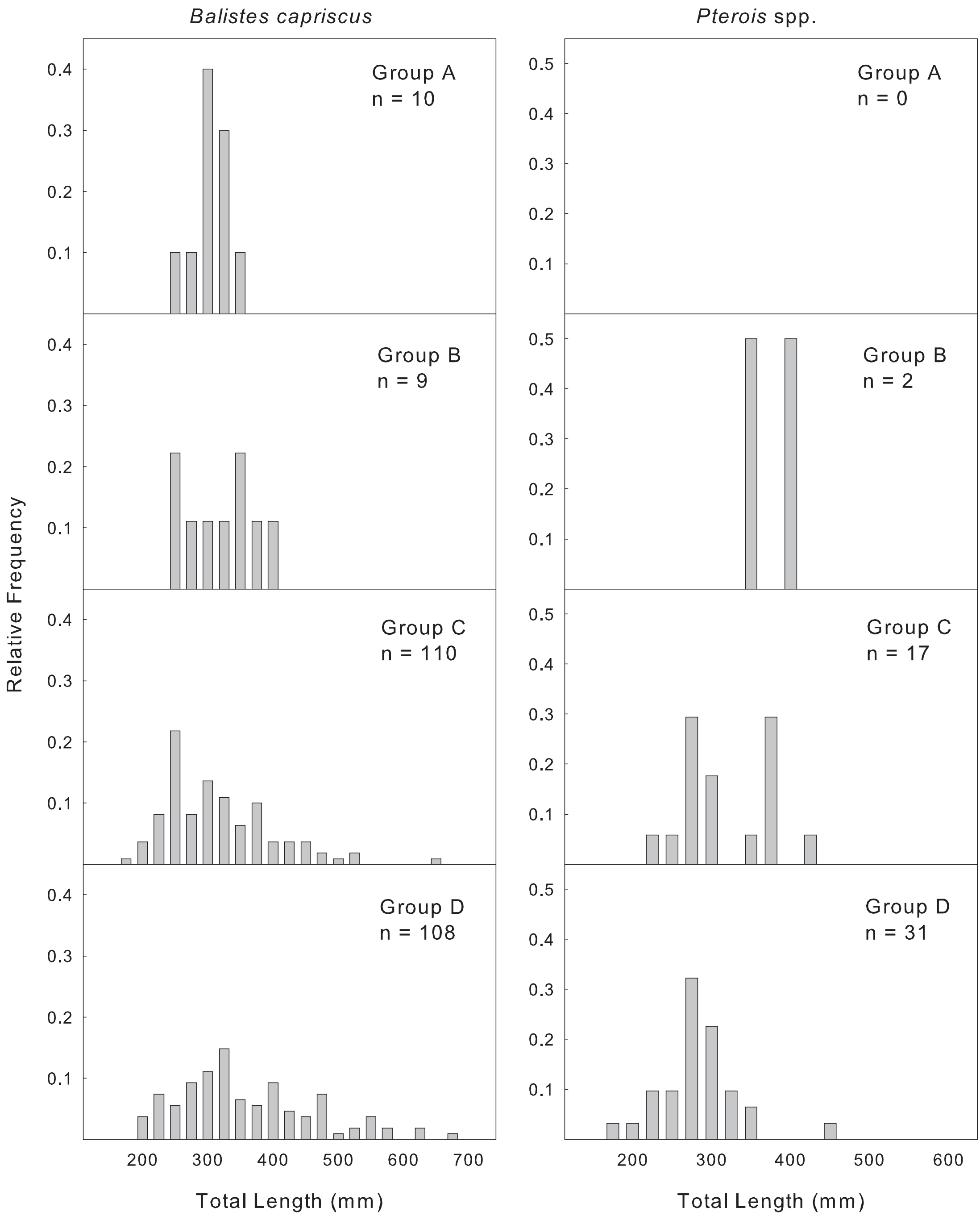

Figure 6. Length-frequency (mm total length) histograms for Gray Triggerfish and lionfishes separated by habitat groups. Habitat groups included group A—VL, MT; group B—CP; group C—HB, FB, MB, LD; and group D—CM, RM, PH, UR. See Table 1 for habitat class abbreviations.

Table 3. Habitat parameters from side-scan-sonar mapping by habitat class. The number of individual habitat features (See Table 1 for abbreviations) and their total area are summarized for all habitats. The area coverage of artificial habitats respective to published Florida artificial reef permit zones is also summarized. Area reported in permit area includes habitats within 100 m of known artificial reef deployments (points); unreported in the permit area are habitats identified in the permit area boundary but outside 100 m.

	Habitat class											
	Geologic				Artificial						Unknown	
	HB	FB	MB	LD	UR	CM	CP	VL	MT	RM	PH	Total
Number of polygons	1,892	692	37	86	1,225	389	236	30	13	782	373	5,755
Total area (km^2)	5.5769	1.0812	0.1327	0.0800	0.0618	0.1362	0.0077	0.0278	0.0010	0.0246	0.0248	7.1546
Area reported inside artificial reef permit zone					0.0081	0.0790	0.0001	0.0125	0.0006	0.0189		0.1192
Area unreported inside artificial reef permit zone					0.0270	0.0489	0.0028	0.0053	0.0004	0.0048		0.0892
Area outside artificial reef permit zone					0.0266	0.0083	0.0048	0.0100	–	0.0009		0.0506

areas of the FWC artificial reef permit areas, most of the mapped artificial habitat had previously been identified or reported, but we identified many unreported artificial reefs. Most artificial habitats exhibited greater coverage within permit areas (i.e., in the FWC database, within 100 m of a documented artificial reef), but unidentified artificial reefs (from side-scan sonar interpretation) and chicken-transport cages also occurred outside the FWC reef permit areas. Less total artificial habitat identified was outside of permit areas (0.051 km^2) than inside (0.208 km^2); however, there was greater coverage of chicken-transport cages outside permit areas (0.005 km^2 versus 0.003 km^2), indicating that these reefs were likely deployed predominantly as private reefs. Since many of these chicken-transport cages had a small footprint (approximately 30 m^2), our limited mapping effort identified hundreds of unreported individual reefs based off the comparative area identified.

Discussion

We demonstrated the utility of incorporating artificial reef surveys into broad-scale (>10,000 km^2), shelf-wide surveys of reef fishes focused primarily on geologic habitats. Most studies comparing reef-fish assemblages between artificial and geologic habitats in the Gulf of Mexico have been limited in spatial extent or have incorporated a limited number of habitat types (Rooker et al. 1997; Patterson et al. 2014; Streich et al. 2017). By examining similarities and differences in reef-fish assemblages between artificial and geologic features, these studies improve understanding of the influence of artificial reefs on marine fish populations (Rooker et al. 1997; Streich et al. 2017). Additionally, these baseline data can help in monitoring changes in fish assemblages associated with environmental perturbations, including invasive species introductions (e.g., lionfishes). Nevertheless, more comprehensive efforts on broad spatial scales are required to most effectively support fishery assessment and management. As did the above-mentioned studies, our study indicated significant differences in assemblage structure and, for certain taxa, size composition between artificial and geologic habitats. Although most species were observed in association with both artificial and geologic habitats, many species were more abundant in artificial habitats, so artificial reef habitats are likely to serve locally as important habitat for a significant proportion of managed reef-fish populations.

Results from this study indicate that artificial reefs can be sampled with BRUVs, although important questions remain as to the overall effectiveness of this approach, including evaluation of gear selectivity (Wells et al. 2008; Patterson et al. 2014). In general, stationary camera gear is more effective at sampling reef-associated species across a wide range of sizes in comparison to traditional hooked gears and traps (Bacheler et al. 2013). Nevertheless, there are concerns regarding deploying remote sampling gear near complex habitats such as sunken vessels, complex artificial reef modules, or naturally forming pinnacles. While most geologic habitats in the northern Gulf of Mexico consist of low-relief reefs covering large expanses, artificial reefs typically have a smaller footprint with higher relief, presenting a twofold challenge to field logistics. Chiefly, it may be difficult to effectively target small-scale reef features with stationary sampling gear deployed remotely from the ocean surface. Second, retrieval of sampling gear near high-relief reef habitats is also challenging. During this study, cameras were deployed 37 times over high-relief (>2 m) artificial habitats, including sunken vessels and tanks and reef modules, as well as six times on ledges (high-relief geologic habitats). All gear was recovered. We also successfully deployed and recovered BRUVs on small-scale geologic features such as depressions (n = 92), many of which were only 3–4 m across. Detectability of fish should also be considered. Many fish may occupy positions above the field of view of the cameras (i.e., higher in the water column) or reside within complex structure out of view of the BRUV (a characteristic of high-relief artificial and geologic reefs). Measures of selectivity and gear effectiveness on reef habitats may therefore benefit from the use of complementary sampling approaches, including active acoustics and ROVs (Dance et al. 2011; Streich et al. 2017).

Evidence suggested that overall fish assemblages differed between artificial and geologic habitats, but the breadth of our sampling effort revealed other differences among several artificial reef habitat groups. All four geologic habitats supported similar reef-fish assemblages that generally differed from those of artificial habitats by more abundant smaller-bodied species such as Blue Angelfish, Bank Sea Bass, Yellowtail Reeffish, and Tattler *Serranus phoebe*. These species are more likely to feed on benthic invertebrates than are the more pelagic and piscivorous species such as Red Snapper or Greater Amberjack (Nelson and Bortone 1996). In contrast, the planktivorous Tomtate (Norberg 2015) occurred in greater densities in artificial reef habitats. Among artificial reef habitats, several distinct habitat groupings were evident. Interestingly, chicken-transport cages supported a unique assemblage characterized by greater abundances of Tomtate, Red Snapper, and lionfishes. Chicken-transport cages, often featuring strong vertical relief (2–3 m; author's personal observation), were generally isolated and surrounded by sand. Because they were most often seen in areas devoid of other reef habitats, they are probably private reefs that few anglers could find. Therefore, these habitats may serve as refugia, experiencing lower fishing rates than other better known reefs, natural or artificial (Addis et al. 2013). Further information is needed to support or refute this assertion, however, as length frequency data from Red Snapper indicated that juveniles also may recruit to these types of habitats (Szedlmayer and Conti 1999). Unidentified depressions, initially considered similar in origin to potholes excavated and maintained by Red Grouper (Coleman et al. 2010; Harter et al. 2017), were found to be chiefly anthropogenic. Red Grouper were never observed in association with these unidentified depressions, which were more likely created by mechanisms such as scouring or excavation from other species. Similarity in assemblage structure among unidentified depressions, unidentified artificial reefs, reef modules, and construction material is notable as it may indicate depressions function similarly to artificial habitats. The ecological function of these habitats warrants further investigation because for several managed reef species (e.g., Red Snapper, Gray Snapper, Vermilion Snapper, and Gray Triggerfish), they typically supported larger individuals.

Habitat

In general, our understanding of the distribution of benthic habitats in the nearshore waters of the northeastern Gulf of Mexico is limited, although general descriptions from Davis (2017) and McBride and Byrnes (1995) summarize sediment composition and large-scale structure. Habitat mapping efforts in support of this project yielded valuable insights into the quantity and distribution of reef habitats in the region. Within the area described in this study (10,885 km^2), more than 600 km^2 has been surveyed and approximately 1% of the area we mapped contained reef habitat. The majority of the reef habitat identified (i.e., flat hard bottom [5.577 km^2]) has little vertical relief, although these habitats often support rich epifaunal assemblages (e.g., sponges, soft corals, etc.). Though not within the scope of this project, the spatial distribution and composition of reef habitat in the area as elucidated in this study does provide insight that will be helpful for planned restoration activities. The large areas of unconsolidated sediment we mapped could be considered for future artificial reef deployments or considered as potential sources for beach renourishment (i.e., the addition of sand to beaches) projects.

The state of Florida has one of the most active artificial reef programs in the United States (FWC 2003), with thousands of artificial reefs in its waters and 3,000 more planned in association with Natural Resource Damage Assessment oil spill recovery efforts (Mille, personal communication). Within the study area, more than 600 artificial reefs have been documented, representing more than 20% of all the artificial reefs known by FWC. Although most reefs occur in artificial reef permit zones established by the FWC, our mapping effort identified hundreds of additional, unreported private reefs on the shelf. When considering that only 5% of the study area has been mapped, well more than 3,000 such habitats may exist within the unmapped portions of the region. Individual private reefs are small in scale, but cumulatively, they may represent a significant component of reef habitat in the region.

Recommendations

This study is an important first step toward incorporating standardized methods for evaluating reef-fish communities across multiple habitats in a large region. Our results highlight the advantages of a randomized approach to habitat mapping in support of fishery-independent surveys. This approach provides reasonable estimates of habitat quantity and quality that are likely representative of those in unmapped areas; therefore, information from these surveys can reasonably be extrapolated to provide regionwide estimates of habitat availability. There is increased demand for finer-scale spatial data to further inform the assessment and management of reef-fishes, and the collection of concurrent fish-habitat data is critical for accurate regionwide estimates of population status (Campbell et al. 2015; Karnauskas et al. 2017; Streich et al. 2017). The sampling gear used in this study (i.e., stereo-video-equipped BRUVs) provided valuable data (counts and lengths) for multiple species across complex habitats in a standardized manner. Moreover, data from this survey have already been used to produce regionwide estimates of size composition of Red Snapper for artificial and geologic reef habitats (Walter et al. 2017). Moving forward, data from FWC and ongoing NMFS surveys will be modeled to generate relative abundance indices that more accurately reflect temporal changes in population abundance by including data from both geologic and artificial reef habitats.

Many unreported artificial habitats have been identified through habitat mapping, and considerations should be made as to how to appropriately incorporate these unreported artificial reefs into the survey design (Dance 2008; Addis et al. 2013). Fishing pressure and fishing mortality are known to differ between reported and unreported artificial reefs (Simard et al. 2016), but with improved navigational and acoustic sensing technology, anglers eventually discover most larger, private reefs. Many of the unreported reefs identified in this study are small and so less likely to be exploited. If these habitats were incorporated into ongoing surveys as a distinct habitat type, information would be generated to better explain their function compared with those of reported and geologic reefs in the region. Artificial reefs are used extensively as restoration tools to mitigate lost angling opportunities, so their function in the Gulf and their relative influence on managed reef species (e.g., Red Snapper, Gray Triggerfish, and Greater Amberjack) merits standardized and routine monitoring to improve stock assessment and management efforts. Our findings indicated that similar reef-fish communities exist on different artificial reef materials, which will contribute to evolving fishery-independent survey design, improve efficiency, and increase confidence in relative abundance estimates.

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