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Characterization and interrelationships of deepwater coral/sponge habitats and fish communities off Florida

John K. Reed, Stacey Harter, Stephanie Farrington, and Andrew David

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Introduction

In 2009 and 2010, the South Atlantic Fishery Management Council (SAFMC) and the U.S. National Oceanographic and Atmospheric Administration (NOAA) through the Magnuson-Stevens Fishery Management Act established eight deepwater, shelf-edge marine protected areas (MPAs) and five deepwater coral habitat areas of particular concern (CHAPCs) along the outer continental shelf and upper slope off the southeastern United States (NOAA 2010). This network of protected areas was established to sustain and restore reef fish populations and to protect deep-sea coral and sponge ecosystems (DSCEs) from destructive fishing practices, such as bottom trawling and the use of longlines of crab pots, which may extend several kilometers with dozens of traps on each one. This study focused on the deepwater protected managed areas on Pourtalès Terrace, south of the Florida Keys, which includes the East Hump MPA and the Pourtalès Terrace CHAPC, and documented the benthic habitats, fish communities, and benthic macrofaunal communities associated with deepwater, high-relief geological features.

In September 2011, a 3-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. The NOAA ship R/V *Nancy Foster* and the University of Connecticut's (UCONN) *Kraken 2* remotely operated vehicle (ROV) were used to survey 14 sites inside and outside the MPA and CHAPC on Pourtalès Terrace (Reed et al. 2013a). This is the first detailed quantitative characterization of the deepwater reef habitats and fish communities within these managed areas in the southern Straits of Florida, and the first extensive multibeam sonar mapping of the terrace.

The primary goal of this research was to document and characterize the deepwater benthic habitats and associated fish communities within these newly established managed areas. These data were analyzed specifically to better understand the interrelationships of the fish communities, including commercially and recreationally important species, relative to the DSCE habitats. These data may then be used as a relative baseline to document changes in these areas due to the implementation of fishing restrictions and to monitor the efficacy and health of these newly designated managed areas. These data will be of value to the SAFMC, NOAA Fisheries Service, and NOAA Office of National Sanctuaries for management decisions on these habitats and managed key species.

Methods

Site description: Pourtalès Terrace

Pourtalès Terrace lies in the southern Straits of Florida, south of the Florida Keys, and consists of extensive, high-relief, hardbottom habitat, and essential fish habitat (EFH) covering 3429 km² at depths of 200–450 m (Figure 5.1). The terrace parallels the Florida Keys for 213 km and has a maximum width of 32 km (Land and Paull 2000). The complex karstlike topography of the terrace surface consists of Tertiary limestone of highly phosphatized, biocalcarenite Eocene and Miocene bedrock. High-relief, hardbottom, topographic features consist of a chain of sinkholes extending for ~100 km along the southwest terrace margin, and numerous high-relief knolls and ridges with elevations up to 90 m (Jordan et al. 1964, Malloy and Hurley 1970, Reed et al. 2005).

ROV survey protocol

ROV video and photographic surveys were conducted at each site to ground-truth new multibeam sonar maps, and to quantify and characterize the benthic habitats, fish



Figure 5.1 Map of Pourtalès Terrace showing *Kraken* ROV dive sites from the 2011 NOAA ship R/V *Nancy Foster* cruise. The NOAA bathymetric contour map shows high-relief topography on Pourtalès Terrace. The East Hump MPA site is indicated with a dotted-line polygon; the deepwater CHAPC is indicated with a black polygon; circles indicate dive sites within the CHAPC, squares indicate MPA dive sites, and triangles indicate dive sites outside management areas.

communities, benthic macrobiota, and coral/sponge cover. Shipboard multibeam echo sounder surveys were conducted at dive sites for which there were no previous multibeam sonar maps. The new sonar maps were used to select dive sites, and surveys were conducted with the UCONN *Kraken 2* ROV, which was equipped with digital video and still cameras mounted with parallel lasers for scale, a CTD (conductivity, temperature, and depth recorder), and a manipulator. Each ROV dive was ~1–2 km in length for a duration of 3–4 h and was documented with continuously recording digital video and digital photographs. The ROV used an integrated navigation system that provided real-time tracking of the ROV every 2 s. Georeferenced multibeam TIFF files, obtained from the sonar surveys, were provided as background files to display target sites and geological features of interest to aid in ROV navigation. All data documentation (digital still images, video, and dive annotations) was georeferenced to the ROV position by matching the time and date to the ROV navigation files.

Fish surveys

An on-screen display video overlay recorded time, date, ROV heading, and ROV depth. The video was digitally recorded continuously throughout each dive from surface to surface. The video camera was typically angled downward ~30° from the horizontal to record fish aggregations and habitat, both near and far to the horizon. The protocol for the fish analyses was to divide the continuous video into 5 min segments, or whenever there was a change in habitat type, whichever came first. Consequently, each video segment consisted of only one habitat type. These habitat designations are described below in the benthic analyses (see Benthic habitat characterization section). During each ROV dive, all fish were identified to the lowest taxonomic level possible and counted. The total distance (km) of each dive was used to calculate the linear density (number of individuals per kilometer) of each fish species. The video camera angle precludes an accurate calculation of areal density of the fish (i.e., number per square kilometer); however, we estimate that the field of view width was generally about 10 m, and most fish were identified within a 5 m distance. So the densities listed in Table 5.1 could be multiplied by 0.1 to estimate the number of fish per square kilometer (based on an average 10 m wide field of view).

Benthic macrobiota characterization

Photographic transects were conducted throughout each ROV dive using the digital still camera directed vertically downward (or as perpendicular as possible to the substrate). The camera was equipped with two parallel lasers (10 cm apart) for scale. In general, two to four digital images were recorded per minute. Each image filename was coded with the corresponding UTC time and date code (using Stamp 2.8 by Tempest Solutions), which was imported into Microsoft Access 2010 and linked to the ROV navigation data using the date/time field of each image. Poor and unusable photos (e.g., blurred, black, off-bottom) or overlapping photos were not included in the analyses. The benthic macrobiota were quantified by analyzing the images for each dive using three measures: (1) species occurrence (presence/absence), (2) percentage of cover of benthic biota, and (3) density of benthic biota.

Percentage of cover of 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, deepwater surveys in this region. Fifty random points overlaid on each image with CPCe were identified as to substrate type and associated benthic biota, and then percentage of cover was calculated. The density of the benthic biota was determined by using the parallel lasers for scale and CPCe to calculate the area of each image. All benthic macrobiota (usually >3 cm total length) were then identified to the lowest taxon level possible, counted, and density calculated (number of organisms per square meter). For this report we used the term "coral" as defined by the NOAA Deep-Sea Coral Program (Partyka et al. 2007) as including hard or stony corals (Scleractinia), other taxa with solid calcareous skeletons (hydrozoan lace corals [Stylasteridae]), and nonaccreting taxa such as gorgonians (Octocorallia) and black corals (Antipatharia).

Benthic habitat characterization

Each ROV dive was divided into transects based on several habitat descriptors that were used as factors to characterize and define the benthic habitats. These factors were used to plot percentage of cover and density of benthic macrobiota and density of fish, and to plot

			_	_			-	Dive	e site						
Scientific name	Common name	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Acropomatidae	Lanternbelly											8.6			
<i>Anthias nicholsi</i> Firth, 1933	Yellowfin bass	344.4	171.9	92.6	9.7	5.2	12.7	2.4	66.1			10.0			743.2
<i>Anthias woodsi</i> Anderson and Heemstra, 1980	Swallowtail bass														1.1
Anthiinae	Anthiid	100.0	338.8	203.7	228.4	47.0	246.0	27.6	373.9		15.8	12.9			475.8
<i>Antigonia capros</i> Lowe, 1843	Deepbody boarfish	75.9	21.5	167.9	178.7	1.5	75.4	3.3	8.7		0.9	8.6			5.3
<i>Bathypterois</i> grallator (Goode and Bean, 1886)	Tripod fish									1.3					
<i>Beryx decadactylus</i> Cuvier, 1829	Red bream												3.8		
<i>Brotula barbata</i> (Bloch and Schneider, 1801)	Bearded brotula								0.9						
<i>Caulolatilus microps</i> Goode and Bean, 1878	Blueline tilefish	3.7	3.3	2.5			7.1	3.3	11.3						2.1
<i>Chaetodon sedentarius</i> Poey, 1860	Reef butterflyfish				0.6										
<i>Chaunax</i> sp. Lowe, 1846	Gaper														
<i>Chaunax stigmaeus</i> Fowler, 1946	Redeye gaper	1.9													
<i>Chlorophthalmus</i> <i>agassizi</i> Bonaparte, 1840	Shortnose greeneye			7.4		0.7					14.0	42.1	3.8		

Table 5.1 Fish Densities Counted at Each Kraken 2 ROV Dive Site on Pourtalès Terrace

Chapter five:

Interrelationships of deep coral/sponge habitats and fish communities

								Dive	site						
Scientific name	Common name	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Congridae <i>Cyttopsis rosea</i> (Lowe, 1843)	Conger eel Rosy dory	1.9								5.0		0.7		2.3	
Decodon puellaris (Poey, 1860)	Red hogfish		0.8			1.5	2.4	1.6	0.9			0.7			
Diodontidae	Pufferfish				0.6										
Emmelichthyidae	Rover			14.8	3.2	5.2									
<i>Epigonus</i> sp. Rafinesque, 1810	Deepwater cardinalfish											8.6			
<i>Etelis oculatus</i> (Valenciennes, 1828)	Queen snapper				0.6	2.2					0.9				
<i>Gephyroberyx</i> <i>darwinii</i> (Johnson, 1866)	Big roughy	13.0	4.1	9.9		91.0	5.6	26.8	24.3		0.9	25.7			6.3
<i>Gymnothorax</i> <i>funebris</i> Ranzani, 1839	Green moray				0.6										
Gymnothorax polygonius Poey, 1875	Polygon moray								0.9						
<i>Gymnothorax</i> sp. Bloch, 1795	Moray eel								0.9						
<i>Helicolenus dactylopterus</i> (Delaroche, 1809)	Blackbelly rosefish	57.4	7.4	8.6	2.6	2.2	7.1	5.7	7.8		19.3	11.4	6.8	4.6	54.7
<i>Hemanthias vivanus</i> (Jordan and Swain, 1885)	Red barbier	5.6	0.8				7.9		4.3			2.1			2.1

Table 5.1 (Continued) Fish Densities Counted from ROV Video Surveys on Pourtalès Terrace

<i>Hyperoglyphe</i> <i>perciformis</i> (Mitchill, 1818)	Barrelfish					20.1			0.9			0.7			
Hyporthodus niveatus (Valenciennes, 1828)	Snowy grouper	25.9	8.3	2.5	10.3	10.4	6.3	8.1	5.2			0.7			12.6
Jeboehlkia gladifer Robins, 1967	Bladefin bass	1.9	0.8			0.7			1.7		1.8				
<i>Laemonema</i> <i>barbatulum</i> Goode and Bean, 1883	Shortbeard codling	38.9	3.3	4.9	0.6	2.2	19.8	0.8	3.5	1.3	0.9	6.4	14.3	10.7	26.3
<i>Laemonema</i> <i>melanurum</i> Goode and Bean, 1896	Codling													9.2	
<i>Laemonema</i> sp. Günther, 1862	Morid cod	11.1	4.9		1.3		1.6	10.6	3.5		0.9	21.4	34.6	20.6	62.1
<i>Leucoraja lentiginosa</i> (Bigelow and Schroeder, 1951)	Speckled skate									1.3					
Lophiodes beroe Caruso, 1981	Goosefish													0.8	1.1
<i>Lutjanus vivanus</i> (Cuvier, 1828)	Silk snapper				0.6										
Macroramphosus scolopax (Linnaeus, 1758)	Longspine snipefish	3.7	1.7			1.5	8.7	4.3				7.9			8.4
<i>Merluccius albidus</i> (Mitchill, 1818)	Offshore hake												0.8		
Muraenidae	Moray				0.6				0.9		0.9				
<i>Nezumia</i> sp. Jordan and Starks, 1904	Grenadier									2.5			65.4	42.7	
,														(cor	itinued)

								Dive	site						
Scientific name	Common name	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Ophidiidae	Cusk-eel												3.0	3.1	
<i>Oxynotus centrina</i> (Linnaeus, 1758)	Angular roughshark														1.1
<i>Pagrus pagrus</i> (Linnaeus, 1758)	Red porgy								0.9						
Parahollardia lineata (Longley, 1935)	Jambeau						0.8								
<i>Peristedion miniatum</i> Goode, 1880	Armored searobin									1.3					
Plectranthias garrupellus Robins and Starck, 1961	Apricot bass		3.3	2.5	18.1	6.0	5.6		20.0		1.8				
<i>Polymixia</i> sp. Lowe, 1836	Beardfish												45.1		
<i>Priacanthus arenatus</i> Cuvier, 1829	Bigeye				1.9										
Prognathodes aya (Jordan, 1886)	Bank butterflyfish				1.3										
Prognathodes guyanensis (Durand, 1960)	French butterflyfish				1.3										
Pronotogrammus martinicensis (Guichenot, 1868)	Roughtongue bass		52.1	98.8	587.1	22.4	119.8		23.5		67.5				

Table 5.1 (Continued) Fish Densities Counted from ROV Video Surveys on Pourtalès Terrace

<i>Raja</i> sp. Linnaeus, 1758	Skate											0.7			
Rajidae	Skates													0.8	
Scyliorhinidae	Catshark							0.8					0.8		1.1
<i>Scyliorhinus meadi</i> Springer, 1966	Blotched catshark													3.8	
<i>Scyliorhinus retifer</i> (Garman, 1881)	Chain catshark	1.9													
Seriola dumerili (Risso, 1810)	Greater amberjack				0.6						4.4				
<i>Seriola rivoliana</i> Valenciennes, 1833	Almaco jack				0.6						0.9				
<i>Seriola</i> sp. Cuvier, 1816	Amberjack	9.3			7.1						4.4				
Serranidae	Sea bass														3.2
<i>Synchiropus</i> sp. Gill, 1859	Dragonet				0.6										
<i>Torpedo nobiliana</i> Bonaparte, 1835	Atlantic torpedo							0.8							
<i>Urophycis</i> sp. Gill, 1863	Phycid hake						0.8								
Total density		696.5	623.0	616.1	1057.0	219.8	527.6	96.1	560.1	12.7	135.3	169.2	178.4	98.6	1406.5
Total number of species		16	15	12	23	16	16	13	20	6	15	17	10	10	16

Note: All fish were identified from each ROV dive to the lowest taxonomic level possible and counted. The total distance (km) of each dive was used to calculate the linear density (number of individuals per kilometer) of each fish species.

transects on the multibeam sonar maps in ArcGIS 10.0. The factors included the following habitat descriptors:

- Geomorphology: The geological feature generally was defined from the multibeam sonar images, for example, mound-top (peak of rock mound), mound-slope (flank of rock mound), mound-wall (steep, near vertical upper slope of rock mound), *Lophelia* mound (deepwater reef, composed chiefly of the branching azooxanthellate scleractinian coral *Lophelia pertusa*), sinkhole (deepwater sinkhole), valley (flat, low slope areas off reef, typically at the base of the mounds), pavement (flat, low-relief hardbottom areas), and mound-deep (isolated mound separate and at the base of the primary rock mound).
- 2. Substrate: This was a subset of the Southeastern United States Deep-Sea Corals (SEADESC) habitat categories that were developed by the NOAA Deep-Sea Coral Program for use in analysis of deep-sea coral dive surveys (Partyka et al. 2007). On Pourtalès Terrace, the substrate descriptors included soft bottom (unconsolidated sand/mud), and the following hardbottom types: rock pavement, pavement with ledges, pavement with sediment veneer, rock wall, and *L. pertusa* coral. These are illustrated with ROV images in Figure 5.2.
- 3. Depth: The depth range of the transect or dive.
- 4. Slope: Slope was estimated from the ROV video: flat=0°-5°, low=5°-30°, moderate=30°-60°, high (wall)=60°-90°.

Management status was also used to characterize a dive site, that is, whether it was within the protected managed areas (MPA or CHAPC) or outside the protected areas (no protection).

Statistical analyses

Multivariate analyses were used to assess differences in benthic faunal assemblages and fish communities among the dive sites and habitat factors. All analyses were conducted with PRIMER 6.1.13 analytical software based on guidelines outlined in Clarke and Warwick (2001) and Clarke and Gorley (2006). The ROV transects were characterized by the habitat factors described above (geomorphology, substrate, depth, and slope). In addition, the dive sites were compared on the basis of management status (i.e., protected [within the MPA or CHAPC] or unprotected). For the benthic analyses, the number of individuals for each species of benthic macrobiota was counted in each image, then summed by transect, and divided by the total area of the digital still images examined within that transect. This resulted in the density of each benthic species (number per square meter) by transect. The densities were then averaged in PRIMER by site and habitat factors and square-root transformed to reduce the effect of area on the similarity coefficients.

For analyses of the fish communities, the number of individuals of each species was counted within each transect, summed for the entire transect, and then divided by the total distance of that transect. This resulted in the linear density of each species by transect (number per kilometer). The counts were then averaged in PRIMER by site and habitat factors and presence/absence transformed to reduce the dominating influences of abundant species to the similarity matrix. Similarity among dive sites and habitat factors for both fish and benthic biota were then calculated separately using the S17 Bray-Curtis similarity coefficient. A nonmetric multidimensional scaling ordination (NMDS) plot and a dendrogram with group-average linking were created to depict the results of a



Figure 5.2 (See color insert) Representative habitats found on Pourtalès Terrace from ROV dive images. (a) Habitat: deepwater *L. pertusa* coral mound; live coral colony (~1 m diameter), black coral (*Leiopathes* sp.), and mora codling (*Laemonema melanurum*); CHAPC, Site 25, 509 m. (b) Habitat: flat rock pavement with low-relief ledges; big roughy (*G. darwinii*), anemones (*Actinoscyphia* sp.), various gorgonians, hydroids, and crinoids; CHAPC, Mound no. 311 Wall, Site 23, 302 m. (c) Habitat: mound-slope, rock pavement; dense cover of Stylasteridae corals and numerous demosponge species; HAPC, Mound no. 311, Site 22, 233 m. (d) Habitat: flat pavement with sediment; blue-line tilefish (*C. microps*), stylasterid corals; CHAPC, Alligator Bioherm no. 4, Site 18, 183 m. (e) Habitat: mound-slope and edge of mound; dense cover of Stylasteridae coral; MPA, NW Mound, Site 14, 191 m. (f) Habitat: soft bottom; tripod fish (*B. grallator*); unprotected, Pourtalès Escarpment, Site 21, 836 m. (g) Multibeam sonar of CHAPC, Sinkhole site (Site 24) and *Lophelia* mound site (Site 25); dive tracks are shown by solid red lines. (h) Multibeam sonar of CHAPC, Alligator Bioherm no. 3 (Site 20).

concurrent similarities profile (SIMPROF). Similarity percentages (SIMPER) was utilized to determine which species contributed to the dissimilarities between the group pairs. In addition, one-way ANOVA was used to test for differences in the fish densities of the four most abundant commercially and recreationally important species among the management areas.

Results

In September 2011, the 3-week CIOERT Florida Shelf-Edge Exploration II Cruise with the NOAA ship R/V Nancy Foster resulted in 14 ROV dives on Pourtalès Terrace for a total bottom time of 52 h, covering 16.02 km at depths ranging from 154 to 838 m (Figure 5.1). A total of 2866 *in situ* digital images were recorded, including 2253 transect photographs that were used for the quantitative benthic data analyses. Ten sites were surveyed on Pourtalès Terrace with multibeam sonar by the survey team of the R/V Nancy Foster and covered a total of 397.1 km². Except for one site, these sites had not been previously surveyed with high-resolution, multibeam sonar. Three sonar maps were also made for the first time of areas inside the recently designated East Hump MPA site. These new sonar maps enabled the discovery of many new features and EFH. In particular, four deepwater sinkholes were discovered where only one had been previously known (Marathon Sinkhole, Site 24). We also discovered a large deepwater *Lophelia* coral mound, which is the southernmost Lophelia mound known in U.S. waters (Site 25). The ROV dives documented and characterized 14 sites on Pourtalès Terrace including 11 within the CHAPC, of which four were within the East Hump MPA; three dives were outside the protected areas (Table 5.2).

Habitat characterization

A SEADESC Level II Report describing each dive site from this cruise was submitted to NOAA as an unpublished technical report (Reed et al. 2013a). In general, many of the sites were high-relief, flat-topped mounds consisting of eroded Tertiary rock. These were somewhat similar in shape to buttes on land but not as large as seamounts or guyots. Each ROV dive was approximately 1–2 km in length, crossing and surveying a mound or other geological feature. The ROV dives over these topographical features were divided into transects based on various habitat factors. These included geomorphology descriptors, which consisted of mound-slope (the lower slope of a mound was typically inclined at 10°–30° to 30°–60°), mound-wall (typically the upper slope was nearly vertical [60°–90°] and undercut with a series of ledges, almost like a pagoda), and mound-top (flat top or rounded peak). A zone of deepwater sinkholes was discovered at one site (Site 24) that was quite distinct from the mound habitats. Another dive discovered a deepwater *Lophelia* coral mound (Site 25) that also had distinct habitat, benthic fauna, and fish communities. The Pourtalès Escarpment site (Site 21), which was the deepest site and entirely soft bottom, was also distinct in benthic fauna and fish. Examples of the various types of geomorphology and substrate are shown in Figure 5.2.

Site descriptions: Sites within the East Hump MPA (also within CHAPC)

The majority of the newly designated East Hump MPA lies within the Pourtalès Terrace CHAPC. Four ROV dives made within the MPA were the first visual surveys (ROV or submersible) to characterize this MPA. These are described below.

East Hump MPA, Northwest Peak (Site 14). The multibeam sonar showed a large 25 m tall, flat-topped mound (180 m depth at top, 205 m at base), oriented N–S and nearly 1.8 km long. The ROV traveled up the southeast slope, then north across the top, covering about half of the top plateau. The lower slope was 30° rock and sediment, and the upper slope was nearly vertical with ledges of up to 2 m vertical relief. The top edge and ledges had dense cover of stylasterid coral and diverse demosponges.

ROV site number	Site name	Managed area	Depth (m)	% Hardbottom	Fish, species (no.)/ density (number/ km)	Benthic biota, density (number/ m ²)	% Cover, benthic biota	% Cover, coral	% Cover, gorgonians	% Cover, Antipatharia	% Cover, Porifera
13	Jordan Site F	None	183–284	100	16/696	4.29	4.4	1.7	0.2	1.1	0.4
14	NW Mound	MPA	182-213	85.1	15/623	8.38	5.8	2.5	0.07	0	1.9
15	SE Mound	MPA	207-281	100	12/616	10.62	10.7	0.8	0.1	0	7.7
16	Tennessee Bioherm 1	MPA	182–269	100	23/1057	25.1	20.4	4.5	1	0	14.2
17	Tennessee Bioherm 1, East Wall	MPA	203–269	100	16/220	17.79	18.1	1.03	4.08	0	11.9
18	Alligator Bioherm 4	HAPC	176–229	87.7	16/528	11.98	7.2	1.6	0.02	0	4.6
19	Alligator Bioherm 4, East Wall	HAPC	203–249	87.4	13/96	11.94	10.6	1.7	4.1	0.1	2.8
20	Alligator Bioherm 3	HAPC	163–233	98.3	20/560	18.23	16.6	5.7	2.1	0.03	5.2
21	Pourtalès Escarpment	None	817-838	1.5	6/13	0.07	0.2	0	0	0	0
22	Mound 311	HAPC	154-320	100	15/135	29.24	22.2	9	0.02	0	11.8
23	Mound 311, SE Wall	HAPC	280–315	97.1	17/169	2.96	3.9	0.1	0.9	0.08	1
24	Sinkhole	HAPC	473-494	100	10/178	30.44	13.8	0.8	8.6	0.7	2.4
25	<i>Lophelia</i> Mound	HAPC	467–574	99.5	10/99	13.09	23	15	3.3	0.8	1.6
26	Key West Bioherm	None	195–255	96.4	16/1406	11.69	6.5	1.4	0.8	0.3	0.6

Table 5.2 Summary of ROV Video/Photographic Survey Sites on Pourtalès Terrace

Note: Managed areas are areas inside the protected management areas (MPA and CHAPC) or outside (None); fish density (number of individuals per kilometer) and number of species from video analysis; density and percentage of cover of benthic biota from CPCe Point Count analysis of quantitative photo transects.

Chapter five:

Interrelationships of deep coral/sponge habitats and fish communities

East Hump MPA, Southeast Peak (Site 15). The multibeam sonar showed a mound near the border of the MPA. The NW–SE oriented mound was 941 m long and 600 m wide, with a depth of 197 m at the top, and a trench scoured to 292 m at the northeast base. The south slope was paved with sediment, some boulders, and ledges; the north face was a 60° – 90° rock slope with numerous ledges. The benthic cover was dense stylasterid coral, diverse demosponges, hexactinellid sponges, and black coral. Fishing line was observed on the coral, slopes, and peak of the mound.

East Hump MPA, Tennessee Bioherm no. 1 (Site 16). The multibeam survey showed Tennessee Bioherm no. 1 as an elongated mound (170 m depth at top), oriented N–S and 1450 m long, with a depth of 256 m at the south base and 322 m in a deep scoured trench at the NE base. The south face of the mound was a 10°–30° rock pavement slope and ledges; the east slope was 45° with 1–2 m ledges; the top was a rounded rock peak covered with stylasterid coral and rubble. The dominant fauna were dense and diverse demosponges, hexactinellids, stylasterids, and plexaurid gorgonians.

East Hump MPA, escarpment SE of Tennessee Bioherm no. 1 (Site 17). The multibeam sonar showed a 3 km long escarpment oriented NE–SW; the top was 190 m deep and at the base of the wall was a trench at a depth of 270 m. The east face was a 30°–60° rock slope, with steep facies, ledges, and boulders. Dense biota included demosponges, stylasterid coral, and primnoid gorgonians.

Site descriptions: Sites inside the Pourtalès Terrace CHAPC (but outside the East Hump MPA)

In addition to the four MPA sites, seven additional sites were surveyed within the Pourtalès CHAPC (Sites 18–20, 22–25). These included a variety of high-relief mounds, escarpments, and a newly discovered deepwater *Lophelia* coral reef and deepwater sinkholes. Some of these sites were qualitatively described in Reed et al. (2005) and were described in more detail in the NOAA technical report (Reed et al. 2013a). Newly surveyed sites are described below.

Escarpment east of Alligator Bioherm no. 4 (Site 19). The multibeam sonar showed a long escarpment at the easternmost end of the humps region of Pourtalès Terrace (outside the MPA). At the base of the escarpment was a scoured depression, 246 m maximum depth, and the top of the wall was 186 m deep. The slope was 45°–60° rock with vertical escarpments and ledges. Biota consisted of areas with nearly 100% cover of living stylasterid coral and stylasterid rubble, dense primnoid gorgonians, 1.5 m tall black coral, and dense sponges. Large amounts of fishing line were observed on the bottom.

Mound no. 311 (Site 22). This site was first discovered and dived on by one of us (JKR) with the Johnson-Sea-Link submersible in 2006. The multibeam sonar deployed from the R/V Nancy Foster showed an elongate mound (minimum depth 150 m) oriented NW–SE, 920 m long, with a maximum depth of 374 m at the SE base. The east face was very steep from 40°–60° rock slope to 80°–90° rock escarpments and ledges. The cover was dense in areas, with up to 100% living stylasterid coral and stylasterid rubble. Other hard corals included *Madrepora* sp., *Madracis* sp., and *Dendrophyllia* sp. This site appeared the most heavily impacted by fishing as few large fish were present and the mound was criss-crossed with fishing line and tackle.

Marathon Sinkhole (Site 24). The Marathon Sinkhole was first discovered in the 1950s and surveyed by Jordan (1954) and then later described by Land and Paull (2000) using the Navy NR-1 submarine to fly above it. Reed et al. (2005) entered the sinkhole with *Johnson-Sea-Link* submersible dives, but only one sinkhole was known at this site at that time. The multibeam sonar deployed from the R/V *Nancy Foster* in 2011 revealed three additional sinkholes within 900 m of the Marathon Sinkhole. Sinkhole 1 (the actual Marathon Sinkhole) is a double sinkhole, 900 m in diameter E–W, with a maximum depth of 527 m at the base, and 455 m at the top north rim. Sinkholes 2, 3, and 4 range in diameter from 400 to 525 m, with a maximum depth of 529 m (Figure 5.2g). The upper rims of the sinkholes consisted of very rugged, karstlike limestone with undercut ledges and vertical escarpments. The substrate between the sinkholes was flat rock pavement with low-relief ledges and small boulders. This area was dominated by demosponges, dense gorgonians, and black coral. Scleractinian hard corals occurred around the rims and included *L. pertusa, Enallopsanmia profunda, Madrepora* sp., and *Dendrophyllia* sp. Fish included beardfish (*Polymyxia* sp.), sharks, and red bream (*Beryx decadactylus*). The commercially fished golden crab (*Chaceon fenneri*) was also observed.

Lophelia coral mound (Site 25). The multibeam sonar showed an extensive escarpment south of the sinkholes (Figure 5.2g). At the base of this escarpment are several mounds. One surveyed mound was a 48 m tall *Lophelia* coral bioherm, with a depth of 548 m at the south base, and 500 m at the peak. This is the southernmost *Lophelia* coral reef yet discovered in U.S. waters. It appears from the multibeam sonar that other coral mounds may be present and even common along this outer edge of Pourtalès Terrace. The peak and upper slope of the coral mound were covered with thickets of live *L. pertusa*, in 5–8 m long hedgelike rows and up to 50 cm tall, and coral rubble. Hexactinellid sponges and black coral were common, but few fish other than mora codling (*Laemonema* sp.) were observed. The escarpment to the north was smooth rock pavement, with rock slabs, cobble, and outcrops. Sponges and gorgonians were common.

Site descriptions: Sites outside the CHAPC

Three dives were made on Pourtalès Terrace outside the CHAPC boundaries. Extensive areas of high-relief topography are apparent in NOAA regional bathymetric charts extending all along the terrace to the west of the CHAPC boundary (Figure 5.1). Two dives south of Key West (Sites 13 and 26) were in this area of high relief and may be characteristic of the other unprotected areas on the terrace; they appear to provide coral and sponge habitat as well as EFH. The Magnuson-Stevens Act defines EFH as waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity. Site 21, which was the deepest (838 m) of the dive sites, was on the outer edge of Pourtalès Terrace Escarpment near the boundary of the exclusive economic zone where the NOAA bathymetric contour chart shows a steep slope from 700 to 850 m. Because this site lies within the axis of the Florida Current, which may exceed 2 m s⁻¹, tracking and maneuvering of the ROV was difficult. Consequently, we were unable to reach the intended location. The seafloor at the dive site was flat sandy-mud bottom where we recorded video of royal red shrimp (*Pleoticus robustus*), tripod fish (*Bathypterois grallator*), mora codling, armored sea robin (*Peristedion miniatum*), and red deep-sea crab (*Chaceon quinquedens*).

Benthic macrobiota

Some common taxa were identified to genus or species level from the visual recordings, but many could only be identified to a higher taxonomic level such as family, class, order, or even phylum. Sponges, gorgonians, and black coral in this region are especially difficult to identify without a specimen in hand. Many deepwater species in this region appear nearly identical, such as fan sponges that may be in different orders or even classes (i.e., Demospongiae or Hexactinellida). A total of 146 taxa were identified from the quantitative photograph transects and were used for CPCe percentage of cover and density analyses (see Reed et al. 2013a for a complete list, percentage of cover, and densities). These included 58 taxa of Porifera and 47 Cnidaria, which included the following corals: Scleractinia (*L. pertusa, Madracis myriaster, Madrepora oculata, Solenosmilia variabilis*, and Dendrophylliidae); Stylasteridae (five species); Octocorallia (16 gorgonian taxa including, *Ellisella* spp., Plexauridae, Isididae, *Muricea* spp., *Paramuricea* spp., *Plumarella* spp., and Primnoidae); and Antipatharia (*Bathypathes alternata, Leiopathes* spp., *Stichopathes lutkeni*, and *Tanacetipathes* spp.). Noncoral Cnidaria included Actiniaria, Zoanthidea, Cerianthidae, Alcyonacea (Nephtheidae, *Anthomastus* sp., *Capnella* sp.), and Hydroidolina.

The dominant sponges included the following Demospongiae (recently revised by Redmond et al. 2013): order Tetractinellida (*Geodia* spp., including three new species [Paco Cardenas, Evolutionary Biology Center, Uppsala University, Sweden, personal communication], *Pachastrella* sp., and the lithistids Corallistidae, *Theonella* spp., *Leiodermatium* sp.); Hadromerida (encrusting Spirastrellidae); Poecilosclerida (Raspailliidae, encrusting *Hymedesmia* sp.); Halichondrida (*Auletta* sp., *Topsentia* sp., *Phakellia* sp.); and Homoscleromorpha (*Plakortis* spp.). Glass sponges, class Hexactinellida, included *Aphrocallistes beatrix beatrix*, *Hexactinella* sp., *Iphiteon* sp., and a new genus *Nodastrella* gen. nov. (Dohrmann et al. 2012).

Other benthic macrobiota included Annelida, Mollusca, Arthropoda, Bryozoa, Echinodermata, Hemichordata, and Ascidiacea. Some of the shallower mound tops also included algae: Cyanobacteria, Chlorophyta, and Rhodophyta (primarily crustose coralline algae). Alligator Bioherm no. 3 (Site 20) had algae on the top plateau of the mound: Cyanophyta (depth 168 m), thin encrusting Chlorophyta (164 m), and Corallinales (encrusting Rhodophyta, 164–172 m). The Key West Bioherm (Site 26) had encrusting green algae at 195 m, and some unidentified coralline red algae at 193–222 m. The deepest algae recorded in the Atlantic were at 268 m for an unidentified crustose coralline, 210 m for *Ostreobium* sp. (Chlorophyta), and 189 m for *Peyssonnelia* sp. (Rhodophyta), all from San Salvador seamount in the Bahamas (Littler et al. 1985).

Density of benthic macrobiota

Table 5.2 lists, for each site, the percentage of cover of hard substrate, density and numbers of fish species, density of benthic macrobiota, and percentage of cover for other dominant benthic taxa (corals, sponges, and gorgonians). The Pourtalès Escarpment site (Site 21) was the only site that was nearly 100% soft-mud bottom; as a result, it had no corals, sponges, or other sessile benthic fauna. All the other sites were predominantly hard bottom (85%–100% cover) with a relatively high percentage of cover of corals, sponges, and numerous motile invertebrates. Percentage of cover of macrobiota on hardbottom sites ranged from 3.9% (Mound no. 311 SE Wall, Site 23) to 23% (*Lophelia* mound, Site 25). Mean percentage of cover for the four MPA dive sites was 13.7%; Tennessee Bioherm no. 1 (Site 16) had the highest cover of the MPA sites (20.4%). Within the seven CHAPC sites (outside the MPA), the greatest percentages of cover were at the *Lophelia* mound (23% cover), Mound no. 311 (22.2%), and Alligator Bioherm no. 3 (16.6%). The lowest percentage of cover on any hardbottom site was at Mound no. 311, SE Wall (3.9% cover).

The greatest cover by scleractinian framework coral was at the *Lophelia* mound site (15% mean cover); however, the dive track also included a pavement valley and a rock mound slope north of the coral mound. The actual mean cover of standing *L. pertusa* on the coral mound itself was 17.8% on top and 19.7% on the slope. The maximum *L. pertusa* cover in a single photographic image was 44%. *L. pertusa* was also found along the edge of the sinkholes (Site 24, 0.13%), along with *M. oculata* (0.06%). Stylasterid coral had relatively high coverage at most sites: 0.7% - 4.1% within the MPA sites, 5.1% at Alligator Bioherm no. 3, and 6.2% on Mound no. 311. The maximum mean stylasterid coral cover was on top of Mound no. 311 (44%). Many of the mound tops were covered with thick layers of stylasterid coral rubble as well as standing live Stylasteridae. Nonscleractinian corals included gorgonians, which were densest at the sinkhole (8.6% cover), the wall east of Tennessee Bioherm no. 1 (4.1%), and Alligator Bioherm no. 4 (4.1%). Antipatharians were present at most sites but in low numbers where present (0.03% - 1.1%). Sponges were common and diverse at most sites (0.4% - 14.2% cover) and were most abundant at the MPA sites.

Benthic macrobiota: Site relationships

Dive sites within and outside the managed areas (MPA and CHAPC) were compared using a nonmetric multidimensional scaling plot of Bray-Curtis similarity for the benthic macrobiota (species densities averaged by site and then square-root transformed) (Figure 5.3). The muddy Pourtalès Escarpment (Site 21), which did not have hardbottom habitat, was removed from the plot because it was such a strong outlier. The remaining sites could be categorized into five statistically different faunal groups; these are shown by letter designations in the plots (SIMPROF, p < .05). All the MPA sites (Sites 14–17) and some of the CHAPC sites (Sites 18–20, 22) clustered together at 40% similarity (Groups B, C, D). The CHAPC sites (Sites 24 and 25), which were considerably deeper (467–574 m), formed a statistically separate group (Group A). The unprotected sites off Key West (Sites 13, 26)



Figure 5.3 Similarity of sites within and outside the protected management areas (MPA and CHAPC) based on the benthic macrobiota densities (nonmetric, multidimensional scaling plot based on the Bray-Curtis similarity matrix calculated from benthic biota densities averaged by site with square-root transformation). Assemblage similarities at 20%, 40%, and 60% are shown. Sites are indicated by numbers; statistically similar groups (SIMPROF, p < .05) are indicated by the same letters (A through E).

were also distinct and comprised a third group (E). The wall off Mound no. 311 (Site 23) was distinct from the other CHAPC sites; it also had the lowest benthic faunal density and percentage of cover.

Pairwise tests using SIMPER showed which species contributed most to the differences between these groups. The group of CHAPC sites showed 70.2 average dissimilarity from the unprotected sites (outside the CHAPC). This dissimilarity was due primarily to the occurrence of the following taxa: sagartiid anemones (contributing 6.3% of the dissimilarity), stylasterid corals 5.8%, unidentified white gorgonians 4.7%, and primnoids 4.7%. The East Hump MPA group and the unprotected group showed 66.2% average dissimilarity, with demosponges contributing 9.8% of the dissimilarity, sagartiid anemones 7.0%, *Hymedesmia* sp. 3.6%, and primnoids 3.5%.

Fish communities: Site relationships

All fish were identified for each ROV dive site to the lowest taxon practicable and counted. The 14 ROV dives covered a 16.02 km distance and video analysis recorded a total of 7273 individual fish consisting of 62 taxa in 38 families (Table 5.1). The number of species per site ranged from six on the mud slope of the Pourtalès Escarpment (Site 21) to 23 at Tennessee Bioherm no. 1 within the MPA (Site 16) (Table 5.2). Excluding the escarpment mud site, the mean density ranged from 96.1 fish per kilometer at Alligator Bioherm no. 4, East Wall (Site 19) to 1406 per kilometer at Key West Bioherm (Site 26). The four MPA sites had 12–23 species per site and densities of 220–1057 fish per kilometer, with Tennessee Bioherm no. 1 supporting the most diverse and dense populations of the four. The seven CHAPC sites had 10–20 species per site and densities of 96–560, with Alligator Bioherm no. 3 the most diverse and dense. It is important to note that the two unprotected, hardbottom sites, both off Key West (Sites 13, 26), had relatively high diversities and densities of fish. The Key West Bioherm, in particular, had the greatest density of fish. Overall, the fish taxa with the greatest mean densities were unidentified anthiins (138 per kilometer), yellowfin bass (97; Anthias nicholsi), roughtongue bass (65; Pronotogrammus martinicensis), deepbody boarfish (36; Antigonia capros), big roughy (14; Gephyroberyx darwinii), and blackbelly rosefish (13; Helicolenus dactylopterus).

Sites within and outside the managed areas (MPA and CHAPC) were compared using a nonmetric multidimensional scaling plot of the Bray-Curtis similarity coefficient using the presence/absence transformation of fish species (Figure 5.4a). Six statistically different groups resulted from the SIMPROF test (p < .05). The letters by the site numbers in the figure indicate the statistically significant groups. The Pourtalès Escarpment site (Site 21) was distinct from the other sites; this site was the deepest and entirely soft bottom. The Sinkhole and *Lophelia* mound sites (Sites 24 and 25, respectively) formed a distinct group (F) and were also considerably deeper than the other CHAPC sites. All the MPA sites (dives 14–17) formed a statistically significant distinct group (D) with CHAPC Sites 18 and 20. The unprotected sites off Key West (Sites 13 and 26) formed a distinct group (A) with the Alligator Bioherm no. 4 wall site (Site 19).

Pairwise tests using SIMPER showed which species contributed the most to the differences between these groups. The East Hump MPA sites showed 61.2 average dissimilarity from the unprotected sites. Roughtongue bass contributed 12.4% to the dissimilarity, yellowfin bass 9.5%, blackbelly rosefish 9.1%, and deepbody boarfish 8.8%. The CHAPC sites and the unprotected sites showed 63.9 average dissimilarity, with yellowfin bass contributing 11.7% to the dissimilarity, blackbelly rosefish 9.9%, and mora codling 8.7%.



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Figure 5.4 Relationship of fish populations with various habitat factors (nonmetric, multidimensional scaling plots based on the Bray-Curtis similarity matrix calculated from fish species data with average presence/absence transformation). Factors included: (a) protection status, (b) geomorphology, (c) substrate, and (d) depth. (a) and (d) are averaged by site; (b) and (c) are averaged by habitat factor among all sites. Assemblage similarities at 20%, 40%, and 60% are shown. Sites are indicated by numbers; statistically similar groups (SIMPROF, *p* < .05) are indicated by the same letters.

Interrelationships of fish communities and habitat

The interrelationships of the fish communities with habitat factors were analyzed with MDS plots of similarity (Figure 5.4b–d). Depth was the most influential factor contributing to fish species composition. The MDS plot of depth (Figure 5.4d) shows two distinct groupings with all the deep dives (Sites 24, 25, 21; depths of 450–850 m) clustering together at 20% similarity. The shallower sites (depths of 150–300 m) also clustered together at 20%. The two depth categories had 87.6 average dissimilarity between them; grenadier (*Nezumia* sp.) contributed to 15.7% of the dissimilarity, mora codling 13%, anthiins 9.7%, and blackbelly rosefish 9.7%.

Geomorphology was the second most influential factor in determining fish species composition (Figure 5.4b). Five statistically different groups resulted from the SIMPROF test (p < .05). Again, Site 21, the soft-bottom site on Pourtalès Escarpment, was distinct from the other sites. The geomorphology classes of *Lophelia* mound, sinkhole, and pavement formed a statistically distinct group (Group B), clustering together at 60% similarity. Valley and mound-deep sites formed another distinct group (C). Mound-slope, mound-wall, and mound-top grouped together at 60% similarity. The mound-top habitat was slightly different in fish composition from the mound-slope and mound-wall (SIMPER). The species responsible for this dissimilarity were higher abundances of deepbody boarfish, roughtongue bass, and yellowfin bass in the mound-top zone.

Substrate was the third most influential factor in fish community composition. The MDS plot (Figure 5.4c) shows two statistically different groups (SIMPROF, p < .05), with pavement/ledges, pavement, pavement/sediment, and rock wall habitats all forming one group (Group A), and the *Lophelia* coral and mud slope habitats forming the other (B). The average dissimilarities between mud slope and the other habitat zones ranged from 92.3 to 98.2 (SIMPER). The species responsible for these differences were conger eel, which was more abundant on the mud slope, and blackbelly rosefish and mora codling, which occurred in greater densities on the pavement and rock wall substrates. Average dissimilarities between the *Lophelia* coral and other habitat zones ranged from 76.0 to 91.4 (SIMPER). The species responsible for these differences were grenadier and mora codling, which were more abundant in the *Lophelia* coral habitat, and blackbelly rosefish, which were more abundant on the pavement and rock wall substrates.

In addition, all commercially and recreationally important species, including managed species, were analyzed separately. Although they had relatively lower densities than many of the smaller-sized species, these species are important to the SAFMC and NOAA fisheries for management purposes. Eleven commercially and recreationally important fish species were observed, and their densities for each site are listed in Table 5.3. Currently, species that are targeted and managed by the fishery include: blueline tilefish (*Caulolatilus microps*), snowy grouper (*Hyporthodus niveatus*), queen snapper (*Etelis oculatus*), red porgy (Pagrus pagrus), greater amberjack (Seriola dumerili), almaco jack (Seriola rivoliana), and silk snapper (*Lutjanus vivanus*). All of the species in Table 5.3 are represented in the National Marine Fisheries Service landings statistics, with the exception of big roughy. A one-way ANOVA was used to determine significant differences in fish densities among the management areas for the four most abundant targeted species (blueline tilefish, big roughy, snowy grouper, and blackbelly rosefish) (Figure 5.5). The three deeper sites (21, 24, and 25; 450–850 m depths) were omitted from this analysis as no commercial or recreational fish species were observed. The remaining 11 dives compared were between depths of 150 and 300 m. There was no significant difference (p = .39) in mean densities of blueline tilefish among management areas; however, in general, the CHAPC sites had the greatest

ROV site number	Managed area	Blueline tilefish	Big roughy	Snowy grouper	Queen snapper	Blackbelly rosefish	Barrelfish	Red porgy	Greater amberjack	Almaco jack	Red bream	Silk snapper
13	None	3.7	13	25.9		57.4						
14	MPA	3.3	4.1	8.3		7.4						
15	MPA	2.5	9.9	2.5		8.6						
16	MPA			10.3	0.6	2.6			0.6	0.6		0.6
17	MPA		91	10.4	2.2	2.2	20.1					
18	CHAPC	7.1	5.6	6.3		7.1						
19	CHAPC	3.3	26.8	8.1		5.7						
20	CHAPC	11.3	24.3	5.2		7.8	0.9	0.9				
21	None											
22	CHAPC		0.9		0.9	19.3			4.4	0.9		
23	CHAPC		25.7	0.7		11.4	0.7					
24	CHAPC					6.8					3.8	
25	CHAPC					4.6						
26	None	2.1	6.3	12.6		54.7						

Table 5.3 Densities (number of individuals per kilometer) of Commercially and Recreationally Important Fish Species for Each ROV Dive Site

Note: Managed areas are inside the protected management areas (MPA and CHAPC) or outside (None). See Table 5.1 for scientific names.



Figure 5.5 (a–d) Mean density (standard error is indicated by the vertical line on each bar) of commercially and recreationally important fish species from ROV dive sites within and outside the East Hump MPA, CHAPC, and nonprotected areas on Pourtalès Terrace. p values (p < .05) indicate statistically significant differences between the groups.

densities and the MPA sites had the lowest densities. Mean densities of big roughy were highest in the protected areas, but variances were too great to make it significant (p=.77). Mean densities of snowy grouper and blackbelly rosefish, however, were significantly greater (p=.016 and p=.027, respectively) in the nonprotected sites than in the protected areas. It is important to note that the MPA has only been in effect since 2009 and the CHAPC since 2010. These data will be helpful as relative baseline data for future surveys by SAFMC and NOAA Fisheries Service.

Discussion

Deepwater reef habitat and fish surveys off southeastern United States

Various habitat classifications have been used in surveys of aquatic ecosystems, that is, the Coastal and Marine Ecological Classification Standard (FGDC 2012), the EUNIS system in Europe (Connor et al. 1997), the Integrated Marine and Coastal Regionalisation for Australia (IMCRA 1998), and the Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979). No one classification is sufficient for all deepwater reef habitats. The Cowardin classification system was adopted by the U.S. Fish and Wildlife Service, and although the title implies use for deepwater habitats, "deepwater" is defined as areas where surface water is permanent and often deep. More recently in the United States, NOAA (Partyka et al. 2007) developed a classification system for deepwater coral reefs termed the Southeastern United States Deep-Sea Corals (SEADESC) Initiative to characterize areas of deep-sea corals. Auster et al. (2005) developed a system for seamounts. Regardless of the habitat classification used, it is important to include both geological and biological components. We have applied pertinent SEADESC codes as well as descriptors from other classifications for habitat and geological descriptions that we also have used on other monitoring surveys of shelf-edge MPA and CHAPC sites off the southeastern United States. In this study, we used four factors of habitat classification for analyzing the interrelationships of the fish communities; these included geomorphology (e.g., sinkhole, Lophelia coral mound, rock mound-top, mound-slope, mound-wall), substrate (e.g., soft bottom, rock pavement, rock escarpment, coral), depth, and slope. In addition, we considered the management status of the site as another factor, that is, whether it was within the protected managed areas (MPA and CHAPC) or outside the protected areas (no protection).

Several studies have characterized the deepwater reef habitats and associated fish communities off the southeastern United States. Each has used various habitat classifications and most have been concentrated in the South Atlantic Bight of the Blake Plateau from north Florida to North Carolina (Sedberry 2001, Ross and Quattrini 2007, Fraser and Sedberry 2008, Schobernd and Sedberry 2009). In submersible surveys of deepwater *Lophelia* reefs from North Carolina to north Florida (356–910 m depth), Ross and Quattrini (2007) quantified three habitat types to compare fish distributions: prime reef (*Lophelia* coral), transition zones, and off reef. They documented 99 fish species; the prime reef habitat was characterized by mora codling (*Laemonema melanurum*) (21% of total), roughtip grenadier (*Nezumia sclerorhynchus*) (17%), red bream (14%), and blackbelly rosefish (10%). Several species (e.g., swallowtail bass [*Anthias woodsi*], red bream, American conger [*Conger oceanicus*], and cutthroat eel [*Dysommina rugosa*]) demonstrated specificity to deep-reef habitats, while others (e.g., shortnose greeneye [*Chlorophthalmus agassizi*], electric stingray [*Benthobatis marcida*], Pluto skate [*Fenestraja plutonia*], and longfin hake [*Phycis chesteri*]) were always more common away from reefs. The following 13 species were common to both the

deepwater *Lophelia* reefs (Ross and Quattrini 2007) and Pourtalès Terrace (this study, Reed et al. 2005, 2006): red bream, blackbelly rosefish, swordfish (*Xiphias gladius*), shortnose greeneye, mora codling (*L. melanurum*, *L. barbatulum*), grenadier, catshark (*Scyliorhinus meadi*, *S. retifer*), offshore hake (*Merluccius albidus*), goosefish (*Lophiodes beroe*), redeye gaper (*Chaunax stigmaeus*), and swallowtail bass.

Off central eastern Florida, Harter et al. (2009) analyzed fish assemblages and benthic habitats inside and outside the deepwater *Oculina* coral MPA by using ROV video and photographic transects to determine whether *Oculina varicosa* forms an essential habitat compared to other structure-forming habitats and to examine the effectiveness of the MPA. Comparison of five habitat types (rock pavement, rubble, rock outcrops, standing dead *O. varicosa*, live *O. varicosa*) by multivariate analyses of the 62 fish species indicated no differences in fish communities or diversity among the hardbottom habitat types. However, grouper densities were significantly higher on the most structurally complex habitats (i.e., live *O. varicosa*, standing dead *O. varicosa*, and rock outcrops) compared to the less complex habitats (pavement and rubble).

Only two studies have characterized the deepwater reef habitat and fish assemblages in the southern Straits of Florida and in particular on the Pourtalès Terrace (Reed et al. 2005, 2006). Using submersible-based qualitative photographic and video surveys, the studies documented 30 species (presence/absence only) of fish at two sinkhole sites and several high-relief rocky mounds on the terrace. Six species were found in the 2006 study that were not found in this present survey: silky shark (*Carcharhinus falciformis*), Warsaw grouper (*Hyporthodus nigritus*), marbled catshark (*Galeus area*), ocean sunfish (*Mola mola*), and several swordfish that often attacked the submersible while it was inside the sinkholes. Schools of squid were also common in the sinkholes, which undoubtedly attracted the swordfish. Also, a large spawning aggregation of beardfish (*Polymixia lowei*) in densities up to 117 m⁻² was found in the bottom of one of the sinkholes, and ovarian histology indicated recent spawning activity (Baumberger et al. 2010).

Popenoe and Manheim (2001) described the habitat relationships of wreckfish (*Polyprion americanus*) populations on Charleston Bump, a deepwater limestone feature at depths of 250–1000 m on the Blake Plateau, which is somewhat similar to the hard-ground, limestone habitat found on Pourtalès Terrace. Both features are of Tertiary, phosphoritic limestone that has formed highly resistant pavements and complex erosional features including rock piles, scarps, and undercut ledges. These provide habitat and hiding places for larger fish, which at the Charleston Bump included wreckfish, red bream, and roughy (Trachichthyidae). We found the latter two taxa but did not observe wreckfish on Pourtalès Terrace. However at Miami Terrace, which is just to the north of Pourtalès and at similar depths, we have documented a large permanent population of wreckfish on an isolated pinnacle that may be the southernmost known breeding population off the southeastern United States.

Interrelationships of fish communities and benthic habitats

Sites within and outside the managed areas (MPA and CHAPC) were compared for similarity to determine if the newly designated managed areas were similar to one another or were different from unprotected sites. The MDS plots for both the benthic macrobiota and fish communities show that the sites within the managed areas (MPA and CHAPC sites) were relatively similar, demonstrating a close relationship between benthos and fish at these managed sites (Figures 5.3 and 5.4a). The sinkhole and *Lophelia* mound sites were a distinct group in the plots for both the benthic biota and fish; both sites are within the CHAPC but deeper than the remaining hardbottom sites. The two Mound no. 311 sites also formed distinct groups for both the benthic biota and fish. Mound no. 311 had the greatest percentage of cover of macrobiota of the CHAPC sites (22.2%) and a high cover of Stylasteridae corals; however, it had few large fish. This may be due to fishing. This site was also one of the most impacted by human debris (described later in this section). The southeast wall of Mound no. 311 was a steep escarpment that had few ledges or other microhabitat; as a result, this site only supported a low percentage of macrobiota (3.9%), and, as expected, was one of the sites with a lower density of fish as well (Table 5.2). Other relationships between benthic macrobiota and fish were apparent at Tennessee Bioherm no. 1 within the MPA. This site had the highest number of fish species (23) as well as the second highest cover of macrobiota (20.4%). In addition, Alligator Bioherm no. 3 within the CHAPC had the third highest cover of macrobiota (16.6%) with very dense populations of stylasterid corals and the second highest species richness (20 species) of fish.

The unprotected sites outside the managed areas (Jordan Site F and Key West Bioherm) formed a distinct group in the MDS plots. Both sites had relatively low cover of benthic macrobiota, but Key West Bioherm had the highest density of fish among all sites (Table 5.2) due mostly to a large number of anthiin fish. However, few large fish were observed here, partly because it is the closest to heavy fishing pressure from Key West. This site was also highly impacted by human debris and fishing gear.

The interrelationships of the fish communities and habitat factors were also analyzed with MDS plots of similarity (Figure 5.4b-d). Rather than comparing by sites, fish community data were compiled from the ROV transects based on four habitat factors: geomorphology, substrate, depth, and slope. Depth was the most influential factor contributing to fish species composition, and the similarity plot shows two similar groups: the deep (450-850 m) and the shallower sites (150-300 m). Geomorphology was the second most influential factor and divided the sites into five statistically different groups. One group consisted of the rock mound sites (mound-slope, mound-wall, and mound-top), a second group consisted of the Lophelia coral mound and sinkhole sites, and the third group consisted of the deeper sites in the valleys and deep-mounds. Substrate was the third most influential factor consisting of two groups. One group consisted of the rock substrate categories: pavement, pavement and ledges, pavement and sediment, and rock wall. The second group was the *Lophelia* coral habitat and the deep mud habitat on Pourtales Escarpment, although these two habitats only showed low similarity to one another (<20%). Slope showed little relationship to the fish species composition and any influence of slope was likely overshadowed by the other factors.

While it is well known that deep coral habitats support relatively high diversity and densities of fish species (Costello et al. 2005, Koenig et al. 2005, Ross and Quattrini 2007), it is unclear whether the fish are attracted to live coral or just structure made by the coral habitat. Some research shows a link between deepwater coral habitat and fish nursery grounds (Etnoyer and Warrenchuk 2007, Buhl-Mortensen et al. 2010). In addition to deepwater hard coral habitat, distributional data have shown that deepwater soft corals, gorgonians, sponges, and even sea pens (Pennatulacea) can be important as potential fish habitat (Edinger et al. 2007, Baillon et al. 2012). However, Auster (2007) noted that cooccurrence does not imply a mechanistic relationship between particular habitat types and fish populations and the cooccurrence of fishes with corals does not necessarily mean there is a functional link to population processes. Also, most studies seem to imply that shelf and slope deepwater species exhibit facultative versus obligate habitat use patterns (Auster et al. 1995), although the linkages between coral-associated fishes and their more widely distributed populations remain undefined (Auster 2007). However, in all cases the

presence of high-density aggregations of coral-associated fishes suggests that deepwater coral is important habitat (Auster 2007). Certainly, areas of complex high-relief topography in the South Atlantic Bight and throughout the Straits of Florida, including the deepwater *Lophelia* reefs and Pourtalès Terrace, provide habitat for dense and diverse populations of fish. Combined with the complex bottom topography, these areas have high productivity, strong currents, and upstream larval sources from the Florida Current, which support many ecologically and economically important reef fish species. Many of these species live and spawn on rocky reefs on the edge of the continental shelf and upper continental slope (Koenig et al. 2000, Sedberry 2001, Quattrini et al. 2004). These deepwater reefs, whether rocky or coral, may provide increased food availability, and often are found in areas of upwelling that can concentrate zooplankton. Although food supply generally decreases with depth in the ocean, it can be concentrated by topographic features such as seamounts and pinnacles (Koslow 1997). The deepwater reef habitat may also provide a refuge from predators, and habitat from which to ambush prey (Costello et al. 2005).

Deepwater protected areas

Since 2009, eight deepwater, shelf-edge MPAs and five deepwater CHAPCs have been established by NOAA along the outer continental shelf of the southeastern United States from North Carolina to south Florida (NOAA 2010). This network of protected areas was established to sustain and restore reef fish populations and to protect deep-sea coral/ sponge habitat from destructive fishing practices, such as bottom trawling for royal red shrimp and the use of longlines of crab pots that may extend several kilometers with dozens of traps on each (NOAA 2010). The eight MPAs are classified as Type II by the SAFMC and were designated in particular to protect species of the deepwater snapper–grouper complex. Regulations applicable inside the MPAs prohibit fishing for, or possession of, any snapper/grouper species or use of shark bottom longline gear. Transiting through the MPAs and trolling for pelagic species, however, is allowed. The closures will provide ecosystem-level benefits to the entire complex as well as protect the shelf-edge reef habitat utilized by the protected species. These consist of five species of grouper: snowy grouper, yellowedge grouper (*Hyporthodus flavolimbatus*), Warsaw grouper, speckled hind (Epinephelus drummondhayi), and misty grouper (Hyporthodus mystacinus), and two species of tilefish: tilefish (Lopholatilus chamaeleonticeps) and blueline tilefish. The deepwater, shelfedge MPAs are known to contain reef habitat utilized by these species of grouper as well as deep mud banks used by the two tilefish species.

The primary goal of this research was to gather additional data on benthic habitat and fish assemblages in the South Atlantic MPAs and HAPCs. Our long-term sampling program was designed to document changes in these assemblages after fishing restrictions are implemented. Efficacy testing of this management option will aid fishery managers in future use of area restrictions for the protection of valuable habitat and fishery resources. Area closures constitute a politically charged issue that is unlikely to retain support without evidence indicating increases in the target species. As such, decisions to create future area closures will be based upon the efficacy of these areas and the lessons learned during their implementation.

Additionally, although no lionfish (*Pterois volitans*, *P. miles*) were observed in this survey of Pourtalès Terrace, our recent surveys of the shelf-edge MPAs from North Florida to Carolinas and the Pulley Ridge HAPC in the Gulf of Mexico found areas infested with the invasive lionfish to depths of 100 m. In the Atlantic, lionfish have been recorded to depths of 300 m and their population continues to expand rapidly throughout the western

Atlantic, Caribbean and Gulf of Mexico (Schofield et al. 2013). Their presence on Pourtalès Terrace reefs in the future is probable. Future monitoring will assist in evaluating the effects of this invasion on these ecosystems. The monitoring program for the deepwater MPAs and HAPCs will ensure that SAFMC and NOAA Fisheries remain well informed of changes among reef fish populations and coral habitats associated with these protected areas.

The seafloor in the Straits of Florida has a variety of extensive DSCE habitats including: deepwater coral mounds; various hardbottom habitats off Florida including the Miami Terrace, Pourtalès Terrace, and deepwater canyons (Agassiz and Tortugas Valleys); and deep island slopes off western Bahamas and northern Cuba. In U.S. waters, much of this is now protected as deepwater CHAPCs. NOAA bathymetric contour maps and digital elevation models were used to identify and delineate the areal extent of potential DSCE habitat within and outside the CHAPCs off Florida (Reed et al. 2013b). The total area of the CHAPCs off the southeastern United States, from North Carolina to south Florida, is 62,714 km². Reed et al. (2013b) calculated that 22,057 km² of potential DSCE habitat occurs in U.S. waters off eastern and southern Florida, and that 15,503 km² (70.3%) is within the Florida CHAPCs. This leaves approximately 6554 km² of DSCE habitat that remains unprotected (29.7%) and outside the boundaries of the CHAPCs in U.S. waters off Florida. This includes large portions of hardbottom habitat on the Pourtales Terrace and the escarpment walls of the Tortugas and Agassiz Valleys, which are just west of Pourtalès Terrace. These could remain vulnerable to bottomtending fishing gear.

Impacts from fishing and trawling

Bottom-tending fishing gear, which has deleterious effects upon deepwater coral habitat, is now prohibited in the MPAs and HAPCs except in allowable fishing areas. In 1984, a portion of the deepwater O. varicosa coral reef ecosystem off eastern Florida at depths of 80–100 m was protected as the *Oculina* Habitat Area of Particular Concern (OHAPC), prohibiting bottom trawls, longlines, dredges, and anchors. Unfortunately, the northern twothirds of the known reef system remained open to such gear until 2000 when the OHAPC boundaries were expanded to 1029 km². In the 1970s, the Oculina reefs were teeming with large spawning aggregations of grouper and snapper (Gilmore and Jones 1992). By the early 1990s, commercial and recreational fishing had decimated the fish populations, and the coral had been severely impacted by bottom trawling for rock shrimp. Quantitative analyses of photographic images by point count have revealed drastic losses of live coral cover between 1975 and 2001 (Reed et al. 2007). Six coral reef sites had nearly 100% loss of live coral, whereas only two reefs within the boundaries of the original OHAPC since 1984 survived and were not impacted by trawling. The decline in fish populations, primarily the grouper gag (Mycteroperca microlepis) and scamp (Mycteroperca phenax), on the *Oculina* reefs over that past 20 years is well documented (Gilmore and Jones 1992, Koenig et al. 2000, 2005) and may be attributed to both habitat loss and overfishing. Population densities of the dominant basses (roughtongue bass and red barbier [Hemanthias vivanus]), dominant grouper (scamp, gag, and speckled hind), and pelagic species (greater amberjack and almaco jack) all showed a positive association with intact coral habitat (either sparse or dense live coral) compared to unconsolidated coral rubble habitat (Koenig et al. 2005). Scamp density in intact coral habitat was significantly greater (p = .05) than in other habitats (sparse live coral or rubble). Only one commercially important taxon (snapper *Lutjanus* spp.) was primarily associated with the coral rubble habitat.

At Pourtalès Terrace we found evidence of lost fishing gear (lines and tackle) on the deepwater reefs. In the point count analysis of the digital images from the photographic transects, categories were included for "human debris" and subcategories for "fishing gear" (fishing line, longline, fish/crab traps, and nets). Sites 13, 22, 24, and 26 recorded the largest impact of human debris (fishing gear and other debris). In general, the most fishing gear and other debris were at the sites directly off Key West (Sites 13 and 26), which is understandable as they are the closest sites to heavy fishing and boating traffic. Site 16, which is within the newly designated MPA, also had considerable lost fishing gear on the reef and coral habitats. Many other sites also had fishing gear; for example, at Site 14, within the MPA and closest to shore off Marathon in the Florida Keys, we observed considerable amounts of fishing line, leaders, and tackle on the peak of the mound. We also observed stylasterid corals that apparently had been recently knocked down and still retained their living color. Lost fishing gear was also common on top of the Southeast Mound within the MPA (Site 15) and Mound no. 311 just west of the MPA (Site 22). Site 24 had a lot of debris but is far offshore, and this may be due to shipping traffic following the Florida Current. It also is near the allowable crab fishing area within the CHAPC, where there is a considerable amount of lost trap gear. Deepwater crab fishers estimate that there may be 1000-2000 lost or discarded crab traps within the region of Pourtalès Terrace and several hundred traps within the Pourtalès CHAPC (T. Matthews, Florida Wildlife Research Institute, personal communication). Not all of these traps had biodegradable panels; some crab fishers have indicated that they and their colleagues sealed the decay panel using nonbiodegradable materials to prevent the panel from opening during trap pulling in the strong Florida Current. Such ghost traps could continue fishing for years, indiscriminately killing crabs and fish.

Worldwide, bottom trawling has severely impacted deep-sea coral reef habitats and continues to be a major concern and threat (Rogers 1999, Butler and Gass 2001, Morgan et al. 2005, Mortensen et al. 2005). Bottom trawling causes severe mechanical damage as evident on deepwater *Lophelia* reefs in the northeast Atlantic (Rogers 1999, Fosså et al. 2002), the deepwater *Oculina* reefs (Reed et al. 2007), hardbottom habitats off the southeast-ern United States (Van Dolah et al. 1987), and deepwater seamounts off New Zealand and Tasmania (Koslow et al. 2001).

Future work and conclusions

This research cruise has resulted in a rich set of new data documenting and characterizing the deepwater benthic habitats and associated fish communities within the newly established MPAs on Pourtalès Terrace. New multibeam sonar maps, ground-truthed by ROV dives, enabled the discovery of the southernmost known deepwater *Lophelia* coral reef in U.S. waters as well as previously unknown deepwater sinkholes. It has provided baseline data for characterizing the newly designated East Hump MPA site, and eight additional sites within the newly designated deepwater CHAPC on Pourtalès Terrace.

These data were analyzed specifically to better understand the interrelationships of the deepwater fish communities, including commercially and recreationally important species, relative to the DSCE habitats. Eleven commercially and recreationally important fish species were observed and are important to the SAFMC and NOAA Fisheries for management purposes. Species that are targeted and managed by the fishery included: blueline tilefish (*Caulolatilus microps*), snowy grouper (*Hyporthodus niveatus*), queen snapper (*Etelis oculatus*), red porgy (*P. pagrus*), greater amberjack (*Seriola dumerili*), almaco jack (*Seriola rivoliana*), and silk snapper (*L. vivanus*). Statistical analyses showed clear relationships of habitat types (geomorphology, substrate, and depth) with the deepwater fish communities. While depth was the most influential factor contributing to fish species composition among the sites, the geomorphology factor was second most important, and substrate type was the third most influential factor. It is also interesting to note that the statistical plots for both the benthic macrobiota and fish communities show that the sites within the managed areas (MPA and CHAPC sites) were quite similar compared to the non-protected sites outside the CHAPC. This cruise also provided baseline documentation of the populations of commercially and recreationally important species within and outside the MPAs and their interrelationships with habitat and benthic biota such as deepwater corals.

New information was collected on several high-relief features outside the MPAs, which showed that extensive coral/sponge habitat and potential EFH exist outside the protected CHAPC boundaries. These unprotected areas should be of priority for future research and for possible inclusion in the managed areas. These data provided in this study will be important for managers and scientists with NOAA Fisheries, the SAFMC, Florida Keys National Marine Sanctuary, NOAA Deep-Sea Coral Research and Technology Program, NOAA Coral Reef Conservation Program, and NOAA Mesophotic Reef Ecosystem Program. These data may then be compared with the results of future research cruises to document changes in these areas due to the implementation of fishing restrictions and to monitor the efficacy and health of these newly designated managed areas.

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References

Auster PJ. 2007. Linking deep-water corals and fish populations. Bull Mar Sci. 81(Suppl 1):93–99.

Auster PJ, Malatesta RJ, LaRosa SC. 1995. Patterns of microhabitat utilization by mobile megafauna on the southern New England (USA) continental shelf and slope. Mar Ecol Prog Ser. 127:77–85.

- Auster P, Moore J, Heinonen K, Watling L. 2005. A habitat classification scheme for seamount landscapes: Assessing the functional role of deep-water corals as fish habitat. *In*: Freiwald A, Roberts J, editors. Cold-water corals and ecosystems. New York: Springer-Verlag.
- Baillon S, Hamel J-F, Wareham VE, Mercier A. 2012. Deep cold-water corals as nurseries for fish larvae. Front Ecol Environ. 10(7):351–356.
- Baumberger RE, Brown-Peterson NJ, Reed JK, Gilmore RG. 2010. Spawning aggregation of beardfish, *Polymixia lowei*, in a deep-water sinkhole off the Florida Keys. Copeia. 2010(1):41–46.
- Buhl-Mortensen L, Vanreusel A, Gooday AJ, Levin LA, Priede IG, Buhl-Mortensen P, Gheerardyn H, King NJ, Raes M. 2010. Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. Mar Ecol. 31(1):21–50.

- Butler M, Gass S. 2001. How to protect corals in Atlantic Canada. In: Willison JHM, Hall J, Gass SE, Kenchington ELR, Butler M, Doherty P, editors. Proceedings of the 1st International Symposium on Deep-sea Corals. Halifax, Nova Scotia: Ecology Action Centre, Nova Scotia Museum. p. 156–165.
- Clarke K, Gorley R. 2006. PRIMER v6: User manual/tutorial. Plymouth, UK: PRIMER-E.
- Clarke K, Warwick R. 2001. Changes in marine communities: An approach to statistical analysis and interpretation. 2nd ed. Plymouth, UK: PRIMER-E.
- Connor D, Brazier D, Hill T, Northen K. 1997. Marine Nature Conservation Review: Marine biotope classification for Britain and Ireland. Volume 1. Littoral biotopes. JNCC Report(229). Peterborough, UK: Joint Nature Conservation Committee.
- Costello MJ, McCrea M, Freiwald A, Lundälv T, Jonsson L, Bett BJ, van Weering TC, de Haas H, Roberts JM, Allen D, et al. 2005. Role of cold-water *Lophelia pertusa* coral reefs as fish habitat in the NE Atlantic. *In*: Freiwald A, Roberts J, editors. Cold-water corals and ecosystems. New York: Springer-Verlag.
- Cowardin LM, Carter V, Golet FC, LaRoe ET. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31, GPO 024-010-00524-6. Washington, DC: U.S. Fish and Wildlife Service.
- Dohrmann M, Gocke C, Reed J, Janussen D. 2012. Integrative taxonomy justifies a new genus, *Nodastrella* gen. nov. for North Atlantic "*Rosella*" species (Porifera: Hexactinellida: Rosellidae). Zootaxa. 3383:1–13.
- Edinger EN, Wareham VE, Haedrich RL. 2007. Patterns of groundfish diversity and abundance in relation to deep-sea coral distributions in Newfoundland and Labrador waters. Bull Mar Sci. 81(Suppl 1):101–122.
- Etnoyer P, Warrenchuk J. 2007. A catshark nursery in a deep gorgonian field in the Mississippi Canyon, Gulf of Mexico. Bull Mar Sci. 81(3):553–559.
- FGDC (Federal Geographic Data Committee). 2012. Coastal and marine ecological classification standard. FGDC-STD-018-2012. Reston, VA: Federal Geographic Data Committee.
- Fosså JH, Mortensen PB, Furevik DM. 2002. The deep-water coral *Lophelia pertusa* in Norwegian waters: Distribution and fishery impacts. Hydrobiologia. 471(1–3):1–12.
- Fraser SB, Sedberry GR. 2008. Reef morphology and invertebrate distribution at continental shelf edge reefs in the South Atlantic Bight. Southeastern Nat. 7(2):191–206.
- Gilmore GR, Jones RS. 1992. Color variation and associated behavior in the epinepheline groupers, *Mycteroperca microlepis* (Goode and Bean) and *M. phenax* Jordan and Swain. Bull Mar Sci. 51(1):83–103.
- Harter SL, Ribera MM, Shepard AN, Reed JK. 2009. Assessment of fish populations and habitat on *Oculina* Bank, a deep-sea coral marine protected area off Eastern Florida. Fish B-NOAA. 107(2):195–206.
- IMCRA (Interim Marine Coastal Regionalisation for Australia). 1998. Interim Marine Coastal Regionalisation for Australia Technical Group. An ecosystem-based classification for marine and coastal environments Version 3.3. Canberra: Environment Australia, Commonwealth Department of the Environment.
- Jordan G. 1954. Large sink holes in Straits of Florida. Bull Am Ass Petrol Geol. 38:1810–1817.
- Jordan G, Malloy R, Kofoed J. 1964. Bathymetry and geology of Pourtalès Terrace. Mar Geol. 1:259–287.
- Koenig CC, Coleman FC, Grimes C, Fitzhugh G, Scanlon K, Gledhill C, Grace M. 2000. Protection of fish spawning habitat for the conservation of warm-temperate reef-fish fisheries of shelf-edge reefs of Florida. Bull Mar Sci. 66:593–616.
- Koenig CC, Shepard AN, Reed JK, Coleman FC, Brooke SD, Brusher J, Scanlon KM. 2005. Habitat and fish populations in the deep-sea Oculina coral ecosystem of the Western Atlantic. Amer Fish Soc Symp. 41:795–805.
- Kohler KE, Gill SM. 2006. Coral Point Count with Excel extensions (CPCe): A visual basic program for the determination of coral and substrate cover using random point count methodology. Comput Geosci. 32:1259–1269.
- Koslow JA. 1997. Seamounts and the ecology of deep-sea fisheries: The firm-bodied fishes that feed around seamounts are biologically distinct from their deepwater neighbors—and may be especially vulnerable to overfishing. Am Sci. 85(2):168–176.

- Koslow JA, Gowlett-Holmes K, Lowry J, O'Hara T, Poore G, Williams A. 2001. Seamount benthic macrofauna off southern Tasmania: Community structure and impacts of trawling. Mar Ecol Prog Ser. 21:111–125.
- Land L, Paull C. 2000. Submarine karst belt rimming the continental slope in the Straits of Florida. Geo-Mar Lett. 20(2):123–132.
- Littler MM, Littler DS, Blair SM, Norris JN. 1985. Deepest known plant life discovered on an uncharted seamount. Science. 227:57–59.
- Malloy RJ, Hurley R. 1970. Geomorphology and geologic structure: Straits of Florida. Geol Soc Am Bull. 81:1947–1972.
- Morgan LE, Etnoyer P, Scholz AJ, Mertens M, Powell M. 2005. Conservation and management implications of deep-sea coral and fishing effort distributions in the northeast Pacific Ocean. *In*: Freiwald A, Roberts JM, editors. Cold-water corals and ecosystems. New York: Springer-Verlag.
- Mortensen PB, Buhl-Mortensen L, Gordon DC, Fader GBJ, McKeown DL, Fenton DG. 2005. Effects of fisheries on deepwater gorgonian corals in the Northeast Channel, Nova Scotia. Am Fish Soc Symp. 41:369–382.
- NOAA (National Oceanic and Atmospheric Administration). 2010. Fisheries of the Caribbean, Gulf of Mexico, and South Atlantic; comprehensive ecosystem-based amendment for the South Atlantic region. Fed Reg. 75(119):50 CFR Part 633, 35330–35335.
- Partyka ML, Ross SW, Quattrini AM, Sedberry GR, Birdsong TW, Potter J, Gottfried S. 2007. Southeastern United States deep-sea corals (SEADESC) initiative: A collaborative effort to characterize areas of habitat-forming deep-sea corals. NOAA Technical Memorandum OAR OER 1, Silver Spring, MD.
- Popenoe P, Manheim FT. 2001. Origin and history of the Charleston Bump: Geological formations, currents, bottom conditions, and their relationship to wreckfish habitats on the Blake Plateau. *In*: Sedberry GR, editor. Island in the stream: Oceanography and fisheries of the Charleston Bump. American Fisheries Society. Bethesda, MD, p. 43–94.
- Quattrini AM, Ross SW, Sulak KJ, Necaise AM, Casazza TL, Dennis GD. 2004. Marine fishes new to continental United States waters, North Carolina, and the Gulf of Mexico. Southeast Nat. 3(1):155–172.
- Redmond NE, Morrow CC, Thacker RW, Diaz MC, Boury-Esnault N, Cárdenas P, Hajdu E, Lôbo-Hadju G, Picton BE, Pomponi SA, et al. 2013. Phylogeny and systematics of Demospongiae in light of new small-subunit ribosomal DNA (18S) sequences. Integr Comp Biol. 53(3):388–415.
- Reed JK, Farrington S, David A, Harter S, Murfin D, Stierhoff K. 2013a. CIOERT SEADESC II Report: Extreme Corals 2011: South Atlantic Deep Coral Survey. NOAA Ship *Pisces* Cruise PC-11-03, May 31–June 11, 2011. Report To: NOAA Office of Ocean Exploration and Research and NOAA Deep Sea Coral Research and Technology Program. HBOI Miscellaneous Contribution Number 863.
- Reed JK, Koenig CC, Shepard AN. 2007. Impacts of bottom trawling on a deep-water Oculina coral ecosystem off Florida. Bull Mar Sci. 81(3):481–496.
- Reed JK, Messing C, Walker BK, Brooke S, Correa TBS, Brouwer M, Udouj T, Farrington S. 2013b. Habitat characterization, distribution, and areal extent of deep-sea coral ecosystems off Florida, southeastern U.S.A. Caribb J Sci. 47(1):13–30.
- Reed JK, Pomponi SA, Weaver D, Paull CK, Wright AE. 2005. Deep-water sinkholes and bioherms of South Florida and the Pourtalès Terrace: Habitat and fauna. Bull Mar Sci. 77(2):267–296.
- Reed JK, Weaver DC, Pomponi SA. 2006. Habitat and fauna of deep-water *Lophelia pertusa* coral reefs off the southeastern US: Blake Plateau, Straits of Florida, and Gulf of Mexico. Bull Mar Sci. 78(2):343–375.
- Rogers AD. 1999. The biology of *Lophelia pertusa* (Linnaeus 1758) and other deep-water reef-forming corals and impacts from human activities. Int Rev Ges Hydrobiol. 84:315–406.
- Ross SW, Quattrini AM. 2007. The fish fauna associated with deep coral banks off the southeastern United States. Deep Sea Res Pt I: Oceanogr Res Pap. 54(6):975–1007.
- Schobernd CM, Sedberry GR. 2009. Shelf-edge and upper-slope reef fish assemblages in the South Atlantic Bight: Habitat characteristics, spatial variation, and reproductive behavior. Bull Mar Sci. 84(1):67–92.
- Schofield PJ, Morris Jr. JA, Langston JN, Fuller PL. 2013. Pterois volitans/miles. USGS nonindigenous aquatic species database, Gainesville, FL. http://nas.er.usgs.gov/queries/FactSheet. aspx?speciesID=963. Revision date: 18 September, 2012.

- Sedberry GR. 2001. Island in the stream: Oceanography and fisheries of the Charleston Bump. Volume 25. American Fisheries Society Symposium 25. Bethesda, MD: American Fisheries Society.
- Van Dolah RF, Wendt PH, Nicholson N. 1987. Effects of a research trawl on a hardbottom assemblage of sponges and corals. Fish Res. 5:39–64.
- Vinick C, Riccobono A, Messing CG, Walker BK, Reed JK, Farrington S. 2012. Siting study for a hydrokinetic energy project located offshore southeastern Florida: Protocols for survey methodology for offshore marine hydrokinetic energy projects, U.S. Department of Energy. www. osti.gov/servlets/purl/1035555/.