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IMPACTS OF BOTTOM TRAWLING ON A DEEP-WATER *OCULINA* CORAL ECOSYSTEM OFF FLORIDA

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ABSTRACT

In 1984, a portion of the deep-water *Oculina* coral reef ecosystem off eastern Florida was protected as the *Oculina* Habitat Area of Particular Concern (OHAPC), prohibiting bottom trawls, longlines, dredges, and anchors. Unfortunately, the northern two thirds of the reef system remained open to these gear until 2000 when the OHAPC boundaries were expanded to 1029 km^2. In the 1970s, the *Oculina* reefs were teeming with large spawning aggregations of grouper and snapper. 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. Historical photographic transects, taken in the 1970s with the Johnson-Sea-Link submersibles, provide crucial evidence of the status and health of the reefs prior to heavy fishing and trawling activities. Quantitative analyses of photographic images by point count reveal drastic loss of live coral cover between 1975 and 2001. Six coral reef sites had nearly 100% loss of live coral, whereas only two reefs which were within the boundaries of the original OHAPC since 1984 survived and were not impacted by trawling. Management and conservation plans for deep-sea coral reef ecosystems worldwide must be based on sound scientific understanding as well as adequate surveillance and enforcement; this study will help build a foundation for this understanding.

The deep-water *Oculina varicosa* Lesueur, 1821 coral reef ecosystem is known only off the east coast of Florida. At depths of 70–100 m this azooxanthellate, branching coral produces 1–2 m diameter colonies that coalesce into thicket-like habitats and high-relief bioherms that are similar in structure to deep-water *Lophelia* coral reefs (Reed, 2002a,b; Reed et al., 2005, 2006). The majority of this *Oculina* habitat is known between 27°30′N (Fort Pierce) and 28°30′N (Cape Canaveral) in a zone 2–6 km wide, paralleling the 80°W meridian (Avent et al., 1977; Reed, 1980). Historical accounts in the 1970s and 80s indicate high densities of economically important reef fish including large spawning aggregations of grouper associated with the coral habitat (Gilmore and Jones, 1992; Koenig et al., 2000, 2005; Reed et al., 2005, 2006). In 1984, the South Atlantic Fishery Management Council (SAFMC) designated one third of the known reef system (315 km^2) as the *Oculina* Habitat Area of Particular Concern (OHAPC) to protect the coral habitat from bottom trawling, dredging, longlines, and anchoring. Unfortunately, the northern two thirds of the reef system remained unprotected and was legally open to these mechanically destructive activities. During the 1980s and 90s, bottom trawling within *Oculina* ecosystem was primarily for rock shrimp and brown shrimp and this was the primary cause of major habitat destruction. Also commercial dredging for calico scallops was prominent in the 1970s–1980s but overfishing and destruction of habitat caused the collapse of the industry. By the early 1990s, grouper spawning aggregations, which in the 1970s consisted of hundreds of grouper on each reef, were virtually eliminated primarily by commercial and recreational hook-and-line fishing (Koenig et al., 2000, 2005). This stimulated the SAFMC to ban hook-and-line fishing for grouper in 1994 to test the effectiveness of a fishery reserve. In 2000, the *Oculina* HAPC boundaries were expanded to 1029 km^2 and the

original HAPC, termed the *Oculina* Experimental Closed Area (OECA), continued the additional ban on bottom fishing (Federal Register, June 2000).

Historical photographic records from submersible surveys of the eastern Florida shelf between 1975 and 1977 provide evidence of the status and health of the deep-water *Oculina* reefs prior to heavy fishing and shrimp trawling activities of the 1980s and 1990s (Avent et al., 1977; Avent and Stanton, 1979; Reed, 1980). The *Oculina* reefs were first discovered during these submersible surveys when twelve east-west photographic transects were haphazardly placed along the shelf-edge break. Over 50,000 35-mm photographs were taken during these submersible transects. Portions of these transects that were over reefs were compared to video transects of the same areas made 25 yrs later in 2001. In this study, random photographic images from both surveys were quantitatively analyzed by point count to determine changes in percent cover of live *Oculina* coral, standing dead coral and coral rubble. This study has resulted in the restoration, protection and archiving of these rare and invaluable photographic images and data, and will provide marine managers and scientists with a quantitative assessment of the health and percent cover of live coral in the 1970s, prior to intense trawling, compared to the same sites today.

Methods and Materials

Historical data from 1975–1977 were based on photographic transects of the benthos at twelve sites from the 30 m isobath to 300 m between Cape Canaveral (28°30′N) and Lake Worth, Florida (26°37′N), using the Johnson-Sea-Link (JSL) human-occupied submersibles (owned and operated by Harbor Branch Oceanographic Institution, HBOI) (Avent et al., 1977; Avent and Stanton, 1979). These east-west transects were spaced ~19 km apart and consisted of 50 submersible dives, totaling 298 km (Fig. 1). During these dives, the deep-water *Oculina* reefs were first discovered and described (Avent et al., 1977; Reed, 1980). Navigation was based on LORAN-A which had an accuracy of ± 150–300 m. Detailed records included written transcripts, and ship and submersible logs documenting coordinates, depth, and physical data throughout the dives. Photographs were taken every 1–2 min with a 35-mm Edgerton-type still camera and flash system (Benthos model 372, Benthos Inc.) that was mounted 29° from vertical, providing average frame coverage of 6.3 m^2 at 3.0 m height and 2.5 m mid-frame width. Viewing angle in water was 54° wide and 42° fore-aft. Area was estimated from camera height and in-water viewing angle of the lens and was verified by flying the sub over a 10-m grid on the bottom. Over 50,000 35-mm photographs were taken with 30-m rolls of Ektachrome film. Each image was coded with time and date which corresponded with the navigation data. Eight of the twelve transects encountered deep-water *Oculina* reefs which were used for this study; these images were recently cut from the original 30-m film rolls, digitized with a Nikon LS2000 Coolscan, enhanced in Photoshop®, and saved as high resolution TIFF files (300 dpi, 3.75 mb file).

Recent data (2001) were collected using the human-occupied Clelia submersible (owned and operated by HBOI). Submersible dives that were in proximity to the historical transects were selected for comparison of reef habitat over a 25-yr period. Color videotapes (Mini-DV digital) were recorded with a pan and tilt videocamera which provided a 72.5° × 57.6° field of view (Sony DX2 3000A, 3 chip 2.6 mm CCD, with Canon J8X6B KRS lens, 6–48 mm zoom, and 0.3 m minimum focus). The downward-looking camera was equipped with four parallel lasers (17.5 cm apart along the edge of the diamond shape) providing scale for quadrat size. Ship navigation was determined with differential global positioning system (Magnavox MX 200 GPS) which is accurate to ± 5 m, and submersible tracks were plotted with the Integrated Mission Profiler (Florida Atlantic University) which links to the ship's GPS. Still images were derived from randomly selected video frame grabs for quantitative point count analyses.

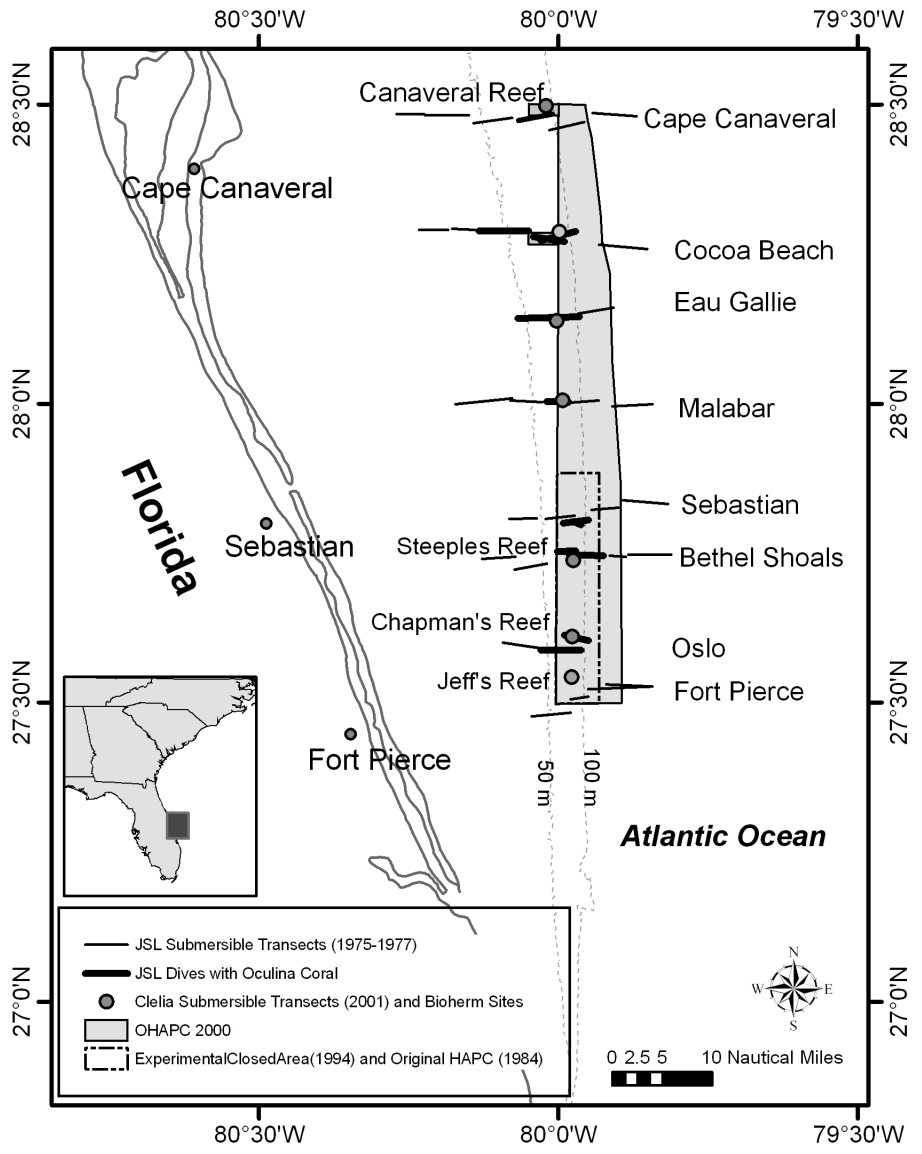

Figure 1. Photographic transect sites and deep-water *Oculina* coral reefs off eastern Florida. Shaded area: 1029 km^2 (300 nmi^2) deep-water *Oculina* Habitat Area of Particular Concern (OHAPC) that was designated in 2000. Dotted boxed area: original boundaries of 315 km^2 (92 nmi^2) OHAPC in 1984 and current boundaries of no-fishing zone of Experimental Closed Area (Marine Protected Area). Photographic transects made from depths of 30–300 m with Johnson-Sea-Link submersible in 1975–1977 (solid lines = individual sub dives; bold line = dives encountering *Oculina* habitat; dots = high-relief *Oculina* reefs and Clelia submersible transect sites in 2001).

Randomly selected historical and recent photographic images from transects that crossed deep-water *Oculina* coral habitat were analyzed for percent cover of three habitat types of *Oculina varicosa* Lesueur, 1821: live coral, dead standing coral, and unconsolidated coral rubble. Each photographic image was overlaid with 100 randomly distributed points to determine percent cover for each habitat type using CPCe software (Kohler and Gill, 2006). The non-parametric Mann-Whitney test was used to determine significant differences between

mean coverage estimates from historical and recent transects for all sites except Jeff's Reef. At this site, where considerable coral habitat is still intact, historical and contemporary coverage estimates were more similar and required a more precise statistic to evaluate significant differences. Therefore, for Jeff's Reef we used analysis of variance (ANOVA) with a normalizing arcsine transformation [arcsine(sqrt(x/100))]. Normality was verified after transformation with a Shapiro-Wilk test and multiple comparisons were made with a Fisher's LSD test.

Results

We compare in detail three transect sites that historically showed the highest coverage of live coral between the surveys of 1976–1978 and 2001: Cape Canaveral, Oslo, and Jeff's Reef.

Cape Canaveral Transect (1976).—The Cape Canaveral transect found live *Oculina* within a depth zone of 70–87 m over a distance of 2.4 km (Table 1; Fig. 1). A high-relief *Oculina* bioherm (Canaveral Reef) was found during one dive (JSL II-063) and was described in written transcripts as an 18-m tall coral mound (87 m depth) with 30–45° degree slopes and ~0.35 km width at the base (Fig. 2A). No exposed rock was observed on the slopes or crest of the reef but it appeared to be entirely covered with living and dead *Oculina* coral and sediment. Colonies of live *Oculina* were ~1 m tall (maximum coral colony diameter was 1.7 m in quantified image analyses) on the flanks and the observers estimated 25% live coral cover. Coral colonies along the peak were ~50 cm tall. Some colonies appeared to have been severed into 2 or 3 pieces, possibly by an anchor or cable. A 6-m long, 5-cm diameter cable was found on the bottom near the reef. Dominant fish associated with the reef were snowy grouper *Epinephelus niveatus* (Valenciennes in Cuvier and Valenciennes, 1828), greater amberjack *Seriola dumerili* (Risso, 1810), and smaller reef fish including bank butterflyfish *Prognathodes aya* (Jordan, 1886), blue angelfish *Holacanthus bermudensis* Goode, 1876, and various damsels and wrasses. West of the bioherm were a series of smaller reefs of moderate to low relief (3–5 m to flat pavement). The dive on the *Oculina* bioherm was divided into four photographic transects (E base, E slope, top ridge, W slope and base). Mean live coral coverage of these transects was the third highest for all sites (mean 19.2%; range 7%–35.1%); standing dead coral was 31.4% and coral rubble 17% (Fig. 3) Maximum coral density for individual photographic quadrats ranged from 32.0%–73.2%.

Cape Canaveral Transect (2001).—In 2001, transects were made at the Canaveral *Oculina* Reef previously mapped in 1976. The submersible dive (Clelia 616) consisted of six transects (W base, N slope, western peak ridge, eastern peak ridge, E slope and base, and SE base). During the 25 yrs between submersible dives, the reef had been reduced to coral rubble (Fig. 2B). Although the 18-m mound still existed, the peaks and flanks on all sides were covered in thick layers of unconsolidated dead coral rubble consisting of pieces ~2–10 cm in length. Some of the dead coral rubble on the upper south and east slopes and peak were somewhat consolidated rubble and well encrusted with demosponges (*Erylus*? sp., *Geodia* sp., Axinellidae) and possibly blue-green algae. Tracks in the coral rubble, apparently made by heavy shrimp trawl doors, appeared as deep, straight grooves (~30 cm deep, 60 cm wide) cut into the coral rubble. A few 1-m colonies of standing dead coral were found at the west base. The only living *Oculina* coral observed was at the southeastern base (82–85 m) where a few 15–60 cm live colonies were observed apparently unattached on sand. The only

Table 1. Comparisons of historical (1975–1982) and recent (2001) estimates of mean percent cover of live colonies of *Oculina varicosa* (OV), standing dead coral (SDC), and coral rubble (CR) on deep-water *Oculina* reefs off eastern Florida. Percent cover estimates are from randomly selected images (quadrats) of photographic transects within the coral habitat at eight transect sites. Statistical differences of percent cover between years at each site are indicated as *** = $P < 0.0001$, ** = $P < 0.001$, * = $P < 0.05$, no symbol = no significant difference ($P \geq 0.05$). Comparisons at Jeff's Reef are for 1977–1996 and 1977–2001.

Transect site	Year	# Quadrats (# transects)	OV Mean (range)	SDC Mean (range)	CR Mean (range)
Cape Canaveral	1976	59 (4)	19.2 (7–35.1)	31.4 (1.8–52.9)	17.0 (11.5–29.7)
	2001	120 (6)	***0.2 (0–0.9)	***1.7 (0–6.6)	***80.5 (26.8–99.7)
Cocoa Beach	1975, '77	24 (3)	3.1 (0.4–5.3)	0.2 (0–0.6)	21.4 (0.5–62.7)
	2001	60 (3)	***0.0 (0)	**0.0 (0)	***75.3 (62.5–93.1)
Eau Gallie	1977	51 (6)	6.6 (0.2–19.1)	5.9 (1.1–15.5)	25.1 (5.2–49.9)
	2001	80 (4)	***0.1 (0–0.3)	18.9 (6.9–32.3)	***78.8 (64.9–91.2)
Malabar	1975	53 (4)	4.2 (1.7–8.8)	3.8 (0.6–7.3)	13.8 (0–51.0)
	2001	not available			
Sebastian	1975, '76	35 (4)	3.2 (0.9–6.9)	3.7 (1.1–6.8)	1.9 (0–5.9)
	2001	40 (4)	***0.1 (0–0.1)	*5.7 (2.7–11.6)	***92.5 (87.3–95.3)
Bethel Shoals	1975	46 (2)	7.1 (6.8–7.4)	12.4 (8.7–16.2)	33.6 (11.9–55.3)
	2001	40 (4)	***0.0 (0)	***5.6 (0.6–20.0)	***92.6 (79.9–98.9)
Oslo (Chapman's)	1977, '82	17 (2)	21.2 (7.0–35.3)	38.2 (27.5–48.8)	40.6 (15.7–65.4)
	2001	80 (5)	11.4 (7.0–22.3)	16.1 (0–27.1)	not available
Jeff's Reef	1977	104 (5)	39.3 (30.6–47.7)	25.8 (20.2–37.8)	25.3 (19.4–31.7)
	1996	70 (5)	***10.3 (8.2–15.0)	***60.2 (36.7–76.7)	25.4 (11.7–53.4)
	2001	100 (5)	***13.4 (7.2–18.8)	*34.0 (26.4–42.3)	***43.4 (34.9–59.6)

large fish were amberjack and a few small reef fish. Since 1976, nearly 100% of the live coral had been lost; mean cover was reduced from 19.2% to 0.2% (Mann-Whitney: $P < 0.0001$) and standing dead coral had dropped from 31.4% to 1.7% ($P < 0.0001$; Table 1, Fig. 3). Concurrently, cover of coral rubble had increased by 64%, from 17% to 80.5% (Mann-Whitney: $P < 0.0001$; Fig. 3C).

Oslo Transect (Chapman's Reef) (1977).—The zone of *Oculina* coral occurred from 65–85 m over a distance of 2.07 km (JSL II-197). Most of the coral was associated with low relief (1–2 m) knolls. Adjacent to this transect an additional dive was made in 1982 on a high relief *Oculina* bioherm named Chapman's Reef (JSL I-1201) which was added to the transect data. This was a steep (30°–45°) sloped feature with 1–2 m live *Oculina* colonies (maximum coral diameter from quantitative image analyses was 1.52 m) forming dense thickets on the slope and peak. No rock outcrops were apparent and the flanks were entirely live coral, coral rubble, and sediment. Quantitative analyses of the two photographic transects showed mean live *Oculina* cover was the second highest of any of the transects (21.2%) and also had large amounts of standing dead coral (38.2%) and unconsolidated coral rubble (40.6%) (Fig. 3). The transect from Chapman's Reef alone had 35.3% mean live coral, 48.8% standing dead coral, and 15.7% coral rubble. Maximum coral density of individual quadrats was 35.6%–47.4% .

Oslo Transect (Chapman's Reef) (2001).—Recent multibeam maps of Chapman's Reef complex show three high-relief *Oculina* banks in close proximity to the historical Oslo Transect. Echosounder transects further showed Chapman's North Reef to be the tallest feature of the three (35 m relief, 57 m at peak, 92 m at north

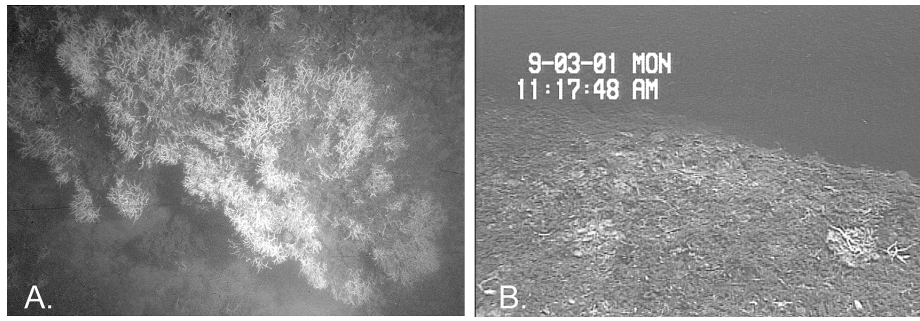

Figure 2. Deep-water *Oculina* bioherm at Cape Canaveral (67 m depth). (A) Historical photo from submersible dive (JSL II-063) in 1976; (B) Same site (Clelia 613) in 2001 reduced to rubble from apparent bottom trawling.

base). The South Reef was 23 m tall and the West Reef was 12 m. Due to inconsistencies between LORAN A and GPS, it is uncertain exactly which of these reefs was surveyed in 1977. In 2001, five photographic transects (Clelia 621) were made on Chapman's Reef West which are described in Koenig et al. (2005). They reported mean live coral cover at 11.4% and mean standing dead coral at 16.1%; coral rubble cover data were not included (Table 1). Because of the limited number of quadrats available from the 1982 dive on Chapman's Reef (9), these data were not statistically compared. However, since 1977 there was a 46% decrease in live coral, a 58% loss of standing dead coral, but the maximum coral diameter remained relatively unchanged (1.52 m and 1.43 m, respectively).

Fort Pierce Transect (Jeff's Reef) (1977).—The original transect site off Fort Pierce consisted of four submersible dives from 30–261 m over 23.3 km; however, no live *Oculina* coral or coral rubble was encountered on this transect. During the same time period a massive live *Oculina* bioherm was discovered just 4 km north of the transect line and is the southern-most living *Oculina* bioherm known. An extensive photographic survey was made by JKR in 1977 on this bioherm (JSL II-164). This 18-m tall bioherm was ~300 m wide and consisted of three E-W oriented ridges (64–70 m minimum depth). Described in Reed (1980), the mound appeared to be entirely coral and sediment and a true bioherm. The 1977 dive was divided into five photographic transects (N, S, E, W flanks, and peak). The east, west, and south slopes and ridges at the peak were covered with massive live *Oculina* coral, 90–150 cm tall. The steep south slope (45°) and south faces of the ridges were covered with dense coral, forming nearly continuous rows of coral bushes. The 30° north slope had more coral rubble, less live coral, and generally smaller colonies of live coral. Dense spawning aggregations consisting of hundreds of scamp *Mycteroperca phenax* Jordan and Swain, 1884 and gag *Mycteroperca microlepis* (Goode and Bean, 1879) grouper were described on this reef and other *Oculina* bioherms in the early 1980s (Gilmore and Jones, 1992). Mean live coral cover was the greatest of all sites (39.3%); standing dead coral was 25.8%, and coral rubble 25.3% (Fig. 3). Maximum coral density from individual quadrats ranged from 46.3%–67.4% and maximum coral diameter was 2.01 m; however, in many cases the corals appeared to grow together into continuous hedges (which exceeded the width of the photograph, ~2.5 m) and it was difficult to ascertain individual colonies.

Fort Pierce Transect (Jeff's Reef) (1996).—In 1996, JKR revisited the reef for the first time in over a decade (JSL II-2800). Video transects were made with similar

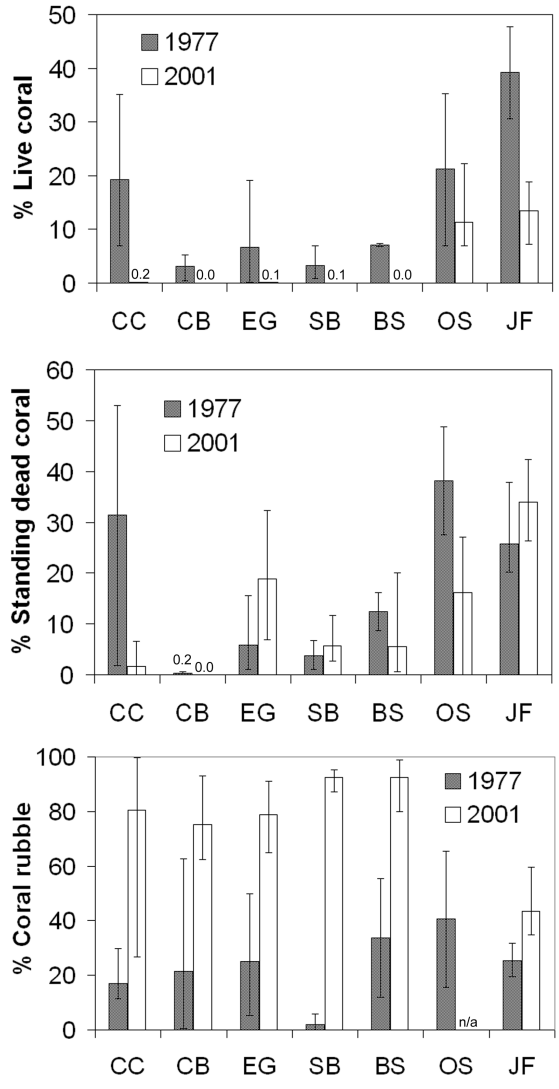

Figure 3. Mean percent (A) live *Oculina* coral, (B) standing dead *Oculina* coral, and (C) *Oculina* coral rubble at submersible transect sites in 1977 (solid bars) and 2001 (open bars) (range bars = range of transect means). CC = Cape Canaveral, CB = Cocoa Beach, EG = Eau Gallie, SB = Sebastian, BS = Bethel Shoals, OS = Oslo (= Chapman's Reef), JF = Jeff's Reef.

methodology and generally in similar locations as the 1977 dive. Five transects were selected for quantitative analyses (N slope, S slope, and top ridges). Mean live coral cover was 10.3%, standing dead coral 60.2%, and coral rubble 25.4%. Maximum coral cover ranged from 12%–36%.

Fort Pierce Transect (Jeff's Reef) (2001).—In 2001, ten video transects were randomly laid out on the reef (Clelia 606). These were divided into the following reef regions (S, W, E, and N slopes, and top ridges). Maximum coral density ranged from 20.4%–55.0%. Mean live coral cover decreased significantly (ANOVA: $P < 0.0001$, Table 1) by 30% between 1977 (39.3%) and 1996 (10.3%), but showed no significant

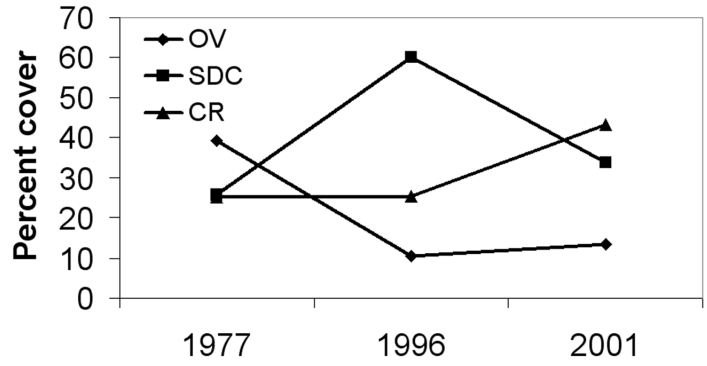

Figure 4. Mean percent cover of live *Oculina* coral (OV), standing dead *Oculina* coral (SDC), and *Oculina* coral rubble at Jeff's Reef bioherm in 1977, 1996, and 2001.

change between 1996 and 2001 (13.4%; ANOVA: $P > 0.05$). Mean standing dead coral cover was significantly different among all 3 yrs (ANOVA: $P < 0.01$) ranging from a low of 25.8% in 1977 to 60.2% in 1996 then down to 34% in 2001. Concurrently, mean coral rubble was similar in 1977 and 1997 (25.3%, 25.4%), but increased to 43.4% in 2001 (ANOVA: $P < 0.001$; Fig. 4).

Four other sites, Cocoa Beach, Eau Gallie, Sebastian, and Bethel Shoals, which had relatively lower live coral cover (mean < 10%) during the 1976–1978 transects also showed nearly 100% coral loss by 2001. The Malabar site also had low live coral cover (4.2%) in 1975 but was not resurveyed in 2001.

Cocoa Beach Transect.—During the historical dives (1975–1977), live *Oculina* was found at this site within a zone extending 6.80 km at depths of 67–82 m that included numerous low to high relief (6–18 m) *Oculina* mounds and ridges. Quantitative analyses showed a mean of 3.1% live coral cover, 0.2% standing dead coral, 21.4% coral rubble, and 37.4% rock pavement and ledges (Fig. 3). Quantitative analyses of the 2001 video transects revealed 0% cover of live coral, 0% standing dead coral, and 75.3% coral rubble. Since 1975 there was 100% loss of live coral (Mann-Whitney: $P < 0.0001$), 100% loss of standing dead coral (Mann-Whitney: $P < 0.001$), and 54% increase in coral rubble (Mann-Whitney: $P < 0.0001$; Table 1).

Eau Gallie Transect.—In 1977, the zone of live coral extended 3.13 km at depths of 59–87 m. At least eight individual moderate relief reefs at depths of ~76 m were found with thickets of live *Oculina*. Within the coral zone, the mean live coral cover was 6.6%, standing dead coral 5.9%, coral rubble 25.1%, and rock pavement and ledges 30.1%. Individual quadrats of the densest coral growth averaged 29.9% and ranged up to 58.3% live coral cover. In 2001, an 18-m tall *Oculina* bioherm was the primary feature of the video survey at this site. The bioherm was 0.37 km wide E-W and consisted of a series of mounds that extended 1.1 km N-S. The submersible dive was divided into four video transects (W, E, and S slopes, and top ridge). The bioherm was entirely covered with thick layers of unconsolidated coral rubble and sediment except for a few 30–90 cm standing dead corals and a few 20–50 cm live colonies. Some colonies were wrapped in monofilament fishing line. The only large fish noted were one gag grouper and a few greater amberjack; no scamp grouper were present. Since 1977 at the Eau Gallie site, mean live coral cover had been almost completely eliminated from 6.6% to 0.1% (Mann-Whitney: $P < 0.0001$), standing dead

coral showed no significant change (from 5.9% to 18.9%; Mann-Whitney: $P > 0.05$), and dead coral rubble has increased more than 3-fold from 25.1% to 78.8% (Mann-Whitney: $P < 0.001$; Fig. 3, Table 1).

Sebastian Transect.—Historical dives (1975–1977) encountered live *Oculina* coral in a zone extending 4.61 km at depths of 54.9–85.0 m. Overall, relatively little live coral and no large bioherms were observed on these dives. The mean live *Oculina* cover was 3.2%, standing dead coral 3.7%, and coral rubble 1.9%. The 2001 dive found a zone of dead coral rubble extending at least 1.6 km in length. The bottom was low relief ridges of dead rubble and sparse standing dead coral. The only living coral observed were two 15 cm colonies. Mean live coral cover was 0.1%, standing dead coral 5.7%, and coral rubble 92.5%. Since 1976 there has been nearly 100% loss of live coral (Mann-Whitney: $P < 0.0001$), a significant increase in standing dead coral (Mann-Whitney: $P < 0.05$), and coral rubble had increased by 90.6% (Mann-Whitney: $P < 0.0001$; Fig. 3, Table 1).

Bethel Shoals Transect (Steeples Reef).—In 1975, two submersible dives encountered *Oculina* coral over a linear distance of 3.7 km at depths of 61–81 m. Patch reefs consisting of large 1.5 m diameter live *Oculina* were present on low relief (0.5–2.5 m) mounds and ridges. Visual observations estimated 5%–10% live coral on these reefs. No large, high relief bioherms were encountered. Mean live *Oculina* coral was 7.1%, standing dead coral 12.4%, and coral rubble 33.6% (Fig. 3). Maximum coral coverage of individual quadrats ranged from 13.1%–33.0%. Additional dives were also made near the Bethel Shoals transect in the late 1970s where two large bioherms were encountered; these were termed the Steeples or the Thompson-Reed Reefs- TR8 and TR9. Although quantitative photographic transects were not made, written transcripts of dive observations indicated that one mound (TR8) had 25-m relief and 1–2 m live *Oculina* colonies were abundant on the south slope and peak. Interestingly, just 0.37 km to the north was a smaller bioherm (TR9, 12.8 m relief) that was entirely dead coral rubble. In 2001, a submersible dive conducted detailed transects over the Steeples (TR8); the south and north slopes and peak were covered with nearly 100% dead *Oculina* coral rubble. The upper south slope had some 30 cm standing dead coral and coral rubble consolidated with encrusting sponges. The live coral showed a significant 100% loss since 1976 from 7.1% to 0% (Mann-Whitney: $P < 0.0001$), and standing dead coral also decreased from 12.4% to 5.6% (Mann-Whitney: $P < 0.0001$) while coral rubble increased a total of 59% from 33.6% to 92.6% (Mann-Whitney: $P < 0.0001$; Fig. 3, Table 1).

Discussion

Oculina Habitat: Changes from 1970s to Recent.—The historical transects ended in 1977 but additional dives continued at many of the reef sites through 1985 for various projects including geology, taxonomy, and ecology. No noticeable reef or coral death was evident from the mid 1970s to the mid 1980s. Very few dives occurred between 1985 and 2001 due to lack of funding. Although there are discrepancies of up to 350-m between LORAN-A coordinates of the 1970s and recent GPS coordinates, at least four of the bioherms (Cape Canaveral, Steeples, Chapman's, Jeff's Reefs) are precisely the same features compared in the 1970s and 2001 transects. In some cases, the reef was revisited during the transformation from LORAN-A to LORAN-C to GPS. Unfortunately, by 2001, most of the deep-water *Oculina* ecosystem

had shown severe or complete loss of standing coral habitat when compared to the 1975–1977 photographic transects. By 2001, only two high-relief bioherm sites had extensive amounts of live coral remaining (Chapman's Reef and Jeff's Reef). Except for these two reefs, all 2001 transect sites had < 0.1% live coral remaining. Overall, the loss of mean live coral cover at each transect site was dramatic and statistically significant, varying from 3% to 26%. In addition, the percent loss of live coral was nearly 100% (range 98.4%–100%) for each site except Chapman's Reef and Jeff's Reef (46.2, 66.4%, respectively). Concurrently, four of the seven sites showed a decrease in standing dead coral, and all showed an increase in percent cover of unconsolidated dead coral rubble. Significant declines in both standing live coral and standing dead coral together with the concurrent increase of coral rubble further indicate that mechanical disruption was the probable cause of the decline.

Only Jeff's Reef had an interim survey in 1996. Using the JSL submersible, video transects were conducted on all sides of the reef in similar locations to the 1977 transects. An alarming and significant drop in percent cover of mean live coral occurred between 1977 (39.3%) and 1996 (10.3%). Between 1996 and 2001, however, there was no significant change in live coral. Concurrently, the percent of standing dead coral coverage also increased significantly from 1977 (25.8%) to 1996 (60.2%). At Jeff's Reef, it appears that the live coral coverage dropped dramatically over the 20 yrs from 1977 to 1996 concurrent with increase in standing dead coral. This strongly implies that impacts other than trawling or mechanical damage were also involved in the decline of *Oculina*. Additional analyses were made for the Jeff's Reef transects to define the loss of live coral. In order to determine whether there was any change in the percent live coral on standing coral colonies (both live and standing dead), data were standardized to include only quadrats that had standing coral and were assessed for percent live coral [(number of point counts of live coral / number live coral + number standing dead coral) × 100]. Although the pattern is similar to the overall mean loss of live coral, there is a statistically significant gain in live coral from 1996 to 2001 (ANOVA: $P < 0.0001$; Fig. 5). This gain in live coral (per standing coral) is coincident with the closure of the original OHAPC boundaries (OECA) to bottom fishing. Although coincidental, this may indicate an actual improvement in coral and habitat health; that is, the coral is regrowing on the standing dead coral as long as it is not mechanically impacted by trawls, bottom longlines, anchors, or fishing weights.

Recent ROV dives (2001–2005) have documented extensive live bottom habitat within the OHAPC, in addition to *Oculina* coral habitat (Reed et al., 2005), that consists of limestone pavement, ledges, and boulders with associated epibenthic fauna (sponges, hydroids, gorgonians) and fish. Based on new multibeam maps, over 100 high-relief (12–18 m tall) bioherms have been recently discovered, mostly adjacent to but outside the current OHAPC boundaries from Eau Gallie to Cape Canaveral. ROV dives have confirmed that most of these, if not all, have been reduced to coral rubble. However, these bioherms support various live bottom habitats. The upper flanks and peaks of these bioherms have dense coral rubble, which in some cases have consolidated from thick encrusting sponges and other fouling organisms, and some sparse standing dead coral is evident. These provide minor relief (15–30 cm) for many small reef fish such as yellowtail reeffish**,** *Chromis enchrysura* Jordan and Gilbert, 1882, and bank butterflyfish, *Prognathodes aya* (Jordan, 1886). On many of the bioherms, sparse, scattered individual colonies of live *Oculina* and small thickets of live coral were discovered, usually near the base of the reefs. Also the northern

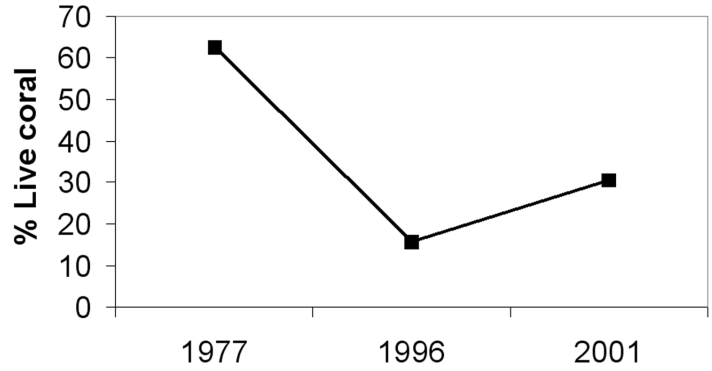

Figure 5. Comparison of percent live *Oculina* coral on all standing coral colonies (both live and standing dead colonies) at Jeff's Reef [(number of point counts of live coral / number of point counts of live coral + number of point counts of standing dead coral) × 100]. Between year comparisons were statistically different for all years including a gain of live coral between 1996 and 2001 (ANOVA: $P < 0.0001$).

base of many of the bioherms has exposed limestone ledges and boulders (1 m relief), which now provide the primary habitat for the larger fish such as scamp and snowy grouper.

Habitat Loss: Effects on the Ecosystem.—The *Oculina* biogenic refuge consists primarily of standing live and dead coral habitat. As long as the coral is standing, the living space within the colony branches supports dense and diverse communities of associated invertebrates (Reed et al., 1982, 2002a,b; Reed and Mikkelsen, 1987). However, once reduced to unconsolidated coral rubble, little living space is left except for the boring infauna (Reed, 1998). When the standing coral habitat is lost due to mechanical damage or natural causes, effects on the ecosystem are dramatic. The decline in fish populations, primarily gag and scamp grouper, on the *Oculina* reefs over that past 20 yrs is well documented (Gilmore and Jones, 1992; Koenig et al., 2000, 2005). This may be attributed to both habitat loss and overfishing. Population densities of the dominant basses [roughtongue bass *Pronotogrammus martinicensis* (Guichenot, 1868) and red barbier *Hemanthias vivanus* (Jordan and Swain, 1885)], dominant groupers [scamp, gag, and speckled hind *Epinephelus drummondhayi* Goode and Bean, 1878), and pelagic species (greater amberjack and almaco jack *Seriola rivoliana* Valenciennes in Cuvier and Valenciennes, 1833) all showed positive association with intact coral habitat (either sparse or dense live coral) compared to unconsolidated coral rubble habitat (Koenig et al., 2005). Scamp grouper density in intact coral habitat was significantly greater than other habitats (sparse live coral or rubble). Only one commercially important species (snapper, *Lutjanus* spp.) was primarily associated with the coral rubble habitat.

A hypothetical trophic model of the *Oculina* coral ecosystem shows the plausible interactions of the various invertebrate and fish species that are associated with the coral habitat (George et al., 2007). Standing live and dead coral provide refuge within the branches for diverse invertebrate communities including polychaete worms, mollusks, crustaceans, sponges, and octocorals. These consist of various suspension feeders, detritivores, carnivores and corallivores (Reed, 2002a), which are prey for smaller reef fish and up the food chain to larger benthic and pelagic fish. The economically important grouper complex, including gag and scamp grouper and speck-

led hind, are closely associated with the standing intact coral habitat (Gilmore and Jones, 1992; Koenig et al., 2005). The whole system, in turn, is also linked to physical factors such as food, nutrients, and plankton from the Florida Current (Gulf Stream) and upwelling events which provide influx of cold nutrient rich water (Reed, 1983). Therefore, significant loss of habitat, particularly intact live and dead standing coral, could feasibly bring dramatic and possibly catastrophic shifts in the ecosystem. As seen with the grouper complex that is associated with the intact coral, the loss of standing coral habitat could result in the loss of several commercially important species that use the *Oculina* ecosystem as spawning and feeding grounds. Some species such as gag grouper utilize inshore mangrove and grassbed habitat as juveniles then move to the deeper high relief reefs once they are sexually mature (Gilmore and Jones, 1992). Also the effects of overfishing are unknown for the *Oculina* ecosystem. Even if the *Oculina* coral is kept intact, how will the lack of top predators affect the whole reef system? Such a loss could cause dramatic shifts in the entire community structure of smaller food prey and ultimately affect the coral itself. Similar ecological concerns are evident for deep-sea coral reefs worldwide where direct and indirect effects of trawling have changed benthic community abundance and composition, degraded species diversity, and resulted in the loss of corals and sponges which have a keystone role in providing habitat for a large number of other organisms (Fosså et al., 2002; Gage et al., 2005).

Impacts from Fishing and Trawling.—From analyses of these photographic transects over a 25 yr period, it is clear that many if not most of the reef sites have shifted from a predominately live coral habitat to coral rubble. Although this has occurred throughout the OHAPC, the only remaining intact reefs of significant size are in the southern portion that has been protected within the boundaries of the original OHAPC since 1984, in which bottom trawls, bottom longlines, dredges, fish traps, and anchoring are all prohibited. Only recently have surveillance and enforcement been sufficient to deter illegal fishing and trawling within the *Oculina* reef ecosystem. Since 2000, when the boundaries of the OHAPC were expanded northward to Cape Canaveral, shrimp bottom trawlers have been caught poaching within the boundaries of the original OHAPC (OECA) and in the vicinity of Chapman's Reef and Jeff's Reef, the only remaining live, high-relief reefs. Also throughout the OHAPC, recent dives with ROVs have documented reefs wrapped with fishing lines, piles of bottom longlines, discarded trawl nets, and anchor lines (Reed et al., 2005). Since the 1970s, bottom trawling within the *Oculina* ecosystem has been primarily for rock shrimp and brown shrimp and this may be the primary cause of major habitat destruction. Also commercial dredging for calico scallops was prominent in the 1970s–1980s but overfishing and destruction of habitat caused the collapse of the industry. Photographic transects in the 1970s showed deep mounds of living scallops, but these tended to be in sandy/shelly bottom in shallower water west the *Oculina* reefs and were not likely the cause of impacts to the majority of *Oculina* bioherms.

Worldwide, bottom trawling has severely impacted deep-sea coral reef habitat and continues to be a major concern and threat (Rogers, 1999; Butler and Gass, 2001; Morgan et al., 2003; Barnes and Thomas, 2005; Mortensen et al., 2005). Bottom trawling causes severe mechanical damage as evident on deep-water *Lophelia* reefs in the northeast Atlantic (Rogers, 1999; Fosså et al., 2002), hard bottom habitats off the southeastern United States (Van Dolah et al., 1987), and deep-water seamounts off New Zealand and Tasmania (Jones, 1992; Koslow et al., 2001). In a research experi-

ment, a single pass of a bottom trawl removed 1000 kg of *Primnoa* coral off Alaska and resulted in the detachment of 27% of the corals (Krieger, 2001). ROV surveys of extensive deep-water *Lophelia* coral reefs off Norway found that 30%–50% of the reefs were damaged from fishing gear; at some sites almost all corals were crushed or dead (Fosså et al., 2002). Heavily fished seamounts off Tasmania have up to 90% coral loss and 83% less biomass than unfished sites (Koslow et al., 2001). Unfortunately, damage to deep-sea coral reefs has dramatically changed with larger vessels, advent of new gear such as roller trawls, and an increase in navigation technology such as precision depth recorders and inexpensive geo-positioning electronics which allows specific areas and even spawning aggregations to be targeted (Morgan et al., 2005).

Conclusions

The long term prospects for the deep-water *Oculina* coral ecosystem remain tentative at best. Certainly, mechanical damage from bottom trawling has occurred and is extensive. Between 1977 and 2001, six of the coral reef transects in this study had nearly 100% loss of live coral cover (range 98.4%–100%) whereas only two reefs which were within the original OHAPC since 1984 have survived. Significant declines in both standing live coral and standing dead coral with the concurrent increase of coral rubble suggest that mechanical disruption was the cause of the decline. Certainly, trawling continues to be the primary threat to the ecosystem as evident from recent photographs of trawl nets found on the bottom, destroyed reefball modules, the documented destruction of the Cape Canaveral *Oculina* bioherm, and evidence of trawl scars in the rubble (Reed et al., 2005).

But positive efforts are showing results. Legislation now prohibits anchors and destructive fishing gear, such as bottom trawls, dredges, and longlines throughout the entire 1029 km^2 OHAPC (NOAA, 2000). Since this legislation was enacted several illegal trawlers have been intercepted and fined by the U.S. Coast Guard. Recent legislation also requires shrimp-trawling vessels operating in the area to have an active vessel monitoring system (VMS) aboard which allows vessels to be tracked continuously by satellite. Since the ban on bottom hook-and-line fishing within the boundaries of the OECA was enacted in 1994, there was a statistically significant gain in live coral from 1996 to 2001 at one of the remaining *Oculina* bioherm sites. We are hopeful that this is actual improvement in coral and habitat health and that the coral is regrowing as long as it is not mechanically impacted by trawls, bottom longlines, anchors or fishing weights. In addition, the deep-water *Oculina varicosa* Lesueur, 1821 coral has been nominated as an endangered species (Hirshfield et al., 2005). The indefinite ban on bottom fishing for grouper within the OECA boundaries may enhance recovery of spawning aggregations of these commercially important species. Management must prevent future disruption of the bottom within the current OHAPC to allow coral larval settlement on the rubble and extensive hard bottom areas, promote recovery of healthy reefs, and allow credible monitoring programs to proceed. Unparalleled research opportunities are possible to document the effectiveness of deep-water coral reserves. The *Oculina* bioherms and coral habitat occur both within and outside of the OHAPC, relatively close to shore and at depths that are much more accessible than most other deep coral ecosystems. Further research is needed on deep-water coral reproduction, recruitment, mortality, disease, trophic models, bentho-pelagic pathways, and physical processes. In addition, adequate sur-

veillance and enforcement along with severe penalties are necessary to protect and conserve the *Oculina* reefs as well as other deep-water coral reserves for future generations.

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Nuclear sequences reveal mid-range isolation of an imperilled deep-water coral population

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Abstract

The mitochondrial DNA of corals and their anthozoan kin evolves slowly, with substitution rates about two orders of magnitude lower than in typical bilateral animals. This has impeded the delineation of closely related species and isolated populations in corals, compounding problems caused by high morphological plasticity. Here we characterize rates of divergence and levels of variation for three nuclear gene regions, then use these nuclear sequences as markers to test for population structure in *Oculina*, a taxonomically confused genus of corals. Rates of sequence divergence (obtained by comparison to *Solenastrea hyades*) were at least five (and sometimes over 10) times faster for the three nuclear markers than for a mitochondrial reference sequence. Nuclear sequence variation was also high within populations, although it tended to decline north of Cape Canaveral. Significant subdivision was evident among samples from 10 locations from between North Carolina and the Florida Panhandle, but neither nominal species designation nor population depth explained much of this variation. Instead, a single population from the unique deep (> 70 m) water reefs at the Oculina Banks off central Florida was a strong genetic outlier: all pairwise measures of subdivision involving this population were greater than those involving all other populations, and multilocus clustering recognized the Oculina Banks as distinct from other populations, despite its close proximity (≤ 36 km) to populations from shallower waters nearby and its location at the centre of the sampled range. Genetic isolation of the Oculina Banks population suggests that focused efforts will be needed to conserve the foundation species of these monotypic reefs and that depth may play a role in isolating marine populations and perhaps facilitating initial steps towards speciation.

Keywords: multilocus genotyping, Oculina Banks, *Oculina*, population isolation

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Introduction

Appearances can be a misleading guide to distinguishing closely related, but genetically isolated species. The species delineation problem is especially difficult for taxa with simplified morphologies (e.g. cave salamanders, Niemiller *et al*. 2008; earthworms, King *et al*. 2008; parasitic acanthocephalans, Steinauer *et al*. 2007; sponges Klautau *et al*. 2003), especially when combined with high levels of phenotypic plasticity (e.g. sponges, Erwin & Thacker 2007; octocorals, Prada *et al*. 2008; freshwater mussels, Baker *et al*. 2003). Despite these difficulties, species delineation is a necessary component of understanding the speciation process, of characterizing ecological variation among habitats and geographical locales, and of targeting imperilled species and populations for conservation efforts.

DNA sequences offer a large potential pool of characters for inferring species boundaries and relationships. Until recently, genetic studies aimed at understanding differentiation near the species interface have used primarily mitochondrial DNA (mtDNA) sequences (at least for bilateral

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animals). One region of this genome (*coxI*) has even been nominated for use as a universal genetic barcode (Hebert *et al*. 2003). Mitochondrial DNA has several advantages relative to nuclear DNA in these contexts: high rates of nucleotide substitution produce abundant identifiable variants and these variants sort to reciprocal monophyly quickly due to low effective population size. However, the lack of recombination means that all mtDNA sequences from an individual share a single history that may not necessarily reflect species relationships, as demonstrated by recent examples of phylogenies based on multiple nuclear loci conflicting with mtDNA-based trees (Leache & McGuire 2006; Carling & Brumfield 2008). Moreover, and more germane for the issue of species delineation, rapid rates of mtDNA change cannot be assumed for a substantial proportion of eukaryotes.

For plants, fungi, and many lower metazoans, rates of nucleotide substitution for mtDNA are about 100-times slower than those in bilateral animals (Wolfe *et al*. 1987; Hellberg 2006). Mitochondrial DNA thus will have far less power to reveal phylogeographical structure and recognize cryptic species in eukaryotes with slow mtDNA than in bilateral animals (Huang *et al*. 2008). Nuclear gene sequences may provide an alternative to mtDNA. Rates of nucleotide substitution for nuclear DNA (nDNA) in plants and fungi are not exceptionally slow: they are similar to those in bilateral animals, or about 10 times faster than those for mtDNA from the same taxa (Wolfe *et al*. 1987). Allozyme surveys in taxa with slow mtDNA have revealed ample variation and subdivision (e.g. Hellberg 1994; McFadden *et al*. 1997), suggesting nuclear variation is not constrained as mtDNA is. Thus, nDNA sequences may succeed in flagging isolated populations in lineages where slowly evolving mtDNA cannot.

Hard (scleractinian) corals are perhaps the animal group most sorely in need of an alternative to mtDNA for delineating species and recognizing isolated populations (Lopez *et al*. 1999; Ridgway & Gates 2006). Several aspects of the biology of reef corals make the identification of recently diverged populations especially difficult. First, scleractinian morphology is highly plastic, both at the level of entire colonies and single corallites (Foster 1979; Willis 1985; Bruno & Edmunds 1997; reviewed in Todd 2008), which has led to extreme confusion in their taxonomy and systematics (Fukami *et al*. 2004, 2008). Second, coral mtDNA evolves too slowly to distinguish some close relatives (Shearer *et al*. 2002; Hellberg 2006); even comparisons of entire mtDNA genomes reveal only a small numbers of changes (e.g. in *Montastrea*, Fukami & Knowlton 2005; *Pocillopora*, Flot & Tillier 2007). Third, the potential for interspecific hybridization appears great in some reef corals, sometimes producing morphological intermediates (van Oppen *et al*. 2001; Marquez *et al*. 2002; Combosch *et al*. 2008; reviewed in Willis *et al*. 2006). Many reef corals face threats to their existence (Hoegh-Guldberg *et al*. 2007), therefore despite the aforementioned challenges, the identification of genetically isolated corals is critical to rational conservation efforts aimed at repopulation and the maintenance of genetic diversity (Knowlton 2001; Baums 2008).

Corals of the genus *Oculina* exemplify how the ability to distinguish isolated populations matters. Several nominal species of *Oculina* occur in coastal North American waters, generally living in waters that are cooler and more turbid than other tropical stony corals can tolerate. Members of this genus are gonochoric broadcast spawners (Brooke & Young 2003), and their larvae recruit well on to artificial hard substrate, especially when algal competitors are absent (Miller & Hay 1996). The ecological adaptability of shallow water *Oculina* is further supported by reports from the Mediterranean, where *Oculina patagonica* appears to have invaded over the last four decades (Fine *et al*. 2001). Such hardiness, however, does not mean all populations of *Oculina* are immune to anthropogenic disturbance. Off the southeastern coast of the USA, *Oculina varicosa* occurs as small (< 30 cm) facultatively zooxanthellate colonies at depths shallower than 30 m. In addition, off the eastern coast of central Florida, nominal populations of *O. varicosa* have formed extensive bioherms of unconsolidated coral rubble and sediment, capped with large colonies (~1–2 m) of living coral in deep (70–100 m) water. These deep-water colonies have more slender branches than shallow colonies and are azooxanthellate. These bioherms, collectively termed the Oculina Banks, have been heavily damaged by illegal trawling and dredging (Reed *et al*. 2007), despite Federal Protection that was initiated in 1984 (Reed 2002). Recovery of the framework species of this unique habitat depends critically on whether the *Oculina* populations at the Oculina Banks are isolated from other *Oculina* populations: ample recruits could be transplanted from shallow populations if they are genetically homogeneous, whereas distinct Oculina Banks populations would minimally require locally targeted recovery strategies, and more broadly warrant greater efforts to conserve the unique habitat they create.

Here we use single-copy nuclear DNA sequences to distinguish genetically isolated populations among continental North American populations of the coral genus *Oculina*. We first compare levels of divergence for three nDNA markers to that for a commonly used region of mtDNA, cytochrome oxidase I. Next, we assess levels of variation in these nDNA markers among four North American *Oculina* nominal species (*O. arbuscula, O. diffusa, O. robusta,* and *O. varicosa*). Finally, we use the nDNA markers to assess differentiation and genetic isolation among named morphospecies of *Oculina*, among geographically distant sites, and among populations found at different depths.

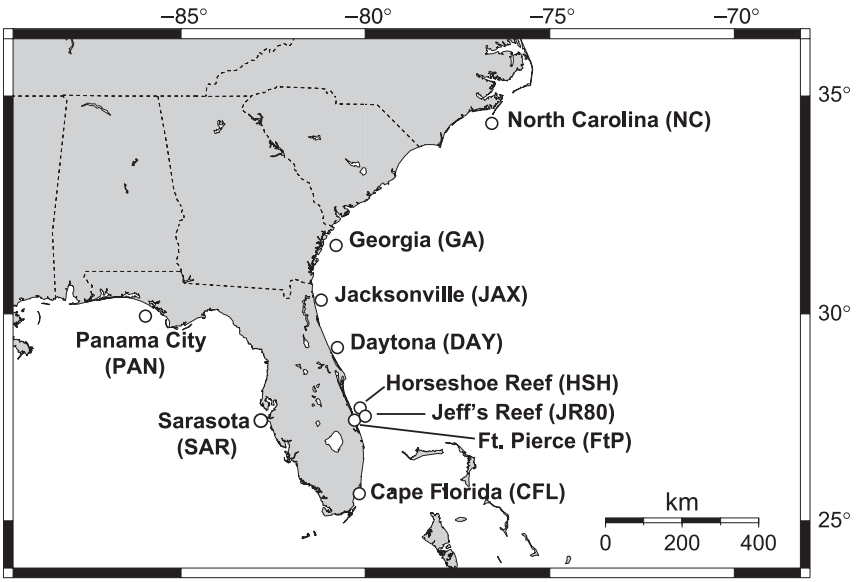

Fig. 1 Geographical locations from which samples of *Oculina* were taken.

Methods

Population sampling

We obtained samples of the four most common nominal species of *Oculina* from the southeastern USA (Fig. 1, Appendix), trying to sample each species from as broad a geographical and bathymetric range as possible. Sample sizes ranged from 8 to 16 colonies per location.

Species identifications were based on colony form, branch thickness, and corallite form. The genus *Oculina* has long been recognized as taxonomically challenging, with original descriptions that are often very sparse on details and virtually every species-level treatment calling for revision going back over 100 years (e.g. Verrill 1902; Zlatarski & Martinez Estalella 1982; Cairns 1991). We based our identifications of *Oculina diffusa* (Lamarck 1816), *O. robusta* (Pourtalès 1871), and *O. varicosa* (LeSueur 1821) on both their original descriptions and on subsequent work and guides (Verrill 1902; Zlatarski & Martinez Estalella 1982; Humann 1993). *Oculina diffusa* has short thin branches and its corallites are clearly raised. Colonies of *O. robusta* are, as the name suggests, more robust, with long thick branches that taper and corallites that are nearly flush with the branch. The branches of *O. varicosa* fall between these extremes: they are generally sturdier than those of *O. diffusa* and extend further between branch points. The corallites of *O. varicosa* extend from a swollen base (Verrill 1902). Individuals from North Carolina and Georgia were designated *Oculina arbuscula* (Agassiz in Verrill 1864; Rupert & Fox 1988), although this appears to be a regional moniker because no characters clearly separate them from *O. varicosa*.

RNA isolation, cDNA library construction and expressed sequence tag sequencing

We chose to use sequences from nuclear gene coding regions to evaluate rates of DNA evolution and patterns of population variability and subdivision. Microsatellite markers have been successfully used to identify regional population isolation in reef corals (Baums *et al*. 2005); however, patterns of nucleotide substitution around these hypervariable regions may be atypical (Stallings 1995; Vowles & Amos 2004). Primers that amplified single-copy nuclear genes that are sufficiently variable for population-level studies in cnidarians were not available when we started this study, so we generated expressed sequence tags (EST) to produce new markers.

RNA was isolated from a single live specimen of *Oculina varicosa* collected at Jeff's Reef, Florida. This deep water (80 m) individual was free of symbiotic algae (zooxanthellae), which might otherwise have contaminated coral tissue (Shearer *et al*. 2005). RNA was isolated through a procedure modified from Chomczyniski & Sacchi (1987). A tissue sample of a live individual was ground in ice cold GIT (4 M guanidine isothiocyanate, 25 mM NaOAc pH 6, 0.82% β-mercaptoethanol) in a Dounce homogenizer. Seven millilitres of the resulting homogenate was layered over 3 mLs of a CsCl cushion (5.7 M CsCl, 25 mM NaOAc pH 6.0) and centrifuged at 115 000 *g* in a Beckman SW41 rotor 16 h at 20 °C. The resulting RNA pellet was resuspended in 150 μL RNase-free 0.1 M EDTA. To concentrate this RNA, 1/10 V of RNase-free 5 M ammonium acetate, 5 μg RNase-free glycogen and 2.5 V 100% EtOH were added and RNA was precipitated at –20 C overnight. RNA was spun down at 10 000 *g* at 4 °C for 15 min,

Table 1 Primers used in this study. Putative marker identification (based on BLASTp searches) shown parenthetically.

Marker	Primers
p14	(Fatty acid elongase)
	Ocp14F: TGTACCACTTGGGATGAACG
	Ocp14R: TCAAGCTTCCAGTCTTGTGAAA
p62	(Elongation factor 1α)
	p62Fb: TGATTGTCCTCAACCATCCA
	p62R: CTCCTGACAGACTTTCGATGG
	p62Rd: ACCACCTTTCTGGGCTTTCT
p302	(Tachylectin-2 motif)
	p302F: TTATACGGCGTCACAAACGA
	p302R: TCGTCATCACCCTTTTATTCC
COI*	(Mitochondrial cytochrome oxidase *c* subunit I)
	HCO2198: TAAACTTCAGGGTGACCAAAAAATCA
	LCO1490: GGTCAACAAATCATAAAGATATTGG

*Primers from Folmer *et al.* (1994).

resuspended in a few microlitres of RNase-free 0.1 M EDTA, then an aliquot was inspected on a gel for degradation. Total RNA from this procedure was accumulated and saved at –80 °C. Poly A RNA was isolated from 30 μg total RNA using Ambion's Poly(A)Purist-MAG kit. The ultimate mRNA yield was ~739 ng of mRNA.

A cDNA library was constructed from the *O. varicosa* mRNA using Strategene's ZAP-cDNA kit according to the manufacturer's instructions with two exceptions. The kit directions suggest starting with ≥ 1.5 μg poly A mRNA. Because we had only half this amount, all reaction volumes were halved as well. To size fractionate cDNAs, we used Pharmacia's SizeSeptember 400 column rather than the Sepharose CL-2B column provided with the kit. The resulting primary library had over 250 000 pfu before amplification. We sequenced 91 random inserts, with an average size of 571 bp. 67 of these contained open reading frame (ORF) of at least 60 residues, and 50 of these returned significant matches to existing sequences (31 March 2008 search) using BLASTp.

DNA isolation and polymerase chain reaction

Genomic DNA was isolated from a small piece of coral using either cetyltrimethyl ammonium bromide extraction protocols (R. J. Toonen, unpublished, available online at http://www2.hawaii.edu/~toonen/files/MsatsV1.pdf) or the MoBio Ultra Clean Soil DNA Isolation Kit.

From the 50 ESTs with putative matches, 23 primers pairs were designed (using Primer 3, Rozen & Skaletsky 2000) to amplify regions 300–500 bp long that included both parts of the ORF and 3′ untranslated region (UTR). Of the 16 pairs that amplified a single band of the proper size (or larger), three were selected (Table 1) for use as markers based on consistency of amplification and sequencing, variation found in an initial screening of individuals from the geographical extremes sampled, and single-copy status (based on finding ≤ 2 alleles in cloned heterozygotes). All three of these nuclear gene regions aligned with sequences from the closest animal for which genomic data are available, the anemone *Nematostella vectensis*. The closest BLASTp hits were to sequences from *N. vectensis* (p14, fatty acid elongase, Putnam *et al*. 2007), from the coral *Pocillopora damicornis* (p62, elongation factor 1α, Flot *et al*. 2008), or the coral *Montastraea faveolata* (p302, tachylectin-2, Schwarz *et al*. 2008). No introns were present in the three amplified gene regions.

Products for each of these nuclear markers were amplified from genomic DNA using the same polymerase chain reaction (PCR) profile consisting of an initial denaturation (94 °C) for 3 min, initial annealing step (50 °C) of 2 min, and initial elongation (at 72 °C) of 2 min, followed by 35 cycles of 35 s at 94, 1 min at 50, and 1 min 15 s at 72. A final elongation at 72 for 10 min completed the profile.

Sequencing, alignment and phasing

PCR amplicons were directly sequenced (with ABI BigDye version 3.1) using both of the amplification primers (GenBank accession numbers FJ966395–FJ966875). Many individuals had indels that obscured complete reads in both directions. All of these indels occurred in portions of the amplified region lying in the 3′ UTR of the sequenced gene except for one 3-bp indel in the ORF of tachylectin-2. Sequences containing indels were cloned to resolve constituent allelic sequences using ¼ reactions of the Invitrogen TOPO TA Cloning Kit for Sequencing. Resulting colonies were screened by PCR with the primers M13For(–20) and M13Rev. Eight to 16 clones of the proper size (or more if needed to find both alleles) were sequenced using the M13 primers. The initial direct sequences were always used in determining allelic sequences from cloned DNA to avoid scoring any changes that resulted from errors introduced by the PCR. In total, 945 cloned sequences were generated to resolve all individuals heterozygous for indels.

The COI and EF-1α sequences contained no gaps and were aligned by eye. The fatty acid elongase and tachylectin-2 sequences contained numerous gaps. Most commonly used multiple alignment programs make use of an initial guide tree as a framework for determining the optimal alignment and the placement and length of gaps is determined by a particular set of parameters. However, an incorrect guide tree may introduce bias into the resulting alignment. To avoid this problem, we employed a Bayesian approach to multiple sequence alignment, implemented in BAli-Phy version 2.0.1 (Suchard & Redelings 2006) which does not condition on a single alignment estimate. BAli-Phy finds the multiple alignment with the highest posterior probability by estimating both the alignment and the topology simultaneously, using a Markov chain Monte

Carlo (MCMC) sampler. This approach is computationally intensive, thereby limiting the number of sequences that can be included in the analysis (Redelings & Suchard 2005).

We reduced the full data sets for fatty acid elongase and tachylectin-2 for input into BAli-Phy using a two-step process. First, sequences were grouped by their length and aligned using Muscle (Edgar 2004), implemented in Geneious version 3.6 (Drummond *et al*. 2007). Second, networks were then constructed for each of the different alignments in TCS version 1.21 (Clement *et al*. 2000). For each network, the most common sequence was used to represent all sequences of that length, except when a sequence was more than 10 mutational steps from the most common one, in which case it was represented individually.

Both fatty acid elongase and tachylectin-2 were analysed in BAli-Phy using the GTR substitution model and the default indel model. By default, the MCMC sampler in BAli-Phy collects information after each iteration and runs until stopped by the user. We chose when to stop by first determining when convergence had occurred through visual inspection of output using Tracer version 1.4 (Rambaut & Drummond 2007). After convergence, the Markov chain was then allowed to run until the effective sample size from the Markov chain was equal to or greater than 1000. To ensure that the Markov chain had truly converged, we repeated this process an additional three times, for a total of four independent runs. The final output from each run was separately analysed, with all the samples before convergence discarded as burn-in. The consensus alignment from the run with the highest posterior probability was used for subsequent analyses.

To resolve alleles from sequences with multiple heterozygous single nucleotide polymorphisms (SNP), we employed a Bayesian statistical method implemented in Phase version 2.1.1 (Stephens *et al*. 2001; Stephens & Donnelly 2003; Stephens & Scheet 2005). Each marker data set was split into two inputs for haplotype reconstruction, one containing only individuals from the JR-80 population and the other containing the rest of the data set. This was carried out because preliminary analyses indicated that individuals from the JR-80 population might not be freely interbreeding with those in populations at other depths, which would violate the assumptions of the coalescent model used in Phase (Stephens *et al*. 2001).

Input files were prepared as suggested in the Phase documentation, but with several modifications. First, all variable sites were used. Second, gaps were coded as a fifth allele. The '–d1' option, which specifies a parent-independent mutation model rather than a stepwise one for multi-allelic loci, was used in the analysis of any data set that contained at least one tri-allelic SNP (true for all markers, but not for the data sets with only JR-80 individuals). Alleles determined by cloning heterozygotes were used to create a known file. A default probability threshold of 0.9 was used for all runs. We performed 10 independent runs for each data set analysed, using different random number seeds. The goodness-of-fit measure for each independent run was then plotted and compared to check for consistency between runs.

After the initial Phase runs, all data sets contained some individuals with unresolved SNPs. We cloned a subset of these individuals to directly determine their haplotype phase. The direct haplotype observations were then added to the 'known' file and the data sets were re-analysed. This was carried out iteratively until the phase of all SNPs was recovered with > 0.9 probability or we ran out of tissue. Final data sets contained no more than three individuals for which the phase of a single SNP was not resolved to 0.9 (one for tachylectin-2, three for elongation factor 1α and fatty acid elongase).

After alignment and phasing of heterozygous SNPs, the final nuclear data set contained 122 individuals (244 alleles). The average number of nucleotide differences between haplotypes, k (Tajima 1983; equation A3), was calculated for each marker and population in DNAsp version 4.5.0.2 (Rozas *et al*. 2003), excluding sites with alignment gaps.

Interspecific sequence divergence

We determined relative rates of synonymous and nonsynonymous substitution between *Oculina* and *Solenastrea hyades*, a species for which a congener (*Solenastrea bournii*) has previously shown to be a close relative of *O. diffusa* (Fukami *et al*. 2004). These estimates were made using MEGA version 4.0.1 (Tamura *et al*. 2007) and took into account only the coding regions of the four markers. Appropriate substitution models for calculating genetic distances were chosen by jModelTest (Posada 2008): K80 + Γ for the three nuclear markers and JC for COI under the BIC criteria. For mitochondrial COI, three *Oculina* individuals, representing the unique haplotypes for the genus, and one *Solenastrea* sequence (individuals in this genus were invariant) were used for this comparison. For nuclear genes, between-species means were calculated from the full data set of 122 *Oculina* (with the four nominal species pooled) and two *Solenastrea* individuals. For the nuclear genes, N and S were calculated using the modified Nei–Gojobori method (Nei & Kumar 2000), which accounts for differences in the frequencies of transitions and transversions, because jModelTest had chosen the K80 substitution model. The standard Nei–Gojobori method (Nei & Gojobori 1986) was used to calculate N and S for COI to reflect the JC model selected.

Recombination

Recombination can create DNA sequences with different histories, a violation of the assumptions underlying most

coalescent analyses. We tested for recombination using a combination of haplotype network and population genetic analyses. Networks were constructed for each nuclear marker in TCS version 1.21 (Clement *et al*. 2000), with alignment gaps counted as missing data. Recombination events were inferred if reticulations were present (Crandall 1999). The four-gamete test for recombination (Hudson & Kaplan 1985) was implemented in IMgc (Woerner *et al*. 2007).

Haplotype networks (not shown) for all three markers contained multiple reticulations, consistent with recombination linking regions with different histories (Crandall 1999). All three nuclear gene regions also failed the four-gamete test for detection of recombination. For this reason, we chose to use an infinite allele model, with each unique haplotype scored as a unique allele for each of the three markers.

Population structure

Identical alleles were collapsed for subsequent analyses. For EF-1α, which did not contain indels, this was carried out using the online implementation of FaBox (Villesen 2007). FaBox ignores indels when collapsing sequences, however, and both fatty acid elongase and tachylectin-2 contained numerous indels. To preserve information from these indels, alignments for these two markers were collapsed using Map (Aylor *et al*. 2006), part of the Snap suite of tools for nucleotide analysis (Price & Carbone 2005).

Hierarchical genetic subdivision, as measured by Φ_{ST}, was analysed using an AMOVA framework (Excoffier *et al*. 1992; Michalakis & Excoffier 1996), implemented in GenoDive version 2.0b11 (Meirmans & Van Tienderen 2004). The categories used for the AMOVA were location, nominal species, and population depth. Three depth ranges were used: shallow (< 12 m), medium (between 20 and 35 m), and deep (> 70 m). Pairwise Φ_{ST} values among populations were also calculated in Genodive using an AMOVA, which for this purpose are exactly equivalent to Weir and Cockerham's θ (Weir & Cockerham 1984). The Φ_{ST} values were plotted against pairwise geographical distances among populations. These were calculated in Google Earth version 4.3.7284.3916 (beta) using the shortest nautical distance among populations. Analyses were repeated with and without the differentiated deep-water population from the Oculina Banks and designating samples from North Carolina and Georgia as either *Oculina arbuscula* or *O. varicosa*. Because high levels of variation within populations necessarily reduce measures of the proportion of variation partitioned among populations (see Hedrick 2005), Φ_{ST} measures were also estimated using a standardizing procedure (Miermans 2006) implemented by GenoDive.

Table 2 Nucleotide sequence divergence between *Oculina* and *Solenastrea*

	Uncorrected *P**	K80 + Γ*	d*S*†	d*N*†
FA elongase	0.0681	0.0752	0.194	0.0208
EF-1α	0.0803	0.109	0.197	0.0456
Tachylectin	0.0582	0.0654	0.070	0.0541
COI	0.0088	0.0089‡	0.025	0.0039

*Full sequence; †coding region only, modified Nei–Gojobori; ‡Jukes–Cantor.

In order to detect significantly differentiated populations (*k*) without the need to define populations a priori, we used the Bayesian clustering analysis implemented by Structure version 2.2 (Pritchard *et al*. 2000). We used the default (and more conservative) admixture model with uncorrelated allele frequencies. Although the default correlated allele model (Falush *et al*. 2003) implemented by Structure is more robust to departures from model assumptions than the uncorrelated model, the correlated model is also more prone to overestimates of *k* (and thus the inference of spurious clusters) than is the uncorrelated model (Pritchard *et al*. 2007). We performed 20 replicates runs for *k* values between 1 (no population differentiation) and 7 (a pragmatic maximum given the number of localities sampled and the relative homogeneity of populations north of Cape Canaveral). Each replicate was run for 10^6 iterations following an initial burn-in of 100 000 iterations. Best estimates of *k* were inferred using Structurama (Huelsenbeck & Andolfatto 2007), which explicitly estimates *k*. Three replicates were each run for 10 000 000 generations, sampling every 100.

Results

Rates of divergence for all three nuclear gene markers were substantially higher than for mitochondrial COI (Table 2). Divergence for the slowest of the three nuclear genes (tachylectin-2) was more than five times faster than for COI, whether rates were corrected for multiple hits or not and whether synonymous or nonsynonymous rates were considered. Corrected divergences for EF-1α were over 10 times greater than those for COI.

Within *Oculina*, levels of variation at the different markers paralleled those for divergence rates. Mitochondrial COI was nearly invariant, regardless of sampling locality or species designation, with 119 of 122 individuals sharing the same haplotype over 681 bp. The three variants within *Oculina* were all singletons and all differed from the dominant haplotype by a single synonymous base pair substitution. In contrast, levels of intraspecific variation at

Table 3 *Oculina* sequence variation

	Full sequence					
	Length (bp)	*S*	No. of haplotypes*	Hap div*	*K*	π
FA elongase	425–510	45	73	0.863	4.027	0.0095
EF-1α	470	10	36	0.806	1.898	0.0054
Tachylectin	429–444	38	53	0.835	5.096	0.0119
	ORF					
	Length (bp)	*S*	No. of haplotypes *	Hap div*	*K*	π
FA elongase	276	24	34	0.819	2.391	0.0087
EF-1α	351	10	23	0.780	1.898	0.0054
Tachylectin	276	25	40	0.809	3.560	0.0130

*Haplotype values calculated under infinite allele model in Arlequin version 3.1.1; *S*, number of segregation sites; *K*, average number of nucleotide differences; π, nucleotide diversity.

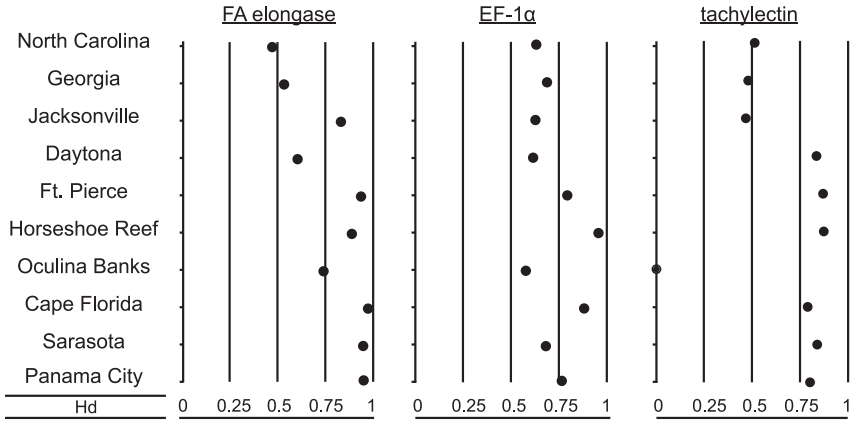

Fig. 2 Variation among populations in haplotype diversity (H_d) for the three nuclear markers used in the study. Populations are arranged contiguously top to bottom beginning with the northernmost population, North Carolina. The biogeographical break at Cape Canaveral occurs between Ft. Pierce and Daytona.

the three nuclear markers were quite high (Table 3). The number of segregating sites varied from 10 (EF-1) to 45 (FA elongase). EF-1 alleles differed by about 2 bp on average, while tachylectin alleles differed by about 5 bp. Nucleotide diversity (π) ran between 0.005 and 0.012. Variation in the ORFs of the three markers was similarly high (Table 3).

Variation in haplotype diversity (Fig. 2) approaches its theoretical maximum, ranging from zero for tachylectin from the Oculina Banks population to near unity (0.95) for EF-1 at Horseshoe Reef (just 29 km away). Two patterns emerged from inspection of these values. First, the four populations north of Cape Canaveral (North Carolina, Georgia, Jacksonville and Daytona) were less variable than populations elsewhere in the range. Second, the Oculina Banks population had the lowest levels of variation among the southern populations for all three nuclear markers.

Analysis of molecular variation revealed Φ_{ST} values that were significant at the $P = 0.05$ level when individuals were partitioned by location, nominal species, and depth (Table 4). Location had the highest values, with the values for nominal species and depth both dropping when location was accounted for. AMOVA results were roughly similar across loci (with the exception of the effect of depth on tachylectin subdivision). Overall, about 16% of all variation could be traced to subdivision among all 10 sampled populations. Depth accounted for about 10% of variation overall. Genotypes from shallow (Radio Island and Piver's Island, 1.5–4 m) and mid-depth (38 km Reef and ISO5, 23–26 m) sites off North Carolina were shared and similar (data not shown). Nominal species designations meant even less than depth, accounting for about 8.5% of variation. Proportions became higher once Φ_{ST} was standardized for levels of variation within populations (Table 4), but the rank order of importance for the three sources of variation remained the same. When the potentially differentiated population from the Oculina Banks was removed from the analysis, nominal species and depth had a further diminished impact, failing even to reach significance over all three loci (Table 4). Pooling the *Oculina arbuscula* samples with *Oculina varicosa* had little impact on the proportion of overall variance explained by species or the other factors (not shown).

Table 4 Analysis of molecular variation among locations, nominal species, and collection depths

		Φ_{ST}*				Standardized Φ_{ST}*			
	Source of variation	FAelo	EF-1α	Tachy	Overall	FAelo	EF-1α	Tachy	Overall
w/Oculina Banks	Location	0.119	0.136	0.233	0.163	0.552	0.464	0.677	0.554
	'Species'	0.079	0.077	0.098	0.085	0.421	0.320	0.431	0.391
	Depth	0.055	0.057	0.189	0.102	0.338	0.251	0.663	0.417
	'Species' — Location	0.050	0.038	0.019	0.036	0.310	0.183	0.120	0.204
	Depth – Location	0.025^n	0.021^n	0.152	0.088	0.181^n	0.104^n	0.601	0.295
w/o Oculina Banks	Location	0.094	0.118	0.134	0.115	0.418	0.422	0.470	0.437
	'Species'	0.081	0.080	0.088	0.083	0.398	0.326	0.366	0.383
	Depth	0.001^n	0.019	0.025	0.015	0.008^n	0.096	0.132	0.079
	'Species' — Location	0.066	0.049	0.055^n	0.057^n	0.347	0.224	0.258^n	0.265^n
	Depth — Location	–0.020^n	–0.005^n	–0.001^n	–0.012^n	–0.155^n	–0.030^n	–0.017^n	–0.067^n

*All Φ_{ST} values significant at the $P = 0.05$ level unless marked with n.

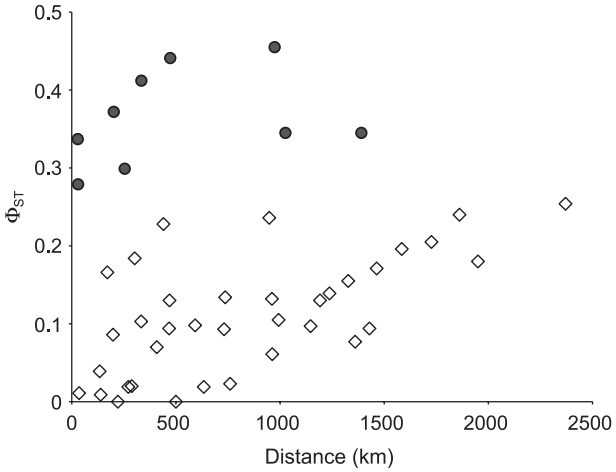

Fig. 3 Pairwise Φ_{ST} values for the concatenated nuclear gene data set, plotted against nautical distance. Closed circles indicate comparisons involving the 80 m Oculina Banks (Jeff's Reef) population, open diamonds indicate comparisons for all other populations.

Pairwise values of Φ_{ST} were plotted against distance of population separation to see whether overall measures of subdivision masked any population-specific patterns (Fig. 3). The relationship between Φ_{ST} and distance was weak ($r^2 = 0.021$). However, this analysis identified the Oculina Banks population as a strong outlier: the values of Φ_{ST} for every pairwise comparison involving the Oculina Banks were higher than for Φ_{ST} involving all other pairs of populations (Fig. 3). This difference held true even though the three populations in the Ft. Pierce area (Jeff's Reef, Horseshoe Reef, and Ft. Pierce) were all within 36 km of each other, while some of the other (genetically closer) populations were separated by up to 2370 km. When the Oculina Banks population was removed from the analysis, distance then explained a significant proportion of the variation in Φ_{ST} ($r^2 = 0.39$).

Results from the Bayesian clustering analyses further supported the conclusion that the Oculina Banks population is genetically isolated from all other populations sampled. Using Structurama, $k = 3$ had the highest posterior probability for both the full length data and the ORF-only data. The full-length data identify one of the three multilocus clusters as strongly associated with the Oculina Banks population (Fig. 4). All individuals from Oculina Banks have at least 93% of their genome assigned to the same cluster, while no individuals from outside the Oculina Banks have > 68% of their genome assigned to this (the red in Fig. 4a) cluster, with no more than one individual per locality greater than 45%. Truncating the full-length sequences to just ORFs reduced the number of distinguishable alleles for all three loci (e.g. from 73 to 34 for FA elongase, from 38 to 23 for EF-1, and from 53 to 40 for tachylectin), but the Oculina Banks population remains distinct using the ORF data (Fig. 4b).

The two other clusters (aside from the Oculina Banks) were partitioned among populations as well. The genomes of all individuals from the four populations north of Cape Canaveral fell largely into one of these clusters (blue in Fig. 4), which was also prevalent in several individuals from the distant Sarasota population. This clustering appears to be driven in large part by the presence of the most common northern alleles at FA elongase. This allele is frequent (at 62.7%) in the four populations north of Cape Canaveral, and next most common in Sarasota (20.8%), the southern population with the highest northern component. The genotypes of exceptional individuals (those that cluster differently from others in their same population based on the full sequence analysis) are also instructive here: 9 of 13 individuals with a high (> 60%) proportion of north (blue) in the Ft. Pierce, Cape Florida and Sarasota

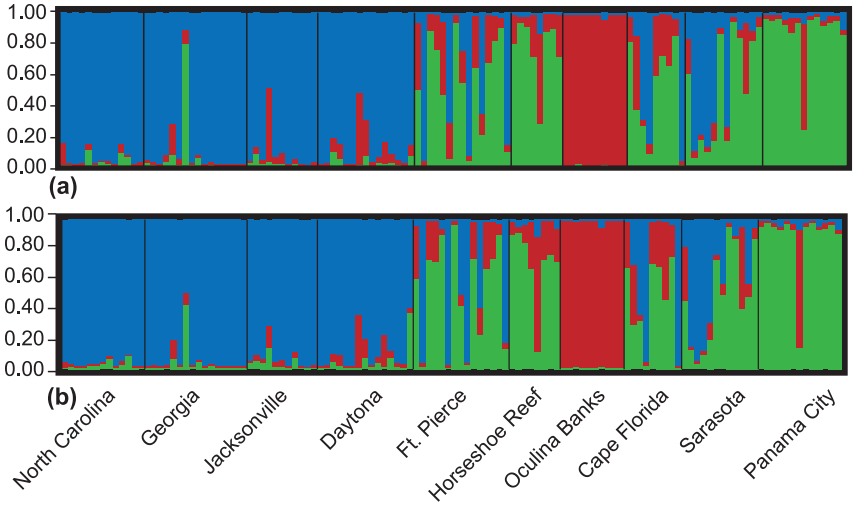

Fig. 4 Graphical summary of the results from the Structure analysis for $k = 3$ for (a) full and (b) coding region only data sets. Each individual is represented by a vertical line broken into three segments to represent the estimated proportions of that individual's genome originating from each of the three inferred clusters.

populations possessed at least one copy of the most common FA elongase northern allele (otherwise rare in the south), while the single individual from Georgia with a more southern (green) genome did not.

The northern and southern clusters did not correlate with nominal species (compare Fig. 4 and the Appendix). For example, nominal *O. arbuscula* (North Carolina and Georgia) falls into the northern cluster with *O. varicosa* from Jacksonville and Daytona, although nominal individuals of *O. varicosa* fall into the other two clusters as well. Individuals from the Sarasota population are all *O. robusta* by morphology, but genetically appear to be mixed between the northern and southern clusters.

Discussion

Nuclear sequence markers for taxa with slow mtDNA: possibilities and problems

Previous studies on plants, fungi, sponges, and anthozoans, including corals, have reported extremely low levels of mtDNA variation among populations of the same nominal species (references in Hellberg 2006). When divergence rates have been estimated, these appear to be 50–100× slower than for bilateral animals. In plants, these slow rates of mitochondrial sequence evolution are not paralleled by relatively slow rates for nuclear genes (Wolfe *et al*. 1987). This same pattern holds for corals: rates of divergence for *Oculina* and *Solenastrea* were 6.6–9.1 times faster (uncorrected *p*) for nDNA than for mtDNA (Table 2).

Levels of nucleotide diversity were also far higher for nuclear markers examined here (Fig. 2) than for mtDNA (which was nearly fixed). Such high levels of nDNA sequence variation are similar to those seen previously in plants (Moeller & Tiffin 2005) and marine animals (Taylor & Hellberg 2006), including corals (Nunes and Knowlton, unpublished data). These higher rates offer hope for revealing population isolation within coral species; however, nuclear markers in these taxa will still offer challenges beyond those commonly seen for mtDNA in bilateral animals.

The two nuclear loci with the highest levels of nucleotide sequence variation (fatty acid elongase and tachylectin-2, Table 3) also showed high frequencies of indels. Biologically, it may be that nucleotide sequence variation and indel variation are linked mechanistically (Tian *et al*. 2008). Practically, for the population geneticist looking to score both alleles at multiple individuals, resolving indels by cloning can (and, for us, did) prove costly and time-consuming. We found most indels in the 3′ UTR regions we sequenced, which we initially targeted in the belief that they would be richer sources of informative variation. Recent work and our results suggest this need not be the case. Andolfatto (2005) found silent sites within open reading frames are at least three times as variable as noncoding sites elsewhere in the genome, compensating for their threefold lower frequency within exons. Here we found that ORF-only sequences were nearly as variable as those including the 3′ UTR (Table 3), and that Structure could still identify the Oculina Banks population as isolated using the reduced, ORF-only data (Fig. 4). These results suggest that sequencing markers set in ORFs may reveal ample power to resolve population differences while avoiding the practical problems of resolving indel heterozygotes.

Indel heterozygotes also complicate analysis of another feature associated with high levels of nucleotide variation: recombination (Begun & Aquadro 1992). Four-gamete tests found recombination at all three nuclear loci, although these tests were complicated by problems with coding indels. High levels of recombination are not rare for population surveys of nuclear sequences, even for sequences shorter than those surveyed here (e.g. Ibrahim *et al*. 2002). Inspection of recombination patterns can reveal stretches

of sequence that have maintained their integrity, thus indicating a recent shared history and an appropriate basis for coalescent analyses. Indels can complicate these analyses because some programs don't allow them as input. At loci with high rates of recombination, remaining stretches may have few variable sites and thus limited statistical power. Our results thus represent a worst-case scenario in which recombination restricted data analysis; however, analyses based on infinite-allele assumptions nevertheless revealed patterns consistent with population isolation in *Oculina*.

Subdivision, population isolation and species status within Oculina

Populations of *Oculina* from the southeastern coast of the USA are genetically subdivided (Table 4). Limited larval dispersal may underlie some of this pattern: the larvae of *Oculina varicosa* swim actively and are negatively geotactic for 1–2 weeks after hatching and become negatively phototactic after about 14 days (Brooke & Young 2005). The high proportion (≈ 40%) of the variation in Φ_{ST} between populations that is due to geographical separation also suggests most dispersal occurs between neighbouring populations, as in other coastal corals (Hellberg 1995).

Characteristics shared by more than one population generally explain little of the overall genetic variation in *Oculina*. Species designations have been considered problematic in the genus, and those used here do not designate genetically meaningful entities. Much of the variation attributable to species in the AMOVA analysis (Table 4) stems from the geographical nature of existing species definitions: all *Oculina* from North Carolina and Georgia have been called *O. arbuscula*, while *O. robusta* has been largely restricted to the Gulf of Mexico. The possibility remains, however, that the genetically distinguishable clusters identified here, while not coincident with existing species definitions, nonetheless represent species or populations on a course towards reproductive isolation.

For northern (blue, Fig. 4) and southern (green) clusters, this does not seem to be the case. Populations to the north of Cape Canaveral were largely united by the Structure analysis. These same northern populations also show reduced variation (Fig. 2). The alleles present in these populations are a subset of those found over the rest of the sampled range, not in any way phylogenetically distinct, and there is no indication of differentiation among these northernmost populations. In combination, these patterns are consistent with a relatively recent range expansion north of Cape Canaveral, a long-recognized marine phylogeographical break (Avise 2000). Unlike a traditional phylogeographical break, which separates reciprocally monophyletic clades, the break here marks a decline in heterozygosity beyond a barrier. Similar patterns have been seen for other marine animals, including an intertidal snail moving poleward past a historical barrier at Point Conception in California (e.g. Hellberg *et al*. 2001) and a tropical goby returning to habitat denuded by recent sea level changes (Thompson *et al*. 2005).

The major source of subdivision that we found in *Oculina* involved the deep-water corals from the Oculina Banks. The combination of AMOVA, pairwise Φ_{ST}, and Structure analyses all suggest that the Oculina Banks population is genetically isolated from all others and perhaps already a separate reproductively isolated species. Multilocus clustering singled out this population as distinct (Fig. 4), and every pairwise value of Φ_{ST} was greater for comparisons involving the Oculina Banks population than for all other comparisons (Fig. 3). These results strongly suggest that the Oculina Banks population is genetically isolated from all shallower (*c*. 30 m or less) populations. While larvae from deep and shallow populations have similar broad temperature tolerances (Brooke & Young 2005), colony growth rates appear to be faster for the deep population (Reed 1981). Furthermore, Brooke (2002) found that shallow populations in the Ft. Pierce area spawn 2 or 3 weeks before those on the Oculina Banks. Such a difference in reproductive timing may result from responding to similar seasonal cues that differ with depth, or could indicate species-specific breeding seasonality. Whichever the reason, these differences should facilitate the continued isolation and divergence of populations. That two closely related but genetically isolated populations should be segregated by depth is not unusual for marine organisms. Geographically sympatric sister species that live at different depths have been reported many times (see Knowlton 1993; Hellberg 1998; Hyde *et al*. 2008), including for corals and other anthozoans (Knowlton *et al*. 1992; Carlon & Budd 2002; Prada *et al*. 2008).

The isolated Oculina Banks population occurs in an ecologically different habitat below 50 m, a bathymetric line that has been drawn between deep and shallow water corals (Cairns 2007). Alleles from the deep-water population nest phylogenetically within the more broadly distributed (and paraphyletic) shallow form, consistent with the notion that deep sea species are often derived from shallow water ones (Jablonski *et al*. 1983), although hydrocorals provide a counterexample (Lindner *et al*. 2008). More unusual is the geographical nesting of its range: the deep-water population occurs near the centre of *Oculina*'s continental geographical range (Fig. 1) and only a short distance (< 50 km) from shallow-water populations. High relief reef habitat at the depth of the Oculina Banks is presently rare along Florida's eastern coast (Parker *et al*. 1983), and the Oculina Banks population may represent a geographically restricted relic of a formerly more broadly distributed form. Genetic analysis of newly discovered deep-water populations of *O. varicosa* from the northeastern Gulf of Mexico (Barnette 2006), as well as populations from further south in *Oculina*'s range, may help resolve the origins of this curious population.

Whatever that history, the corals of the Oculina Banks have created an ecosystem that harbours exceptionally high diversity (Reed 2002) and provides a nursery and feeding grounds to several commercially harvested fish (Koenig *et al*. 2000). Our results suggest that any efforts to preserve and restore this ecosystem will have to be based on the recognition that the population of *Oculina* at the Oculina Banks are genetically isolated from shallow water populations of the genus.

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RIE is interested in the origin and maintenance of marine biodiversity, particularly in coral reef taxa. MH is a Research Associate who applies molecular genetics, functional genomics and biochemical approaches to the study of host microbe interactions, using plants, invertebrates and bacteria as model organisms. His current research focuses on secreted bacterial virulence proteins and their role in plant disease. PAR is a Research Associate currently working on fat cells and canine restoration. MM is a NOAA scientist working on coral population ecology and restoration. MEH is broadly interested in population isolation, speciation and molecular evolution in marine animals, especially anthozoans and gastropods.

Appendix

Oculina *sampling localities*

Location information for sublocalities included when individuals came from more than one place, with numbers from each sublocality indicated parenthetically. Average collecting depth or range indicated, along with depth class: shallow: < 12 m; medium: 20–30 m; deep: > 70 m

North Carolina *O. arbuscula* (13)	
Radio Island Jetty (9)	34°42.58′N, 76°40.85′W (S, 2–4 m)
38 km Reef (2)	34°19.99′N, 76°53.90′W (M, 26 m)
ISO5 (2)	34°23.29′N, 76°34.23′W (M, 23 m)
Georgia*O. arbuscula* (16)	
J Reef (6)	31°36 06′N, 80°47.43′W (M, 21 m)
R2 tower (10)	31°22.10′N, 80°35.03′W (M, 27 m)
Jacksonville, FL *O. varicosa* (11)	
Paul Mains (6)	30°19.81′N, 81°10.98′W (M, 23 m)
Pablo G Culverts (5)	30°20.09′N, 81°11.74′W (M, 21 m)
Daytona, FL *O. varicosa* (15)	
Mindinao (9)	29°11.97′N, 80°44.85′W (M, 21 m)
Culverts (6)	29°19.27′N, 80°44.67′W (M, 23 m)
Fort Pierce Inlet, FL (15) *O. diffusa* (5), *O. robusta* (4), *O. varicosa* (6)	27°27.61′N, 80°16.99′W (S, < 2 m)
Horseshoe Reef, FL *O. varicosa* (8)	27°45.22′N, 80°07.86′W (M, 29 m)
Jeff's Reef, FL *O. varicosa* (10)	27°31.86′N, 79°58.81′W (D, 80 m)
Cape Florida, FL *O. diffusa* (9)	25°39.99′N, 80° 09.34′W (S, 2 m)
Sarasota, FL *O. robusta* (12)	27°26.64′N, 82°49.20′W (S, 11 m)
Panama City, FL *O. diffusa* (13)	
Site 1 (8)	30°03.26′N, 85°51.99′W (M, 29 m)
Site 2 (5)	30°02.09′N, 85°51.12′W (M, 28 m)

CIOERT SEADESC II Report
Extreme Corals 2011: South Atlantic Deep Coral Survey

NOAA Ship *Pisces* Cruise PC-11-03 (11)
May 31 – June 11, 2011

NOAA Deep-Sea Coral Research and Technology Program
(CIOERT Project #: II-CO-DCE-5)

NOAA Office of Ocean Exploration and Research
(OER Grant #: NA09OAR4320073)

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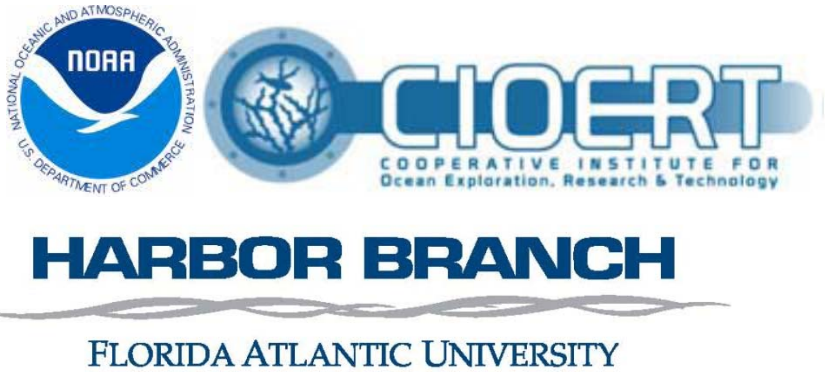

February 28, 2013

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This provides the following data for each dive site: cruise and ROV dive metadata, figures showing each ROV dive track and habitat zone overlaid on multibeam sonar maps, dive track data (start and end latitude, longitude, depth), objectives, general description of the habitat and biota, and images of the biota and habitat that characterize the dive site. In addition, this SEADESC Level II Report provides quantitative analyses of each dive site including: 1) CPCe 4.1© Coral Point Count analysis of percent cover of benthic biota and substrate type, 2) densities of benthic macro-fauna (# organisms/m^2 for each species), and 3) densities of fish populations (# individuals/km for each species).

EXECUTIVE SUMMARY

In June 2011, a 12 day research cruise was conducted by NOAA National Marine Fisheries in collaboration with the Cooperative Institute for Ocean Exploration, Research, and Technology (CIOERT) at Harbor Branch Oceanographic Institute, Florida Atlantic University (HBOI-FAU), and other academic and federal partners (including NOAA NCCOS, Florida State University, and University of Louisiana), using the NOAA Ship *Pisces* and the NOAA Southwest Fisheries Science Center's ROVs. This cruise is part of an ongoing study of deep-sea coral habitats off the coast of the southeast United States. Primary research objectives of the multi-year science plan include mapping and characterizing coral and fish populations inside and adjacent to new managed areas. The focus of the 2011 expedition is to explore hard grounds out to 550 m depth off south Florida, with emphasis on assessing areas that are coral/sponge habitat and areas that are still open to bottom fishing activities (Allowable Fishing Areas) within the managed areas.

This Final Cruise Report provides a detailed analysis of the benthic habitats, biota, and fish populations at each dive site based on the ROV photo/video transects, CTD casts, and multibeam sonar surveys. This report also provides a SEADESC Level II Report (Appendix 2) for each dive site which includes: cruise and ROV dive metadata, figures showing each ROV dive track and habitat zone overlaid on multibeam sonar maps, dive track data (start and end latitude, longitude, depth), objectives, general description of the habitat and biota, and images of the biota and habitat that characterize the dive site. In addition, the SEADESC Level II Report provides quantitative analyses of each dive site including: 1) CPCe 4.1© Coral Point Count analysis of percent cover of benthic biota and substrate type, 2) densities of benthic macro-fauna (# organisms/m^2 for each species), and 3) densities of fish populations (# individuals/km for each species).

A total of 10 ROV dives were conducted from June 1 to June 10, 2011, resulting in a total bottom time of 31.0 hours, covering 112 km, at depths from 56 to 375 m (Table 3, Fig. 1). A total of 4,445 in situ digital images were taken and included 339 general habitat and species photos, and 4,104 quantitative transect photos which were used for the SEADESC Level II analyses. Six sites were surveyed with multibeam sonar and covered a total area of 112 km^2 (Table 1). These sites had never been surveyed previously with high-resolution multibeam sonar. Georeferenced sonar maps were made for the North Florida MPA site, the Jacksonville *Lophelia* coral mound site, St. Lucie MPA, and portions of the Miami Terrace CHAPC. In addition two regions of deepwater *Oculina* coral reefs were mapped for the first time north and outside of the current boundaries of the *Oculina* HAPC. These new *Pisces* sonar maps and ROV dives enabled us to discover and ground-truth many new deepwater *Oculina* coral reefs that had not been documented previously, and these are now under consideration by the South Atlantic Fishery Management Council for addition to the OHAPC.

Ultimately the primary benefits of these data are to characterize and document the habitat, benthic and fish communities within Habitat Areas of Particular Concern (HAPCs; including the deepwater Coral HAPCs and *Oculina* HAPC) and the shelf-edge Marine Protected Areas (MPA) along the southeastern U.S. from North Carolina to south Florida. These data may then be compared to previous and future research cruises and to areas adjacent to the protected areas to better understand the long-term health and status of these important deepwater coral/sponge

ecosystems. These data will be of value to the SAFMC, NOAA Fisheries, NOAA DSCRTP, NOAA CRCP, and NOAA Mesophotic Reef Ecosystem Program for management decisions on these habitats and managed key species.

ACKNOWLEDGEMENTS

We gratefully acknowledge the NOAA Cooperative Institute for Ocean Exploration, Research, and Technology (CIOERT) at Harbor Branch Oceanographic Institute, Florida Atlantic University (HBOI-FAU), and thank the Robertson Coral Reef Research and Conservation Program at HBOI. The crews of the NOAA Ship *Pisces* and the NOAA Southwest Fisheries Science Center's ROV are thanked for their support and efforts which made this cruise a success.

CIOERT gratefully acknowledges funding provided by the NOAA Office of Ocean Exploration and Research (OER Grant #: NA09OAR4320073). The NOAA Deep Sea Coral Research and Technology Program (DSCRTP; CIOERT Project #: II-CO-DCE-5) provided funding for the ROV, data management, data analysis and development of this SEADESC Cruise Report. The NOAA Office of Marine and Aviation Operations (OMAO) provided support for ship time. Funding for data analysis of the shelf-edge MPA and HAPC sites was also provided in part by the NOAA Coral Reef Conservation Program (CRCP) through the South Atlantic Fishery Management Council (Grant #: NA11NMF4410061). Funding by NOAA DSCRTP also co-sponsored the 2012 Fifth International Deep Sea Coral Symposium at which some of these data were presented.

DELIVERABLES

This Final Cruise Report and SEADESC Level II Report finalizes the deliverables required by our grant from NOAA DSCRTP and provides data for our NOAA CRCP/SAFMC grant. Other deliverables were completed and detailed in the Preliminary Cruise Report.

CIOERT/NOAA COLLABORATION

The primary focus of this CIOERT Cruise is to advance NOAA OER goals while complementing the management objectives of NOAA DSCRTP, NOAA Mesophotic Reef Ecosystem Program, and the South Atlantic Fishery Management Council (SAFMC).

For this cruise we collaborated with NOAA NMFS (Andrew David, Stacey Harter, Panama City) in order to assess habitat and fish communities, targeting grouper, snapper and tilefish. Other NOAA collaborators included: Laura Kracker, NOAA-NCCOS; Jeff Hyland, NOAA-NCCOS; Stephen Roth, NOAA-NCCOS; James Daugomah, NOAA-NCCOS; Cindy Cooksey, NOAA-NCCOS; John Butler, NMFS-La Jolla; Scott Mau, NMFS-La Jolla; Kevin Stierhoff, NMFS-La Jolla; and David Murfin, NMFS-La Jolla.

SCIENTIFIC PARTICIPANTS

Andrew David	Chief Scientist	NMFS-Panama City Lab
John Reed	Co-Principal Investigator	HBOI, CIOERT
Laura Kracker	Mid-Watch Lead	NOAA/NCCOS-Charleston, SC
Jeff Hyland	Night Watch Lead	NOAA/NCCOS-Charleston, SC
Stephen Roth	Investigator	NOAA/NCCOS-Charleston, SC
James Daugomah	Investigator	NOAA/NCCOS-Charleston, SC
Andrew Shepard	Logistics Manager	UNCW, CIOERT
Stephanie Farrington	Data Manager	HBOI, CIOERT
Jana Thoma	Investigator	Univ. of Louisiana-Lafayette
Diego Figueroa	Investigator	Florida State University
John Butler	ROV Lead	NMFS-La Jolla Lab
Scott Mau	ROV Team	NMFS-La Jolla Lab
Kevin Stierhoff	ROV Team	NMFS-La Jolla Lab
David Murfin	ROV Team	NMFS-La Jolla Lab
Sue Zupko	Teacher-at-Sea	Weatherly Heights Elem School, AL

PROJECT OVERVIEW

Deep and shallow coral ecosystems are ocean hot spots for biodiversity and productivity, and provide essential habitat for fish and other marine life. Recent research has revealed the extent and ecological importance of deep-sea coral communities and the threats they face. Sound management of these ecosystems requires scientifically based information on their condition. In 2010, the Department of Commerce and the South Atlantic Fishery Management Council designated the largest (23,000 nm^2) marine managed area on the U.S. east coast to protect deep coral ecosystems from North Carolina to Florida. In 2009-2011, NOAA's Deep Sea Coral Science and Technology Program (DSCRTP) partnered with several federal and academic partners to explore deep-sea coral ecosystems off the Southeast U.S. Research objectives of the multi-year science plan included to mapping and characterizing coral and fish populations in and adjacent to the new managed areas. Previous expeditions in 2009 and 2010 (http://cioert.org/xcorals) explored deep coral ecosystems from North Carolina to Florida. This CIOERT *Extreme Corals 2011* cruise continues support for the DSCRTP southeast regional program. In support of the DSCRTP's 2011 Science Plan, major objectives included: map coral habitat and describe fish communities in and outside the CHAPCs with emphasis on Allowable Fishing Areas, use *Pisces'* ME70 sonar system for assessing pelagic communities associated with DSCE, quantify the benthic infaunal community adjacent to deep coral habitats, and look for contaminants in sediments near DSCE close to and remote from population centers along the SE coast.

OBJECTIVES

Objectives for this 2011 NOAA *Pisces* expedition included:

1. Explore unique and likely coral habitats with ROV, ground-truth sonar maps, and obtain video, photos, and samples that can be used to describe habitats and faunal assemblages in depths from 50 to 500 m.
2. Conduct ME-70 Echosounder surveys to study diel patterns of mid-water nekton biomass to study associations with hard bottom and coral habitat.
3. Collect sediment samples to study animal-sediment relationships and chemical contaminants.
4. Describe faunal changes along transects across hard bottom habitat areas and adjacent soft bottom areas.
5. Collect new and unusual species for taxonomic, genetic, biomedical, life history studies, and educational purposes.
6. Collect samples of corals, sponges, mollusks, decapods and other taxa for genetic analyses and to elucidate patterns of recruitment.
7. Develop data management and educational materials from the cruise.

OUTREACH AND EDUCATION

The goal of the expedition's education and outreach activities was to promote ocean literacy, knowledge of deep coral ecosystems and challenges of exploring and managing deep ocean frontiers, for public and classroom audiences. Related outreach/education activities included:

- Expedition web site (cioert.org/xcorals2011)
- News media—press kit and news releases
- Promote ocean literacy, knowledge of deep coral ecosystems and challenges of exploring and managing deep ocean frontiers, for classroom audiences; NOAA Teacher-at-Sea; Skype live-link with classrooms; web materials.

METHODS

Quantitative and qualitative ROV video and photographic surveys were made at each site to ground-truth bottom sonar maps, quantify and characterize the benthic habitats, sessile fauna, fish populations, and coral/sponge cover. Shipboard multibeam echo-sounder (ME70) surveys were conducted at dive sites where there was no previous multibeam sonar maps. Prior to each ROV dive the georeferenced sonar maps were uploaded to the ROV navigation software; the co-PIs (J. Reed and A. David) then selected pre-dive waypoints which were overlaid on the map for ROV dive targets.

ROV Operations

Initially the deep-water (550 m depth limit) *Arc* ROV owned and operated by NOAA Fisheries SWFSC was used. The ROV was equipped with high-definition digital video and digital still cameras with parallel lasers for scale, CTD, and a single-function manipulator. Two ROV dives were planned each day; approximately 0800-1200 and 1400-1800. Unfortunately during the third dive the umbilical cable became twisted breaking the fiber optics to the Hi-Def video

camera. Luckily the ROV team had a backup ROV which is a very rare event. The remainder of the cruise used the *Phantom* ROV which only had standard definition video.

ROV Transects

During each dive the primary objectives were to document benthic habitat and fauna (fish, corals, sponges), collect samples, and conduct photo/video transects which were used for quantitative analyses of the benthic macro-biota, fish, and habitat types. During the photo/video transects, we attempted to keep the ROV <1 m off bottom with a speed over ground of ~¼ knot. Variable, strong currents often made this difficult.

The video footage was recorded continuously throughout each dive from surface to surface. The camera was typically angled down ~30^{o} to view both near and far to the horizon for fish aggregations and habitat. A headset microphone was used for continuous audio annotations by the PIs describing events, habitat, and fauna which were recorded onto the video recordings and later transcribed into a Microsoft Access 2010 database. Along with being used as the main "pilot" view, the video was the primary data source for the quantitative analysis of the fish populations.

Benthic Data Survey and Analysis

Quantitative photo transects were conducted at each ROV dive site using the digital still camera pointing straight down (or perpendicular to the substrate as possible) with parallel lasers (20 cm) for scale. In general, two digital images were taken per minute (depending on the recycling rate of the strobe). Each photo filename was coded with corresponding UTC time and date code (using Stamp 2.8 by Tempest Solutions©) which was imported into MS Access and linked to the ROV navigation data for site specific data of coordinates and depth and then imported into ArcGIS™ 10.0. Species-specific or general habitat photos were not included in the quantitative analyses. Poor and unusable photos (blurred, black, off bottom) or overlapping photos were removed from the analyses. Images were analyzed by three methods: 1) species occurrence (presence/absence), 2) percent cover, and 3) density (number of organisms per m^2). Some common species could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phyla.

Percent cover of substrate type and benthic macro-biota was determined by analyzing the images with Coral Point Count with Excel extensions (CPCe 4.1©, Kohler and Gill, 2006), and following protocols established by Vinick et al. (2012) for offshore, deepwater surveys in this region. Random points overlaid on each image were identified as substrate type and biota. Substrate categories included: soft bottom (unconsolidated sand, mud) and hard bottom which was subdivided into rock (pavement, boulder, ledge), rock rubble/cobble (generally, 5-20 cm), coral rubble, and framework coral (standing coral colonies). The density of the benthic biota was then analyzed using CPCe© to calculate the area of each image using the parallel lasers for scale. All macro-benthic biota (usually >3 cm) were identified to the lowest taxa level possible. For this, some colonial taxa and thin encrusting taxa were counted accordingly: 1) thin, encrusting algae (Corallinales, Peyssonneliaceae, or Chlorophyta) were counted as individual clusters if >3 cm diameter. 2) Solitary cup corals (which were often quite abundant) were counted as 1 = few (1-10), 5 = common (10-20), 10 = abundant (>20). Hydroida and Hemichordates were counted as clusters.

Summary of ROV Survey Protocol

1) During the photo/video transects, we attempted to keep the ROV <1 m off bottom with a speed over ground of ~¼ knot.
2) Underwater video was viewed in real time on the support vessel by biologists familiar with the local deep-water fauna; the audio descriptions were recorded onto the video and transcribed into a MS Access database.
3) Still images were captured with the digital still camera ~2/ minute depending on the recycling rates of the strobe.
4) Field notes and video images were reviewed and summarized to identify habitats and fauna. These summaries were compiled in GIS format and used to produce a habitat maps.
5) Still images captured from the photo transects were analyzed using CPCe© software to determine relative percent cover of benthic biota and habitat types. Organisms larger than 3 cm were enumerated for density analysis.
6) Video transects were used for analysis of fish populations.

Multibeam Sonar Mapping and Fisheries Acoustic Surveys

Table 1. Multibeam and split beam sonar surveys conducted during 2011 *Pisces* cruise: South Atlantic Deep Coral Survey (L. Kracker, NOAA).

Site	Total length of transects (nmi)	Extent (km^2)	ME-70 Mulitbeam Bathymetric survey	EK-60 Split-beam Fisheries survey
Jacksonville	42	18	X	X
North Florida MPA	31	15	X	X
Daytona *Oculina* Pinnacles	78	19	X	X
Titusville *Oculina* Pinnacles	52	16	X	X
St. Lucie MPA	29	27	X	X
Miami Terrace	50	17	X	X

NOAA Acoustic surveys using both split beam sonar (Simrad EK-60) to collect water column data and multibeam sonar (Simrad ME-70) for bathymetric data were run concurrently at all ROV dive sites where multibeam maps were not available. The main objective of the sonar surveys was to provide background maps to guide ROV exploration at dive sites. Maps of benthic features along with information on fish distribution at each site will be beneficial in terms of understanding the relationship between biota and benthic features. The ME-70 as configured on the NOAA ship *Pisces* was not intended to be used for bathymetric mapping without the Bathymetry software module. A Matlab routine, developed and provided by Randy Cutter (NOAA, SWFSC), was applied to this data to detect and extract bottom depths. The output was then imported into Fledermaus 3D visualization software and converted to geotiffs. The Ek-60 split beam data will be analyzed in Echoview® software to examine relative abundance of fish detected along survey tracks. These data will be reported elsewhere (L. Kracker, NOAA).

CTD Operations

One CTD continuous profile of conductivity, temperature, pH, dissolved oxygen, and depth was cast at each sediment station. These CTD data were used for the multibeam sonar surveys (sound velocity). The ROV's also recorded CTD data at each dive site for site characterization. A summary of these data are shown for each dive in Appendix 2.

Sediment Grab Sampling

Sediment sampling was conducted using a 200-lb Van Veen grab which included one 0.1 m^2 sampler in the frame. Contents of the grabs were used for analysis of benthic macro-infaunal communities, concentration of sediment contaminants, % sand- silt-clay, and total organic-carbon content (TOC). Three Van Veen grab samples were taken at each station to acquire adequate sediment for both benthic infaunal analysis and chemistry/granulometric analyses. Benthic grab samples were collected at locations deemed appropriate from the visual ROV observations. The approach was to take samples as close to the reefs as possible without impacting coral. These data will be reported elsewhere (J. Hyland, NOAA).

Table 2. Benthic grab sample sites conducted during 2011 *Pisces* cruise: South Atlantic Deep Coral Survey (J. Hyland, NOAA).

Grab Station	Latitude	Longitude	Depth (m)	Date	Location
PC11001	30.3818	-80.2181	65	40696	N-FL MPA
PC11002	30.0229	-80.1967	246	40697	Jacksonville Lophelia Coral Site; 250 m S of top of feature
PC11004	30.0274	-80.1964	244	40697	250 m N of top of feature
PC11005	30.0286	-80.1961	248	40698	375 m N of top of feature
PC11006	29.2389	-80.1672	90	40699	Daytona Oculina Reef Site; 90 m site; flat area between Peaks 4&5
PC11007	29.1822	-80.1511	86	40699	Daytona Oculina Reef Site; 25 m SE of base of reef
PC11008	28.7548	-80.069	88	40700	Cape Canaveral Oculina Reef Site; ~150 m SE of base of Peak 1
PC11009	28.7549	-80.0708	88	40700	~50-60 m S of base of Peak 1
PC11010	28.7579	-80.071	84	40700	~100 m N of base of Peak 1 & 100 m S of base of Peak 2.
PC11011	27.6066	-79.9859	73	40701	Inside Oculina MPA; ~350 m S of NW end of Chapman's Reef
PC11012	27.6091	-79.9864	62	40701	Inside Oculina MPA; ~50 m S of NW end of Chapman's Reef
PC11013	27.5414	-79.9784	81	40701	Inside Oculina MPA; ~100 m S of base of Peak 1 along Jeff's Reef
PC11014	25.6232	-79.9984	330	40704	SW corner of Miami Terrace; within HAPC and at western-most edge of Allowable Fishing Zone; ~5.5 nm west of start of ROV transect

RESULTS

Study Areas

The pre-cruise dive plans were to survey deepwater sites primarily within the deepwater coral Habitat Areas of Particular Concern (CHAPCs) and shelf-edge MPA sites off eastern Florida and also targeting alternate sites within the Allowable Fishing Corridors within the CHAPCs. After the first dives were made in deeper water (200 m *Lophelia* site off north Florida), we found that the this small ROV could not operate in deeper water with the strong Florida Current. Plans were revised by the Chief Scientist and Co-PI with approval by NOAA DSCRTP to move inshore, out of the stronger currents, to survey the shelf-edge MPA sites and deepwater *Oculina* coral habitat.

Cruise Summary

A total of 10 ROV dives were conducted from June 1 to June 10, 2011, during CIOERT's 2011 *Pisces* cruise resulting in a total bottom time of 31.0 hours, covering 112 km, at depths from 56 to 375 m (Table 3, Fig. 1a,b). A total of 44:51 hours of ROV dive videotapes with audio annotations were recorded on hard drives (14) and DVDs (44) for backup. A total of 4,445 in situ digital images were taken and included 441 general habitat and species photos, and 4,104 quantitative transect photos which were used for the SEADESC Level II Report (Appendix 2). Only a few specimens were collected as the ROV only had a single function manipulator. A total of 10 benthic specimens were collected, including 2 Cnidaria (1 Scleractinia and 1 Antipatharia), 6 Arthropoda, 1 Mollusca, and 1 Polychaeta.

Six sites were surveyed with multibeam and split beam sonar by L. Kracker (NOAA) and the *Pisces* survey team and covered a total area of 112 km^2 (Table 1). These sites had never been surveyed previously with high-resolution multibeam sonar. Georeferenced maps were made for the Jacksonville *Lophelia* coral mound site, the North Florida MPA, St. Lucie MPA, and portion of the Miami Terrace CHAPC. In addition, two regions of deepwater *Oculina* coral reefs were mapped for the first time, north and outside of the current boundaries of the *Oculina* HAPC. These new *Pisces* sonar maps and ROV dives enabled us to discover and ground-truth many new deepwater *Oculina* coral reefs that had not been previously documented and these are now under consideration by the SAFMC for addition to the OHAPC.

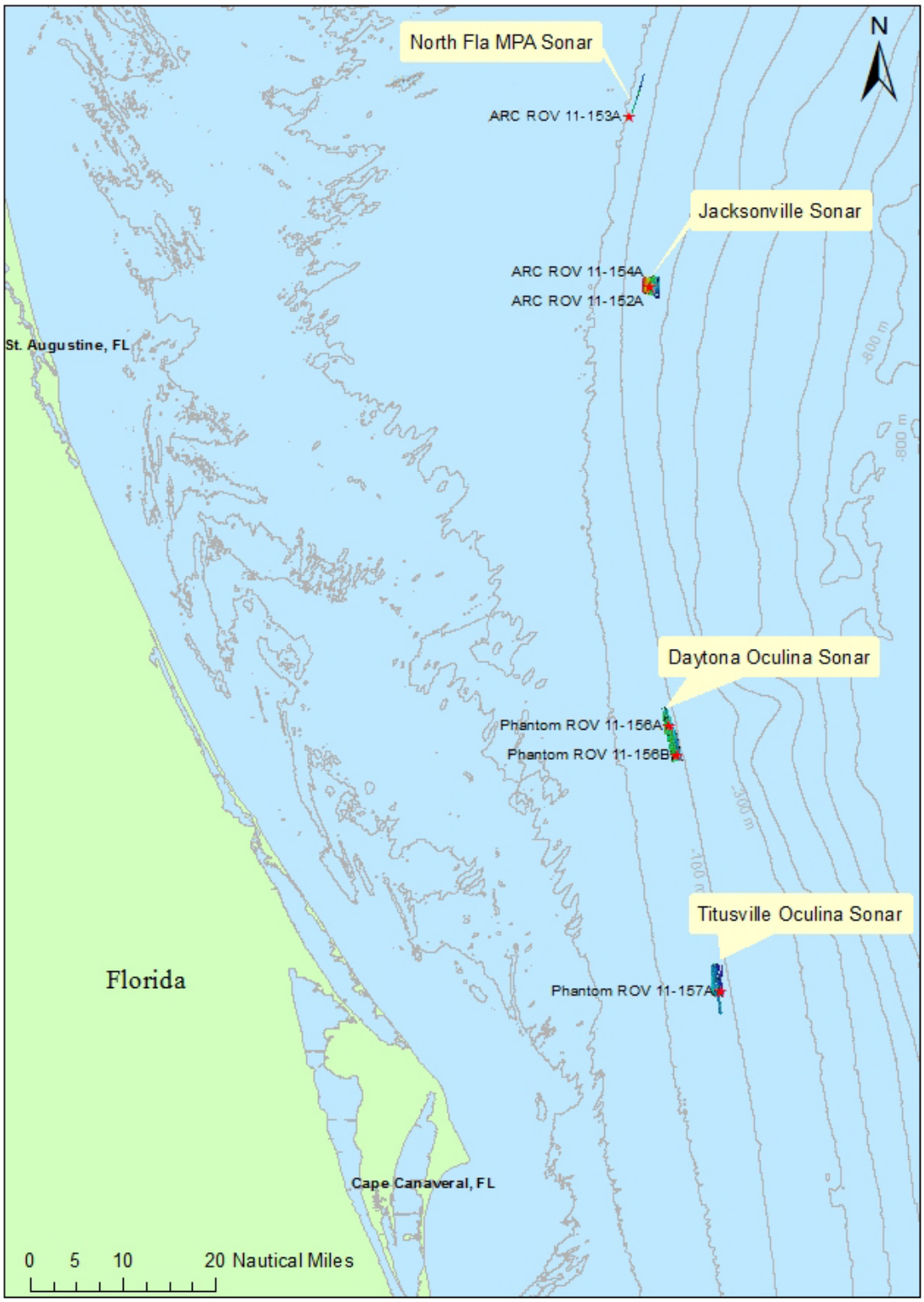


Figure 1a. Locations of ROV dive sites and multibeam sonar surveys during 2011 *Pisces* cruise: South Atlantic Deep Coral Survey, May 31-June 11, 2011. North Florida sites.

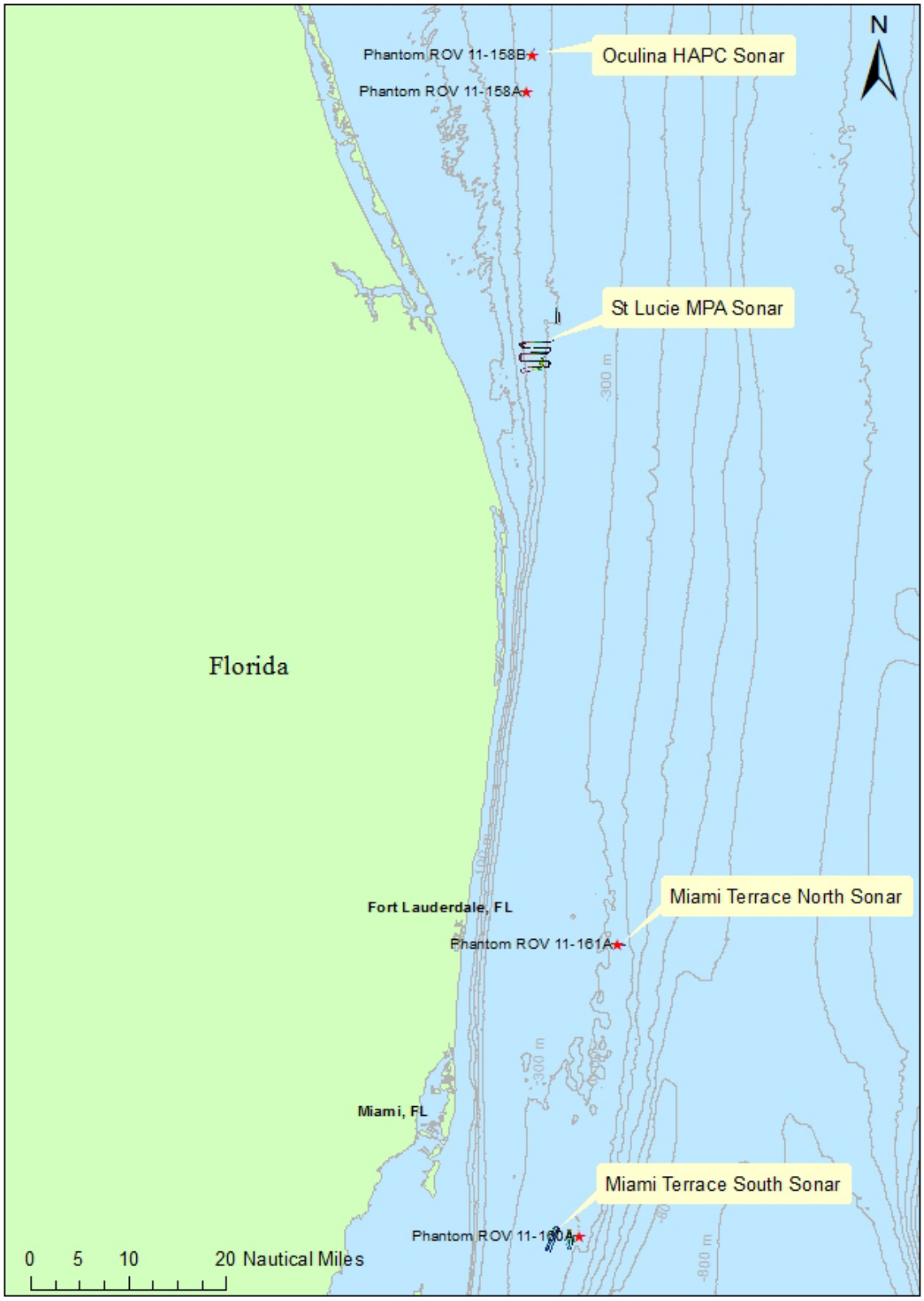


Figure 1b. Locations of ROV dive sites and multibeam sonar surveys during 2011 *Pisces* cruise: South Atlantic Deep Coral Survey, May 31-June 11, 2011. Central and south Florida sites.

Table 3. ROV dive stations during 2011 *Pisces* cruise: South Atlantic Deep Coral Survey.

SITE NUMBER (DATE + SITE #)	LATITUDE	LONGITUDE	METHOD	DEPTH RANGE (Feet)		NUMBER of SAMPLES
1-VI-11-1	30 01.5060'N	80 11.8000'W	ARC ROV 11-152A	702	699	0
2-VI-11-1	30 23.6400'N	80 24.7620'W	ARC ROV 11-153A	213	184	0
3-VI-11-1	30 01.5060'N	80 11.8000'W	ARC ROV 11-154A	1017	682	0
5-VI-11-1	29 14.1700'N	80 09.8020'W	Phantom ROV 11-156A	295	230	3
5-VI-11-2	29 10.9482'N	80 09.0585'W	Phantom ROV 11-156B	292	230	0
6-VI-11-1	28 45.4971'N	80 04.2835'W	Phantom ROV 11-157A	289	210	7
7-VI-11-1	27 32.8000'N	79 59.7000'W	Phantom ROV 11-158A	308	223	0
7-VI-11-2	27 36.5944'N	79 59.1923'W	Phantom ROV 11-158B	262	210	0
9-VI-11-1	25 35.8290'N	79 54.2900'W	Phantom ROV 11-160A	1279	810	0
10-VI-11-1	26 05.6560'N	79 50.3890'W	Phantom ROV 11-161A	1036	820	0

SEADESC II REPORT- Habitat and Benthic Biota Characterizations

The SEADESC Level II Report (Southeastern United States Deep-Sea Corals) is presented in Appendix 2. This provides the following data for each dive site: cruise and ROV dive metadata, figures showing each ROV dive track and habitat zones overlaid on multibeam sonar maps, dive track data (start and end latitude, longitude, depth), objectives, general description of the habitat and biota, and images of the biota and habitat that characterize the dive site. In addition, this SEADESC Level II Report provides quantitative analyses of each dive site including: 1) CPCe 4.1© analysis of percent cover of benthic biota and substrate types, 2) densities of benthic macro-fauna (# organisms/m^2 for each species), and 3) densities of fish populations (# individuals/km for each species).

Terminology

For this SEADESC II Report we used the following terminology. Hard bottom is sometimes referred to as live bottom due to the amount of living organisms attached to these substrates (SAFMC, 1998). Hard bottom provides anchorage for sessile or semi-sessile organisms (e.g., corals, octocorals, anemones, hydroids). Coral is defined by NOAA [Lumsden, S.E., T. Hourigan, A. Bruckner, and G. Dorr, eds., 2007, The state of deep coral ecosystems of the United States. NOAA Technical Memorandum CRCP-3] as hard corals (stony corals-Scleractinia) and other taxa with solid calcareous skeletons (e.g., Stylasteridae), as well as non-accreting taxa such as octocorals (Alcyonacea- Gorgonacea) and black coral (Antipatharia). Hard-bottom habitat includes various sizes of rock (rubble, cobble, boulders, and slabs), rock pavement, ledges, coral rubble, and framework coral (standing live and/or dead coral colonies). Vertical relief of bottom features (e.g., boulders, ledges, mounds) are reported in this report as low relief (<0.5 m), moderate relief (0.5-1.0 m), or high-relief features (>1.0 m). These are relative terms and depend on the size of features within an area and field of view. Soft substrates are defined as unconsolidated sediments (sand or mud).

Species List and Density of Benthic Macro-Biota

Appendix 1 lists all of the benthic macro-invertebrates and algae that were identified and counted from the quantitative photo transects at each dive site. Density of each species (# organisms/m^2) was calculated based on the area of each digital image from the photo transects. These are discussed in detail for each dive in Appendix 2. As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge" or "unidentified Demospongiae", which could consist of numerous species. These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different classes.

Deepwater *Oculina* Coral Reef Dives

Due to strong currents, we were unable to dive successfully on the deeper reef sites within the deepwater coral HAPC as planned. The deeper sites were near the axis of the Florida Current, often 2-3 knots, and we were unable to station-keep the ship with the ROV. Although we made three deep dives: one on the 200 m deep *Lophelia* coral reef site off Jacksonville, and two sites on Miami Terrace, it was very difficult to keep the ROV on the bottom or to maneuver at slow speeds (<0.5 kn). We were, however, able to dive on several shelf-edge reef sites instead, including the North Florida MPA site and several deepwater *Oculina* reef sites.

A total of 5 dives were made on the shelf-edge deepwater *Oculina* coral reef sites. Two new multibeam sonar maps were made with the NOAA ship *Pisces* off Daytona and Titusville which are north of the boundaries of the current *Oculina* HAPC. The PI suspected that the *Oculina* reef system actually extended north of the northern OHAPC boundary at Cape Canaveral, and this was the first time we had the capabilities to map and ground-truth these northern *Oculina* reef sites. Three dives were made outside of the *Oculina* HAPC and were used to ground-truth the new sonar maps (Daytona site- Dives 156A, 156B; Titusville site- Dive 157A). Two dives were made within the *Oculina* HAPC boundaries which was originally designated in 1984. Appendix 2 describes each of these dives in detail but we have summarized some of the data below to compare the sites within the *Oculina* HAPC to sites outside of the OHAPC boundaries.

Table 4. Summary *Oculina* reef dives comparing coral, sponge, and fish fauna within and outside of the *Oculina* Habitat Area of Particular Concern (OHAPC). CPCe analysis of the quantitative digital still images was used to calculate percent cover of fauna, and density analysis calculated the number of organism/m^2. Each cell shows the range of percent cover or density for the various habitat zones for that dive (Coral Mound Peak, Slope, Base), the number in parenthesis is the average for the entire dive. Total Coral Substrate includes framework coral (living *Oculina varicosa* and standing dead *Oculina*) and coral rubble; Alcyonacea coral (primarily Gorgonacea and some soft corals); Antipatharia (black coral); Porifera (sponges); Estimated Total # Live is based on the video analysis and extrapolating to the entire reef area.

Dive Site	Total Coral Substrate (% Cover)	Framework Coral (% cover)	Live *Oculina* Coral (Density-#/m^2)	Standing Dead *Oculina* Coral (Density-#/m^2)	Alcyonacea (Density-#/m^2)	Antipatharia (Density-#/m^2)	Porifera (Density-#/m2)	Est. Total # Live *Oculina* Colonies	Fish (# spp./ density-#/km)
Daytona North	59.1	2.26-7.41 (5.15)	0.09-0.29 (0.14)	0.34-0.89 (0.72)	.86-4.03 (2.36)	0 - 0.46 (0.11)	1.29-5.40 (2.31)	217.8	25 / 485
Daytona South	73.1	2.70-6.35 (4.27)	0.09-0.47 (0.25)	0.74-2.32 (1.83)	0.32-0.85 (0.54)	0-0.85 (2.36)	1.27-2.84 (2.07)	107.0	15 / 223
Titusville	56.2	2.71-13.89 (4.68)	0.04-0.21 (0.14)	0.55-2.65 (0.68)	0.28-1.42 (0.97)	0.16-0.40 (0.45)	0.22-2.05 (1.73)	114.1	26 / 812
Chapman's Reef-OHAPC	51.7	36.14-43.71 (37.85)	7.32-4.23 (6.12)	1.00-1.45 (1.18)	4.72-14.55 (10.72)	0.28-0.44 (0.97)	26.28-39.17 (34.16)	Abundant	33 / 2739
Jeff's Reef-OHAPC	45.0	26.29-29.48 (28.67)	4.12-4.19 (4.13)	1.09-1.98 (1.22)	8.83-10.67 (9.09)	0.38-0.73 (10.72)	9.60-11.51 (9.87)	Abundant	24 / 1160

There are considerable differences in the fauna at the *Oculina* reef sites within the OHAPC compared to those outside of the OHAPC. Overall, all of the sites are comprised of coral mounds (10-30 m relief) that are bioherms, that is, they were built up over thousands of years of coral growth. The exposed exterior of the mounds are predominately coral, both within and outside the OHAPC, ranging from 45% to 73% cover of both standing coral, termed framework coral, and coral rubble. However, there are striking differences in the amount standing coral framework between the sites: the HAPC sites have 37.8 and 28.6% cover of standing coral compared to 5.5-4.35% at the non-HAPC sites. The density of the coral is also much different between the sites: the HAPC sites have 6.1 and 4.1 colonies/m^2 of live *Oculina*; the non-protected sites have 0.14 to 0.25 colonies/m^2. Gorgonaceans (Alcyonacea) are also more abundant at the HAPC sites (10.7-9.1), as are Porifera (34.1-9.9). The fish populations which are described in more detail below had similar numbers of species among the sites, but densities were up to 10 times greater at the HAPC sites.

In addition to these analyses of the digital still images, a total count of live standing *Oculina* coral colonies was made from the forward-looking video camera for each entire dive within the non-protected *Oculina* coral reef sites (Table 4). The majority of the live *Oculina* at these sites were much smaller in size compared to the HAPC sites, ranging in size of ~15 to 30 cm, which is equivalent to possibly 10-20 years old. So it appears that the impact to these reefs occurred primarily in the 1970s or 80s. Since the actual video field-of-view is just a small portion of the total mound area, we calculated the estimated field-of-view area for each dive [field-of-view width (~10 m) x transect length = area of the video transect]. From this we estimated the total number of live *Oculina* corals that may occur over the entire mound area at that dive site. In ArcGIS we calculated the total planar surface area of the coral mounds that were transected during the dive. We then multiplied the density of coral in the video by the total mound surface area. Table 4 shows this estimate of possible number of live coral colonies that are on the coral mounds for each of the non-protected *Oculina* coral reef sites (218 to 107 coral colonies).

Figures 2 and 3 use one-way analysis of similarity (ANOSIM, Bray Curtis) to compare the density of the benthic macro-biota from the quantitative photo transects of the dive sites within the *Oculina* HAPC and the sites outside the OHAPC. The density of each species for each dive was entered in PRIMER. The table was filtered to include the five *Oculina* coral reef dives (11-156A, 11-156B, 11-157A, 11-158A, 11-158B). The table was square root transformed and factors of "No Protection" or OHAPC were added (11-156A, 11-156B, 11-157A = No Protection; and 11-158A, 11-158B = OHAPC). A resemblance matrix was calculated using S17 Bray Curtis similarity between Samples (dives). A 2D MDS Plot was created and resulted in 0 stress (Figure 2 shows the MDS with the cluster overlaid). A cluster dendrogram was created for the Samples (dives) with SIMPROF (Fig. 2). SIMPROF shows significant difference between the OHAPC sites (11-158A, 11-158B) and the No Protection Sites (11-156A, 11-156B, 11-157A) (at 74.96; Pi: 0 Sig(%): 100).

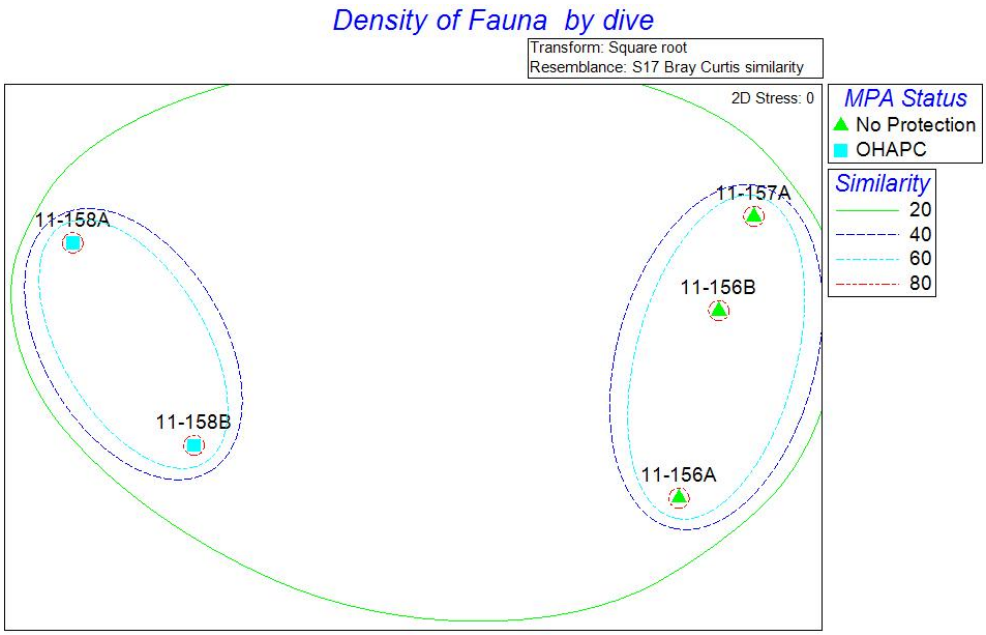


Figure 2. MDS plot of Bray Curtis similarity of density of macro-benthic biota among sites within the *Oculina* HAPC (blue squares) and *Oculina* reef sites outside of the OHAPC (green triangles). Ovals show the percent similarity of the clusters.

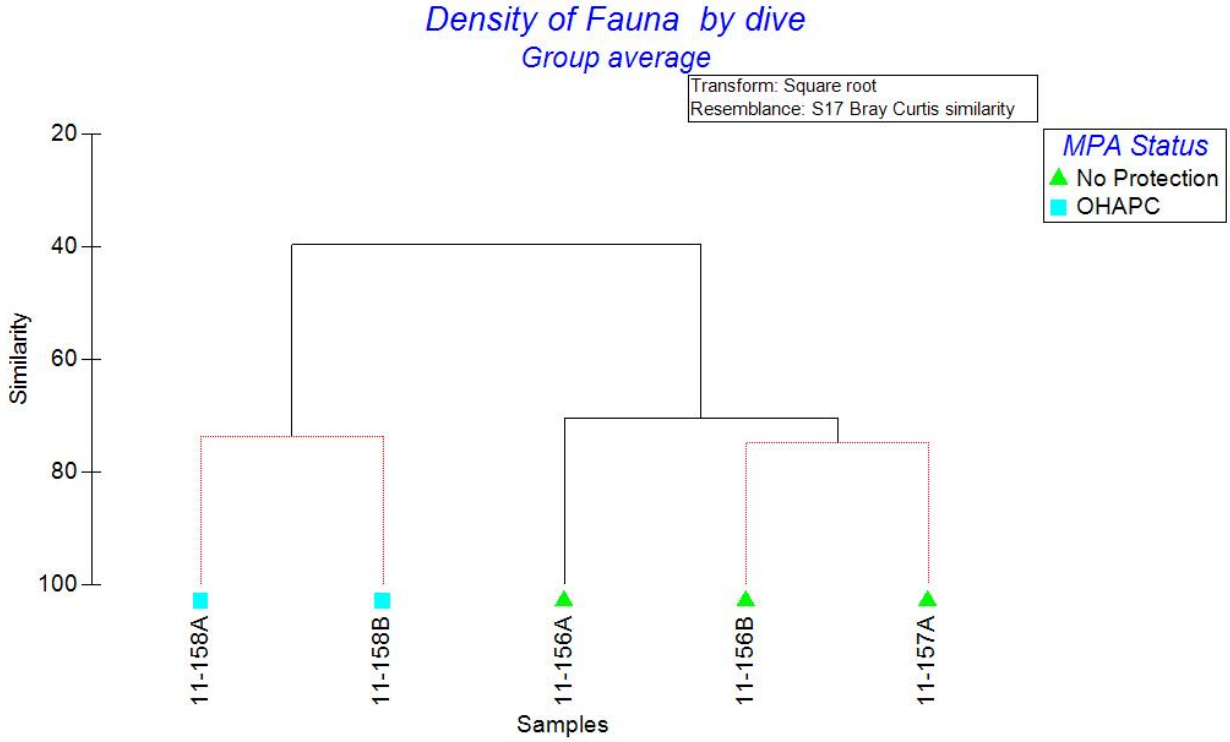


Figure 3. Dendrogram of Bray Curtis similarity of density of macro-benthic biota among sites within the *Oculina* HAPC (blue squares) and *Oculina* reef sites outside of the OHAPC (green triangles). The darker black branches indicate significant differences from SIMPROF.

These analyses clearly show the disparity of the protected *Oculina* reef sites within the OHAPC compared to the sites outside of the OHAPC, and provide evidence that the OHAPC is working to protect the coral habitat, benthic biota, and fish populations. The protected *Oculina* reef sites compared to the unprotected reef sites have greater abundances of standing coral framework, gorgonian corals, sponges, and much greater densities of fish. However, the newly discovered reef sites (non-OHAPC) show recent coral growth where most of the live *Oculina* coral colonies are 10-30 cm diameter. Previous research has shown that a single coral colony of about 20 cm diameter can provide habitat to nearly 2000 animals including juvenile fish and hundreds of species (Reed et al., 1982, 1987, 2002 a,b). Scleractinian corals as well as colonies of gorgonians, black corals, and sponges attract large numbers of fish and invertebrates. The high biodiversity associated with deepwater coral communities is intrinsically valuable and provides essential fish habitat for many commercially and recreationally important fish species, and as well, may provide numerous targets for chemical and biological research on marine organisms. However, the presence of dead coral should not be used to discount the habitat value. For example, the Southeastern United States Deep-Sea Coral Initiative (SEADSC) committee described 14 habitats found on the continental slope and concluded the presence of live versus standing dead coral did not matter in habitat classification (see Partyka et al. 2007). Live coral, standing dead coral, and even coral rubble all provide habitat and substrate for hundreds of species of invertebrates and juvenile fish (e.g., Reed et al., 1982, 1987, 2002 a,b; Ross and Quattrini, 2007), in addition to commercially valuable species (e.g., Reed and Farrington, 2010).

These data suggest that these small *Oculina* coral colonies at the non-OHAPC sites have recently settled as larvae and are growing on the coral rubble as long as the rubble is not overturned by bottom longlines or trawls. As a result of the new multibeam sonar maps made during the 2011 NOAA Ship *Pisces* cruise and ground-truth data collected by the ROV dives, the South Atlantic Fishery Management Council is now considering adding these newly discovered deepwater *Oculina* coral reefs to the *Oculina* HAPC. Given the presence of relatively young *Oculina* coral colonies, black coral, gorgonian coral, and sponges found on the newly discovered *Oculina* coral mounds, gives hope that these deepwater reefs could rebound after years of impact from bottom fishing and fisheries, especially in the 1970s and early 80s.

Human Debris

During the density analysis of the quantitative digital images from the photo transects, categories were included for 'human debris' and subcategories for fishing gear included fishing line, long line, fish traps/crab traps, nets, anchor line, bottles/cans, and other. The density of human debris (number/m^2) is plotted in Figures 4 and 5 showing all dives with debris (North Florida MPA site= dive 153A; *Oculina* coral reef sites outside of the OHAPC = 156 A, 156 B, and 157 A; the *Oculina* HAPC sites = 158A and 158 B). All these sites showed impact from human debris and primarily from fishing gear and even anchors. The other deeper sites which had no debris are probably too far offshore for most fishers. All of the *Oculina* reef sites showed fishing gear or litter on the bottom. Unfortunately both of the sites within the *Oculina* HAPC had the most fishing gear including bottom trawl nets. This could be in part that these sites are closest to shore and had very limited enforcement or surveillance prior to 2000. The age of this gear is unknown but we have evidence of trawling occurring at site 158B after the deployment of artificial Reef Blocks in 1997 (C. Konig, personal communication) and poachers using bottom

trawls were caught in the area of these reefs in early 2000; shrimp, bottom fish, lobster and even *Oculina varicosa* coral were confiscated by NMFS.

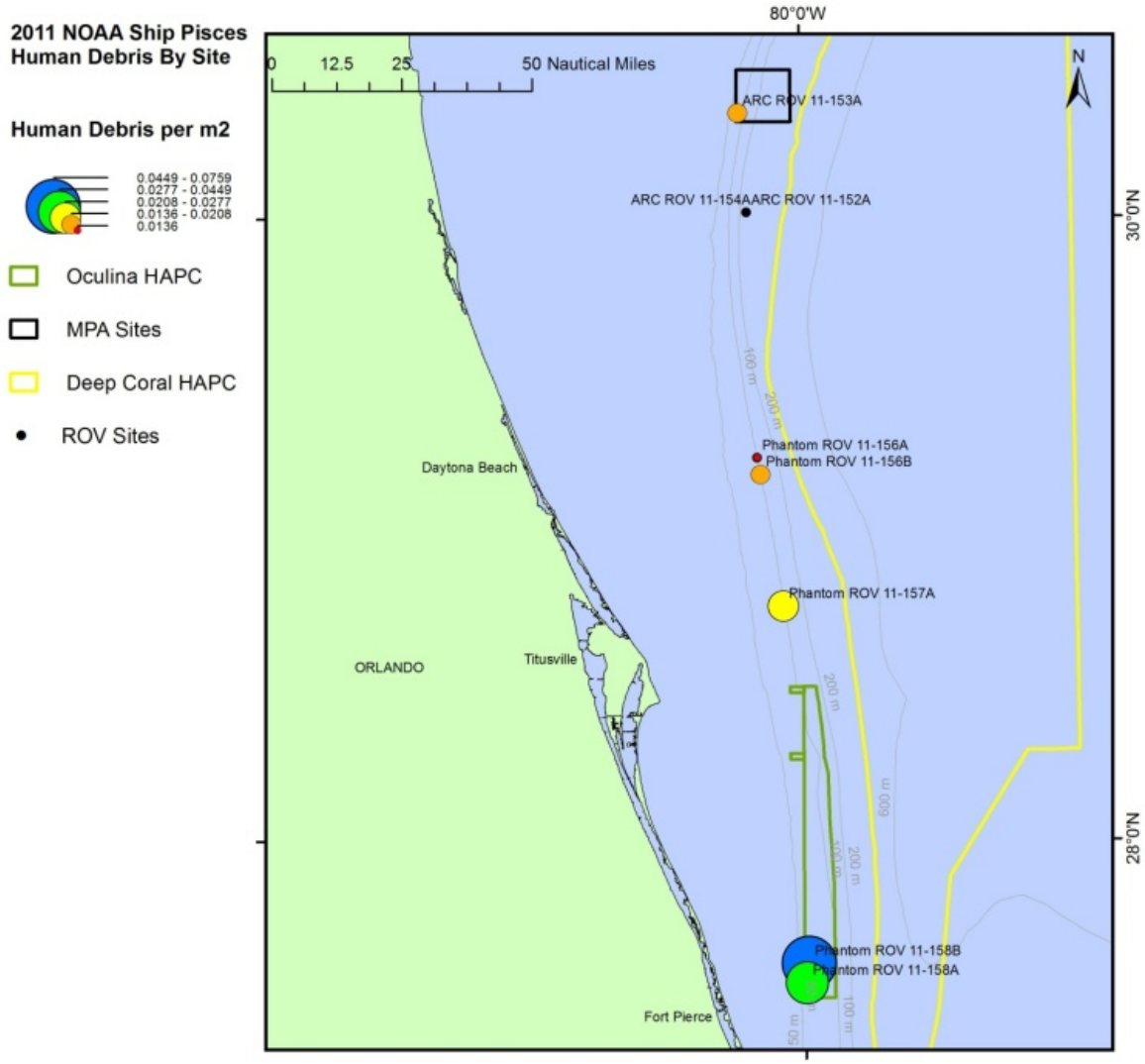


Figure 4. Plot of human debris at each ROV dive site during the 2011 NOAA Ship *Pisces* cruise. Numbers indicate number of points calculated from density analysis of digital images from the quantitative photo transects.

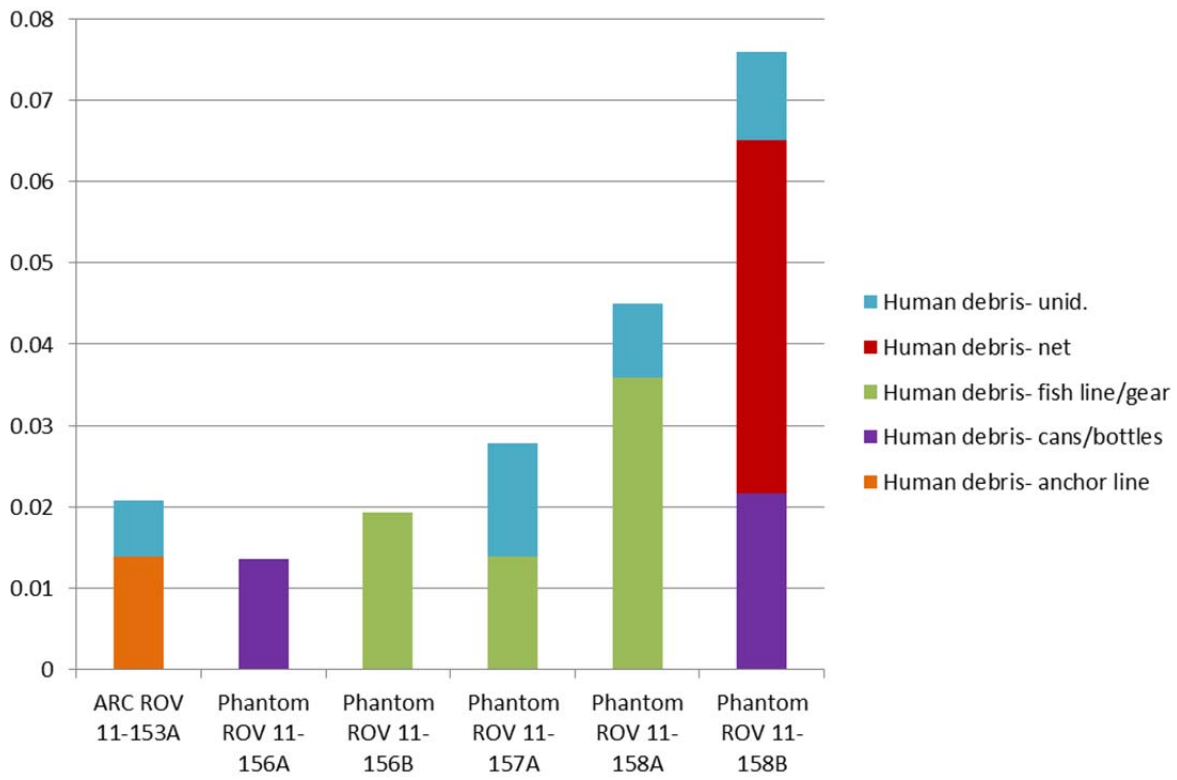


Figure 5. Graph of distribution of human debris at the ROV dive sites based on density (#/m^2) from the quantitative photo transects.

FISH POPULATIONS ANALYSIS (Andy David, Stacey Harter)

Methods

Video transects were used to analyze the fish populations and densities. Protocol for the fish analyses was to divide the continuous video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. A species list and densities are listed for each dive in the attached SEADESC II Report (Appendix 2).

Eight ROV dives were used in this fish analysis. Dives 152A and 161A were too short to be included in the analysis. Three reef types were examined on this cruise. One dive was on the shelf-edge North Florida MPA site (Dive 153A), five dives were made on the deepwater *Oculina* coral reefs (3 outside the OHAPC and 2 inside the OHAPC; Dives 156A to 158B), and 2 deep dives (200 m *Lophelia* coral mound site- Dive 154A, and Miami Terrace CHAPC- Dive 160A).

The dives on deepwater *Oculina* coral habitat were further analyzed to compare sites within the *Oculina* HAPC and the newly discovered *Oculina* reef sites outside of the OHAPC boundaries. A one-way ANOVA was run for each of the major managed species (amberjack, *Centropristes* spp., scamp, and snowy grouper) to test for differences in densities within and outside of the OHAPC. In addition, all fish species were counted and analyzed for each dive site. These are grouped by reef type (shelf edge MPA site, *Oculina* sites, and deep sites). Then each reef type was analyzed with PRIMER to show differences within the various habitat types (e.g., sand, rock pavement, ledges, coral) of each particular reef type.

Essential Fish Habitat

A total of 1196 grouper and snapper were observed in both the shelf-edge and *Oculina* reef types (1150 of these were vermilion snapper). No snapper or grouper were observed on the deep reefs (*Lophelia* site and CHAPC site). The following is a breakdown of species observed by reef type and inside vs. outside the *Oculina* HAPC. Scamp was the most abundant grouper and they were more abundant inside the *Oculina* HAPC compared to outside. Snowy grouper, however, were more abundant outside the *Oculina* HAPC.

Table 5. Managed fish species at North Florida MPA and deepwater *Oculina* coral reef sites.

Shelf-Edge		**Oculina**			
		Outside OHAPC		**Inside OHAPC**	
vermilion snapper	1149	scamp	17	scamp	23
scamp	16	snowy grouper	14	snowy grouper	2
snowy grouper	3			gag grouper	1
snapper - *Lutjanus*	1			vermilion snapper	1

Table 6. Densities of managed fish species for each dive site and ANOVA comparisons of species within and outside the Oculina HAPC.

****Numbers Inside the Table Represent Densities (#/km)**

These are all of the managed species observed on this cruise. No managed species were observed on the 2 deep dives.

Dive	amberjack - mix of greater and almaco jacks	Centropristis sp. - mix of black and bank sea bass	gag grouper	grey triggerfish	hogfish	red porgy	scamp	snowy grouper	tomtate	vermilion snapper	Reef Type	HAPC
1	2.7	17.8	0	1.1	0.8	23.9	2.6	0.5	96.2	185.7	Shelf-Edge	
3	1.6	373.6	0	0	0	1.6	6.3	0.8	0	0	Oculina	Outside
4	0.7	38.9	0	0	0	0	0	0.7	0	0	Oculina	Outside
5	4.8	707.8	0	0	0	4.8	0.8	2.9	0	0	Oculina	Outside
6	2.9	38.1	0.6	0	0	0	12.7	1.2	0	0	Oculina	Inside
7	0.5	70.1	0	0	0	0	1.6	0	0	0.5	Oculina	Inside

ANOVAs were run to test for differences in densities inside vs. outside the Oculina HAPC for amberjack, Centropristis sp., scamp, and snowy grouper

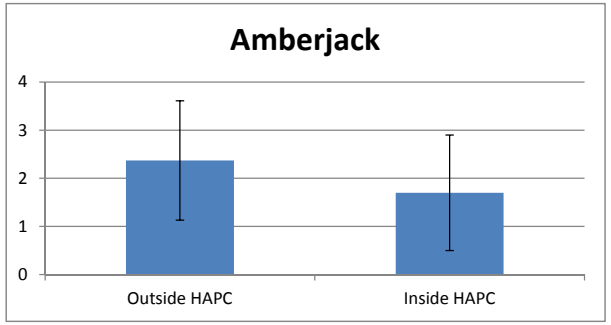
Amberjack Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Outside HAPC	3	7.1	2.366666667	4.6433333
Inside HAPC	2	3.4	1.7	2.88

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.533333333	1	0.533333333	0.1315068	0.7409177	10.12796
Within Groups	12.16666667	3	4.055555556			
Total	12.7	4				



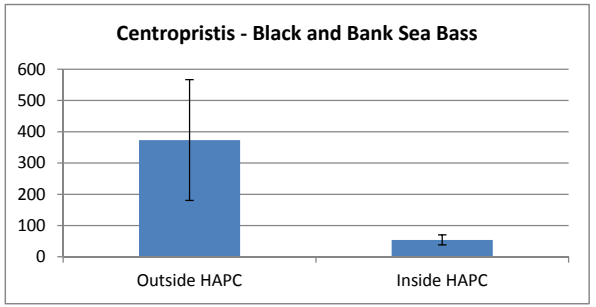
Centropristis sp. Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Outside HAPC	3	1120.3	373.4333333	111856.82
Inside HAPC	2	108.2	54.1	512

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	122368.5333	1	122368.5333	1.637215	0.2906926	10.12796
Within Groups	224225.6467	3	74741.88222			
Total	346594.18	4				



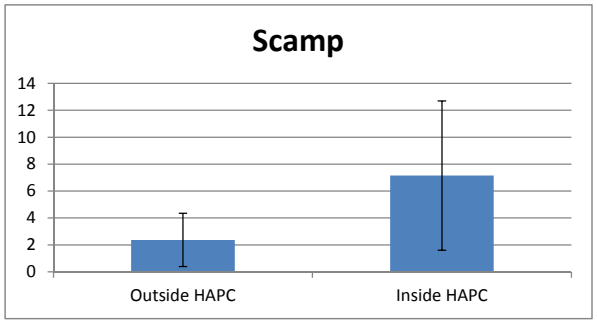
Scamp Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Outside HAPC	3	7.1	2.366666667	11.763333
Inside HAPC	2	14.3	7.15	61.605

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	27.45633333	1	27.45633333	0.9675483	0.3978224	10.12796
Within Groups	85.13166667	3	28.37722222			
Total	112.588	4				



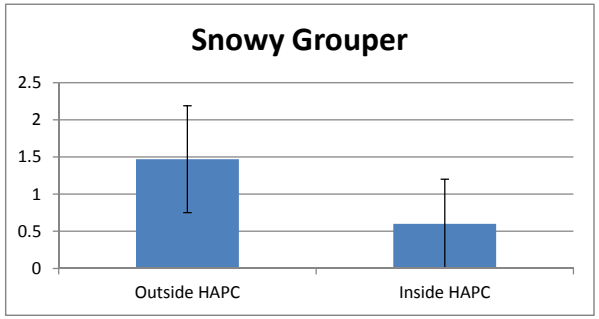
Snowy Grouper Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Outside HAPC	3	4.4	1.466666667	1.5433333
Inside HAPC	2	1.2	0.6	0.72

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.901333333	1	0.901333333	0.7103327	0.4612231	10.12796
Within Groups	3.806666667	3	1.268888889			
Total	4.708	4				



Fish Community Analyses

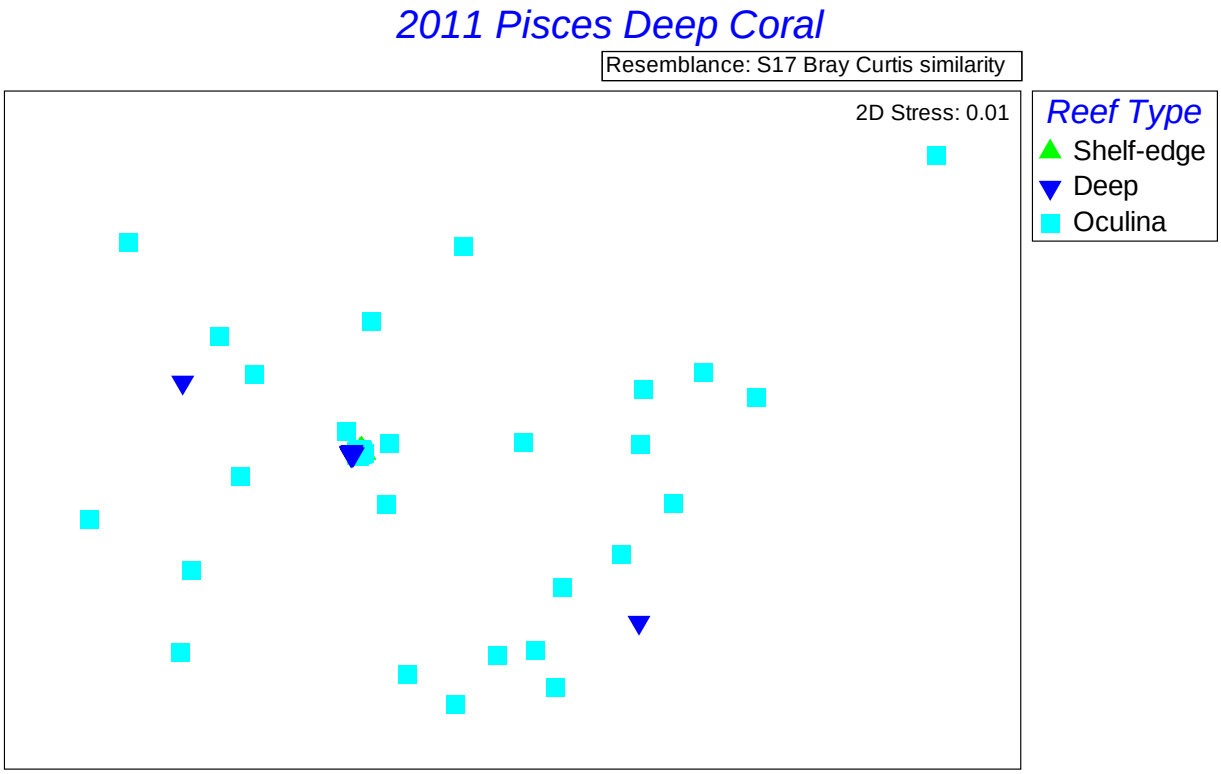
PRIMER was used to analyze fish assemblages from all hardbottom transects by reef type. A non-metric multi-dimensional scaling (MDS) ordination of ROV transects was constructed from a Bray-Curtis similarity matrix of presence/absence data for all fish species.

Table 7. Species list of all fish taxa at each reef site from 2011 *Pisces* cruise.

Common Name	Species Name	Shelf-edge	Oculina	Deep
almaco jack	*Seriola rivoliana*	X	X	
amberjack	*Seriola* sp.	X	X	
anthiid	*Anthias* sp.			X
anthiid	Anthiinae		X	X
apricot bass	*Plectranthias garrupellus*		X	
bandtail puffer	*Sphoeroides spengleri*	X		
bank butterflyfish	*Chaetodon aya*	X	X	
bank sea bass	*Centropristis ocyurus*	X	X	
barracuda	*Sphyraena barracuda*	X		
batfish	*Ogcocephalus* sp.		X	
beardfish	*Polymixia* sp.			X
belted sand bass	*Serranus subligarius*		X	
bigeye	*Priacanthus arenatus*	X		
black sea bass	*Centropristis striata*		X	
blackbar drum	*Pareques iwamotoi*		X	
blackbar soldierfish	*Myripristis jacobus*	X		
blackbelly rosefish	*Helicolenus dactylopterus*			X
blue angelfish	*Holacanthus bermudensis*	X	X	
cardinalfish	*Apogon* sp.	X		
catshark	*Scyliorhinus* sp.			X
chain catshark	*Scyliorhinus retifer*			X
conger eel	*Conger* sp.		X	
creole-fish	*Paranthias furcifer*	X		
cubbyu	*Equetus umbrosus*	X	X	
cusk eel	Ophidiidae		X	
deepwater flounder	*Monolene sessilicauda*			X
flounder	Bothidae		X	
gag grouper	*Mycteroperca microlepis*		X	
greater amberjack	*Seriola dumerili*	X	X	
grey triggerfish	*Balistes capriscus*	X		
hake	Phycidae			X
hogfish	*Lachnolaimus maximus*	X		
lionfish	*Pterois volitans*	X		
lizardfish	*Synodus* sp.		X	

longnose batfish	*Ogcocephalus corniger*		X	
mora	*Laemonema melanurum*			X
mora	*Laemonema sp.*			X
moray eel	Muraenidae		X	
ocellated moray	*Gymnothorax saxicola*		X	
orangeback bass	*Serranus annularis*	X	X	
porcupinefish	*Didon hystrix*		X	
purple reeffish	*Chromis scotti*	X	X	
red barbier	*Hemanthias vivanus*		X	
red hogfish	*Decodon puellaris*		X	
red porgy	*Pagus pagrus*	X	X	
reef butterflyfish	*Chaetodon sedentarius*	X		
reticulate moray eel	*Muraena retifera*		X	
roughtonge bass	*Pronotogrammus martinicensis*	X	X	
saddle bass	*Serranus notospilus*		X	
sand diver	*Synodus intermedius*	X	X	
sand tilefish	*Malacanthus plumieri*	X		
scamp	*Mycteroperca phenax*	X	X	
scorpionfish	Scorpaenidae	X	X	
scrawled cowfish	*Lactophrys quadricornis*	X		
sea bass	*Centropristis* sp.		X	
searobin	Triglidae		X	
sharpnose puffer	*Canthigaster rostrata*	X		
short bigeye	*Pristigenys alta*	X	X	
shortbeard codling	*Laemonema barbatulum*			X
shortnose greeneye	*Chloropthalmus agassiz*			X
snake eel	Ophichthidae		X	
snapper	*Lutjanus* sp.	X		
snowy grouper	*Epinephelus niveatus*	X	X	
soldierfish	Holocentridae	X	X	
spotfin butterflyfish	*Chaetodon ocellatus*	X		
spotfin hogfish	*Bodianus pulchellus*	X		
spotted hake	*Urophycis regius*			X
squirrelfish	Holocentridae	X		
sunshinefish	*Chromis insolatus*	X		
swallowtail bass	*Anthias woodsi*			X
tattler	*Serranus phoebe*	X	X	
tilefish	*Caulolatilus* sp.		X	
toadfish	*Opsanus* sp.		X	
tomtate	*Haemulon aurolineatum*	X		
trunkfish	*Lactophrys* sp.	X		
twospot cardinalfish	*Apogon pseudomaculatus*	X		

vermilion snapper	*Rhomboplites aurorubens*	X	X
wrasse	*Halichoeres* sp.	X	X
wrasse bass	*Liopropoma eukrines*	X	X
yellowtail reeffish	*Chromis enchrysurus*	X	X



The shelf-edge transects (green triangle) are not visible on this MDS plot, but they are all located beneath the middle of the deep reef transects. The low stress value indicates that there is very good graphical representation of the data (the points aren't randomly put on the map), however it is apparent there is a lot of variability among the *Oculina* transects as well as a considerable amount among the deep reef transects.

ANOSIM (Analysis of Similarity) was used to test for differences among the reef types and the results from the MDS were made clearer. There are some differences in fish assemblages among reef types.

One-Way Analysis

Factor Values
Factor: Reef Type
Shelf-edge
Deep
Oculina

Global Test
Sample statistic (Global R): 0.216
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Shelf-edge, Deep	0.928	0.1	Very large	999	0
Shelf-edge, Oculina	0.063	4.5	Very large	999	44
Deep, Oculina	0.452	0.1	Very large	999	0

While the overall R value is fairly low (0.216), R values among a couple of the pairwise comparisons are quite high. There are obviously some differences in fish assemblages between the deep reefs and both the shelf-edge (R = 0.928) and *Oculina* reefs (0.452).

SIMPER (Similarity Percentages) analysis was used to see what fish species were responsible for those differences. The deep reef transects had a completely different fish species list from the other two reef types. They did not even have 1 fish species in common (average dissimilarity = 100.00, the highest it can be).

Deepwater *Oculina* Reef Dives (Dives 156A, 156B, 157A, 158A, and 158B)

Transects for these dives were divided between "on mound" and "in between mound" habitats. Habitats that were found on the mounds were rubble, rock outcrop, and live & standing dead *Oculina*. Habitats that were found in between the mounds (or "off mound") were sand, pavement, rubble, and low relief outcrops (<1 m relief).

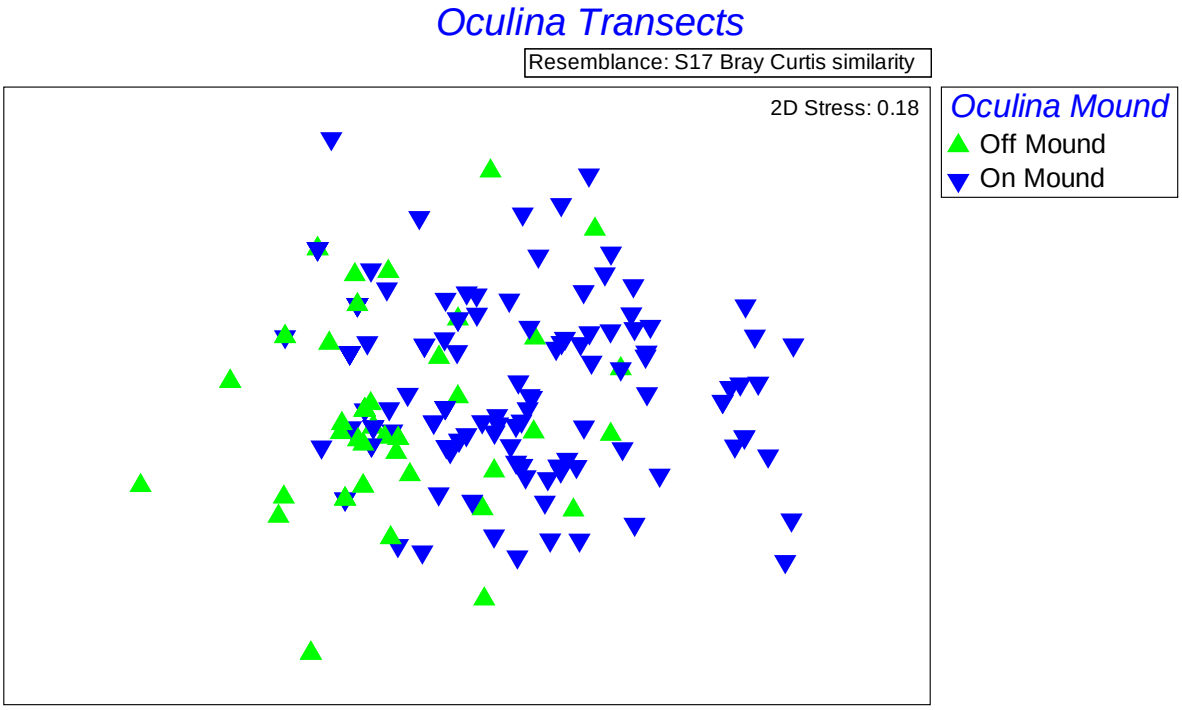
PRIMER was used to analyze fish assemblages from hardbottom transects to look for differences on vs. off mound. A non-metric multi-dimensional scaling (MDS) ordination of ROV transects was constructed from a Bray-Curtis similarity matrix of presence/absence data for all fish species, however no significant differences were noted. An ANOSIM was also run to confirm this. These analyses were run with presence/absence data. It is possible that if abundance or density data were used instead, there may be some significant differences between fish assemblages on and off mounds.

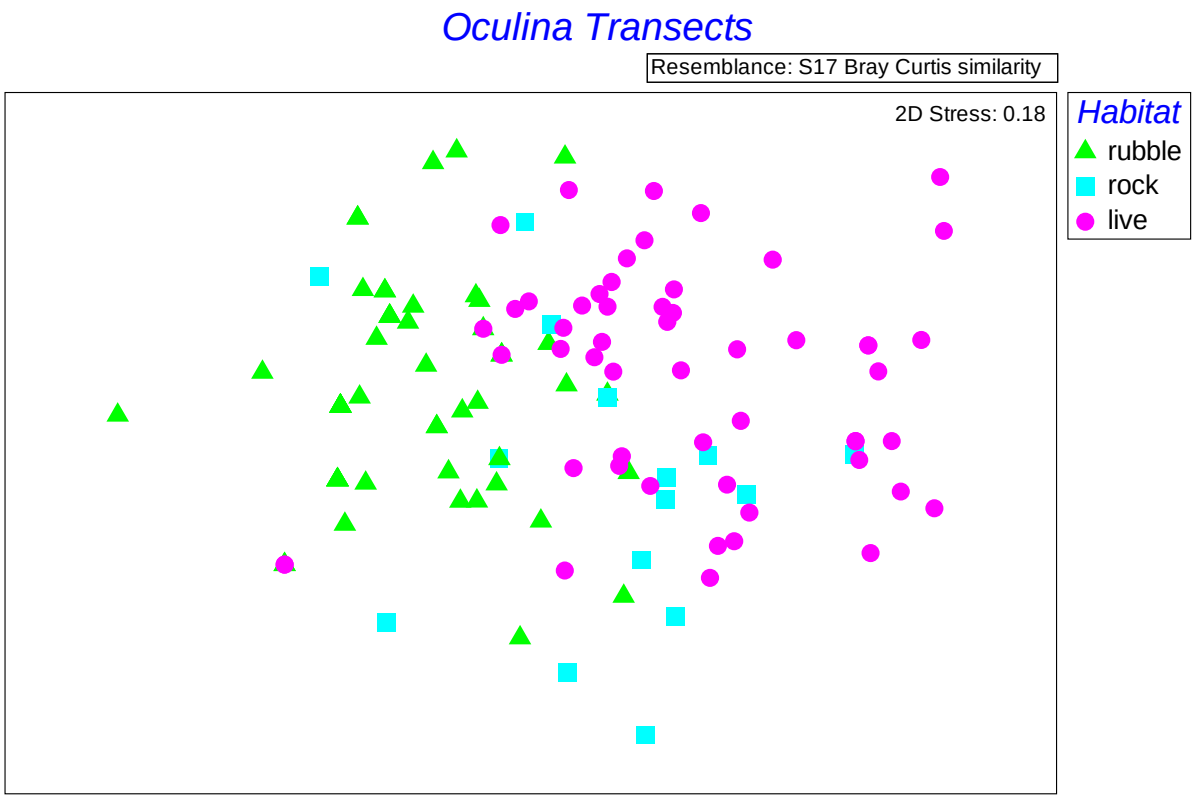
Table 8. Comparison of fish taxa at various habitat types within the *Oculina* reef ecosystem.

		On Mound			In Between Mounds			
Common Name	Species Name	rubble	rock outcrop	live & standing dead Oculina	sand	pavement	rubble	low relief outcrops
amberjack	*Seriola* sp.	X		X				
anthiid	Anthiinae	X		X	X	X		

apricot bass	*Plectranthias garrupellus*	X		X				
bank butterflyfish	*Chaetodon aya*	X	X	X		X	X	X
bank sea bass	*Centropristis ocyurus*	X	X	X	X	X	X	X
batfish	*Ogcocephalus* sp.	X			X		X	
belted sand bass	*Serranus subligarius*			X				
black sea bass	*Centropristis striata*	X	X	X	X	X	X	X
blackbar drum	*Pareques iwamotoi*							X
blue angelfish	*Holacanthus bermudensis*	X	X	X				
conger eel	*Conger* sp.		X					
cusk eel	Ophidiidae		X					
flounder	*Bothidae*				X			
gag grouper	*Mycteroperca microlepis*			X				
greater amberjack	*Seriola dumerili*			X	X			
lizardfish	*Syndodus* sp.			X				
longnose batfish	*Ogcocephalus corniger*				X			
moray eel	Muraenidae	X		X				
ocellated moray	*Gymnothorax saxicola*						X	
orangeback bass	*Serranus annularis*			X				
porcupinefish	*Diodon hystrix*			X				
purple reeffish	*Chromis scotti*			X				
red barbier	*Hemanthias vivanus*		X	X				X
red hogfish	*Decodon puellaris*		X	X		X		X
red porgy	*Pagrus pagrus*	X	X		X		X	X
reticulate moray	*Muraena retifera*			X				
roughtongue bass	*Pronotogrammus martinicensis*	X	X	X		X	X	X
saddle bass	*Serranus notospilus*		X		X	X	X	
sand diver	*Synodus intermedius*			X	X			
scamp	*Mycteroperca phenax*	X	X	X			X	X

scorpionfish	Scorpaenidae	X	X	X			X	X
sea bass	*Centropristis* sp.	X	X	X		X	X	X
searobin	Triglidae				X			
sea bass	*Serranus* sp.			X	X			
short bigeye	*Pristigenys alta*		X	X		X	X	X
snake eel	Ophichthidae				X			
snowy grouper	*Epinephelus niveatus*		X	X		X	X	X
soldierfish	Holocentridae			X				
tattler	*Serranus phoebe*	X	X	X	X	X	X	X
tilefish	*Caulolatilus* sp.				X			
toadfish	*Opsanus* sp.		X			X		
wrasse	*Halichoeres* sp.	X	X	X			X	
wrasse bass	*Liopropoma eukrines*		X	X		X	X	X
yellowtail reeffish	*Chromis enchrysurus*	X		X			X	X





"On mound" and "off mound" transects were compared to determine whether there were any differences in fish assemblages among habitat types. There were no differences among the habitat types found in between mounds, but there were some among "on mound" habitats.

ANOSIM – Oculina On Mound
Analysis of Similarities

One-Way Analysis

Factor Values
Factor: Habitat
rubble
rock
live

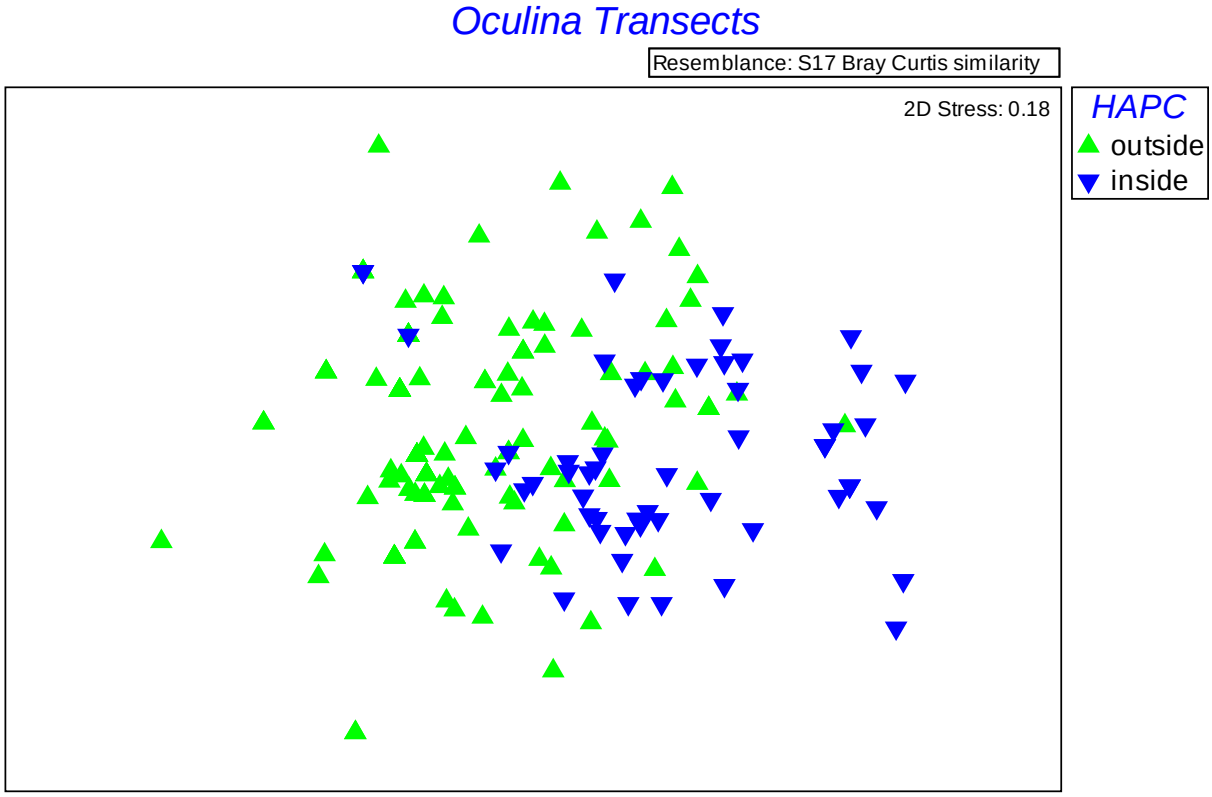
Global Test
Sample statistic (Global R): 0.392
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
rubble, rock	0.506	0.1	Very large	999	0
rubble, live	0.425	0.1	Very large	999	0
rock, live	0.16	2	Very large	999	

In particular, it appears fish assemblages were different on rubble habitat compared to both rock outcrops, and live/standing dead *Oculina*. SIMPER analyses demonstrated that these differences were due to higher abundances of anthiids, bank butterflyfish, and scamp on rock or live/standing dead *Oculina* compared to rubble as well as higher abundances of black and bank sea bass on rubble.

The following compares the fish assemblages inside and outside the *Oculina* HAPC.



ANOSIM – Oculina Inside vs. Outside HAPC
Analysis of Similarities
One-Way Analysis

Factor Values
Factor: HAPC
outside
inside

Global Test
Sample statistic (Global R): 0.321
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

The MDS plot and ANOSIM demonstrate there may be some differences in fish assemblages inside and outside the OHAPC. SIMPER analyses indicate that these difference are primarily due to higher abundances of anthiids, bank butterflyfish, and scamp inside the OHAPC while bank sea bass and black sea bass are more abundant outside the OHAPC.

On one dive (158B), the ROV crossed over several of artificial reef blocks (concrete reef blocks deployed in the late 1990s by Chris Koenig). Several of these had new growth of *Oculina* coral colonies. Fish species that were found on the reef blocks include: bank butterflyfish, blue angelfish, cubbyu, reticulate moray eel, scamp, short bigeye, vermilion snapper, and yellowtail reeffish.

Shelf-Edge Reef Dive (North Florida MPA Site, Dive 153A)

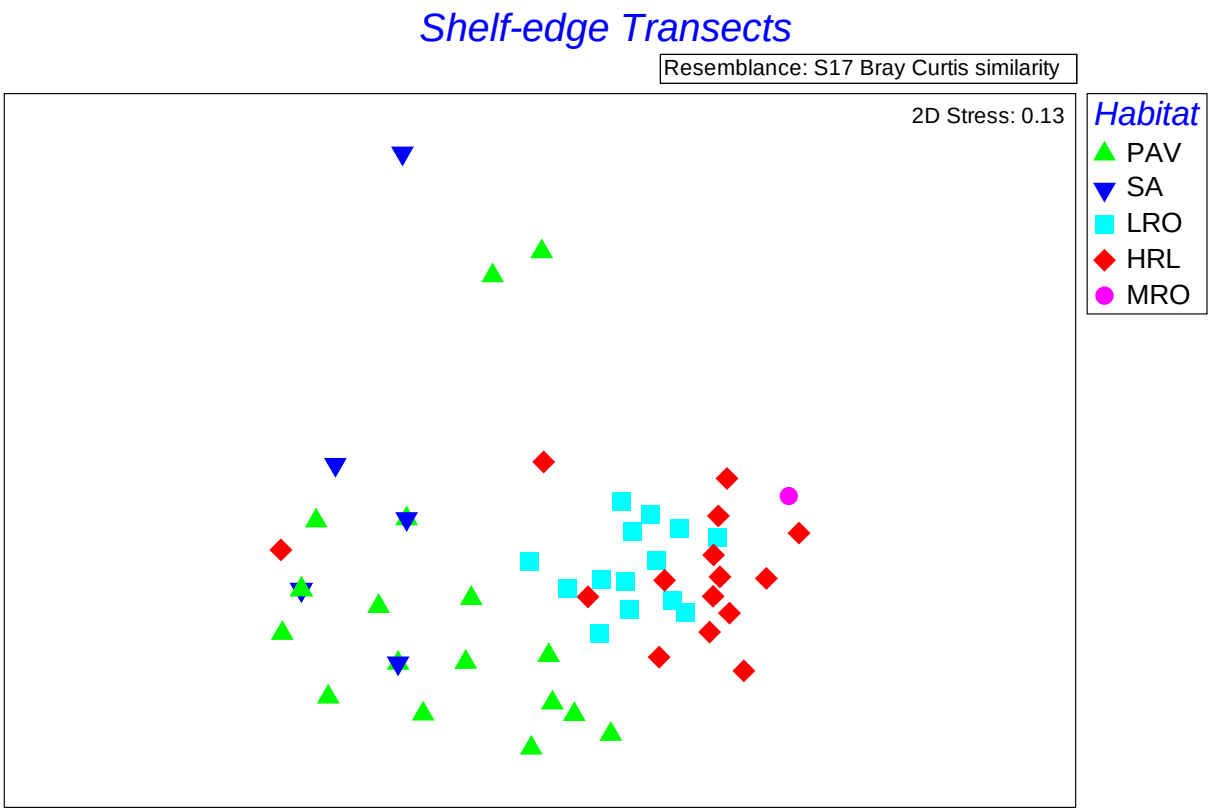
Five habitat types were identified from the shelf-edge dive. Sand, pavement (flat but with obvious signs of hardbottom, sometimes cracks/crevices are present), low relief outcrops (rock outcrops < 1 m relief), moderate relief outcrops (rock outcrops between 1 and 3m relief), high relief ledge (rock outcrops >3 m relief).

PRIMER was used to analyze fish assemblages from all shelf-edge transects by habitat type. A non-metric multi-dimensional scaling (MDS) ordination of ROV transects was constructed from a Bray-Curtis similarity matrix of presence/absence data for all fish species.

Table 9. Comparison of fish taxa at various habitat types within N. Florida MPA site.

Common Name	Species Name	Sand	Pavement	Low relief outcrops	Moderate relief outcrops	High relief ledge
almaco jack	*Seriola rivoliana*	X		X		
amberjack	*Seriola* sp.		X	X	X	
bandtail puffer	*Sphoeroides spengleri*					X
bank butterflyfish	*Chaetodon aya*			X		X
bank sea bass	*Centropristis ocyurus*		X	X		X
barracuda	*Sphyraena barracuda*		X			
bigeye	*Priacanthus arenatus*		X			X
blackbar soldierfish	*Myripristis jacobus*			X		X
blue angelfish	*Holacanthus bermudensis*		X	X	X	X
cardinalfish	*Apogon* sp.		X	X		
creole-fish	*Paranthias furcifer*				X	

cubbyu	*Equetus umbrosus*			X	X	X
greater amberjack	*Seriola dumerili*	X		X		X
grey triggerfish	*Balistes capriscus*		X			X
hogfish	*Lachnolaimus maximus*			X		
lionfish	*Pterois volitans*			X	X	X
orangeback bass	*Serranus annularis*					X
purple reeffish	*Chromis scotti*			X	X	X
red porgy	*Pagrus pagrus*		X	X	X	X
reef butterflyfish	*Chaetodon sedentarius*		X	X	X	X
roughtongue bass	*Pronotogrammus martinicensis*			X		
sand diver	*Synodus intermedius*		X			
sand tilefish	*Malacanthus plumieri*		X			
scamp	*Mycteroperca phenax*			X	X	X
scorpionfish	Scorpaenidae				X	
scrawled cowfish	*Lactophrys quadricornis*					X
sharpnose puffer	*Canthigaster rostrata*			X	X	X
short bigeye	*Pristigenys alta*	X	X	X		
snapper	*Lutjanus* sp.			X		
snowy grouper	*Epinephelus niveatus*					X
soldierfish	Holocentridae				X	
spotfin butterflyfish	*Chaetodon ocellatus*					X
spotfin hogfish	*Bodianus pulchellus*			X	X	X
squirrelfish	*Holocentrus adscensionis*		X	X	X	X
squirrelfish	*Holocentrus* sp.			X		X
sunshinefish	*Chromis insolatus*			X		X
tattler	*Serranus phoebe*	X	X	X		X
tomtate	*Haemulon aurolineatum*			X	X	X
trunkfish	*Lactophrys* sp.		X	X		
twospot cardinalfish	*Apogon pseudomaculatus*		X			
vermilion snapper	*Haemulon aurolineatum*		X	X	X	X
wrasse	*Halichoeres* sp.	X	X	X	X	X
wrasse bass	*Liopropoma eukrines*			X		X
yellowtail reeffish	*Chromis enchrysurus*	X	X	X		X



The stress value on this MDS plot is slightly higher than is ideal, but it shows there are some distinct fish assemblages. High relief ledge, moderate relief outcrops, and low relief outcrops are all spatially separate from sand and pavement transects indicating there may be differences in the fish assemblages between those habitat types. The same holds true for low relief outcrops and moderate relief outcrops.

An ANOSIM was run on this data and these differences in fish assemblages were confirmed.

ANOSIM – Shelf-Edge
Analysis of Similarities

One-Way Analysis

Factor Values
Factor: Habitat
PAV
SA
LRO
HRL
MRO

Global Test
Sample statistic (Global R): 0.434
Significance level of sample statistic: 0.1%

Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
PAV, SA	-0.03	56.4	888030	999	563
PAV, LRO	0.5	0.1	Very large	999	0
PAV, HRL	0.523	0.1	Very large	999	0
PAV, MRO	0.734	4.8	21	21	1
SA, LRO	0.899	0.1	116280	999	0
SA, HRL	0.737	0.1	170544	999	0
SA, MRO	0.66	12.5	8	8	1
LRO, HRL	0.241	0.1	77558760	999	0
LRO, MRO	0.765	6.7	15	15	1
HRL, MRO	-0.041	43.8	16	16	7

The Global R (0.434) is probably high enough to indicate some significant differences among habitat types. Differences in fish communities are probably evident in those habitats where pairwise tests displayed $R \geq 0.5$. SIMPER analysis to see what fish species were responsible for those differences.

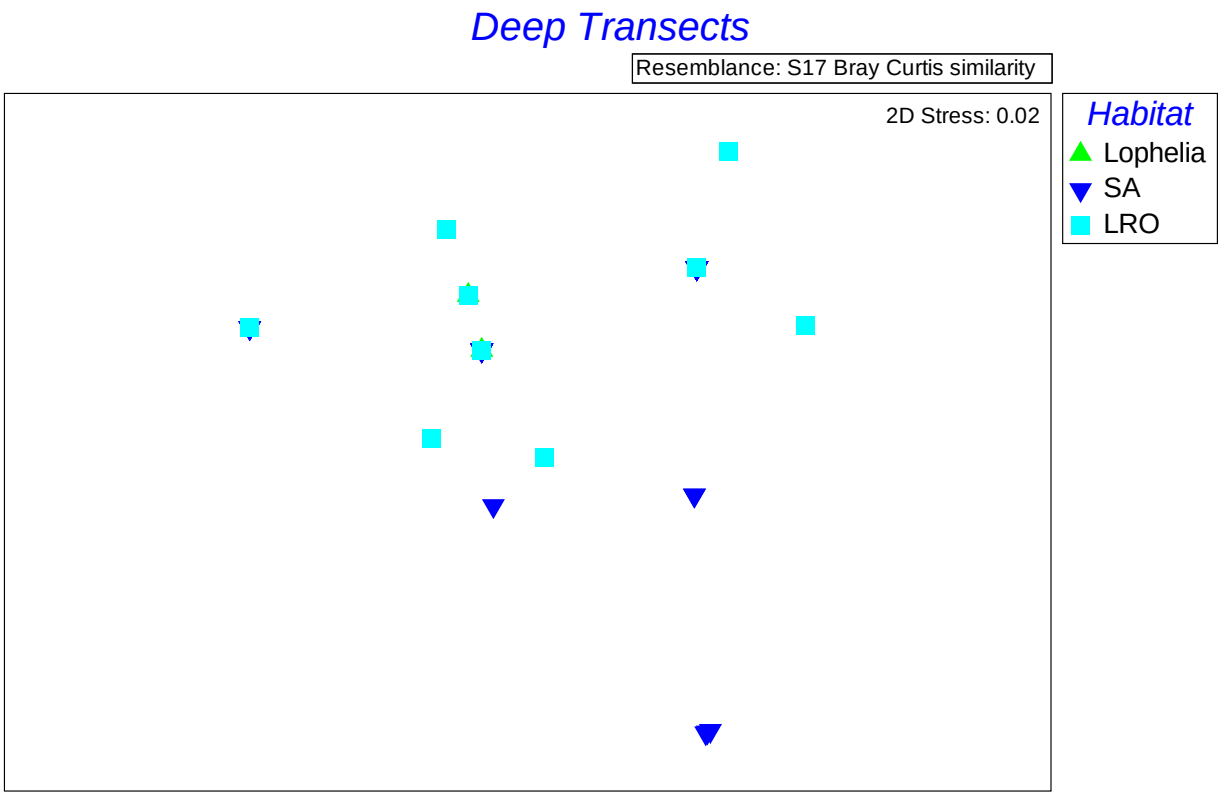
Deep Reef Dives (*Lophelia*- Dive 154A; Miami Terrace CHAPC- Dive 160A)

Three habitat types were identified from the deep dives. Sand, low relief outcrops (rock outcrops <1m relief), and live *Lophelia*. PRIMER was used to analyze fish assemblages from all deep transects by habitat type. A non-metric multi-dimensional scaling (MDS) ordination of ROV transects was constructed from a Bray-Curtis similarity matrix of presence/absence data for all fish species, however no significant differences were noted. An ANOSIM was also run to confirm this.

Table 10. Comparison of fish taxa at various habitat types within the deepwater reef sites.

Common Name	Species Name	Sand	Low Relief Rock Outcrops	Lophelia
anthiid	*Anthias* sp.		X	
anthiid	Anthiinae			X
beardfish	*Polymixia* sp.		X	
blackbelly rosefish	*Helicolenus dactylopterus*	X	X	X
catshark	*Scyliorhinus* sp.		X	
chain catshark	*Scyliorhinus retifer*	X		
deepwater flounder	*Monolene sessilicauda*	X	X	
hake	Phycidae	X	X	
mora	*Laemonema*		X	

	melanurum			
mora	*Laemonema* sp.	X	X	X
shortbeard codling	*Laemonema barbatulum*	X	X	X
shortnose greeneye	*Chloropthalmus agassiz*		X	
spotted hake	*Urophycis regius*	X	X	
swallowtail bass	*Anthias woodsi*		X	



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APPENDIX 1

Species List and Density of Benthic Macro-Biota

Appendix 1 lists all of the benthic macro-invertebrates and algae that were identified and counted from the quantitative photo transects for each dive. Density of each species (# organisms/m^2) was calculated based on the area of each digital image from the photo transects.

Density	Site										
Phylum/Class/Order/Scientific Name	11-152A	11-153A	11-154A	11-156A	11-156B	11-157A	11-158A	11-158B	11-160A	11-161A	Total
Porifera		**6.14**	**0.13**	**2.31**	**2.07**	**1.73**	**34.16**	**9.87**	**3.66**	**2.76**	**62.83**
Demospongiae		**6.13**	**0.13**	**2.31**	**2.07**	**1.73**	**34.16**	**9.87**	**1.70**	**2.76**	**60.86**
Astrophorida							29.39	6.37	0.27	0.11	36.14
Astrophorida									0.19		0.19
Astrophorida- fan									0.07	0.11	0.18
Erylus sp.							26.66	5.57			32.22
Geodia- flat top							1.82	0.37			2.19
Geodia- flat top red							0.23	0.16			0.40
Geodia- flat top yellow							0.57	0.26			0.84
Geodia sp.							0.03	0.01	0.01		0.04
Geodia sp.- tan sp ap pore							0.07				0.07
Pachastrellidae									0.01		0.01
Chondrosida					0.73	0.24	0.03				1.00
Chondrosia sp.					0.73	0.24	0.03				1.00
Dictyoceratida		0.43		0.03	0.02				0.01		0.48
Dictyoceratida		0.05									0.05
Ircinia campana		0.09		0.01							0.10
Ircinia felix				0.01							0.01
Ircinia sp.		0.28			0.02				0.01		0.31
Ircinia strobilina		0.01									0.01
Hadromerida		2.71		1.23	0.12		3.15	2.76			9.96
Cliona sp.		0.01									0.01
Placospongia sp.		0.04									0.04
Spirastrellidae		2.66		1.23	0.12		3.15	2.76			9.91
Halichondrida									0.07		0.07
Phakellia sp.									0.07		0.07
Haplosclerida		0.03							0.15		0.18
Haplosclerida		0.03									0.03
Oceanapia sp.									0.07		0.07
Petrosia sp.									0.07		0.07
Lithistida									0.10		0.10
Lithistida									0.10		0.10
Poecilosclerida		0.03					0.24	0.04	0.01	2.43	2.76
Clathria sp.		0.02									0.02
Hymedesmia sp.- blue morph										0.33	0.33
Hymedesmia sp.- yellow morph									0.01		0.01
Poecilosclerida		0.01					0.24	0.04			0.30
Raspailiidae- fan mesh										2.10	2.10
Spirophorida		0.01									0.01
Cinachyra sp.		0.01									0.01
Verongida		0.02					0.02				0.04
Aplysina sp.		0.01					0.02				0.03
Verongida		0.01									0.01
Demospongiae		2.89	0.13	1.05	1.20	1.50	1.33	0.71	1.09	0.22	10.12
Demospongiae		2.74	0.13	1.05	1.20	1.42	1.14	0.68	1.09	0.22	9.67
Demospongiae- am white							0.05	0.02			0.08
Demospongiae- orange sphere						0.08					0.08
Demospongiae- tan starlet thick encrusting		0.15									0.15
Demospongiae- thin curtain									0.01		0.01
Demospongiae- ye brain		0.01									0.01
Demospongiae- ye lobate							0.13				0.13
Hexactinellida									**1.96**		**1.96**
Hexactinosida									0.61		0.61
Aphrocallistes beatrix									0.03		0.03
Farrea sp.									0.58		0.58
Lyssacinosida									0.06		0.06
Hertwigia falcifera									0.02		0.02
Nodastrella nodastrella									0.01		0.01
Vazella pourtalesii									0.04		0.04
Hexactinellida									1.29		1.29
Hexactinellida									1.15		1.15
Hexactinellida- curtain									0.12		0.12
Hexactinellida- fan									0.02		0.02
Homoscleromorpha		**0.01**									**0.01**
Homosclerophorida		0.01									0.01
Plakortis sp.		0.01									0.01

Density	Site										
Phylum/Class/Order/Scientific Name	11-152A	11-153A	11-154A	11-156A	11-156B	11-157A	11-158A	11-158B	11-160A	11-161A	Total
Cnidaria		**5.37**	**4.91**	**10.47**	**8.11**	**8.85**	**22.12**	**17.24**	**4.71**	**5.19**	**86.99**
Anthozoa		**3.21**	**4.80**	**8.96**	**6.58**	**5.98**	**20.64**	**16.36**	**3.23**	**4.42**	**74.19**
Actiniaria		0.01	1.75	0.37	0.23	1.00	1.29	0.14	0.21	0.77	5.77
Actiniaria		0.01	1.09	0.37	0.23	1.00	0.76	0.14	0.20	0.66	4.46
Actiniaria- mat anemone							0.53				0.53
Actinoscyphia sp.									0.01		0.01
Liponema sp.										0.11	0.11
Sagartiidae			0.66								0.66
Alcyonacea		0.50	1.62	2.36	0.54	0.97	10.72	9.09	1.55	1.77	29.13
Alcyonacea				0.20	0.02	0.01	0.02	0.01	0.16		0.42
Alcyonacea- brown sphere										0.88	0.88
Anthomastus sp.									0.32	0.55	0.87
Callipodium rubens (=Anthopodium rubens)							0.06	0.09			0.15
Capnella sp.									0.10		0.10
Diodogorgia sp.		0.31		0.01			0.57	0.30			1.20
Ellisella barbadensis		0.01									0.01
Ellisellidae		0.01	0.11			0.28		0.01	0.18	0.11	0.69
Eunicella sp.						0.08			0.30		0.39
Gorgonacea (accepted as Alcyonacea)		0.04	0.05	0.01	0.08	0.10	9.76	7.48	0.16	0.11	17.79
Isididae										0.11	0.11
Leptogorgia sp.							0.01				0.01
Muricea sp.		0.05									0.05
Nicella sp.		0.02					0.01	0.01			0.04
Nidalia occidentalis				0.10	0.08	0.32	0.28	1.19	0.01		1.97
Nidalia sp.		0.01									0.01
Paramuricea sp.									0.01		0.01
Plexauridae		0.01									0.01
Plexauridae- purple		0.03									0.03
Plumarella sp.									0.09		0.09
Primnoidae			1.46						0.22		1.68
Telesto sp.		0.01		2.03	0.37	0.18	0.01				2.60
Titanideum frauenfeldii		0.01									0.01
Antipatharia		2.43	0.03	0.11	0.15	0.29	0.34	0.68			4.04
Antipathidae		0.03	0.03	0.01	0.06	0.11	0.03	0.22			0.49
Stichopathes lutkeni				0.05	0.04	0.10	0.27	0.40			0.86
Stichopathes sp.		2.21									2.21
Tanacetipathes hirta		0.19		0.04	0.06	0.08	0.04	0.07			0.49
Ceriantharia			0.03	0.18	0.75	0.68	0.48	0.21			2.32
Cerianthidae			0.03	0.18	0.75	0.68	0.48	0.21			2.32
Corallimorpharia			0.11	0.08	0.29	0.04	0.09	0.23	0.04		0.87
Corallimorpharia			0.11						0.04		0.14
Corallimorphus sp.				0.08	0.29	0.04	0.09	0.23			0.73
Pennatulacea		0.07									0.07
Virgularia sp.		0.07									0.07
Scleractinia		0.17	1.25	2.68	3.36	1.19	7.31	5.47	0.60	1.88	23.90
Cladocora sp.				1.17	1.04	0.22	0.01				2.45
Lophelia pertusa			0.42						0.10	0.22	0.75
Lophelia- standing dead									0.12		0.12
Madracis myriaster (=Madracis mirabilis)		0.02									0.02
Oculina varicosa				0.14	0.25	0.14	6.12	4.13			10.78
Oculina varicosa- dead standing				0.72	1.83	0.68	1.18	1.22			5.63
Phyllangia americana				0.40	0.02		0.01	0.10			0.52
Scleractinia- unid colonial								0.01	0.06		0.07
Scleractinia- unid cup		0.15	0.82	0.25	0.21	0.15		0.01	0.32	1.66	3.56
Zoanthidea		0.03	0.03	3.18	1.26	1.80	0.40	0.54	0.83		8.08
Palythoa sp.				0.05							0.05
Zoanthidae		0.03	0.03	3.13	1.26	1.80	0.40	0.54	0.83		8.03
Hydrozoa		**2.16**	**0.11**	**1.52**	**1.53**	**2.87**	**1.48**	**0.88**	**1.48**	**0.77**	**12.80**
Anthoathecata		0.03							1.35	0.66	2.05
Stylasteridae		0.03							1.35	0.66	2.05
Leptothecata						0.60					0.60
Aglaophenia trifida						0.60					0.60
Hydrozoa		2.13	0.11	1.52	1.53	2.28	1.48	0.88	0.13	0.11	10.16
Hydroidolina		2.13	0.11	1.39	1.53	2.28	1.48	0.88	0.13	0.11	10.03
Hydroidolina- long pine				0.12							0.12

Density	Site										
Phylum/Class/Order/Scientific Name	11-152A	11-153A	11-154A	11-156A	11-156B	11-157A	11-158A	11-158B	11-160A	11-161A	Total
Annelida		**4.67**	**0.42**	**5.26**	**3.71**	**6.30**	**0.06**	**0.73**			**21.15**
Polychaeta		**4.67**	**0.42**	**5.26**	**3.71**	**6.30**	**0.06**	**0.73**			**21.15**
Amphinomida				0.01		0.01		0.01			0.04
Amphinomida				0.01							0.01
Hermodice carunculata						0.01		0.01			0.02
Sabellida		2.45		1.60	1.78	3.12	0.06	0.27			9.29
Filograna sp.		1.61									1.61
Sabellidae		0.74		0.90	1.10	2.97	0.06	0.27			6.04
Serpulidae		0.01		0.70	0.68	0.15					1.53
Spirobranchus giganteus		0.10									0.10
Polychaeta		2.22	0.42	3.65	1.93	3.16		0.44			11.83
Mollusca	**0.27**	**0.02**	**0.53**	**0.20**	**0.23**	**0.06**	**0.04**	**0.02**	**0.04**		**1.41**
Bivalvia					**0.06**						**0.06**
Pectinoida					0.02						0.02
Plicatula gibbosa					0.02						0.02
Bivalvia					0.04						0.04
Cephalopoda			**0.05**								**0.05**
Octopoda			0.05								0.05
Gastropoda	**0.27**	**0.02**	**0.48**	**0.20**	**0.17**	**0.06**	**0.04**	**0.02**	**0.04**		**1.30**
Caenogastropoda				0.11							0.11
Vermicularia knorrii				0.11							0.11
Littorinimorpha							0.04	0.02	0.01		0.06
Cypraea sp.							0.04	0.02			0.06
Cypraeidae									0.01		0.01
Neogastorpoda				0.03							0.03
Murex sp.				0.03							0.03
Umbraculida					0.04						0.04
Umbraculum sp.					0.04						0.04
Gastropoda	0.27	0.02	0.48	0.07	0.14	0.06			0.04		1.07
Calliostoma sp.				0.01							0.01
Gastropoda	0.27	0.02	0.48	0.05	0.14	0.06			0.04		1.05
Arthropoda	**0.27**	**0.17**	**0.45**	**1.27**	**1.72**	**3.25**	**0.59**	**0.27**	**0.05**	**0.11**	**8.16**
Malacostraca	**0.27**	**0.06**	**0.45**	**1.16**	**1.35**	**2.98**	**0.49**	**0.14**	**0.05**	**0.11**	**7.07**
Amphipoda				1.00	0.93	2.78	0.25	0.01			4.96
Corophiidea				1.00	0.93	2.78	0.25	0.01			4.96
Chelicerata								0.05			0.05
Pycnogonida								0.05			0.05
Decapoda	0.27	0.06	0.45	0.16	0.42	0.21	0.23	0.08	0.05	0.11	2.05
Brachyura					0.04						0.04
Cancer sp.			0.05								0.05
Chaceon fenneri			0.03						0.01		0.04
Decapoda				0.01	0.02		0.15	0.02		0.11	0.32
Eumunida sp.			0.19								0.19
Majidae				0.01	0.02	0.01					0.05
Paguroidea		0.04	0.19	0.05	0.33	0.17	0.01		0.04		0.82
Parthenope sp.				0.01							0.01
Rochinia sp.	0.27										0.27
Stenocionops sp.				0.01							0.01
Stenorhynchus seticornis		0.02		0.05	0.02	0.03	0.07	0.05			0.25
Maxillopoda		**0.11**				**0.08**					**0.19**
Maxillopoda		0.11				0.08					0.19
Cirripedia		0.11				0.08					0.19
Pycnogonida				**0.11**	**0.37**	**0.18**	**0.11**	**0.13**	**0.01**		**0.90**
Pantopoda				0.11	0.37	0.18	0.11	0.13	0.01		0.90
Anoplodactylus lentus				0.11	0.37	0.18	0.11	0.13	0.01		0.90
Bryozoa		**0.45**		**0.05**					**0.04**		**0.55**
Gymnolaemata		**0.03**		**0.05**							**0.09**
Cheilostomatida		0.03		0.05							0.09
Hippoporidra		0.02		0.05							0.08
Schizoporella sp.		0.01									0.01
Bryozoa		**0.42**							**0.04**		**0.46**

Density	Site									
Phylum/Class/Order/Scientific Name	11-152A	11-153A	11-154A	11-156A	11-156B	11-157A	11-158A	11-158B	11-160A	11-161A	Total
Echinodermata		**0.06**	**0.16**	**5.28**	**5.39**	**5.58**	**1.19**	**1.71**	**1.42**	**10.83**	**31.63**
Asteroidea		**0.01**		**0.22**	**0.44**	**0.22**	**0.48**	**1.31**	**0.02**		**2.70**
Forcipulatida				0.01			0.48	1.09	0.01		1.58
Coronaster briareus									0.01		0.01
Coscinasterias tenuispina				0.01			0.48	1.09			1.57
Valvatida				0.18	0.27	0.12		0.01			0.58
Goniasteridae				0.16	0.27	0.12		0.01			0.57
Narcissia trigonaria				0.01							0.01
Asteroidea		0.01		0.03	0.17	0.10		0.22	0.01		0.53
Asteroidea		0.01		0.01	0.17	0.10		0.18	0.01		0.49
Asteroidea- red spotted				0.01				0.03			0.05
Crinoidea						**0.01**			**0.04**	**0.22**	**0.28**
Comatulida						0.01			0.04	0.22	0.28
Echinoidea		**0.03**	**0.11**	**5.02**	**4.60**	**5.07**	**0.06**	**0.18**	**0.01**	**1.22**	**16.30**
Arbacioda				1.31	1.85	2.85	0.04	0.04			6.10
Arbacia punctulata				1.31	1.85	2.85	0.04	0.04			6.10
Arbacioida					0.02						0.02
Coelopleurus floridanus					0.02						0.02
Cidaroida		0.01	0.11	3.60	2.63	2.14	0.01	0.01		1.22	9.72
Cidaroida			0.11		0.14	0.12				1.22	1.58
Eucidaris tribuloides		0.01		3.60	2.49	2.01	0.01	0.01			8.14
Diadematoida				0.08	0.08	0.08	0.01	0.13			0.38
Centrostephanus longispinus				0.08	0.08	0.08	0.01	0.13			0.38
Echinoidea		0.02		0.03	0.02				0.01		0.07
Holothuroidea		**0.01**					**0.31**	**0.13**			**0.45**
Aspidochirotida							0.31	0.11			0.42
Holothuria lengtiginosa							0.31	0.10			0.40
Isostichopus badionotus							0.01	0.01			0.02
Dendrochirotida		0.01									0.01
Paracolochirus mysticus		0.01									0.01
Holothuroidea								0.02			0.02
Ophiuroidea		**0.01**	**0.05**	**0.04**	**0.35**	**0.28**	**0.34**	**0.09**	**1.35**	**9.39**	**11.90**
Euryalida				0.03	0.02	0.06	0.20	0.05			0.35
Asteroporpa annulata				0.03	0.02	0.06	0.20	0.05			0.35
Ophiurida					0.29	0.22	0.01		0.01		0.53
Ophioderma devaneyi					0.29	0.22					0.51
Ophioderma sp.									0.01		0.01
Ophiothrix sp.							0.01		0.01		0.02
Ophiuroidea		0.01	0.05	0.01	0.04		0.13	0.03	1.34	9.39	11.02
Chordata	**0.27**	**2.34**		**0.03**		**0.22**	**0.15**	**0.14**	**0.07**		**3.23**
Actinopterygii	**0.27**										**0.27**
Anguilliformes	0.27										0.27
Synaphobranchidae	0.27										0.27
Ascidiacea		**2.34**		**0.03**		**0.22**	**0.15**	**0.14**	**0.07**		**2.96**
Aplousobranchia		2.33				0.19	0.02	0.02			2.56
Didemnidae		0.01				0.14	0.02	0.02			0.19
Eudistoma sp.		0.01									0.01
Tridemnum sp.		2.31				0.06					2.36
Ascidiacea		0.01		0.03		0.03	0.13	0.12	0.07		0.40
Human debris		**0.02**		**0.01**	**0.02**	**0.03**	**0.04**	**0.08**			**0.20**
Human debris		**0.02**		**0.01**	**0.02**	**0.03**	**0.04**	**0.08**			**0.20**
Human debris		0.02		0.01	0.02	0.03	0.04	0.08			0.20
Human debris- anchor line		0.01									0.01
Human debris- cans/bottles				0.01				0.02			0.04
Human debris- fish line/gear					0.02	0.01	0.04				0.07
Human debris- net								0.04			0.04
Human debris- unid.		0.01				0.01	0.01	0.01			0.04
Cyanophyta		**0.01**					**0.51**	**0.27**			**0.79**
Chlorophyta		**0.01**									**0.01**
Rhodophyta		**0.37**				**0.36**		**0.11**			**0.84**
Florideophyceae						**0.01**					**0.01**
Rhodymeniales						0.01					0.01
Rhodymenia sp.						0.01					0.01
Rhodophyta		**0.37**				**0.35**		**0.11**			**0.83**
Rhodophyta		0.37				0.35		0.11			0.83
Corallinales or Peyssonneliaceae		0.22				0.35		0.07			0.63
Rhodophyta		0.15									0.15
Rhodophyta- flat oval								0.04			0.04
Total	**0.81**	**19.65**	**6.61**	**24.89**	**21.24**	**26.38**	**58.88**	**30.45**	**9.99**	**18.90**	**217.79**

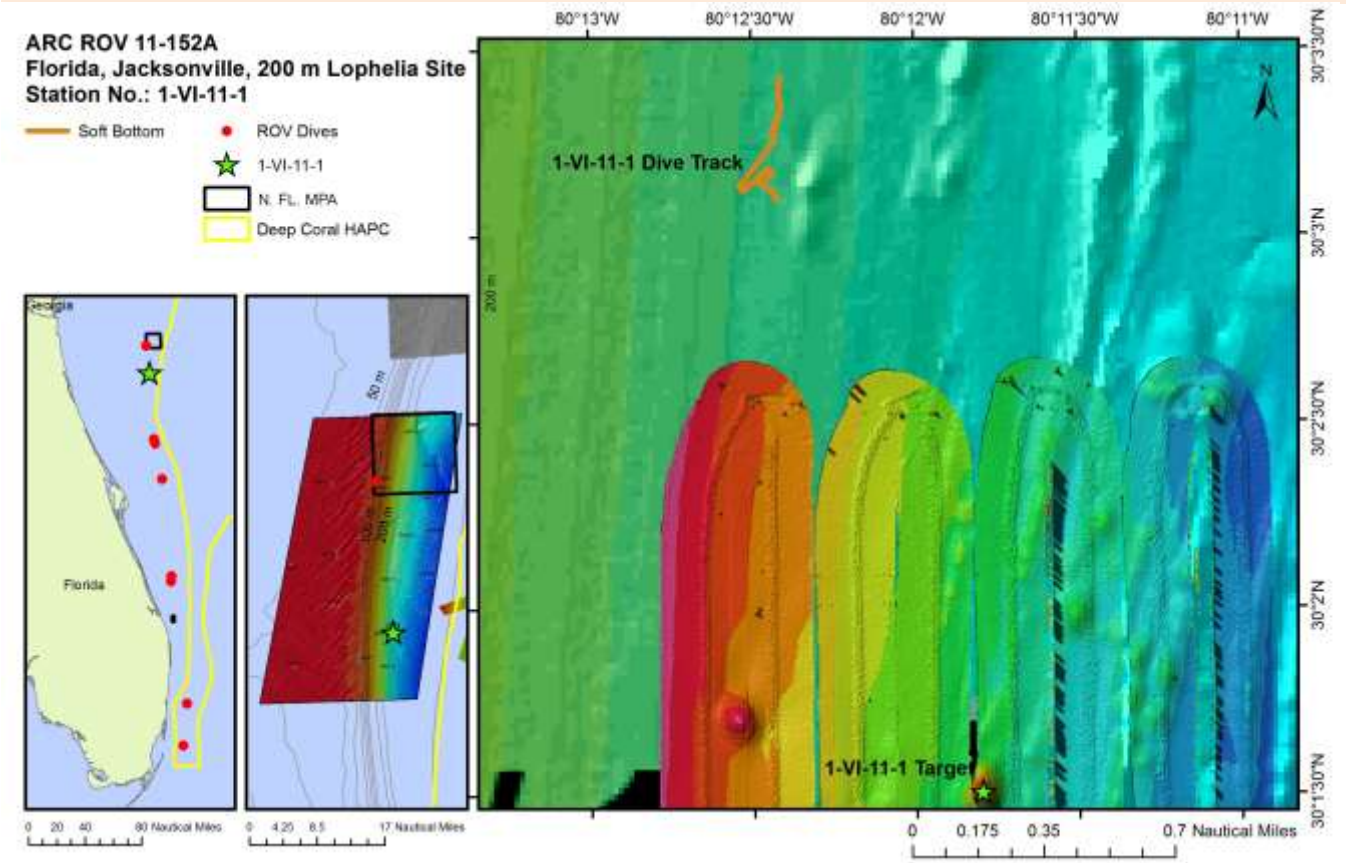
APPENDIX 2

SEADESC II REPORT- Habitat and Benthic Biota Characterizations

Provides the following data for each dive site: cruise and ROV dive metadata, figures showing each ROV dive track and habitat zone overlaid on multibeam sonar maps, dive track data (start and end latitude, longitude, depth), objectives, general description of the habitat and biota, and images of the biota and habitat that characterize the dive site. In addition, this SEADESC Level II Report provides quantitative analyses of each dive site including: 1) CPCE 4.0© Coral Point Count analysis of percent cover of benthic biota and substrate type, 2) densities of benthic macro-fauna (# organisms/m^2 for each species), and 3) densities of fish populations (# individuals/km for each species).

Dive Number: ARC ROV 11-152A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site

General Location and Dive Track:



Site Overview:

Project:	2011 Extreme Corals, NOAA DSCP
Principal Investator:	Andrew W. David
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408
Website:	http://coralreef.noaa.gov/deepseacorals
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington
Data Management:	Access Database, Excel Spreadsheet, WinFrog
ROV Navigation Data:	WinFrog
Ship Position System:	DGPS
Report Analyst:	John Reed, Stephanie Farrington

Dive Overview:

Vessel:	NOAA Ship *Pisces*
Sonar Data:	Jacksonville: 1C_dusk.tif
Purpose:	Map and characterize DSCE off SE USA
ROV:	NOAA SW Fisheries ARC ROV
Sensors Used:	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Date of Dive:	6/1/2011
Specimens:	0
Digital Photos:	2
DVD:	0
Hard Drive:	1
Date Compiled:	2/20/2013

Dive Number: ARC ROV 11-152A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site

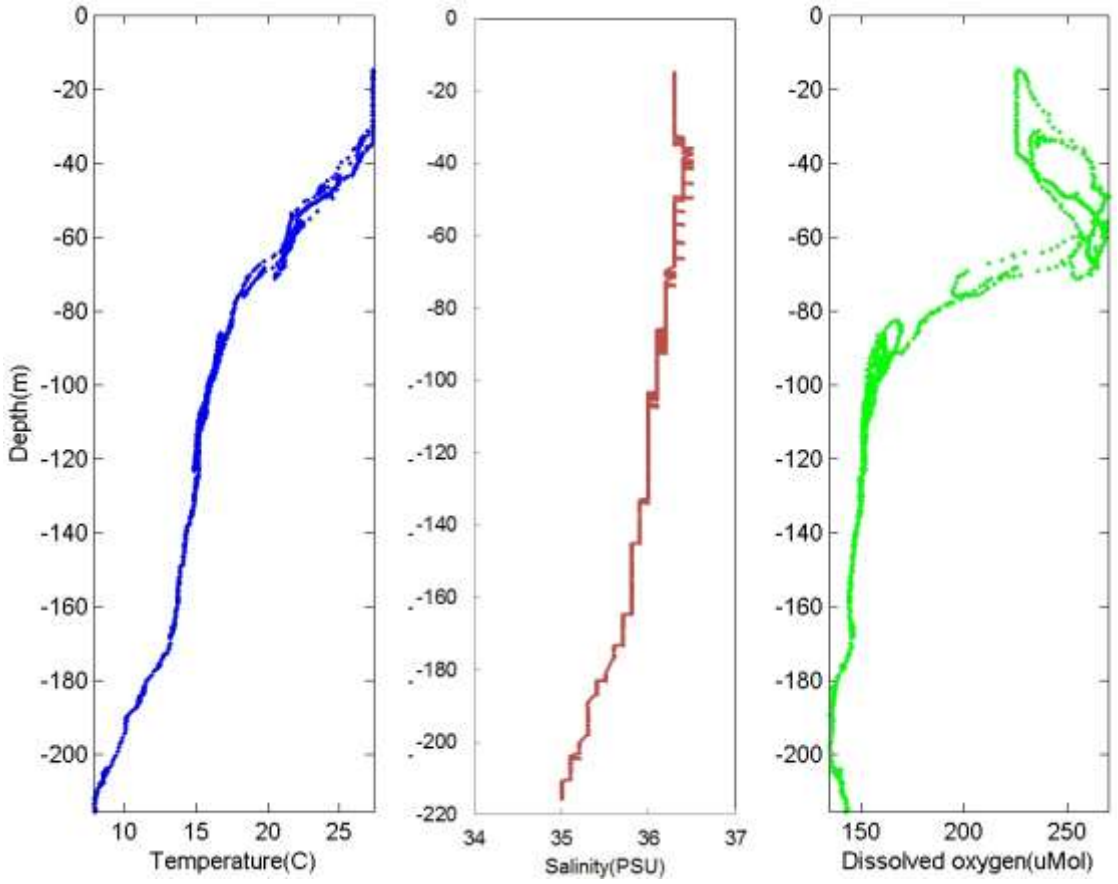
Dive Data:

Minimum Bottom Depth (m):	213	**Total Transect Length (km):**	0.745
Maximum Bottom Depth (m):	214	**Surface Current (kn):**	1.75
On Bottom (Time- GMT):	19:33	**On Bottom (Lat/Long):**	30°03.0960'N; 80°12.4200'W
Off Bottom (Time- GMT):	19:49	**Off Bottom (Lat/Long):**	30°03.4020'N; 80°12.4160'W

Physical (bottom); Temp (°C): 7.94 **Salinity:** 35.03 **Visibility (ft):** 30 **Current (kn):**

Physical Environment:

CTD Number 11-152A_CTDD



All CTD data were collected with the ARC ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (215.4 m): temperature- 7.9, salinity- 35, and dissolved oxygen- 142.7. Surface temperature was 27.6 and there was a slight thermocline near 40 m depth; salinity peaked between 35 and 40 m, dissolved oxygen peaked at 60 m. Visibility was estimated at 9-12 m from the ROV video.

Dive Number: ARC ROV 11-152A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site

Dive Imagery:

Figure 1: 30°3.2561'N, 80°12.4332'W 213.4 m
Muddy soft bottom west of the *Lophelia* coral mound. Strong currents prevented the ROV from landing on the targeted coral site. Dense bioturbation from benthic fauna (bivalves, worms, crustaceans, fish) form the pits and mounds (parallel red lasers- 20 cm top, 40 cm bottom).

Figure 2: 30°3.2653'N, 80°12.4375'W 213.7 m
Rochinia? sp. spider crab on soft mud bottom with 20-40 cm diameter pits and mounds formed by benthic fauna.

Dive Number: ARC ROV 11-152A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

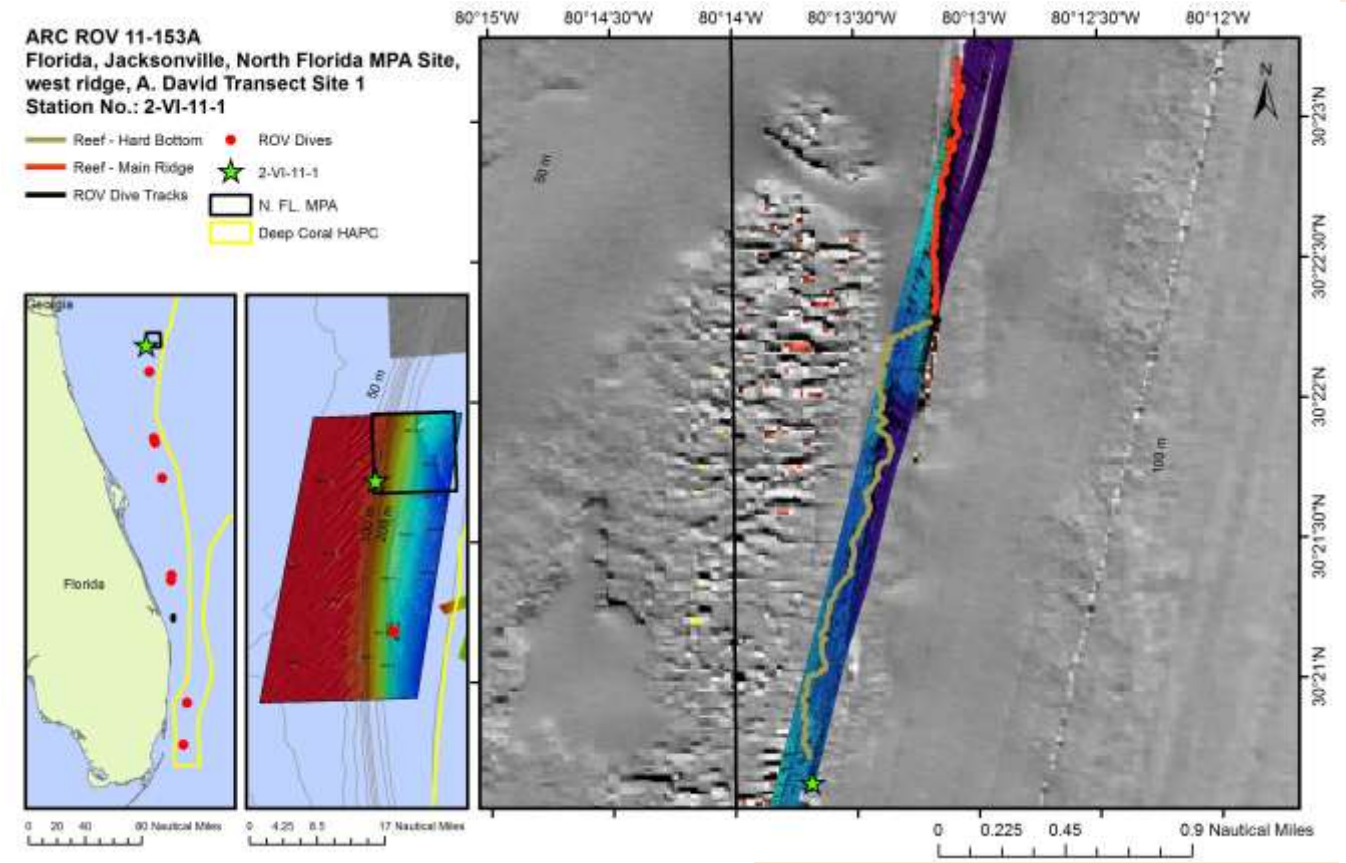
Objective: Survey *Lophelia* coral mound discovered last year on NOAA DSC cruise (Jason II-547, 11/18/2010) and ground truth *Pisces* sonar survey of site. Target site- *Lophelia* mound (from *Pisces* multibeam): 30° 1.506'N, 80° 11.8'N; 208-246 m.

Dive Events: Dive is terminated after 16 minutes on bottom due to loss of video and tracking. Umbilical cable twisted, breaking fiber optics. Drifted 1.5 nmi during 1-hour descent; difficulty station keeping, maneuvering ship and ROV in current (surface current 1.75 kn). ROV landed 1.5 nmi north of target site and 200 m west of another mound. Never reached the target site or hard bottom. Umbilical was replaced after the dive. [Note- Depth recorded on video and WinFrog displays are incorrect; add 10 m to readings; depths in this report are corrected. The *Arc* ROV's top parallel lasers are calibrated at 20cm, bottom lasers 40 cm.]

Site Description/Habitat/Fauna: Bottom is 100% soft sediment, flat with dense bioturbation, 10-20 cm mounds and pits; depth 213-214 m. Dominant species: Fish- *Laemonema* (codling), eels; Crustaceans- hermit crabs, *Cancer*, *Rochinia*, *Chaceon fenneri* (golden crab).

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

General Location and Dive Track:



Site Overview:

Project:	2011 Extreme Corals, NOAA DSCP
Principal Investator:	Andrew W. David
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408
Website:	http://coralreef.noaa.gov/deepseacorals
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington
Data Management:	Access Database, Excel Spreadsheet, WinFrog
ROV Navigation Data:	WinFrog
Ship Position System:	DGPS
Report Analyst:	John Reed, Stephanie Farrington

Dive Overview:

Vessel:	NOAA Ship *Pisces*
Sonar Data:	North Florida MPA: 2A_NFL_MPA_dusk.tif
Purpose:	Map and characterize DSCE off SE USA
ROV:	NOAA SW Fisheries ARC ROV
Sensors Used:	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Date of Dive:	6/2/2011
Specimens:	0
Digital Photos:	313
DVD:	6
Hard Drive:	2
Date Compiled:	2/20/2013

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

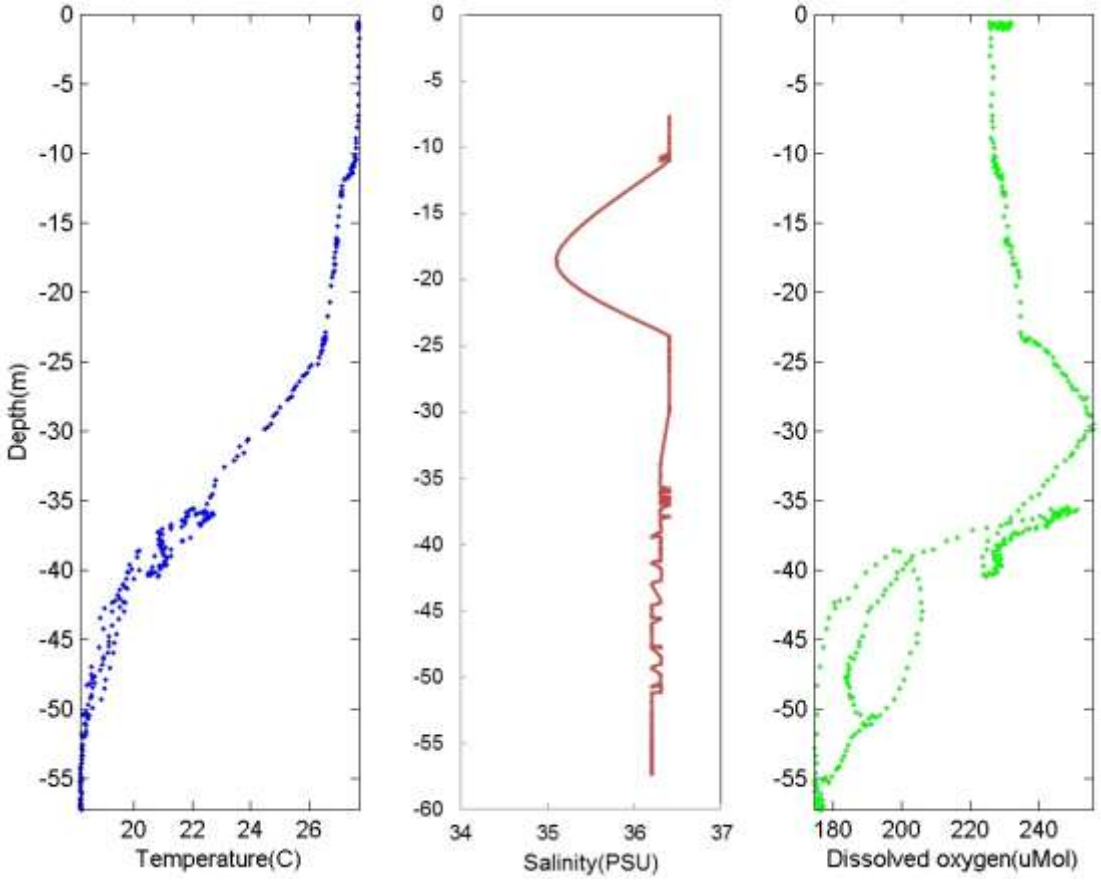
Dive Data:

Minimum Bottom Depth (m):	56	**Total Transect Length (km):**	6.187
Maximum Bottom Depth (m):	65	**Surface Current (kn):**	slight
On Bottom (Time- GMT):	18:46	**On Bottom (Lat/Long):**	30°20.6340'N; 80°13.6854'W
Off Bottom (Time- GMT):	23:57	**Off Bottom (Lat/Long):**	30°23.2320'N; 80°13.0800'W

Physical (bottom); Temp (°C): 19.54 **Salinity:** 36.29 **Visibility (ft):** 50 **Current (kn):**

Physical Environment:

CTD Number 11-153A_CTDU



All CTD data were collected with the ARC ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (57.3 m): temperature- 18.2, salinity- 36.2, and dissolved oxygen- 175.8. Surface temperature was 27.2 and there was a thermocline near 25-40 m depth; salinity had a large dip at 19 m, dissolved oxygen peaked at 30 m. Visibility was estimated at 15-18 m from the ROV video.

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

Dive Imagery:

Figure 1: 30°22.4225'N, 80°13.1684'W 58.9 m

High-relief rock ledges along main ridge of N. Florida MPA site provide habitat for a variety of sponges, corals, and fish. Black wire coral (*Stichopathes lutkeni*), polychaete worms (*Filograna* sp.- white coral like colonies), cake sponges (*Ircinia strobilina*), black coral (Antipathidae), encrusting sponges (Spirastrellidae, various unidentified Demospongiae), and coralline algae. Tomtate (*Haemulon aurolineatum*), moray eel (*Gymnothorax* sp.), vermilion snapper (*Rhomboplites aurorubens*), and reef butterflyfish (*Chaetodon sedentarius*).

Figure 2: 30°22.842'N, 80°13.118'W 57.7 m

Snowy grouper (*Epinephelus niveatus*) takes cover among the ledges of the main ridge at the N. Florida MPA site. Dense benthic fauna include sponges (*Clathria* sp.- red club; *Ircinia campana*- purple vase; *Ircinia* spp.- purple lobate; *Erylus* sp.- grey lobate; numerous unidentified Demospongiae; Spirastrellidae- red, orange encrusters), black wire coral (Stichopathes sp.), *Filograna* polychaetes, hydroids, and sea urchins (*Arbacia punctulata*).

Figure 3: 30°22.6369'N, 80°13.1581'W 56.8 m

Unfortunately the invasive lionfish (*Pterois volitans*) was a common sight on many of the dives. This was on the main ledge of the MPA site. Common biota included black wire coral (*Stichopathes* sp.), numerous demosponges, *Filograna* polychaete worms, hydroids, and gorgonians.

Figure 4: 30°21.7385'N, 80°13.4083'W 60.6 m

Large bushy black coral (*Tanacetipathes hirta*, 40 cm diameter), with sponges (*Clathriidae*?- yellow sphere; Dictyoceratida- spiny, brown; *Ircinia campana*- purple vase).

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey North Florida MPA site, west ridge (A. David transect Site 1). Target site: 30° 23.64'N, 80° 24.762'W, 56 m.

Dive Events: [Note- Depth recorded on video and WinFrog displays are incorrect; add 10 m to readings; depths in this report are corrected. The *Arc* ROV's top parallel lasers are calibrated at 20cm, bottom lasers 40 cm.]

Site Description/Habitat/Fauna: Used *Pisces* sonar data (Jacksonville survey). N-S oriented rock ridges comprised of rock slabs, pavement, 1-2 m boulders, and ledges; total relief up to 5 m (depth 57-63 m). Dense sessile faunal cover. Dominant species: Fish- scamp (common), snowy grouper, vermillion snapper, black seabass, red porgy, hogfish, bigeye, grey trigger, barracuda, damselfish, tattler, butterfly fish, Spanish hogfish, Creole fish, bank butterfly, blue angel, queen angel, drum, wrasse bass, tomtate, scorpion fish, chain moray, cowfish, jacks, lionfish (6 noted); Algae; Sponges- *Ircinia*, Axinellidae, Petrosidae, *Clathria*; Polychaete- Filograna; Cnidaria- *Madracis* (hard coral, several 15 cm diameter), Plexauridae, Ellisellidae, black hydroid, Antipatharia- *Tanacetipathes*, *Stichopathes*; Echinoderms- *Arbacia punctulata*; Bryozoa; Ascidiacea- Didemnidae.

Off ridge, in valleys or east of ridge- 100% soft bottom with areas of sand-shell hash, dense bioturbation; dense cover of Sabellidae polychaete tubes, Cerianthidea, Pennatulacea, Mollusca, Asteroidea, longhorn Bryozoa, some tilefish burrows (Malacanthidae).

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

Percent Cover of Benthic Macro-Biota and Substrate:

ARC ROV 11-153A surveyed the southwest corner of the North Florida MPA site. The S-N transect followed the main rock ridge that is apparent in the multibeam sonar map. The dive transects were divided into two habitat types: on the main ridge, and off-ridge hard bottom. Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. Site 11-153A was predominately hard-bottom substrate (53% cover), consisting primarily of rock pavement, 1-2 m boulders, rock slabs, and rock ledges. Benthic macro-biota covered 56.3% of the bottom and consisted of 9.7% Porifera (Demospongiae), 3.9% non-scleractinian coral (Gorgonacea, other Alcyonacea, and Antipatharia), and 42% other organisms (Fig. 2, Table 1; see Table 2 for complete species list). Hard coral was rare and only covered 0.01% of the bottom. The bare substrate (without biota) consisted of 22.8% sediment and 20.5% hard bottom. Figure 3 shows the percent cover of substrate type for each habitat region of the dive site. The main ridge region had the greatest cover of hard-bottom habitat compared to off ridge (47% and 37%, respectively). Soft bottom covered about 23% of the bottom at both habitats. Figure 4 compares the two habitats with cover of biota. The main ridge had 53% cover of biota which was dominated by Porifera (11.1%), non-scleractinian coral (5.1%), and 36.1% other organisms. The off-ridge hard-bottom habitat had greater cover of other organisms (51.9%) but fewer sponges and gorgonians.

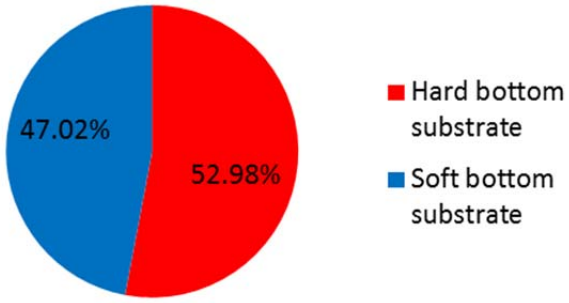


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-153A. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

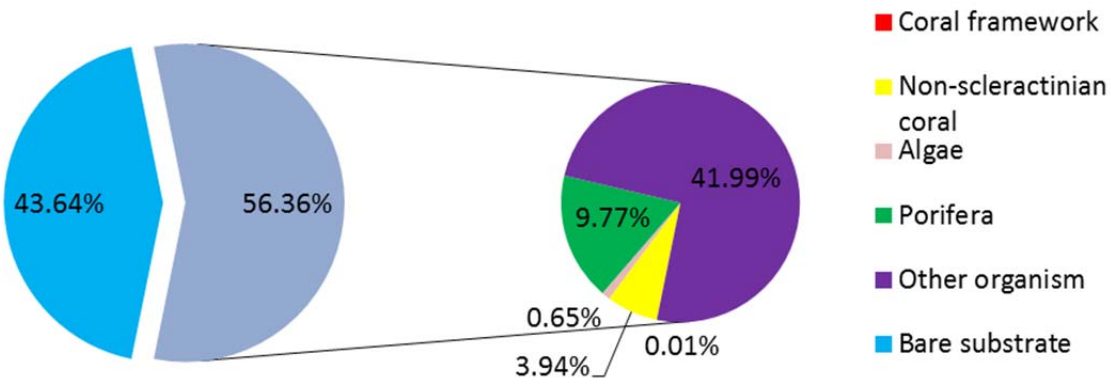


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-153A. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-153A.

Benthic macro-biota and substrate types	% Cover
Coral framework	**0.01%**
Scleractinia, unid	0.01%
Non-scleractinian coral	**3.94%**
Antipatharia	2.97%
Gorgonacea, Unid	0.97%
Porifera	**9.76%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	9.76%
Other organism	**41.97%**
Algae	**0.65%**
Algae- green, brown, red, or cyanobacteria	0.65%
Bare substrate	**43.61%**
Bare Soft Bottom substrate	22.86%
Blueline Tilefish Burrow	0.18%
Coral rubble	0.01%
Rock- pavement, boulder, ledge	13.79%
Rubble	6.78%
Human debris	**0.06%**
Human debris- Other	0.06%
Grand Total	**100.00%**

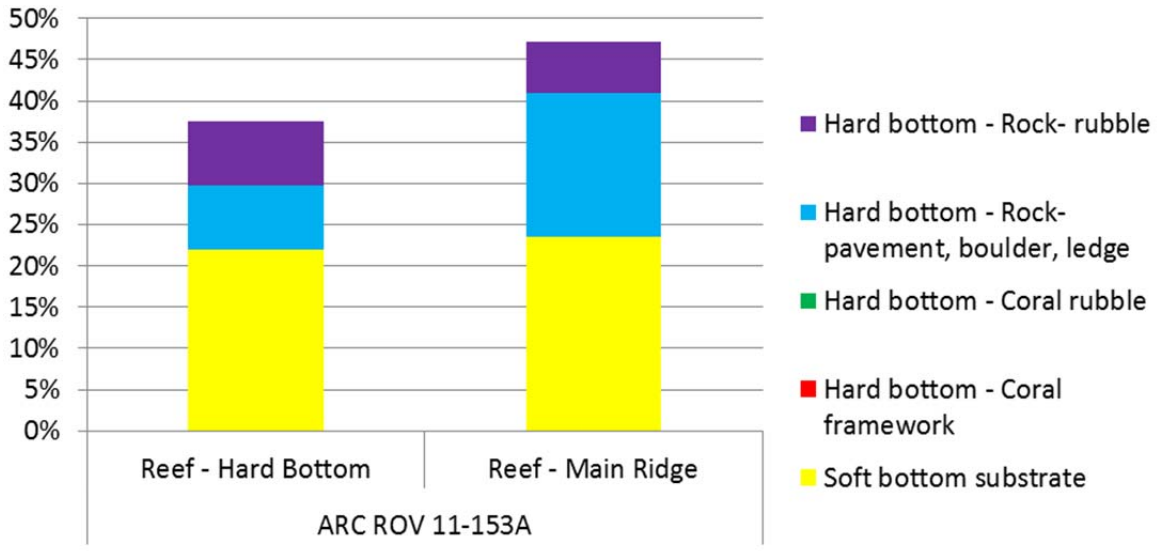


Figure 3. Percent cover of substrate types for each habitat zone at dive site 11-153A.

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

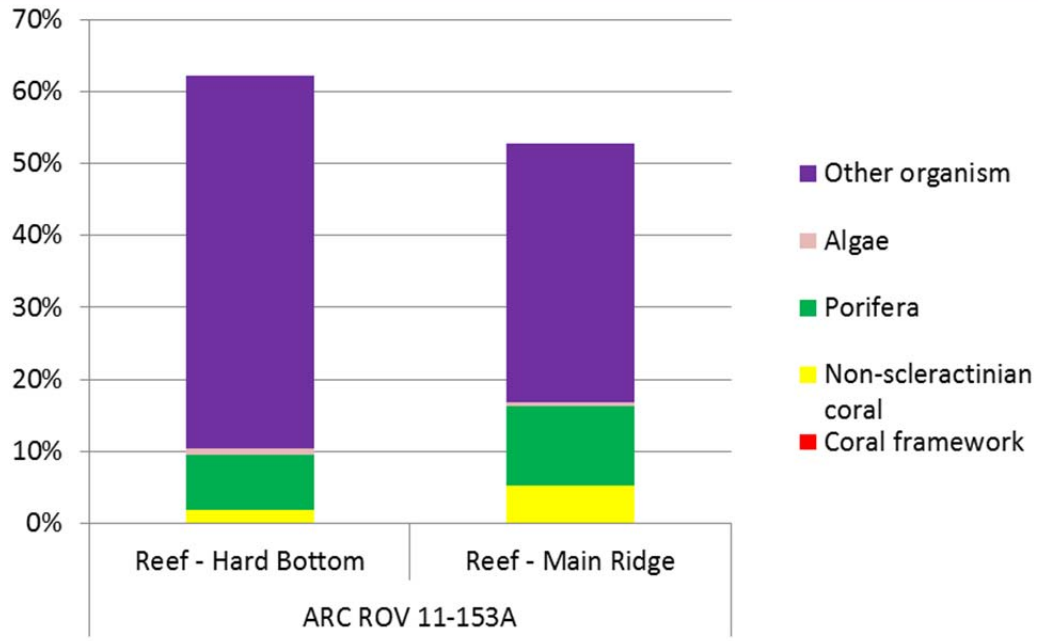


Figure 4. Percent cover of benthic macro-biota for each habitat zone at dive site 11-153A.

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge" or "unidentified Demospongiae", which could consist of numerous species. These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different Classes.

Dive site 11-153A had a total of 60 benthic macro-fauna taxa, consisting of 17 Porifera and 21 Cnidaria (Table 2). Overall density of all benthic macro-fauna was 19.6 organisms/m^2. Cnidaria contributed to 27.3% of the total density at this site, and Porifera 31.2% (5.3 and 6.1 colonies/m^2, respectively). Black coral was also common (12.4% of the density; 2.4 colonies/m^2) and gorgonians were 2.5% (0.5 colonies/m^2). Gorgonians included *Diodogorgia*, *Muricea*, *Nicella*, Plexauridae, and *Telesto* in densities of 0.01 to 0.3 colonies/m^2.

Table 2. Density of benthic macro-biota at site 11-153A (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**885**	**6.14**	**31.24%**
Demospongiae	**884**	**6.13**	**31.20%**
Dictyoceratida	62	0.43	2.19%
Dictyoceratida	7	0.05	0.25%
Ircinia campana	13	0.09	0.46%
Ircinia sp.	41	0.28	1.45%
Ircinia strobilina	1	0.01	0.04%
Hadromerida	391	2.71	13.80%

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

Cliona sp.	2	0.01	0.07%
Placospongia sp.	6	0.04	0.21%
Spirastrellidae	383	2.66	13.52%
Haplosclerida	5	0.03	0.18%
Haplosclerida	5	0.03	0.18%
Poecilosclerida	5	0.03	0.18%
Clathria sp.	3	0.02	0.11%
Poecilosclerida	2	0.01	0.07%
Spirophorida	1	0.01	0.04%
Cinachyra sp.	1	0.01	0.04%
Verongida	3	0.02	0.11%
Aplysina sp.	2	0.01	0.07%
Verongida	1	0.01	0.04%
Demospongiae	417	2.89	14.72%
Demospongiae	395	2.74	13.94%
Demospongiae- tan starlet thick encrusting	21	0.15	0.74%
Demospongiae- ye brain	1	0.01	0.04%
Homoscleromorpha	**1**	**0.01**	**0.04%**
Homosclerophorida	1	0.01	0.04%
Plakortis sp.	1	0.01	0.04%
Cnidaria	**775**	**5.37**	**27.36%**
Anthozoa	**463**	**3.21**	**16.34%**
Actiniaria	1	0.01	0.04%
Actiniaria	1	0.01	0.04%
Alcyonacea	72	0.50	2.54%
Diodogorgia sp.	44	0.31	1.55%
Ellisella barbadensis	1	0.01	0.04%
Ellisellidae	1	0.01	0.04%
Gorgonacea (accepted as Alcyonacea)	6	0.04	0.21%
Muricea sp.	7	0.05	0.25%
Nicella sp.	3	0.02	0.11%
Nidalia sp.	1	0.01	0.04%
Plexauridae	2	0.01	0.07%
Plexauridae- purple	4	0.03	0.14%
Telesto sp.	1	0.01	0.04%
Titanideum frauenfeldii	2	0.01	0.07%
Antipatharia	351	2.43	12.39%
Antipathidae	5	0.03	0.18%
Stichopathes sp.	318	2.21	11.22%
Tanacetipathes hirta	28	0.19	0.99%
Pennatulacea	10	0.07	0.35%
Virgularia sp.	10	0.07	0.35%
Scleractinia	24	0.17	0.85%

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

Madracis myriaster (=Madracis mirabilis)	3	0.02	0.11%
Scleractinia- unid cup	21	0.15	0.74%
Zoanthidea	5	0.03	0.18%
Zoanthidae	5	0.03	0.18%
Hydrozoa	**312**	**2.16**	**11.01%**
Anthoathecata	5	0.03	0.18%
Stylasteridae	5	0.03	0.18%
Hydrozoa	307	2.13	10.84%
Hydroidolina	307	2.13	10.84%
Annelida	**674**	**4.67**	**23.79%**
Polychaeta	**674**	**4.67**	**23.79%**
Sabellida	354	2.45	12.50%
Filograna sp.	232	1.61	8.19%
Sabellidae	106	0.74	3.74%
Serpulidae	1	0.01	0.04%
Spirobranchus giganteus	15	0.10	0.53%
Polychaeta	320	2.22	11.30%
Polychaeta	320	2.22	11.30%
Mollusca	**3**	**0.02**	**0.11%**
Gastropoda	**3**	**0.02**	**0.11%**
Arthropoda	**25**	**0.17**	**0.88%**
Malacostraca	**9**	**0.06**	**0.32%**
Decapoda	9	0.06	0.32%
Paguroidea	6	0.04	0.21%
Stenorhynchus seticornis	3	0.02	0.11%
Maxillopoda	**16**	**0.11**	**0.56%**
Maxillopoda	16	0.11	0.56%
Cirripedia	16	0.11	0.56%
Bryozoa	**65**	**0.45**	**2.29%**
Gymnolaemata	**5**	**0.03**	**0.18%**
Cheilostomatida	5	0.03	0.18%
Hippoporidra	3	0.02	0.11%
Schizoporella sp.	2	0.01	0.07%
Bryozoa	**60**	**0.42**	**2.12%**
Bryozoa	60	0.42	2.12%
Bryozoa	60	0.42	2.12%
Echinodermata	**9**	**0.06**	**0.32%**
Asteroidea	**1**	**0.01**	**0.04%**
Asteroidea	1	0.01	0.04%
Asteroidea	1	0.01	0.04%
Echinoidea	**5**	**0.03**	**0.18%**
Cidaroida	2	0.01	0.07%

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

Eucidaris tribuloides	2	0.01	0.07%
Echinoidea	3	0.02	0.11%
Echinoidea	3	0.02	0.11%
Holothuroidea	**1**	**0.01**	**0.04%**
Dendrochirotida	1	0.01	0.04%
Paracolochirus mysticus	1	0.01	0.04%
Ophiuroidea	**2**	**0.01**	**0.07%**
Chordata	**338**	**2.34**	**11.93%**
Ascidiacea	**338**	**2.34**	**11.93%**
Aplousobranchia	336	2.33	11.86%
Didemnidae	1	0.01	0.04%
Eudistoma sp.	2	0.01	0.07%
Tridemnum sp.	333	2.31	11.75%
Ascidiacea	2	0.01	0.07%
Ascidiacea	2	0.01	0.07%
Cyanophyta	**1**	**0.01**	**0.04%**
Cyanophyta	**1**	**0.01**	**0.04%**
Cyanophyta	1	0.01	0.04%
Cyanobacteria	1	0.01	0.04%
Chlorophyta	**1**	**0.01**	**0.04%**
Rhodophyta	**54**	**0.37**	**1.91%**
Rhodophyta	**54**	**0.37**	**1.91%**
Rhodophyta	54	0.37	1.91%
Corallinales or Peyssonneliaceae	32	0.22	1.13%
Rhodophyta	22	0.15	0.78%
Human debris	**3**	**0.02**	**0.11%**
Human debris	**3**	**0.02**	**0.11%**
Human debris	3	0.02	0.11%
Human debris- anchor line	2	0.01	0.07%
Human debris- unid.	1	0.01	0.04%
Grand Total	**2833**	**19.65**	**100.00%**

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

Figure 5 shows the densities of Porifera and coral for each of the habitats at dive site 11-153A. Coral is defined as hard coral (Stylasteridae and Scleractinia), Antipatharia, and Gorgonacea. The main ridge habitat had the greatest overall density (10 organisms/m^2) with 6.5 Porifera/m^2, 2.8 Antipatharia, and 0.5 Alcyonacea (primarily Gorgonacea). Overall density was slightly lower on hard-bottom habitat off the main ridge (~6 organisms/m^2), and was also dominated by Porifera (4.5 colonies/m^2).

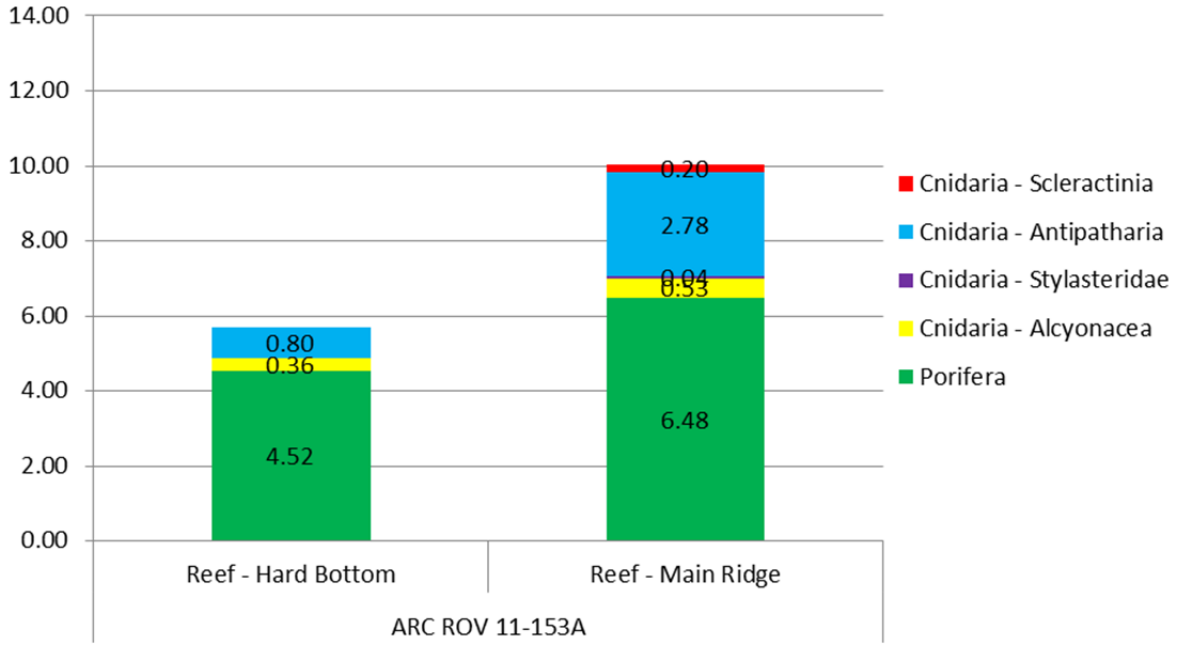


Figure 5. Density (number colonies/m^2) of Porifera, hard coral (Scleractinia and Stylasteridae), Antipatharia, and Alcyonacea (Gorgonacea) for each habitat zone of dive site 11-153A.

Fish Data Analysis:

Video transects were used to analyze the fish populations and densities. Protocol for the fish analyses was to divide the continuous video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. The field of view varied, but generally was 10-15 m. A total of 44 species of fish were identified from dive site 11-153A for a total density of 509 individuals/km (Table 3). These were dominated by vermilion snapper (185/km), tomtate (96), wrasse (55), and tattler (27). Managed species included red porgy (23/km), scamp (2.6), triggerfish (1.1), hogfish, almaco and greater amberjack, snowy grouper and snapper. In addition, 17 lionfish were counted on the dive (2.7/km).

Table 3. Density of fish for all transects at dive site 11-153A (number individuals/km).

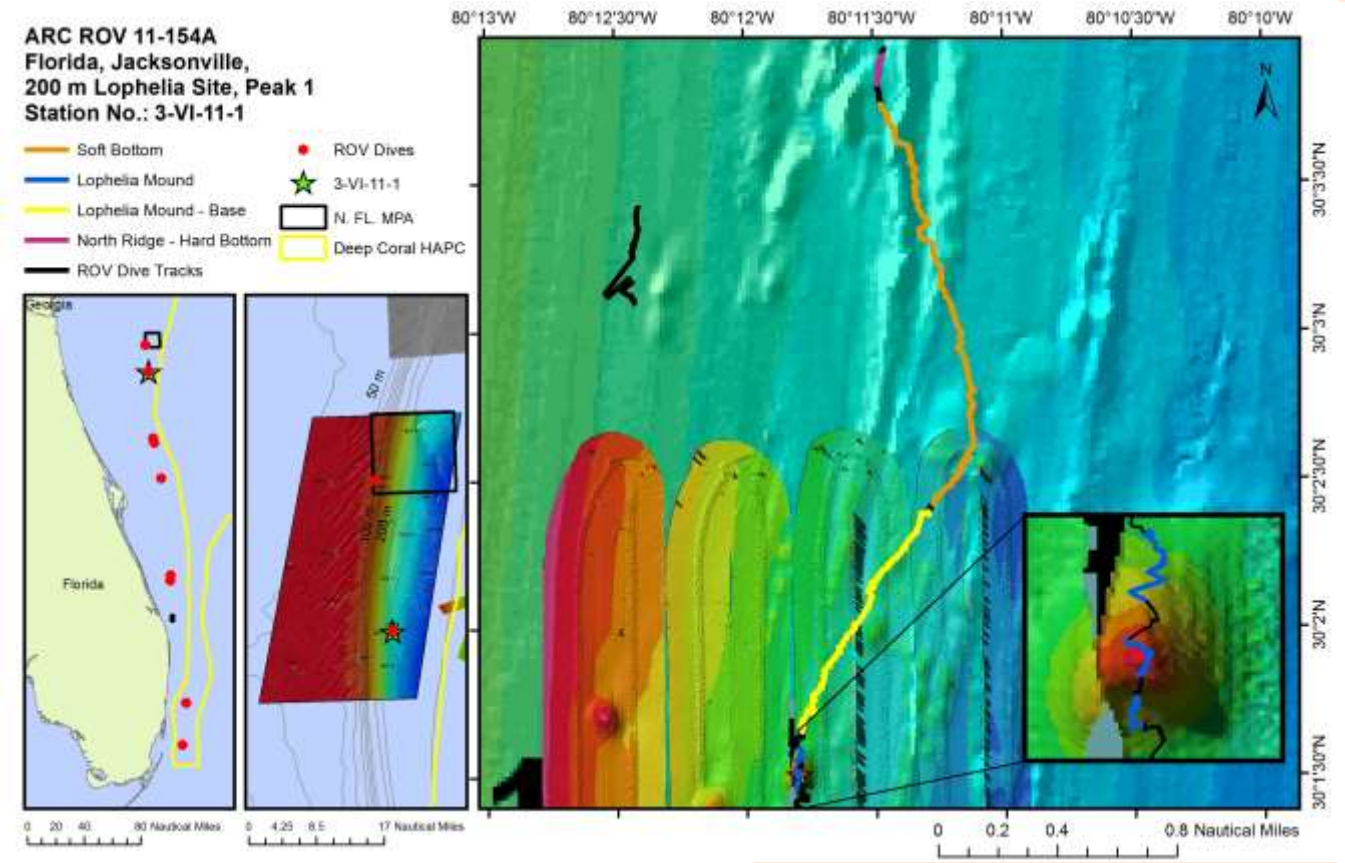
Common Name	Species Name	Density (#/km)
vermilion snapper	*Rhomboplites aurorubens*	185.7
tomtate	*Haemulon aurolineatum*	96.2
wrasse	*Halichoeres sp.*	55.8
tattler	*Serranus phoebe*	27.5
red porgy	*Pagrus pagrus*	23.9

Dive Number: ARC ROV 11-153A **Location:** USA, Florida, Jacksonville, North Florida MPA Site, west ridge, A. David Transect Site 1

yellowtail reeffish	*Chromis enchrysurus*	23.4
reef butterflyfish	*Chaetodon sedentarius*	18.3
bank sea bass	*Centropristis ocyurus*	17.8
blue angelfish	*Holacanthus bermudensis*	7.8
spotfin hogfish	*Bodianus pulchellus*	7.4
blackbar soldierfish	*Myripristis jacobus*	5.8
cubbyu	*Equetus umbrosus*	5.5
purple reeffish	*Chromis scotti*	5.2
sharpnose puffer	*Canthigaster rostrata*	3.1
squirrelfish	*Holocentrus adscensionis*	3.1
lionfish	*Pterois volitans*	2.7
scamp	*Mycteroperca phenax*	2.6
amberjack	*Seriola sp.*	1.8
bigeye	*Priacanthus arenatus*	1.8
short bigeye	*Pristigenys alta*	1.8
roughtonge bass	*Pronotogrammus martinicensis*	1.5
bank butterflyfish	*Prognathodes aya*	1.3
grey triggerfish	*Balistes capriscus*	1.1
squirrelfish	*Holocentrus sp.*	1.1
sunshinefish	*Chromis insolatus*	1.0
hogfish	*Lachnolaimus maximus*	0.8
spotfin butterflyfish	*Chaetodon oceallatus*	0.6
wrasse bass	*Liopropoma eukrines*	0.6
almaco jack	*Seriola rivoliana*	0.5
cardinalfish	*Apogon sp.*	0.5
greater amberjack	*Seriola dumerili*	0.5
snowy grouper	*Epinephelus niveatus*	0.5
trunkfish	*Lactophrys sp.*	0.5
orangeback bass	*Serranus annularis*	0.3
bandtail puffer	*Sphoeroides spengleri*	0.2
barracuda	*Sphyraena barracuda*	0.2
creole-fish	*Paranthias furcifer*	0.2
sand diver	*Synodus intermedius*	0.2
sand tilefish	*Malacanthus plumieri*	0.2
scorpionfish	*Scorpaenidae*	0.2
scrawled cowfish	*Lactophrys quadricornis*	0.2
snapper	*Lutjanus sp.*	0.2
soldierfish	*Holocentridae*	0.2
twospot cardinalfish	*Apogon pseudomaculatus*	0.2

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

General Location and Dive Track:



Site Overview:

Project:	2011 Extreme Corals, NOAA DSCP
Principal Investator:	Andrew W. David
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408
Website:	http://coralreef.noaa.gov/deepseacorals
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington
Data Management:	Access Database, Excel Spreadsheet, WinFrog
ROV Navigation Data:	WinFrog
Ship Position System:	DGPS
Report Analyst:	John Reed, Stephanie Farrington

Dive Overview:

Vessel:	NOAA Ship *Pisces*
Sonar Data:	Jacksonville: 1Ca_dusk.tif
Purpose:	Map and characterize DSCE off SE USA
ROV:	NOAA SW Fisheries ARC ROV
Sensors Used:	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Date of Dive:	6/3/2011
Specimens:	0
Digital Photos:	564
DVD:	8
Hard Drive:	1
Date Compiled:	2/20/2013

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

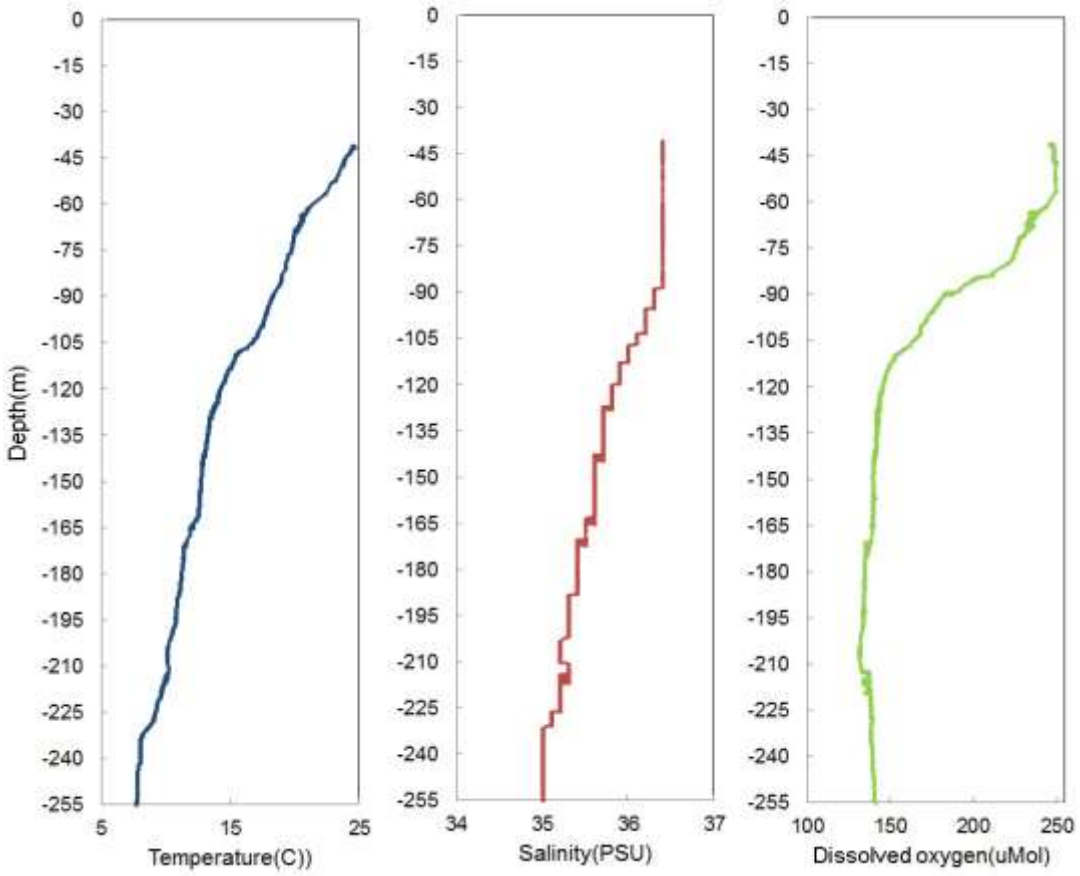
Dive Data:

Minimum Bottom Depth (m):	208	**Total Transect Length (km):**	6.195
Maximum Bottom Depth (m):	310	**Surface Current (kn):**	.5 - 1 kt
On Bottom (Time- GMT):	17:43	**On Bottom (Lat/Long):**	30°01.3740'N; 80°11.8002'W
Off Bottom (Time- GMT):	22:00	**Off Bottom (Lat/Long):**	30°03.9366'N; 80°11.4636'W

Physical (bottom); Temp (°C): 7.61 **Salinity:** 34.99 **Visibility (ft):** 50 **Current (kn):**

Physical Environment:

CTD Number 11-154A_CTDD



All CTD data were collected with the ARC ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (255.9 m): temperature- 7.7, salinity- 35, and dissolved oxygen- 141. The CTD did not start recording until 41 m. Temperature was 20.24 at that depth and there was no distinct thermocline below that depth; salinity peaked between 45 and 90 m, dissolved oxygen peaked at 45 m. Visibility was estimated at 15-18 m from the ROV video.

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

Dive Imagery:

Figure 1: 30°1.4737'N, 80°11.8101'W 228.2 m
South slope of Lophelia coral mound, shallowest known in western Atlantic waters (200 m depth). *Lophelia pertusa* coral (white- live, and rubble), squat crab (*Eumunida picta*), anemones (Sagartiidae), and cidaroid urchins. (Bottom red lasers = 40 cm).

Figure 2: 30°1.7429'N, 80°11.7505'W 244.8 m
Scattered phosphoritic rocks and soft bottom occur to the north of the coral mound. Gorgonacea (*Plumeralla* sp., Primnoidae) with three cutthroat eels (Synaphobranchidae), solitary cup Scleractinia, various small sponges (Demospongiae, Hexactinellida). (Bottom lasers = 40 cm; station keeping with the ROV on this dive was very difficult in the current; as a result, the video and digital still images were very poor quality).

Figure 3: 30°3.292'N, 80°11.2742'W 249.1 m
Swallowtail bass (*Anthias woodsi*) and blackbelly rosefish (*Helicolenus dactylopterus*) on scattered rock habitat north of the coral mound. Rocks encrusted with primnoid gorgonacea (*Plumerella* sp.), sabellid worm tubes, cup corals, and hydroids.

Figure 4: 30°3.6086'N, 80°11.3631'W 246.3 m
Golden crab (*Chaceon fenneri*) were observed on both soft and hard bottom habitats during the dive.

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey apparent *Lophelia* coral mound discovered last year on NOAA DSC cruise (Jason II-547, 11/18/2010) and ground truth *Pisces* sonar survey of site. Target site- *Lophelia* mound (from *Pisces* multibeam): 30° 1.506'N, 80° 11.8'N; 208-246 m.

Dive Events: Surface current 2-3 kn; unable to station keep ROV due to current; so continued transect northerly over the target reef and then northeast, skirting several mounds; then north across apparent ledges. [Note- Depth recorded on video and WinFrog displays are now correct. The *Arc* ROV's top parallel lasers are calibrated at 20cm, bottom lasers 40 cm. The fiber optic cable to the ROV became twisted and broke again. The *Arc* ROV was taken out of service after this dive.]

Site Description/Habitat/Fauna: *Pisces* shipboard multibeam shows three high-relief mounds, shaped like typical *Lophelia* bioherms; conical, ~250 m diameter (color sonar, Fig. 1). Several smaller mounds and ledges are evident along the eastern survey area. ROV transect crossed the target *Lophelia* coral mound from S to N: south base- 246 m, peak- 208 m, north base- 244 m; maximum relief- 37 m; diameter at base ~250 m. South face (10-30o slope), with nearly 70-100% cover coral rubble and scattered 10-40 cm diameter (up to 1 m) live *Lophelia pertusa* colonies. Peak with 100% coral rubble cover, and scattered 10-30 cm live *Lophelia*. North slope 100% coral rubble and mud with sparse standing dead coral. North of mound, relatively flat mud with coral rubble. Dominant fauna in coral habitat: Fish- black belly rosefish, *Laemonema* (codling), anthiids; Sponges- Hexactinellida; Cnidaria- *Lophelia pertusa*, Plexauridae, Primnoidae; Echinodermata- *Centrostephanus*; Crustacea- *Eumunida*, *Rochinia*, *Cancer*, *Chaceon fenneri* (golden crab).

Skirted the western bases of three other mounds to the NE within the *Pisces* multibeam; these are coral rubble with sparse live and dead standing *Lophelia*. ROV transect continued along double ridge apparent in the Navy side-scan (black and white, Fig. 1); however, the ridges are not apparent in the ROV video; mostly soft sediment with 20-40% cover coral and rock rubble, small boulders to 20 cm; depth 239-242 m.

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

Percent Cover of Benthic Macro-Biota and Substrate:

ARC ROV 11-154A surveyed a *Lophelia* coral mound and hard-bottom rock habitat to the north of it. With a surface current of 2-3 knots, the ROV and ship were unable to station keep, resulting in a poor survey of the site. We basically had one quick transect over the mound, then northerly, skirting several other mounds, and then some hard-bottom ledges. The photo transects were divided into 3 hard-bottom habitats: *Lophelia* coral mound, base of the mound (hard bottom immediately north of the mound), and north ridge (hard-bottom habitat consisting of rock ledges ~2 nmi north of the *Lophelia* mound). Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate for the entire dive; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. The dive had 27.2% cover of hard bottom which consisted of standing live *Lophelia pertusa* coral, coral rubble, rock pavement, small boulders and ledges. Benthic macro-biota covered 8.3% of the bottom and consisted of coral framework (0.4% cover), non-scleractinian corals (1.5%), and other organisms (6.3%) (Fig. 2, Table 1; see Table 2 for complete species list). The bottom was predominately bare (67.2% bare soft substrate, and 24.4% bare hard bottom). Figure 3 shows the percent cover substrate type for each habitat region of the dive site; the *Lophelia* coral mound was predominately coral rubble (67.3% cover) and standing coral framework (3.3%). The north base of the mound had 18.7% cover of coral rubble but no live coral. The *Lophelia* coral mound had 8.6% cover of biota, including 3.3% coral framework, 0.96% non-scleractinian corals, and 4.3% other organisms (Fig. 4). The north ridge had no framework coral, but more non-scleractinian coral (2.1%) and other organisms (10.2%). Overall sponges were uncommon with <0.1% cover.

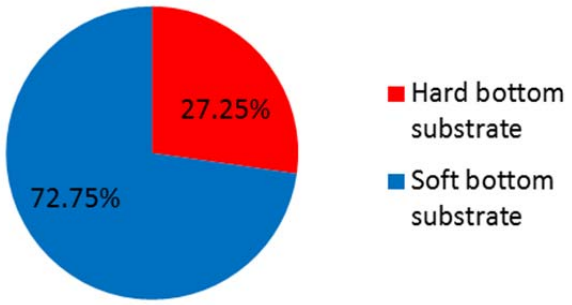


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-154A. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

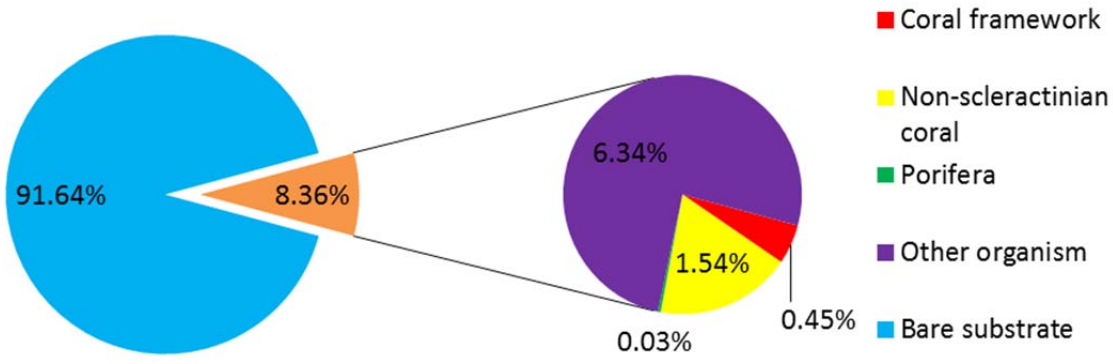


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-154A. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-154A.

Benthic macro-biota and substrate types	% Cover
Coral framework	**0.45%**
Lophelia pertusa	0.45%
Non-scleractinian coral	**1.54%**
Gorgonacea, Unid	1.54%
Porifera	**0.03%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	0.03%
Other organism	**6.34%**
Bare substrate	**91.64%**
Bare Soft Bottom substrate	67.21%
Coral rubble	16.39%
Rock- pavement, boulder, ledge	6.66%
Rubble	1.38%
Grand Total	**100.00%**

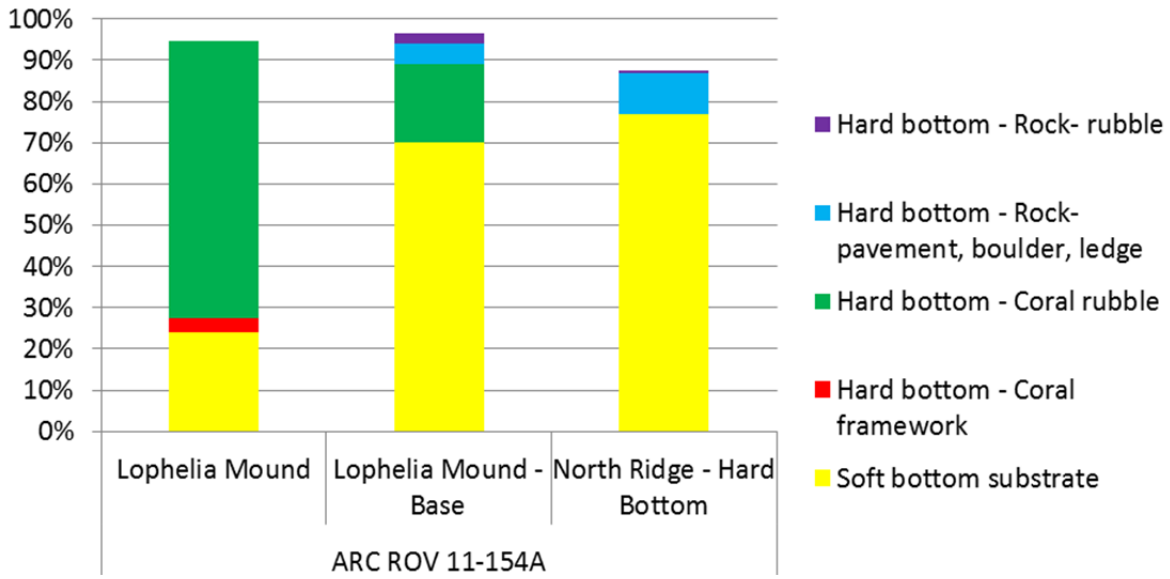


Figure 3. Percent cover of substrate types for each habitat zone at dive site 11-154A.

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

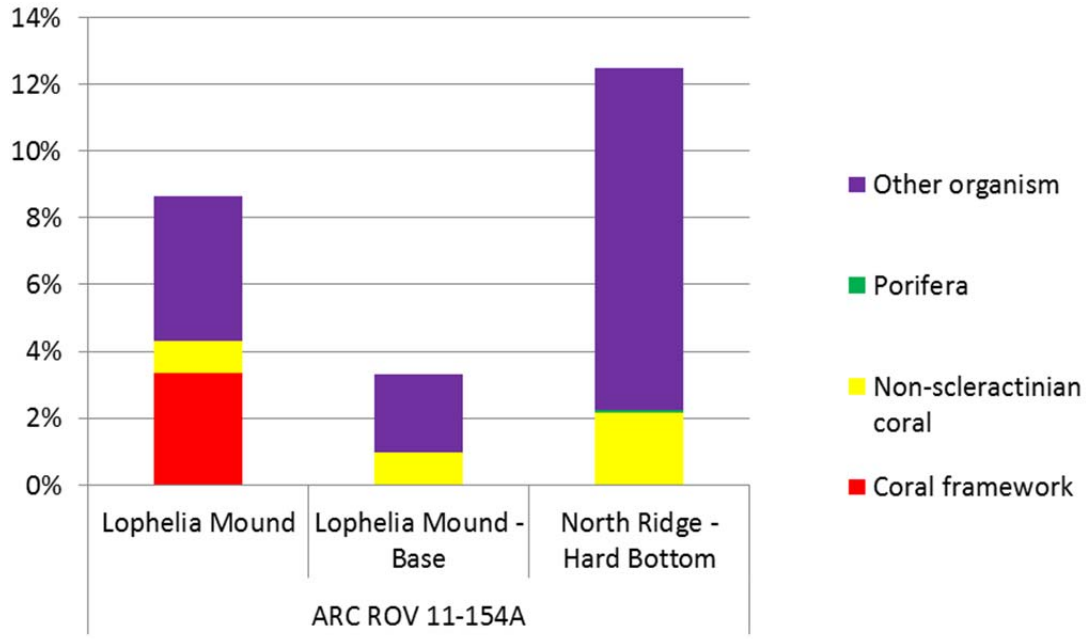


Figure 4. Percent cover of benthic macro-biota for each habitat zone at dive site 11-154A.

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge" or "unidentified Demospongiae", which could consist of numerous species. These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different classes.

Dive site 11-154A had a total of 21 benthic macro-fauna taxa, consisting of 12 Cnidaria and 1 Porifera (Table 2). Overall density of all benthic macro-fauna was 6.6 organisms/m^2. Cnidaria contributed to 74.3% of the total density at this site, and Porifera 2.0%. Cnidaria dominated with densities of 4.9 organisms/m^2; including 0.4 colonies of *Lophelia*/m^2 and 1.6 Gorgonacea, primarily Primnoidae (*Plumeralla* sp.).

Table 2. Density of benthic macro-biota at site 11-154A (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**5**	**0.13**	**2.01%**
Demospongiae	**5**	**0.13**	**2.01%**
Cnidaria	**185**	**4.91**	**74.30%**
Anthozoa	**181**	**4.80**	**72.69%**
Actiniaria	66	1.75	26.51%
Actiniaria	41	1.09	16.47%
Sagartiidae	25	0.66	10.04%
Alcyonacea	61	1.62	24.50%

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

Ellisellidae	4	0.11	1.61%
Gorgonacea (accepted as Alcyonacea)	2	0.05	0.80%
Primnoidae	55	1.46	22.09%
Antipatharia	1	0.03	0.40%
Antipathidae	1	0.03	0.40%
Ceriantharia	1	0.03	0.40%
Cerianthidae	1	0.03	0.40%
Corallimorpharia	4	0.11	1.61%
Corallimorpharia	4	0.11	1.61%
Scleractinia	47	1.25	18.88%
Lophelia pertusa	16	0.42	6.43%
Scleractinia- unid cup	31	0.82	12.45%
Zoanthidea	1	0.03	0.40%
Zoanthidae	1	0.03	0.40%
Hydrozoa	**4**	**0.11**	**1.61%**
Hydrozoa	4	0.11	1.61%
Hydroidolina	4	0.11	1.61%
Annelida	**16**	**0.42**	**6.43%**
Polychaeta	**16**	**0.42**	**6.43%**
Mollusca	**20**	**0.53**	**8.03%**
Cephalopoda	**2**	**0.05**	**0.80%**
Octopoda	2	0.05	0.80%
Octopoda	2	0.05	0.80%
Gastropoda	**18**	**0.48**	**7.23%**
Arthropoda	**17**	**0.45**	**6.83%**
Malacostraca	**17**	**0.45**	**6.83%**
Decapoda	17	0.45	6.83%
Cancer sp.	2	0.05	0.80%
Chaceon fenneri	1	0.03	0.40%
Eumunida sp.	7	0.19	2.81%
Paguroidea	7	0.19	2.81%
Echinodermata	**6**	**0.16**	**2.41%**
Echinoidea	**4**	**0.11**	**1.61%**
Cidaroida	4	0.11	1.61%
Ophiuroidea	**2**	**0.05**	**0.80%**
Grand Total	**249**	**6.61**	**100.00%**

Dive Number: ARC ROV 11-154A **Location:** USA, Florida, Jacksonville, 200 m Lophelia Site, Peak 1

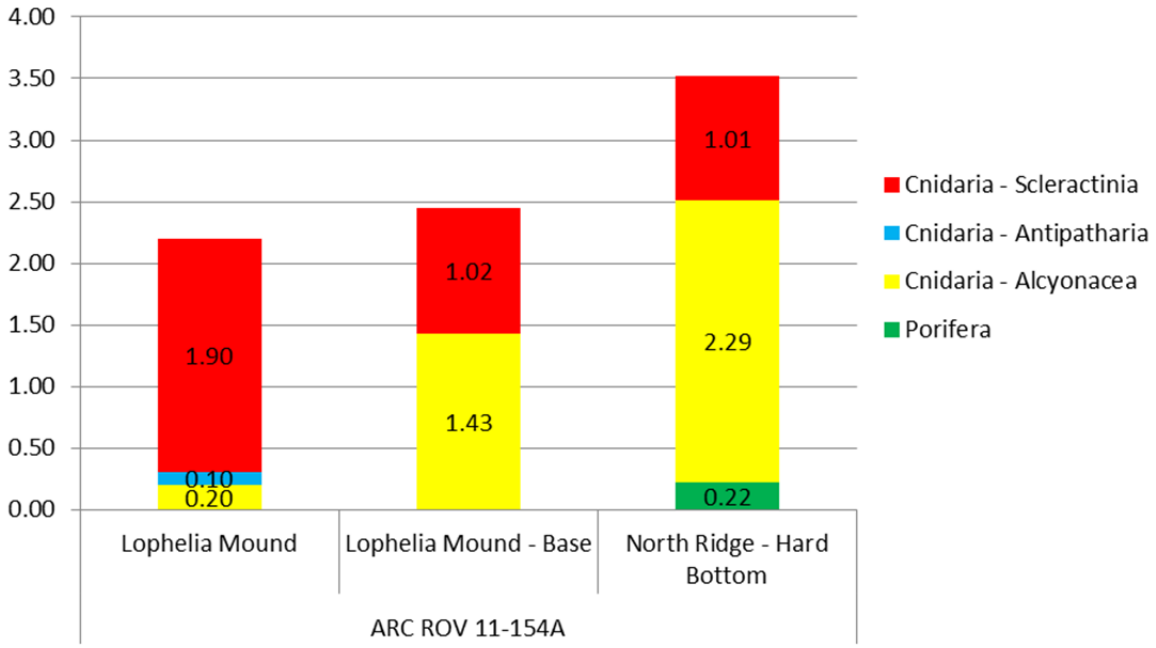


Figure 5. Density (number colonies/m^2) of Porifera, hard coral (Stylasteridae, Scleractinia), Antipatharia, and Alcyonacea (Gorgonacea) for each habitat zone of dive site 11-154A.

Figure 5 shows the density of coral for each of the habitat zones at dive site 11-154A. Coral is defined as hard coral (Stylasteridae and Scleractinia), Antipatharia, and Gorgonacea. The *Lophelia* mound had an overall coral density of 2.2 colonies/m^2, which included 1.9 Scleractinia. The hard-bottom rock ridge had greater overall density of 3.5 organisms/m^2; the density of Gorgonacea was greater (2.3 colonies/m^2) than at the other habitats, and the Scleractinia were all cup corals.

Fish Data Analysis:

Video transects were used to analyze the fish populations and densities. Protocol for the fish analyses was to divide the continuous video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. The average field of view was about 10-15 m. A total of 10 taxa of fish were identified from dive site 11-154A for a total density of 62 individuals/km (Table 3). These were dominated by *Laemonema* spp. (41 individuals/km), black belly rosefish (15), and anthiids (2.4).

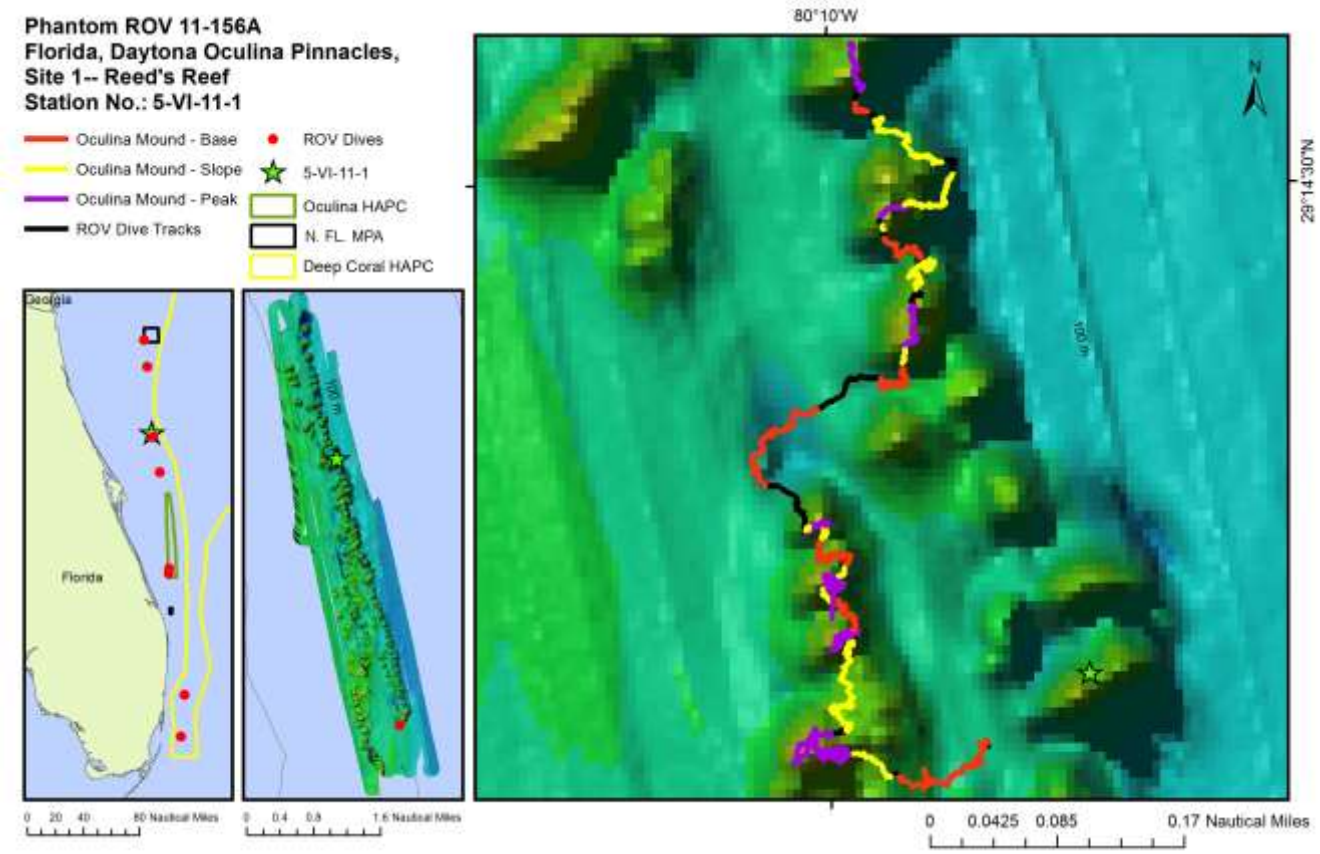
Table 3. Density of fish for all transects at dive site 11-154A (number individuals/km).

Common Name	Species Name	Density (#/km)
mora	*Laemonema sp.*	33.3
blackbelly rosefish	*Helicolenus dactylopterus*	15.8
shortbeard codling	*Laemonema barbatulum*	8.1
anthiids	Anthiinae	1.6
hake	Gadiformes	1.3
deepwater flounder	*Monolene sessilicauda*	0.5

swallowtail bass	*Anthias woodsi*	0.5
spotted hake	*Urophycis regius*	0.3
anthiids	*Anthias sp.*	0.2
chain catshark	*Scyliorhinus retifer*	0.2

Dive Number:	Phantom ROV 11-156A	**Location:**	USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

General Location and Dive Track:



Site Overview:

Project:	2011 Extreme Corals, NOAA DSCP
Principal Investator:	Andrew W. David
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408
Website:	http://coralreef.noaa.gov/deepseacorals
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington
Data Management:	Access Database, Excel Spreadsheet, WinFrog
ROV Navigation Data:	WinFrog
Ship Position System:	DGPS
Report Analyst:	John Reed, Stephanie Farrington

Dive Overview:

Vessel:	NOAA Ship *Pisces*
Sonar Data:	Daytona Oculina Pinnacles: 3_Daytona8.tif
Purpose:	Map and characterize DSCE off SE USA
ROV:	NOAA SW Fisheries Super Phantom ROV
Sensors Used:	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Date of Dive:	6/5/2011
Specimens:	3
Digital Photos:	574
DVD:	5
Hard Drive:	2
Date Compiled:	2/20/2013

Dive Number:	Phantom ROV 11-156A	**Location:**	USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

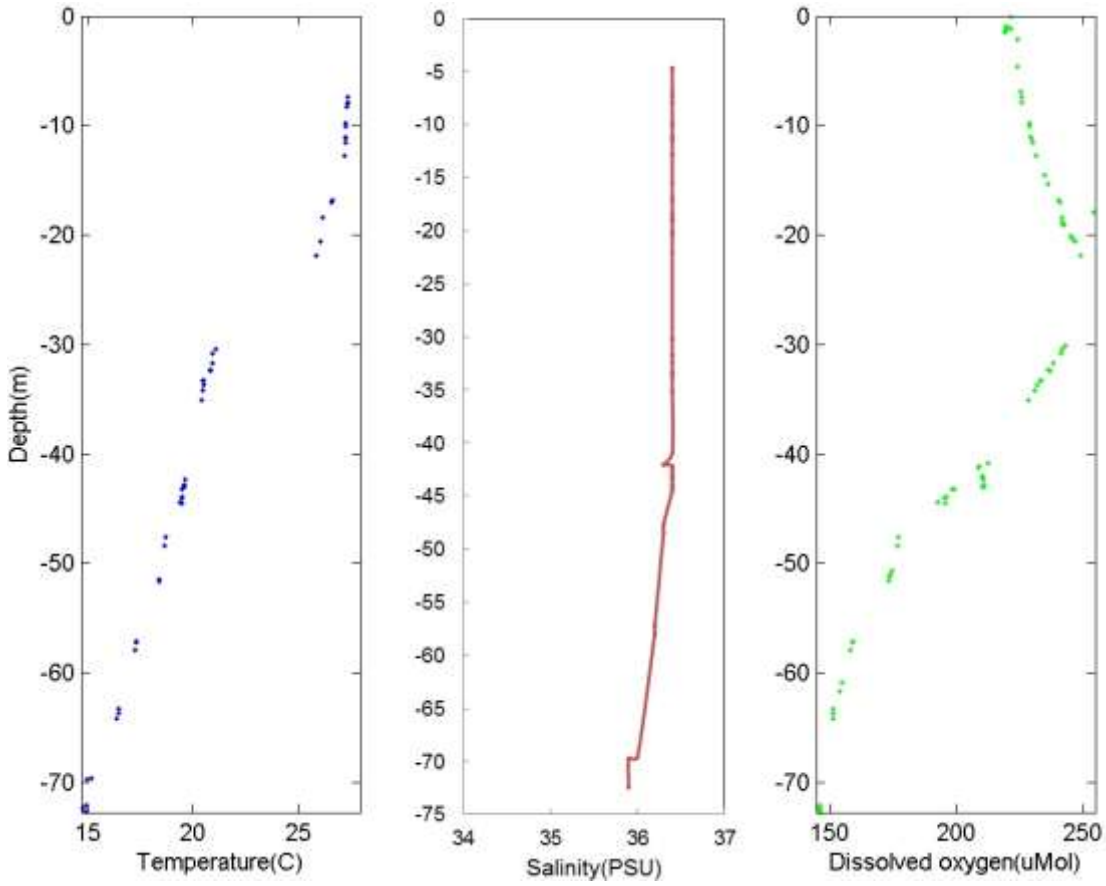
Dive Data:

Minimum Bottom Depth (m):	70	**Total Transect Length (km):**	2.524
Maximum Bottom Depth (m):	90	**Surface Current (kn):**	0
On Bottom (Time- GMT):	13:34	**On Bottom (Lat/Long):**	29°14.1116'N; 80°09.8650'W
Off Bottom (Time- GMT):	17:53	**Off Bottom (Lat/Long):**	29°14.5875'N; 80°09.9818'W

Physical (bottom); Temp (°C): 14.10 **Salinity:** 35.80 **Visibility (ft):** 60 **Current (kn):** 0

Physical Environment:

CTD Number 11-156A_CTDU



All CTD data were collected with the Super Phantom ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (-72.7 m): temperature- 14.9, salinity- 35.9 (taken at 69.7 m), and dissolved oxygen- 146. Surface temperature was 26.7 and there was a thermocline near 20-30 m depth; salinity peaked between 5 and 40 m, dissolved oxygen peaked at 22-30 m. Visibility was estimated at 18-21 m from the ROV video.

Dive Number: Phantom ROV 11-156A **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

Dive Imagery:

Figure 1: 29°14.23'N, 80°9.9951'W 71.4 m

Seven deepwater *Oculina* coral mounds (20-35 m relief) were crossed during this ROV dive. The slopes of the mounds are mostly coral rubble and standing dead coral framework which still provides habitat for many benthic species. Corals (*Telesto* sp.- purple gorgonian, *Epizoanthus* sp.- white zoanthids, *Callipodium rubens*- pink Alcyonacea), sponges (Poecilosclerida- orange lobate, Spirastrellidae- orange encrusting), sea urchins (*Eucidaris tribuloides*). Bank butterflyfish (*Prognathodes aya*) and yellowtail reeffish (*Chromis enchrysurus*).

Figure 2: 29°14.5833'N, 80°9.9801'W 77.1 m

Small live *Oculina varicosa* colonies are scattered over the coral rubble bottom on these 20-35 m tall coral mounds which are thousands of years old. These individual coral colonies are new growth, less than 10-20 years old, and only grow about 10 mm or less a year. The coral provides habitat for hundreds of species of small invertebrates and in turn for juvenile fish and breeding populations of grouper.

Figure 3: 29°14.3688'N, 80°9.9606'W 85.4 m

Scamp (*Mycteroperca phenax*) takes shelter in ledges of the deepwater Oculina coral reef. Corals (Ivory tree coral- *Oculina varicosa*, solitary cup Scleractinia), anemones (*Corallimorphus* sp.), various encrusting sponges, serpulid worms and hydroids.

Figure 4: 29°14.3654'N, 80°9.9467'W 78.1 m

Snowy grouper (*Epinephelus niveatus*) are common on the *Oculina* reefs.

Dive Number: Phantom ROV 11-156A **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey *Oculina* coral mounds and ground truth sonar survey in area outside *Oculina* HAPC and never surveyed previously. Target site- *Oculina* mound (from *Pisces* multibeam): 29° 14.17'N, 80° 9.802'W; 70-90 m.

Dive Events: Surveyed seven *Oculina* mounds at the northern end of the *Pisces* Daytona sonar survey area. [Note- Prior to this dive, the *Arc* ROV was replaced with the *Phantom* ROV for the remainder of the dives. The *Phantom* had standard definition video. The *Phantom*'s top parallel lasers are calibrated at 20 cm, bottom lasers 61 cm. Depth recorded in WinFrog is correct; video overlay display is incorrect.]

Site Description/Habitat/Fauna: *Pisces* shipboard multibeam surveyed for first time an area of deep-sea *Oculina* coral mounds along the shelf-edge break, ~40 nmi north of the *Oculina* HAPC. The sonar survey off Daytona covered 5.7 x 0.8 nmi, discovering >100 mounds, 15-35 m relief, forming a very dense linear pattern oriented NNW-SSE. Individual mounds are conical to E-W oriented ridges, 100-500 m wide at the base, and with base depths of 90-95 m, and peaks 60-70 m. Mounds are *Oculina* bioherms; 70-90% coral rubble and mud on slopes (10-45°) and peaks, with scattered live and dead standing colonies of *Oculina varicosa* (white, azooxanthellate); most live colonies are ~10-30 cm diameter. The peaks are generally E-W ridges covered with coral rubble and patches of abundant standing dead coral. Near the base of some mounds is exposed rock pavement and 1-2 m ledges. Valleys between the mounds is mostly soft sediment, sandy mud, and shell hash. Dominant fauna: Fish- scamp (common), few gag and snowy grouper, red porgy, amberjack, tilefish burrow, black seabass, bank butterfly, blue angel, moray, roughtongue bass, bigeye, scorpionfish, batfish, wrasses, Ogcocephalidae; Sponges- Demospongiae, barrel sponge; Cnidaria- *Oculina varicosa* (Ivory tree coral)*, Telesto*, Plexauridae, *Titanideum*, *Condylactis gigantea*, Cerianthidae, Antipatharia; Polychaeta-Sabellidae; Echinoderms- *Eucidaris tribuloides*, *Centrostephanus*, *Narcissia trigonaria*, *Astroporpa annulata*.

Dive Number: Phantom ROV 11-156A	**Location:** USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

Percent Cover of Benthic Macro-Biota and Substrate:

Phantom ROV 11-156A surveyed seven newly discovered *Oculina* mounds at the northern end of the new *Pisces* Daytona sonar survey area. The entire sonar survey covered 4.5 nmi^2 and had >100 high-relief coral mounds. The dive transects were divided into three habitat types: *Oculina* mound peak, mound slope, and base (area between the mounds). Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. Hard bottom in this region may consist of coral framework which is defined as standing colonial hard coral (either live or dead), coral rubble, rock pavement, or rock ledges. Site 11-156A was predominately hard bottom substrate (94.3% cover), consisting primarily of coral framework (5.1%), coral rubble (53.9%), and rock pavement and ledges (11.2%) (Fig. 2, Table 1). Benthic macro-biota covered 24% of the bottom and consisted of 5.1% coral framework (0.34% live *Oculina*, 4.2% standing dead *Oculina*), 1.5% Porifera, 0.8% non-scleractinian coral, and 16.5% other organisms (Fig. 2, Table 1; see Table 2 for complete species list). Figure 3 shows the percent cover of substrate type for each habitat zone of the dive site. Both the *Oculina* peaks and slopes had >80% cover of coral substrate, consisting of standing coral framework (7.4% and 5.4%, respectively) and coral rubble (66.8% and 64.9%, respectively). Exposed rock ledges and pavement was the predominate substrate at the mound base (35.9% cover). Dead coral is typically described as standing dead or coral rubble, however, it is recognized to be an important component of the habitat. Live coral, coral rubble, and standing dead coral all provide habitat for hundreds of species of invertebrates and juvenile fish (e.g., Reed et al., 1982, 1987, 2002; Ross and Quattrini, 2007), in addition to commercially valuable species (e.g., Reed and Farrington, 2010).

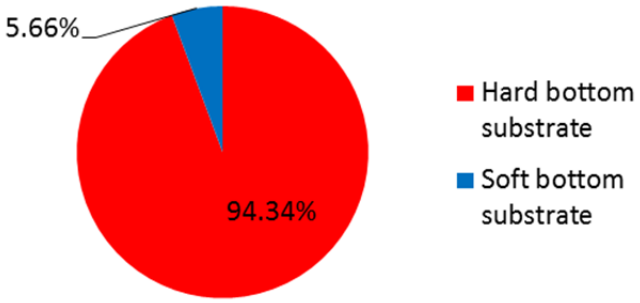


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-156A. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

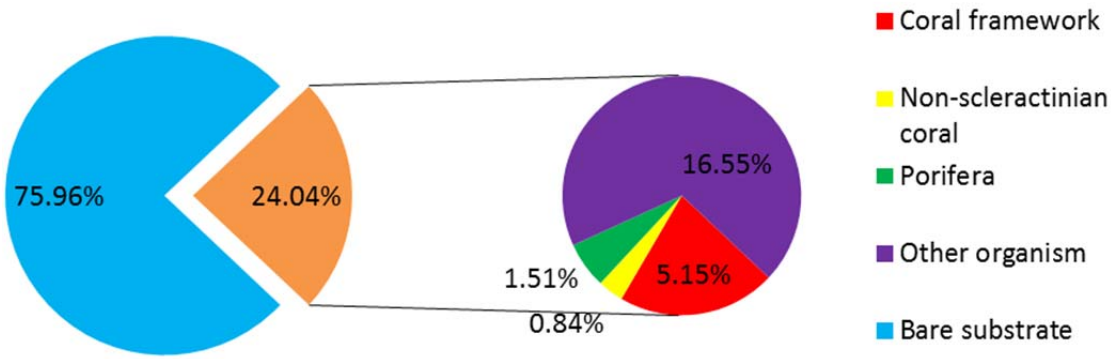


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-156A. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: Phantom ROV 11-156A **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-154A.

Benthic macro-biota and substrate types	% Cover
Coral framework	**5.15%**
Oculina varicosa	0.34%
Scleractinia, unid	0.60%
Standing Dead Coral	4.21%
Non-scleractinian coral	**0.84%**
Alcyonacea	0.60%
Antipatharia	0.21%
Gorgonacea, Unid	0.03%
Porifera	**1.51%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	1.51%
Other organism	**16.54%**
Bare substrate	**75.95%**
Bare Soft Bottom substrate	4.88%
Coral rubble	53.94%
Rock- pavement, boulder, ledge	11.22%
Rubble	5.90%
Human debris	**0.02%**
Fishing line/long line	0.02%
Grand Total	**100.00%**

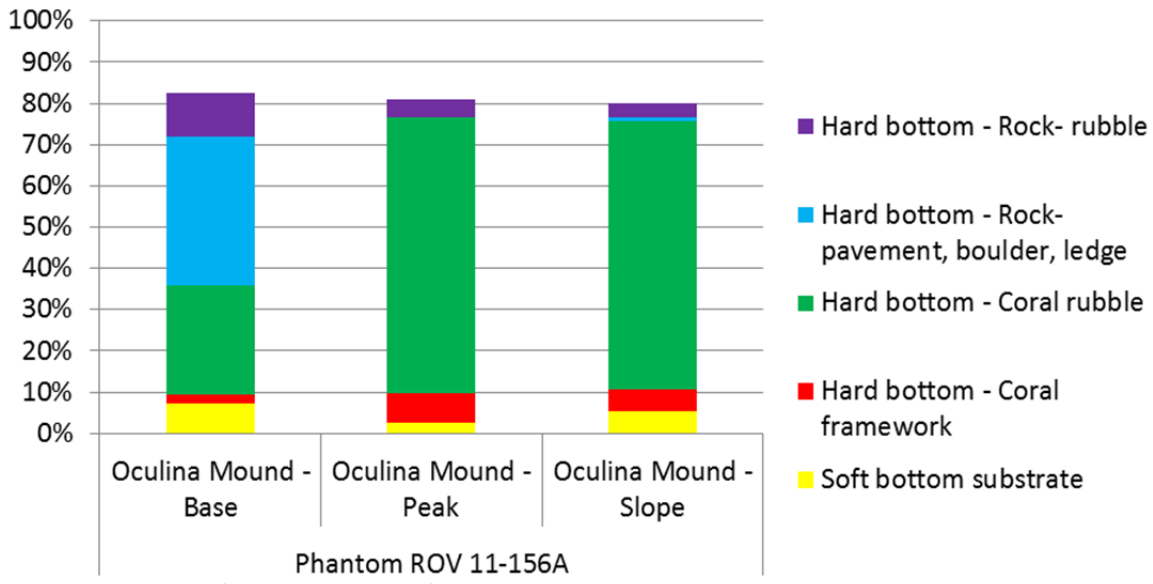


Figure 3. Percent cover of substrate types for each habitat zone at dive site 11-156A.

Dive Number: Phantom ROV 11-156A **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

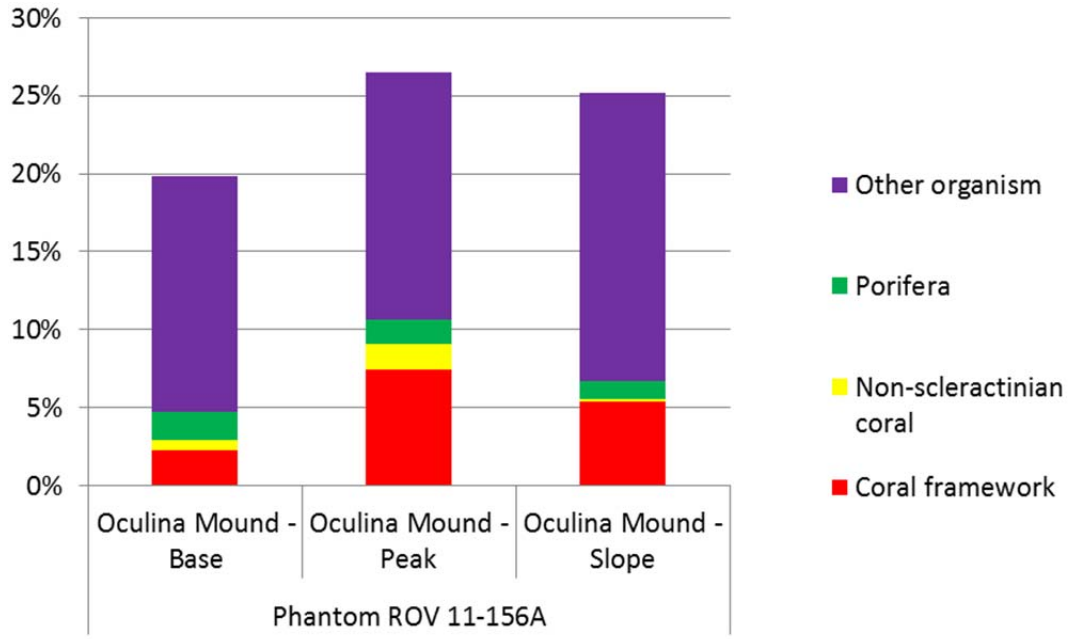


Figure 4. Percent cover of benthic macro-biota for each habitat zone at dive site 11-156A.

The percent cover of biota by habitat type shows the greatest cover of biota was on the *Oculina* mound peaks and slopes (26.% and 25.2%, respectively). Coral framework was greatest on the mounds (7.4% cover on the peaks) although 2.3% cover was also the flat areas between the mounds. Non-scleractinian coral cover on the peaks was 1.6% and sponge cover was also 1.6%.

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge" or "unidentified Demospongiae", which could consist of numerous species. These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different Classes.

Dive site 11-156A had a total of 52 benthic macro-fauna taxa, consisting of 19 Cnidaria and 4 Porifera (Table 2). Overall density of all benthic macro-fauna was 24.9 organisms/m^2. Cnidaria contributed to 42.1% of the total density at this site, and Porifera 9.3%. Demosponges and Cnidaria dominated with densities of 2.3 and 10.5 colonies/m^2, respectively. Alcyonacea, primarily Gorgonacea, contributed to 2.4 colonies/m^2. Scleractinia overall was 2.7 colonies/m^2, with standing *Oculina* colonies at 0.86.

Table 2. Density of benthic macro-biota at site 11-156A (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**169**	**2.31**	**9.27%**
Demospongiae	**169**	**2.31**	**9.27%**

Dive Number: Phantom ROV 11-156A **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

Dictyoceratida	2	0.03	0.11%
Ircinia campana	1	0.01	0.05%
Ircinia felix	1	0.01	0.05%
Hadromerida	90	1.23	4.94%
Spirastrellidae	90	1.23	4.94%
Demospongiae	77	1.05	4.22%
Demospongiae	77	1.05	4.22%
Cnidaria	**767**	**10.47**	**42.07%**
Anthozoa	**656**	**8.96**	**35.98%**
Actiniaria	27	0.37	1.48%
Actiniaria	27	0.37	1.48%
Alcyonacea	173	2.36	9.49%
Alcyonacea	15	0.20	0.82%
Diodogorgia sp.	1	0.01	0.05%
Gorgonacea (accepted as Alcyonacea)	1	0.01	0.05%
Nidalia occidentalis	7	0.10	0.38%
Telesto sp.	149	2.03	8.17%
Antipatharia	8	0.11	0.44%
Antipathidae	1	0.01	0.05%
Stichopathes lutkeni	4	0.05	0.22%
Tanacetipathes hirta	3	0.04	0.16%
Ceriantharia	13	0.18	0.71%
Cerianthidae	13	0.18	0.71%
Corallimorpharia	6	0.08	0.33%
Corallimorphus sp.	6	0.08	0.33%
Scleractinia	196	2.68	10.75%
Cladocora sp.	86	1.17	4.72%
Oculina varicosa	10	0.14	0.55%
Oculina varicosa- dead standing	53	0.72	2.91%
Phyllangia americana	29	0.40	1.59%
Scleractinia- unid cup	18	0.25	0.99%
Zoanthidea	233	3.18	12.78%
Palythoa sp.	4	0.05	0.22%
Zoanthidae	229	3.13	12.56%
Hydrozoa	**111**	**1.52**	**6.09%**
Hydrozoa	111	1.52	6.09%
Hydroidolina	102	1.39	5.60%
Hydroidolina- long pine	9	0.12	0.49%
Annelida	**385**	**5.26**	**21.12%**
Polychaeta	**385**	**5.26**	**21.12%**
Amphinomida	1	0.01	0.05%
Amphinomida	1	0.01	0.05%
Sabellida	117	1.60	6.42%

Dive Number: Phantom ROV 11-156A **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

Sabellidae	66	0.90	3.62%
Serpulidae	51	0.70	2.80%
Polychaeta	267	3.65	14.65%
Polychaeta	267	3.65	14.65%
Mollusca	**15**	**0.20**	**0.82%**
Gastropoda	**15**	**0.20**	**0.82%**
Caenogastropoda	8	0.11	0.44%
Vermicularia knorrii	8	0.11	0.44%
Neogastorpoda	2	0.03	0.11%
Murex sp.	2	0.03	0.11%
Gastropoda	5	0.07	0.27%
Calliostoma sp.	1	0.01	0.05%
Gastropoda	4	0.05	0.22%
Arthropoda	**93**	**1.27**	**5.10%**
Malacostraca	**85**	**1.16**	**4.66%**
Amphipoda	73	1.00	4.00%
Corophiidea	73	1.00	4.00%
Decapoda	12	0.16	0.66%
Decapoda	1	0.01	0.05%
Majidae	1	0.01	0.05%
Paguroidea	4	0.05	0.22%
Parthenope sp.	1	0.01	0.05%
Stenocionops sp.	1	0.01	0.05%
Stenorhynchus seticornis	4	0.05	0.22%
Pycnogonida	**8**	**0.11**	**0.44%**
Pantopoda	8	0.11	0.44%
Anoplodactylus lentus	8	0.11	0.44%
Bryozoa	**4**	**0.05**	**0.22%**
Gymnolaemata	**4**	**0.05**	**0.22%**
Cheilostomatida	4	0.05	0.22%
Hippoporidra	4	0.05	0.22%
Echinodermata	**387**	**5.28**	**21.23%**
Asteroidea	**16**	**0.22**	**0.88%**
Forcipulatida	1	0.01	0.05%
Coscinasterias tenuispina	1	0.01	0.05%
Valvatida	13	0.18	0.71%
Goniasteridae	12	0.16	0.66%
Narcissia trigonaria	1	0.01	0.05%
Asteroidea	2	0.03	0.11%
Asteroidea	1	0.01	0.05%
Asteroidea- red spotted	1	0.01	0.05%
Echinoidea	**368**	**5.02**	**20.19%**

Dive Number: Phantom ROV 11-156A **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 1--Reed's Reef

Arbacioda	96	1.31	5.27%
Arbacia punctulata	96	1.31	5.27%
Cidaroida	264	3.60	14.48%
Eucidaris tribuloides	264	3.60	14.48%
Diadematoida	6	0.08	0.33%
Centrostephanus longispinus	6	0.08	0.33%
Echinoidea	2	0.03	0.11%
Ophiuroidea	**3**	**0.04**	**0.16%**
Euryalida	2	0.03	0.11%
Asteroporpa annulata	2	0.03	0.11%
Ophiuroidea	1	0.01	0.05%
Chordata	**2**	**0.03**	**0.11%**
Ascidiacea	**2**	**0.03**	**0.11%**
Human debris	**1**	**0.01**	**0.05%**
Human debris	**1**	**0.01**	**0.05%**
Human debris	1	0.01	0.05%
Human debris- cans/bottles	1	0.01	0.05%
Grand Total	**1823**	**24.89**	**100.00%**

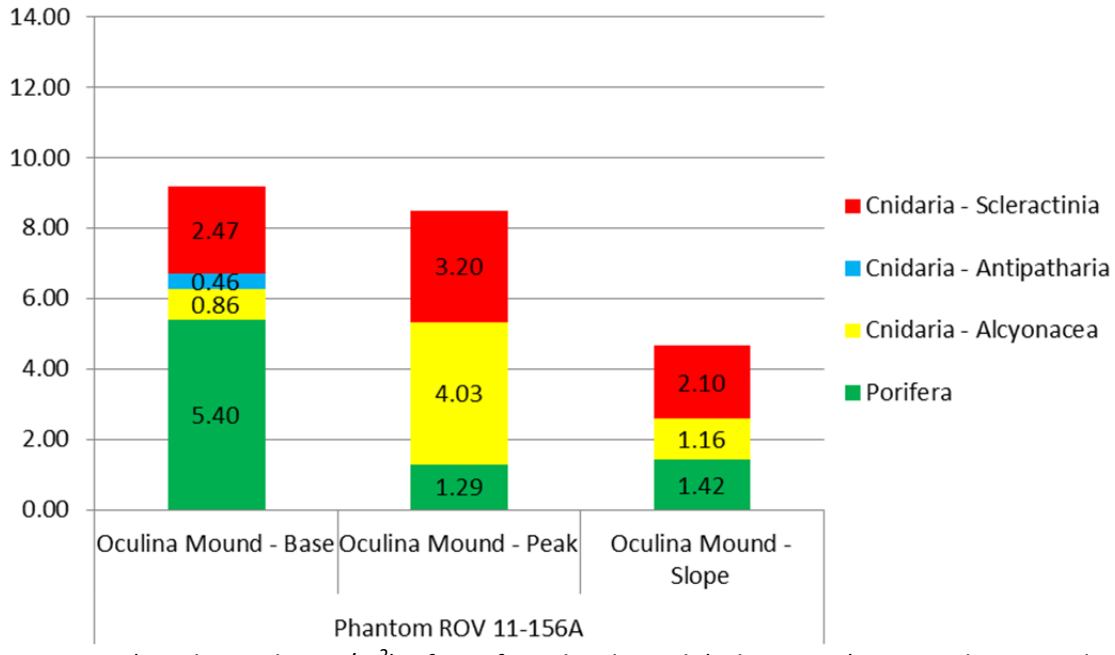


Figure 5. Density (number colonies/m^2) of Porifera, hard coral (Scleractinia), Antipatharia, and Alcyonacea (Gorgonacea) for each habitat zone of dive site 11-156A.

Figure 5 shows the density of Porifera and coral for each of the habitats at dive site 11-156A. Coral is defined as hard coral (Scleractinia), Antipatharia, and Gorgonacea. The *Oculina* peaks had the greatest density of scleractinian corals (3.2 colonies/m^2), but they were also common on the slopes (2.3) and base (2.5). Alcyonacea cover was also greatest on the peaks (4.0) and sponges had the greatest density at the mound bases (5.4 colonies/m^2). In addition to these analyses of the digital still photo transects, a total count of live standing

Oculina coral colonies was made from the forward-looking video camera for the entire dive. For this dive, 33 colonies were counted in the video and ranged in size from ~15 to 30 cm, which is equivalent to possibly 10-20 years old. Since the actual video field-of-view is just a small portion of the total mound area, we calculated the estimated field-of-view area for the dive [field-of-view width (~10 m) x transect length = area of the video transect]. From this we estimated the total number of live *Oculina* corals that may occur over the entire mound area at that dive site. In ArcGis we calculated the total planar surface area of the coral mounds that were transected during the dive which was 160,610 m^2. We then multiplied the density of coral in the video and by the total mound surface area. We estimate a total of 217 live coral colonies may occur on these 7 *Oculina* mounds.

Fish Data Analysis:

Video transects were used to analyze the fish populations and densities. Protocol for the fish analyses was to divide the continuous video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. The average field of view was about 10-15 m. A total of 25 taxa of fish were identified from dive site 11-156A for a total density of 485 individuals/km (Table 3). These were dominated by *Centropristes* sp. (328 individuals/km; either black sea bass and/or bank sea bass but were too far away to distinguish), bank sea bass (41), roughtongue bass (30) and unidentified anthiids (25; either roughtongue bass or red barbier). Managed species included scamp (6.3/km), black sea bass (5.2), amberjack (1.6), red porgy (1.6), and snowy grouper (0.8).

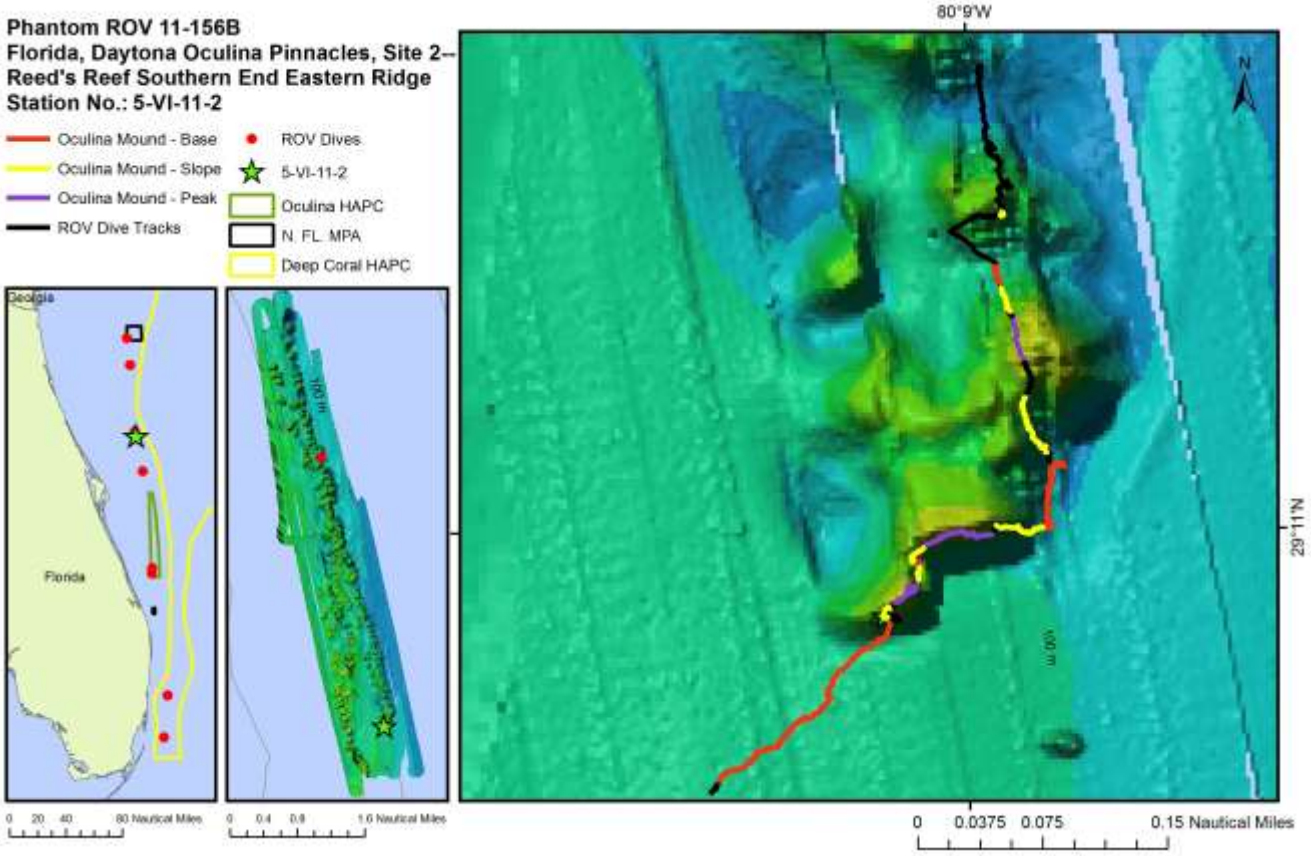
Table 3. Density of fish for all transects at dive site 11-156A (number individuals/km).

Common Name	Species Name	Density (#/km)
sea bass	*Centropristis sp.*	327.7
bank sea bass	*Centropristis ocyurus*	40.8
roughtongue bass	*Pronotogrammus martinicensis*	29.7
anthiids	Anthiinae	24.6
tattler	*Serranus phoebe*	11.1
bank butterflyfish	*Prognathodes aya*	8.3
short bigeye	*Pristigenys alta*	7.1
scamp	*Mycteroperca phenax*	6.3
black sea bass	*Centropristis striata*	5.2
yellowtail reeffish	*Chromis enchrysurus*	4.4
red barbier	*Hemanthias vivanus*	4.0
wrasse	*Halichoeres sp.*	2.8
saddle bass	*Serranus notospilus*	2.0
scorpionfish	Scorpaenidae	2.0
amberjack	*Seriola sp.*	1.6
red porgy	*Pagrus pagrus*	1.6
blue angelfish	*Holacanthus bermudensis*	1.2
apricot bass	*Plectranthias garrupellus*	0.8
longnose batfish	*Ogcocephalus corniger*	0.8
snowy grouper	*Epinephelus niveatus*	0.8

wrasse bass	*Liopropoma eukrines*	0.8
moray eel	Muraenidae	0.4
sand diver	*Synodus intermedius*	0.4
sea bass	Serranidae	0.4
sea bass	*Serranus sp.*	0.4

Dive Number:	Phantom ROV 11-156B	**Location:**	USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

General Location and Dive Track:



Site Overview:

Project:	2011 Extreme Corals, NOAA DSCP
Principal Investator:	Andrew W. David
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408
Website:	http://coralreef.noaa.gov/deepseacorals
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington
Data Management:	Access Database, Excel Spreadsheet, WinFrog
ROV Navigation Data:	WinFrog
Ship Position System:	DGPS
Report Analyst:	John Reed, Stephanie Farrington

Dive Overview:

Vessel:	NOAA Ship *Pisces*
Sonar Data:	Daytona Oculina Pinnacles: 3_Daytona8.tif
Purpose:	Map and characterize DSCE off SE USA
ROV:	NOAA SW Fisheries Super Phantom ROV
Sensors Used:	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Date of Dive:	6/5/2011
Specimens:	0
Digital Photos:	270
DVD:	3
Hard Drive:	1
Date Compiled:	2/20/2013

Dive Number:	Phantom ROV 11-156B	**Location:**	USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

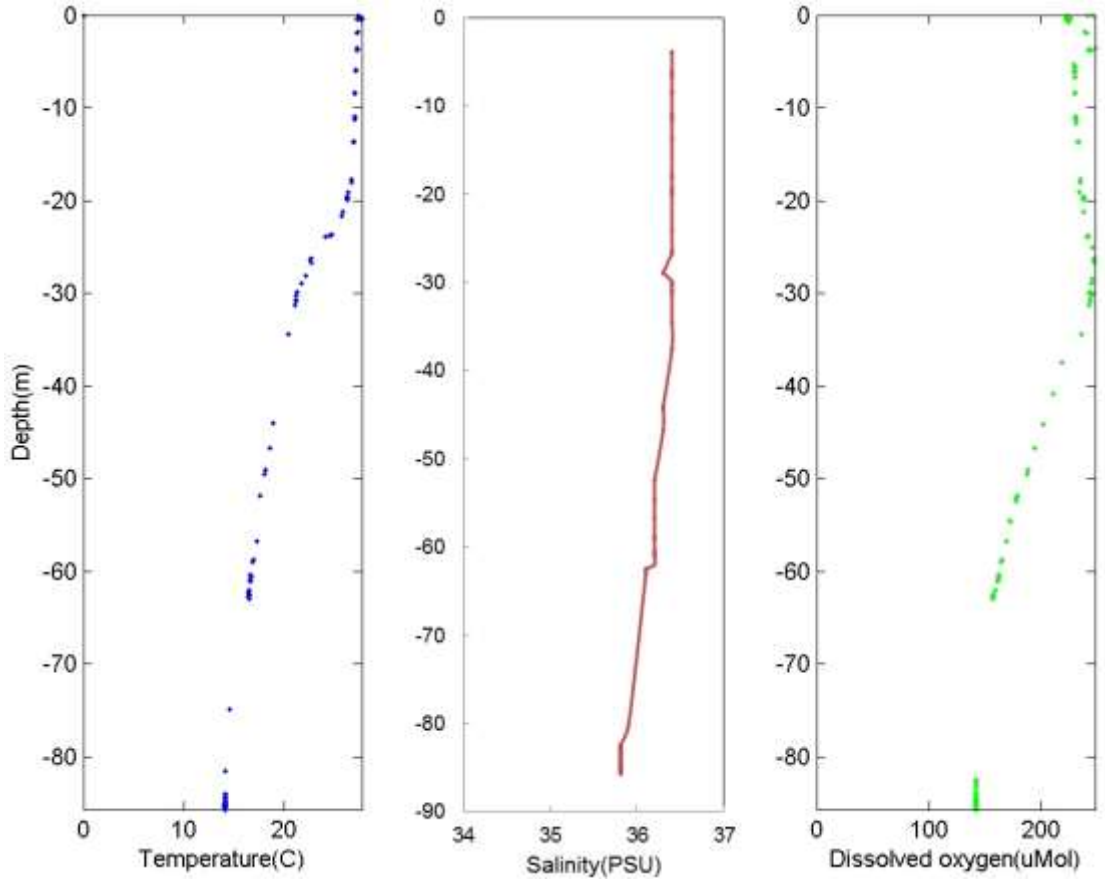
Dive Data:

Minimum Bottom Depth (m):	70	**Total Transect Length (km):**	1.338
Maximum Bottom Depth (m):	92	**Surface Current (kn):**	0
On Bottom (Time- GMT):	19:45	**On Bottom (Lat/Long):**	29°10.8294'N; 80°09.1835'W
Off Bottom (Time- GMT):	21:47	**Off Bottom (Lat/Long):**	29°11.2592'N; 80°08.9894'W

Physical (bottom); Temp (°C): 14.10 **Salinity:** 35.81 **Visibility (ft):** 40 **Current (kn):** 0

Physical Environment:

CTD Number 11-156B_CTDD



All CTD data were collected with the Super Phantom ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (85.7 m): temperature- 14.2, salinity- 35.8, and dissolved oxygen- 142.2. Surface temperature was 27.3 and there was a thermocline near 20 m depth; salinity peaked between 0 and 28 m, dissolved oxygen peaked at 30 m. Visibility was estimated at 12-15 m from the ROV video.

Dive Number: Phantom ROV 11-156B **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

Dive Imagery:

Figure 1: 29°10.9816'N, 80°9.0396'W 71.4 m

Small live *Oculina varicosa* colonies are scattered over the coral rubble bottom on these 20-35 m tall coral mounds which are thousands of years old. These individual coral colonies are new growth, less than 10-20 years old, and only grow about 10 mm or less a year. Coral (Ivory tree coral- *Oculina varicosa*, solitary cup Scleractinia), *Epizoanthus* sp. zoanthids, sea urchins (*Arbacia punctulata*, *Eucidaris tribuloides*), various demosponges, hydroids. Bank sea bass (*Centropristis ocyurus*), juvenile black sea bass (*Centropristis striata*) and apricot bass (*Plectranthias garrupellis*).

Figure 2: 29°10.9745'N, 80°9.0355'W 78.4 m

Four deepwater *Oculina* coral mounds (20-35 m relief) were crossed during this ROV dive. The slopes of the mounds are mostly coral rubble and standing dead coral framework which still provides habitat for many benthic species. This species of giant red brittlestar *(Ophioderma devanyi*) was first discovered and described from the deepwater *Oculina* coral reefs. (Parallel red lasers - 20 cm).

Figure 3: 29°11.0638'N, 80°8.9599'W 80.5 m

This snowy grouper (*Epinephelus niveatus*; ~50 cm) takes shelter in a small cave on the deepwater *Oculina* reef.

Figure 4: 29°11.0015'N, 80°8.9499'W 86.3 m

Ocellated moray eel (*Gymnothorax saxicola*) in a burrow of coral rubble. Coral (*Cladocora* sp.- pink cluster coral, Scleractinia cup corals), anemone (*Corallimorphus* sp.), sabellid polychaetes, and hydroids.

Dive Number:	Phantom ROV 11-156B	**Location:**	USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey *Oculina* coral mounds and ground truth sonar survey in area outside *Oculina* HAPC and never surveyed previously. Target site- *Oculina* mound (from *Pisces* multibeam): 29° 10.948'N, 80° 9.0585'W; 70-90 m.

Dive Events: ROV transect surveyed four *Oculina* mounds at the southern end of the *Pisces* Daytona sonar survey area. One colony (15 cm) of *Oculina varicosa* was collected with a by-catch of two crabs. [Note- The *Phantom* ROV's top parallel lasers are calibrated at 20 cm, bottom lasers 61 cm. Depth recorded in WinFrog is correct; video overlay display is incorrect.]

Site Description/Habitat/Fauna: ROV ground-truthed that the mounds are *Oculina* bioherms; ~70-95% coral rubble and mud on slopes (10-45o) and peaks, with scattered live and dead standing colonies of *Oculina varicosa* (white, azooxanthellate); most colonies are ~10-30 cm diameter. Individual mounds are E-W oriented ridges with base depths of 85-95 m, peaks ~70 m, and 125-340 m wide at the base. The peaks are covered with coral rubble and patches of abundant standing dead coral. Near the base of some mounds is exposed rock pavement and 1-2 m ledges. Valleys between the mounds is mostly soft sediment, sandy mud, and shell hash. Dominant fauna: Fish- snowy grouper, dozens of greater amberjack, black seabass, bank butterfly, bigeye, roughtongue bass; Cnidaria- *Oculina varicosa* (Ivory tree coral), dense burrowing anemones Cerianthidae, *Virgularia*, *Stichopathes*, hydroids; Echinoderms- *Ophioderma devaneyi*, dense congregations of black long-spined urchins *Centrostephanus*, *Arbacia punctulata*, *Eucidaris tribuloides.*

Dive Number: Phantom ROV 11-156B	**Location:** USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

Percent Cover of Benthic Macro-Biota and Substrate:

Phantom ROV 11-156B surveyed four newly discovered *Oculina* mounds at the southern end of the new *Pisces* Daytona sonar survey area. The entire sonar survey covered 4.5 nmi^2 and had >100 high-relief coral mounds. The dive transects were divided into three habitat types: *Oculina* mound peak, mound slope, and base (area between the mounds). Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. Hard bottom in this region may consist of coral framework which is defined as standing colonial hard coral (either live or dead), coral rubble, rock pavement, or rock ledges. Site 11-156B was predominately hard bottom substrate (93.1% cover), consisting primarily of coral framework (4.3%), coral rubble (68.8%), and rock pavement and ledges (2.55%) (Fig. 2, Table 1). Benthic macro-biota covered 21.7% of the bottom and consisted of 4.3% coral framework (0.9% live *Oculina*, 2.9% standing dead *Oculina*), 3.9% Porifera, 0.3% non-scleractinian coral, and 13.2% other organisms (Fig. 2, Table 1; see Table 2 for complete species list). Figure 3 shows the percent cover of substrate type for each habitat zone of the dive site. Both the *Oculina* peaks and slopes have >80% cover of coral substrate, consisting of standing coral framework (3.5% and 6.3%, respectively) and coral rubble (74.3% and 64.9%, respectively). Exposed rock ledges and pavement also occurred on the flat areas of the mound base (8.5% cover). Dead coral is typically described as standing dead or coral rubble, however, it is recognized to be an important component of the habitat. Live coral, coral rubble, and standing dead coral provide habitat for hundreds of species of invertebrates and juvenile fish (e.g., Reed et al., 1982, 1987, 2002; Ross and Quattrini, 2007), in addition to commercially valuable species (e.g., Reed and Farrington, 2010).

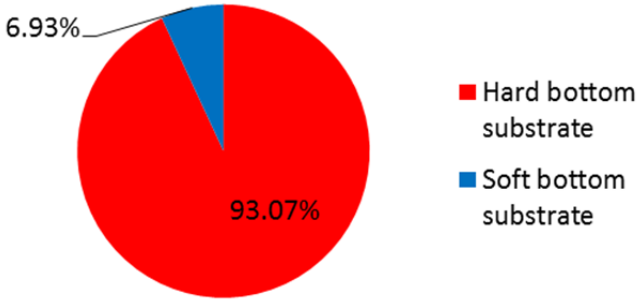


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-156B. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

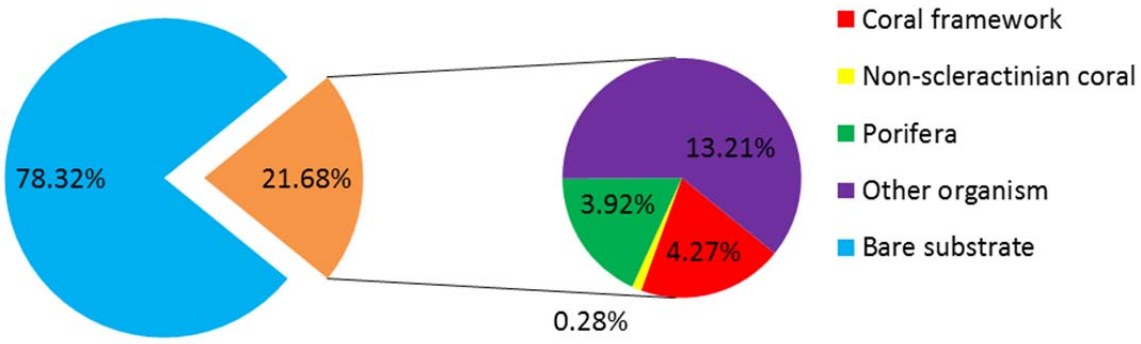


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-156B. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: Phantom ROV 11-156B	**Location:** USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-156B.

Benthic macro-biota and substrate types	% Cover
Coral framework	**4.27%**
Oculina varicosa	0.92%
Scleractinia, unid	0.47%
Standing Dead Coral	2.89%
Non-scleractinian coral	**0.28%**
Alcyonacea	0.11%
Antipatharia	0.17%
Porifera	**3.92%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	3.92%
Other organism	**13.21%**
Bare substrate	**78.32%**
Bare Soft Bottom substrate	6.90%
Coral rubble	68.82%
Rock- pavement, boulder, ledge	2.55%
Rubble	0.06%
Grand Total	**100.00%**

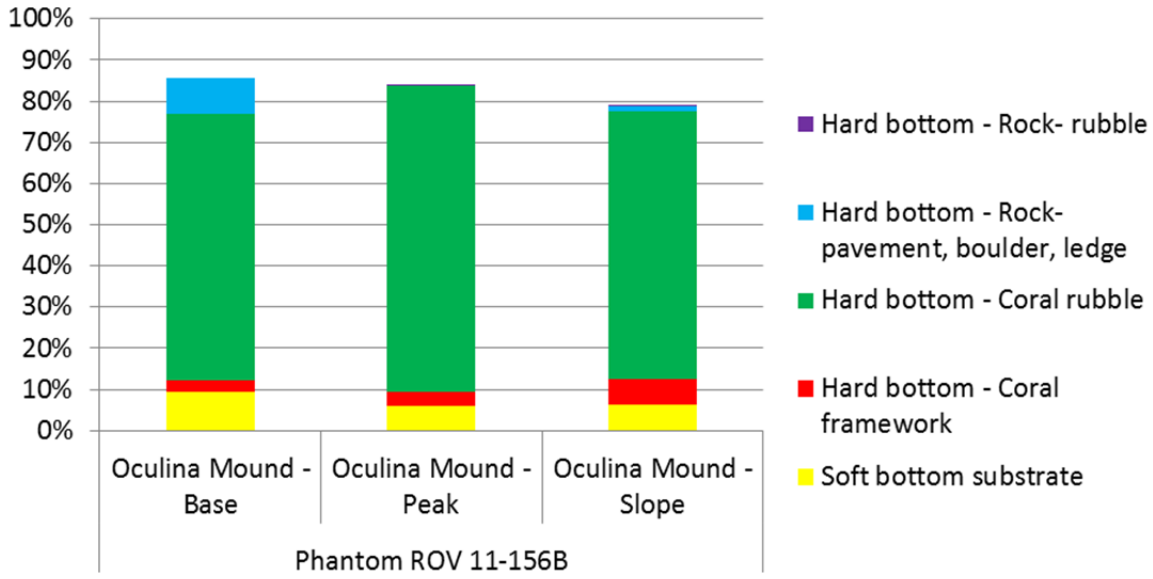


Figure 3. Percent cover of substrate types and biota for each habitat zone at dive site 11-156B.

Dive Number: Phantom ROV 11-156B **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

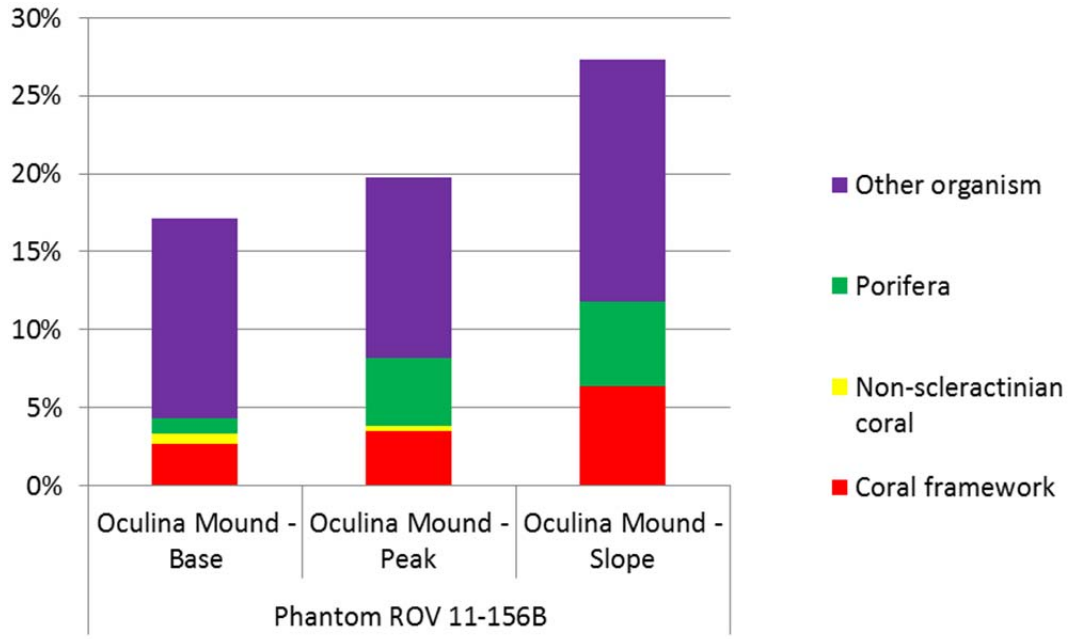


Figure 4. Percent cover of benthic macro-biota for each habitat zone at dive site 11-156B.

The percent cover of biota by habitat type shows the greatest cover of biota was on the *Oculina* mound peaks and slopes (14.7% and 27.3%, respectively). Coral framework was greatest on the mounds (6.3% cover on the slopes and 3.5% cover on the peaks) although 2.7% cover also was on the flat areas between the mounds. Sponge cover ranged from 5.5% cover on the mound slopes to 1.0% at the base.

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge" or "unidentified Demospongiae", which could consist of numerous species. These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different Classes.

Dive site 11-156B had a total of 44 benthic macro-fauna taxa, consisting of 16 Cnidaria and 4 Porifera (Table 2). Overall density of all benthic macro-fauna was 21.2 organisms/m^2. Cnidaria contributed to 38.2% of the total density at this site, and Porifera 9.7%. Cnidaria and demosponges dominated with densities of 8.1 and 2.1 colonies/m^2, respectively. Antipatharia had a density of 0.37 colonies/m^2. Scleractinia overall were 3.4 colonies/m^2, with standing *Oculina* colonies at 2.1. Of the sponges an unidentified *Chondosia*? sp. had a density of 0.7 colonies/m^2.

Table 2. Density of benthic macro-biota at site 11-156B (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**107**	**2.07**	**9.73%**

Dive Number: Phantom ROV 11-156B **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

Demospongiae	**107**	**2.07**	**9.73%**
Chondrosida	38	0.73	3.45%
Chondrosia sp.	38	0.73	3.45%
Dictyoceratida	1	0.02	0.09%
Ircinia sp.	1	0.02	0.09%
Hadromerida	6	0.12	0.55%
Spirastrellidae	6	0.12	0.55%
Demospongiae	62	1.20	5.64%
Cnidaria	**420**	**8.11**	**38.18%**
Anthozoa	**341**	**6.58**	**31.00%**
Actiniaria	12	0.23	1.09%
Actiniaria	12	0.23	1.09%
Alcyonacea	28	0.54	2.55%
Alcyonacea	1	0.02	0.09%
Gorgonacea (accepted as Alcyonacea)	4	0.08	0.36%
Nidalia occidentalis	4	0.08	0.36%
Telesto sp.	19	0.37	1.73%
Antipatharia	8	0.15	0.73%
Antipathidae	3	0.06	0.27%
Stichopathes lutkeni	2	0.04	0.18%
Tanacetipathes hirta	3	0.06	0.27%
Ceriantharia	39	0.75	3.55%
Cerianthidae	39	0.75	3.55%
Corallimorpharia	15	0.29	1.36%
Corallimorphus sp.	15	0.29	1.36%
Scleractinia	174	3.36	15.82%
Cladocora sp.	54	1.04	4.91%
Oculina varicosa	13	0.25	1.18%
Oculina varicosa- dead standing	95	1.83	8.64%
Phyllangia americana	1	0.02	0.09%
Scleractinia- unid cup	11	0.21	1.00%
Zoanthidea	65	1.26	5.91%
Zoanthidae	65	1.26	5.91%
Hydrozoa	**79**	**1.53**	**7.18%**
Hydrozoa	79	1.53	7.18%
Hydroidolina	79	1.53	7.18%
Annelida	**192**	**3.71**	**17.45%**
Polychaeta	**192**	**3.71**	**17.45%**
Sabellida	92	1.78	8.36%
Sabellidae	57	1.10	5.18%
Serpulidae	35	0.68	3.18%
Polychaeta	100	1.93	9.09%

Dive Number: Phantom ROV 11-156B **Location:** USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

Mollusca	**12**	**0.23**	**1.09%**
Bivalvia	**3**	**0.06**	**0.27%**
Pectinoida	1	0.02	0.09%
Plicatula gibbosa	1	0.02	0.09%
Bivalvia	2	0.04	0.18%
Bivalvia	2	0.04	0.18%
Gastropoda	**9**	**0.17**	**0.82%**
Umbraculida	2	0.04	0.18%
Umbraculum sp.	2	0.04	0.18%
Gastropoda	7	0.14	0.64%
Gastropoda	7	0.14	0.64%
Arthropoda	**89**	**1.72**	**8.09%**
Malacostraca	**70**	**1.35**	**6.36%**
Amphipoda	48	0.93	4.36%
Corophiidea	48	0.93	4.36%
Decapoda	22	0.42	2.00%
Brachyura	2	0.04	0.18%
Decapoda	1	0.02	0.09%
Majidae	1	0.02	0.09%
Paguroidea	17	0.33	1.55%
Stenorhynchus seticornis	1	0.02	0.09%
Pycnogonida	**19**	**0.37**	**1.73%**
Pantopoda	19	0.37	1.73%
Anoplodactylus lentus	19	0.37	1.73%
Echinodermata	**279**	**5.39**	**25.36%**
Asteroidea	**23**	**0.44**	**2.09%**
Valvatida	14	0.27	1.27%
Goniasteridae	14	0.27	1.27%
Asteroidea	9	0.17	0.82%
Asteroidea	9	0.17	0.82%
Echinoidea	**238**	**4.60**	**21.64%**
Arbacioda	96	1.85	8.73%
Arbacia punctulata	96	1.85	8.73%
Arbacioida	1	0.02	0.09%
Coelopleurus floridanus	1	0.02	0.09%
Cidaroida	136	2.63	12.36%
Cidaroida	7	0.14	0.64%
Eucidaris tribuloides	129	2.49	11.73%
Diadematoida	4	0.08	0.36%
Centrostephanus longispinus	4	0.08	0.36%
Echinoidea	1	0.02	0.09%
Ophiuroidea	**18**	**0.35**	**1.64%**

Euryalida	1	0.02	0.09%
Asteroporpa annulata	1	0.02	0.09%
Ophiurida	15	0.29	1.36%
Ophioderma devaneyi	15	0.29	1.36%
Ophiuroidea	2	0.04	0.18%
Human debris	**1**	**0.02**	**0.09%**
Human debris	**1**	**0.02**	**0.09%**
Human debris	1	0.02	0.09%
Human debris- fish line/gear	1	0.02	0.09%
Grand Total	**1100**	**21.24**	**100.00%**

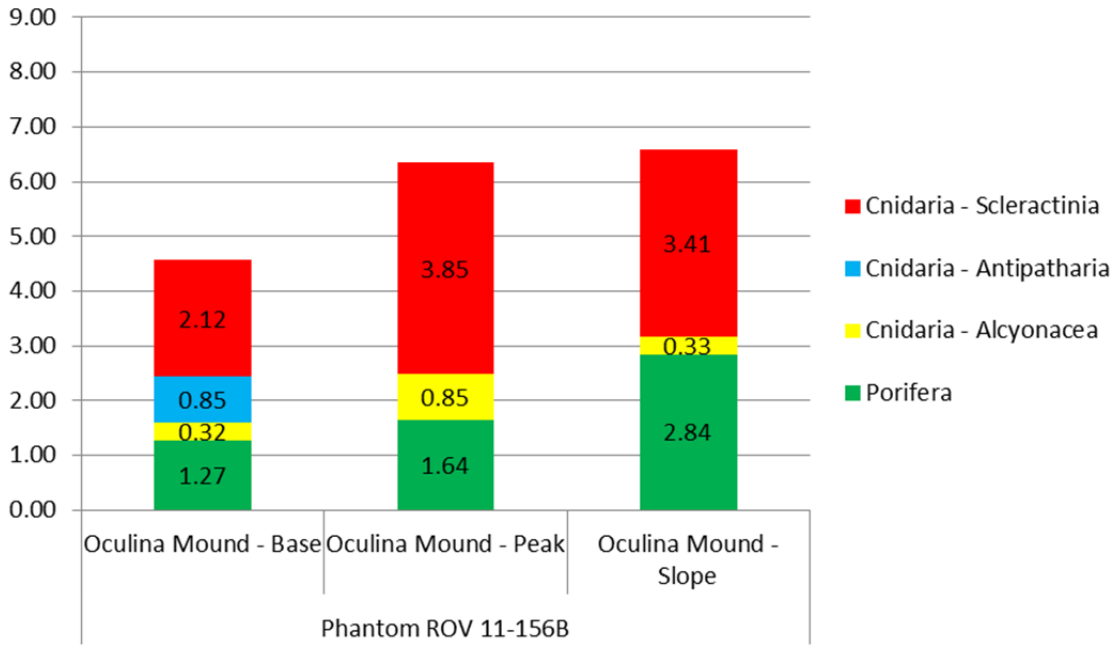


Figure 5. Density (number colonies/m^2) of Porifera, hard coral (Stylasteridae, Scleractinia), Antipatharia, and Alcyonacea (Gorgonacea) for each habitat zone at dive site 11-156B.

Figure 5 shows the density of Porifera and coral for each of the habitats at dive site 11-156B. Coral is defined as hard coral (Scleractinia), Antipatharia, and Gorgonacea. The *Oculina* peaks and slopes had the greatest density of Scleractinia coral (3.8 and 3.4 colonies/m^2, respectively), and Alcyonacea cover was greatest on the peaks (0.8). Coral density was 2.1 colonies/m^2 in the flat areas between the mounds (base), and sponge cover ranged from 2.8 colonies/m^2 on the slopes to 1.6 on the peaks and 1.3 at the base. In addition to these analyses of the digital still photo transects, a total count of live standing *Oculina* coral colonies was made from the forward-looking video camera for the entire dive. For this dive, 16 colonies were counted in the video and ranged in size from ~15 to 30 cm, which is equivalent to possibly 10-20 years old. Since the actual video field-of-view is just a small portion of the total mound area, we calculated the estimated field-of-view area for the dive [field-of-view width (~10 m) x transect length = area of the video transect]. From this we estimated the total number of live *Oculina* corals that may occur over the entire mound area at that dive site. In ArcGis we calculated the total planar surface area of the coral mounds that were transected during the dive which was 88,143 m^2. We then multiplied the density of coral in the video by the total mound surface area. We estimate a total of 107 live coral colonies may occur on these four *Oculina* mounds.

Dive Number: Phantom ROV 11-156B	**Location:** USA, Florida, Daytona Oculina Pinnacles, Site 2--Reed's Reef Southern End Eastern Ridge

Fish Data Analysis:

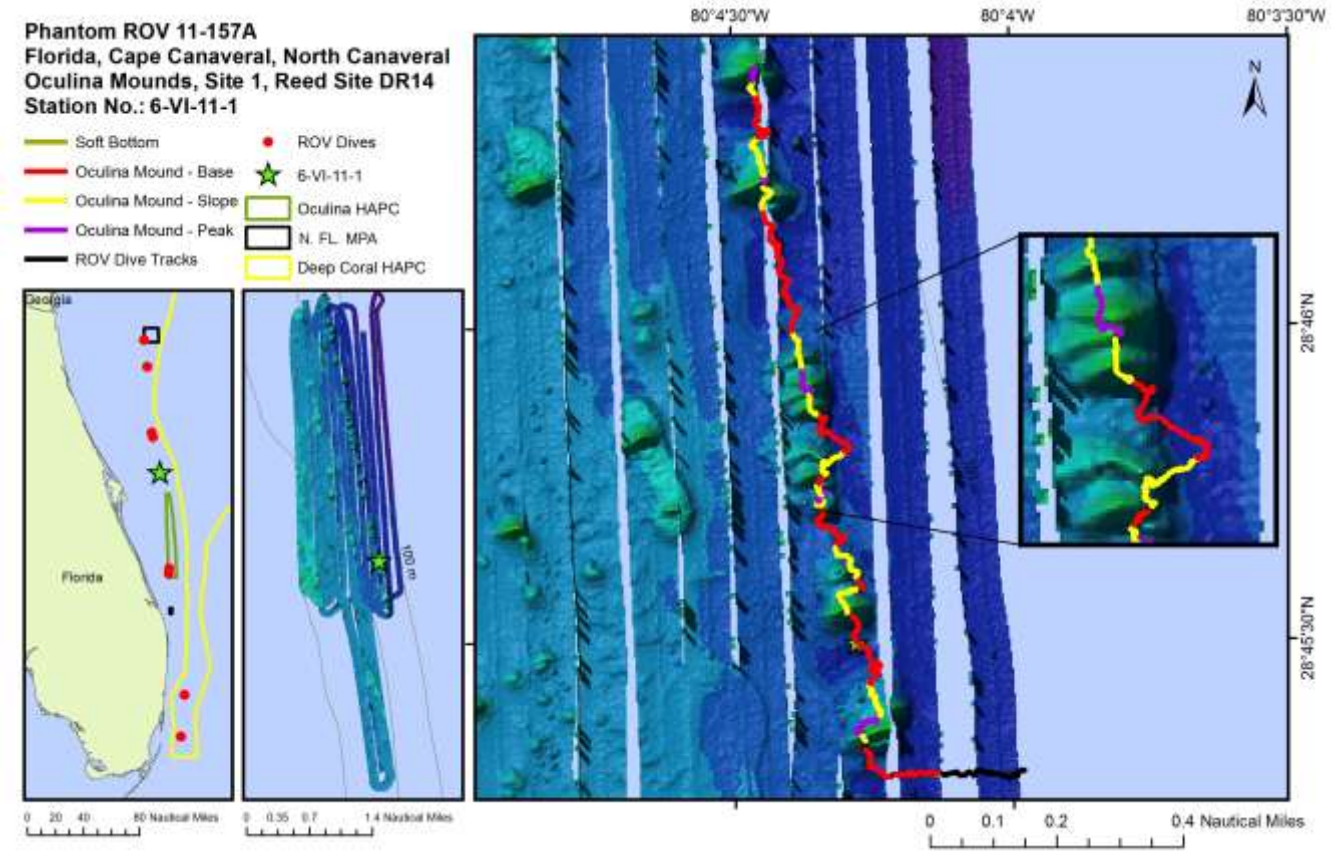
Video transects were used to analyze the fish populations and densities. Protocol for the fish analyses was to divide the continuous video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. A total of 15 taxa of fish were identified from dive site 11-156B for a total density of 223 individuals/km (Table 3). These were dominated by *Centropristes* sp. (114 individuals/km; either black sea bass and/or bank sea bass but were too far away to distinguish), bank sea bass (38.9), roughtongue bass (27) and tatlers (18). Managed and fished species included almaco jack (0.7) and snowy grouper (0.7).

Table 3. Density of fish for all transects at dive site 11-156B (number individuals/km).

Common Name	Species Name	Density (#/km)
sea bass	*Centropristis sp.*	114.3
bank sea bass	*Centropristis ocyurus*	38.9
roughtongue bass	*Pronotogrammus martinicensis*	26.9
tattler	*Serranus phoebe*	17.9
bank butterflyfish	*Prognathodes aya*	12.0
yellowtail reeffish	*Chromis enchrysurus*	5.2
batfish	*Ogcocephalus sp.*	1.5
short bigeye	*Pristigenys alta*	1.5
almaco jack	*Seriola rivoliana*	0.7
blue angelfish	*Holacanthus bermudensis*	0.7
ocellated moray	*Gymnothorax saxicola*	0.7
saddle bass	*Serranus notospilus*	0.7
scorpionfish	Scorpaenidae	0.7
snowy grouper	*Epinephelus niveatus*	0.7
wrasse bass	*Liopropoma eukrines*	0.7

Dive Number:	Phantom ROV 11-157A	**Location:**	USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

General Location and Dive Track:



Site Overview:

Project:	2011 Extreme Corals, NOAA DSCP
Principal Investator:	Andrew W. David
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408
Website:	http://coralreef.noaa.gov/deepseacorals
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington
Data Management:	Access Database, Excel Spreadsheet, WinFrog
ROV Navigation Data:	WinFrog
Ship Position System:	DGPS
Report Analyst:	John Reed, Stephanie Farrington

Dive Overview:

Vessel:	NOAA Ship *Pisces*
Sonar Data:	Titusville Oculina Pinnacles
Purpose:	Map and characterize DSCE off SE USA
ROV:	NOAA SW Fisheries Super Phantom ROV
Sensors Used:	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Date of Dive:	6/6/2011
Specimens:	7
Digital Photos:	1070
DVD:	6
Hard Drive:	2
Date Compiled:	2/20/2013

Dive Number:	Phantom ROV 11-157A	**Location:**	USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

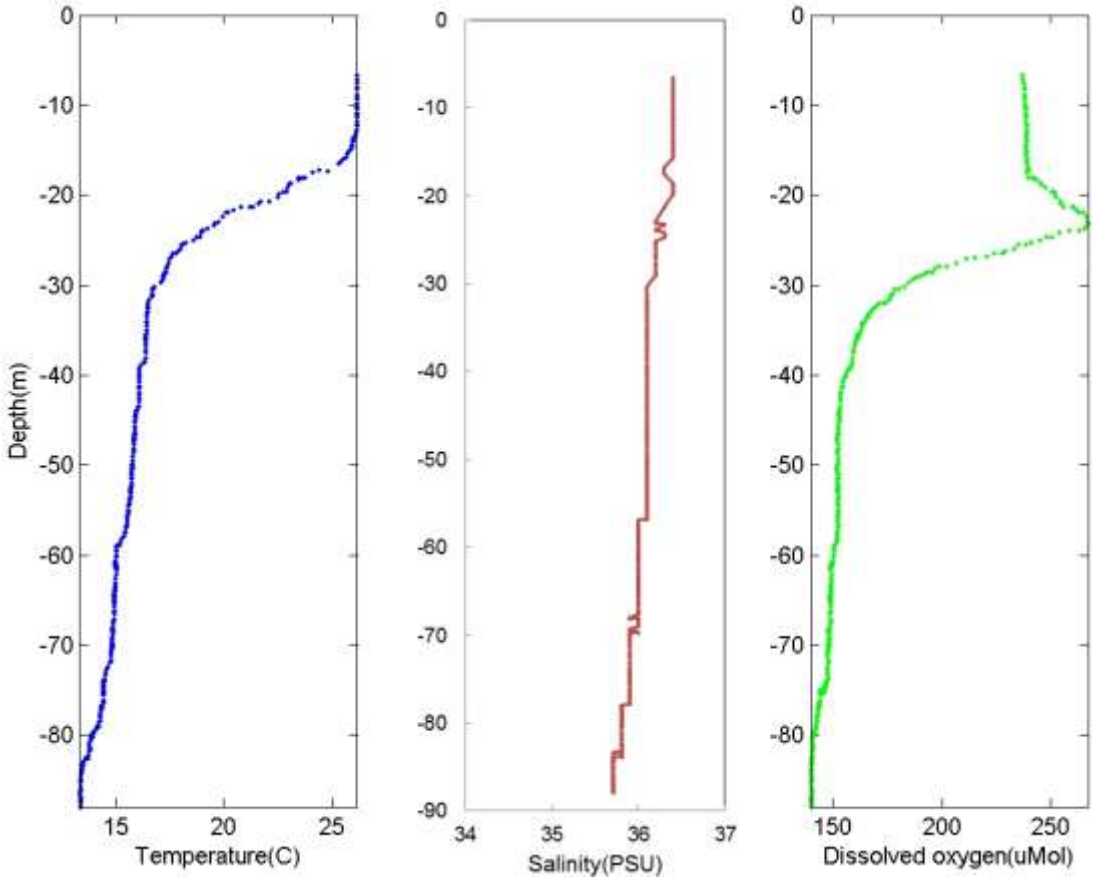
Dive Data:

Minimum Bottom Depth (m):	64	**Total Transect Length (km):**	3.747
Maximum Bottom Depth (m):	88	**Surface Current (kn):**	.3-.6 kt
On Bottom (Time- GMT):	16:11	**On Bottom (Lat/Long):**	28°45.2923'N; 80°03.9855'W
Off Bottom (Time- GMT):	21:41	**Off Bottom (Lat/Long):**	28°46.4133'N; 80°04.4582'W

Physical (bottom); Temp (°C): 13.30 **Salinity:** 35.70 **Visibility (ft):** 50+ **Current (kn):**

Physical Environment:

CTD Number 11-157A_CTDD



All CTD data were collected with the Super Phantom ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (87.9 m): temperature- 13.3, salinity- 35.7, and dissolved oxygen- 140. Surface temperature was 27.1 and there was a thermocline near 20-30 m depth; salinity peaked between 0 and 18, dissolved oxygen peaked at 24 m. Visibility was estimated at 15-18 m from the ROV video.

Dive Number: Phantom ROV 11-157A **Location:** USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

Dive Imagery:

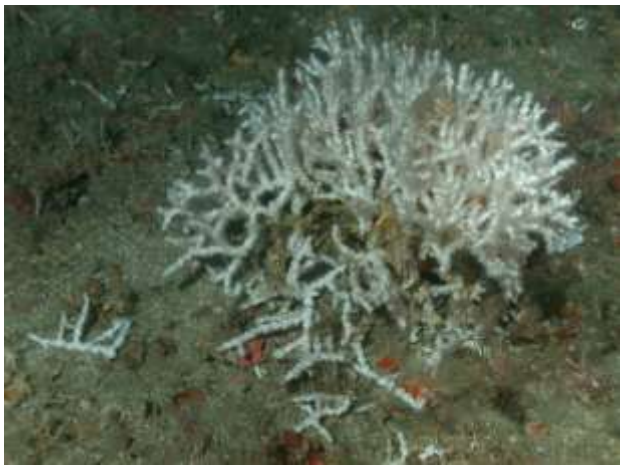


Figure 1: 28°45.6596'N, 80°4.3089'W 82.3 m

Nine deepwater *Oculina* coral mounds (5-20 m relief) were crossed during this ROV dive. The slopes of the mounds are mostly coral rubble and standing dead coral framework which still provides habitat for many benthic species. Small live *Oculina varicosa* colonies like this one (~20 cm diameter) are relatively new growth, less than 10-20 years old, and only grow about 10 mm or less a year.

Figure 2: 28°45.5978'N, 80°4.2814'W 77.2 m

The coral rubble slope of this deepwater *Oculina* mound provides habitat for these black corals (*Tanacetipathes hirta*- 20 cm bushes, *Stichopahthes lutkeni*- spiral whip coral), red ball coral (*Nicella occidentalis*), and hydroids. Bank sea bass (*Centropristis ocyurus*) and juvenile black sea bass (*Centropristis striata*).

Figure 3: 28°46.0496'N, 80°4.4023'W 83.9 m

Pair of snowy grouper (*Epinephelus niveatus*; ~50 cm) on the slope of the deepwater *Oculina* coral reef.

Figure 4: 28°45.8933'N, 80°4.3641'W 66.7 m

Adult and juvenile black sea bass (*Centropristis striata*) are becoming more abundant once again after being overfished from the deepwater *Oculina* reefs during the 1980s and 1990s.

Dive Number:	Phantom ROV 11-157A	**Location:**	USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey *Oculina* coral mounds and ground truth sonar survey in area outside *Oculina* HAPC. Target site- *Oculina* mound (from *Pisces* multibeam): 28° 45.497'N, 80° 04.283'W, 64-88 m. Only one submersible dive has been made in this area in 1982 on Reed Peak DR-14 (JSL I-1209).

Dive Events: ROV transect crossed nine *Oculina* coral mounds on a northerly heading. One colony of black coral (15 cm) was collected: *Tanacetipathes* sp. with six associated animals. [Note- The *Phantom* ROV's top parallel lasers are calibrated at 20 cm, bottom lasers 61 cm. Depth recorded in WinFrog is correct; video overlay display is off by 0.5-1 m.]

Site Description/Habitat/Fauna: *Pisces* shipboard multibeam surveyed for first time an area of deep-sea *Oculina* coral mounds along the shelf edge break, ~15 nmi north of the *Oculina* HAPC. The sonar survey off Titusville covered ~3.2 x 1.0 nmi, discovering ~35 mounds, 5 to 20 m-tall, and oriented in a linear pattern parallel to the shoreline NNW-SSE. Individual mounds are oval, ranging from 50-235 m in diameter at the base, with an E-W oriented ridge at the peak; the peaks range from 65-80 m depth and the bases 75-85 m. Individual mound slopes and peaks are nearly 100% coral, mostly coral rubble, with sparse standing coral framework, and sparse small (10-40 cm) live *Oculina varicosa* coral colonies; the peaks appear hummocky with 20-cm tall patches of standing dead coral. The bases of the mounds have exposed rock boulders and 1 m ledges. Some of the dead coral appears to be coated with black fuzz, possibly cyanobacteria(?). Dominant fauna: Fish- snowy grouper, scamp, gag grouper, red porgy (common), black seabass (abundant), bigeye, bank butterfly, scorpaenids, roughtongue bass, cubbyu, red hogfish, tattler, leopard toadfish, toadfish, greater amberjack; Cnidaria- *Oculina varicosa (*Ivory tree coral)*, Stichopathes*, Plexauridae, *Nidalia*, hydroids, Cerianthidae, Antipatharia; Echinoderms- *Centrostephanus*, *Eucidaris tribuloides*, *Ophioderma devanyi*, *Astroporpa annulata*. Video of trawl door.

Dive Number: Phantom ROV 11-157A	**Location:** USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

Percent Cover of Benthic Macro-Biota and Substrate:

Phantom ROV 11-157A surveyed nine newly discovered *Oculina* mounds within the new *Pisces* Titusville multibeam sonar survey area. The entire sonar survey covered 3.2 nmi^2 and had ~35 high-relief coral mounds. The dive transects were divided into three habitat types: *Oculina* mound peak, mound slope, and base (area between the mounds). Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. Hard bottom in this region may consist of coral framework which is defined as standing colonial hard coral (either live or dead), coral rubble, rock pavement, or rock ledges. Site 11-157A was predominately hard bottom substrate (91.8% cover), consisting primarily of coral framework (4.7%), coral rubble (51.6%), and rock pavement and ledges (4.5%) (Fig. 2, Table 1). Benthic macro-biota covered 25.6% of the bottom and consisted of 4.7% coral framework (0.7% live *Oculina*, 3.6% standing dead *Oculina*), 3.7% Porifera, 0.4% non-scleractinian coral, and 16.7% other organisms (Fig. 2, Table 1; see Table 2 for complete species list). Figure 3 shows the percent cover of substrate type for each habitat zone of the dive site. Both the *Oculina* peaks and slopes have >65% cover of coral substrate, consisting of standing coral framework (13.9% and 4.7%, respectively) and coral rubble (51.4% and 70.5%, respectively). Exposed rock ledges and pavement also occurred on the flat areas of the mound base (6.9% cover). Dead coral is typically described as standing dead or coral rubble, however, it is recognized as live-bottom habitat, and is an important component of the habitat. Live coral, coral rubble, and standing dead coral provide habitat for hundreds of species of invertebrates and juvenile fish (e.g., Reed et al., 1982, 1987, 2002; Ross and Quattrini, 2007), in addition to commercially valuable species (e.g., Reed and Farrington, 2010).

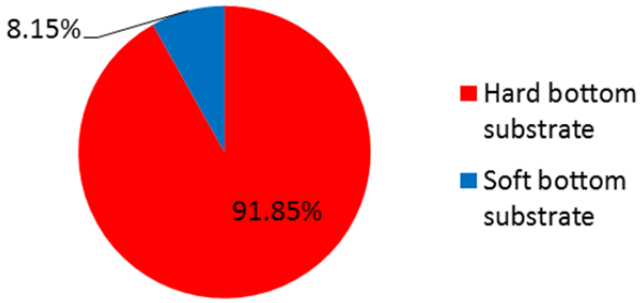


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-157A. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

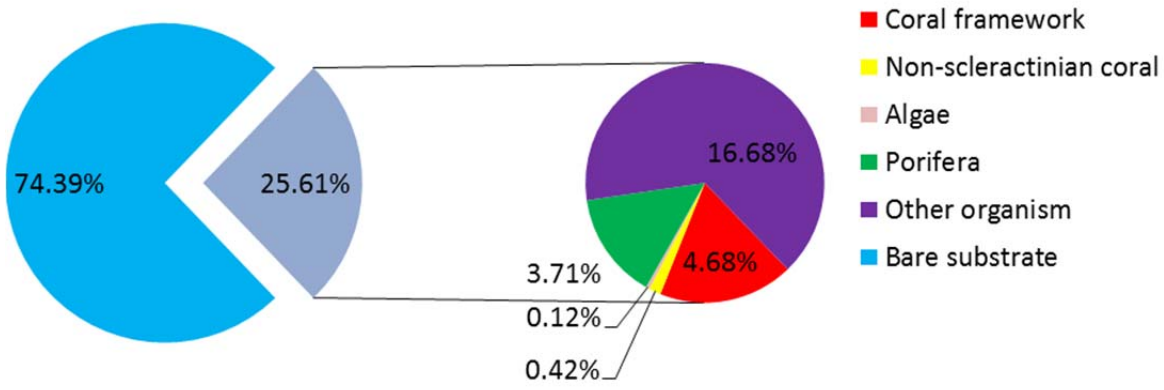


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-157A. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: Phantom ROV 11-157A	**Location:** USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-157A.

Benthic macro-biota and substrate types	% Cover
Coral framework	**4.67%**
Oculina varicosa	0.66%
Scleractinia, unid	0.45%
Standing Dead Coral	3.56%
Non-scleractinian coral	**0.42%**
Alcyonacea	0.10%
Antipatharia	0.26%
Gorgonacea, Unid	0.05%
Porifera	**3.70%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	3.70%
Other organism	**16.64%**
Algae	**0.12%**
Algae- green, brown, red, or cyanobacteria	0.12%
Bare substrate	**74.22%**
Bare Soft Bottom substrate	7.66%
Coral rubble	51.52%
Rock- pavement, boulder, ledge	4.50%
Rubble	10.54%
Human debris	**0.23%**
Human debris- Other	0.23%
Grand Total	**100.00%**

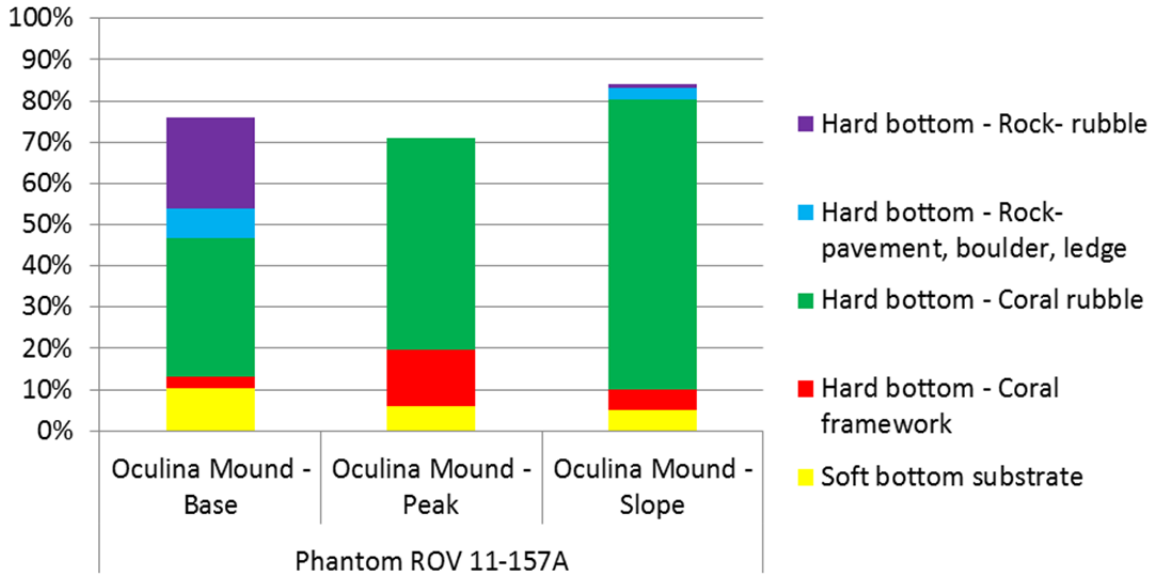


Figure 3. Percent cover of substrate types and biota for each habitat zone at dive site 11-157A.

Dive Number: Phantom ROV 11-157A **Location:** USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

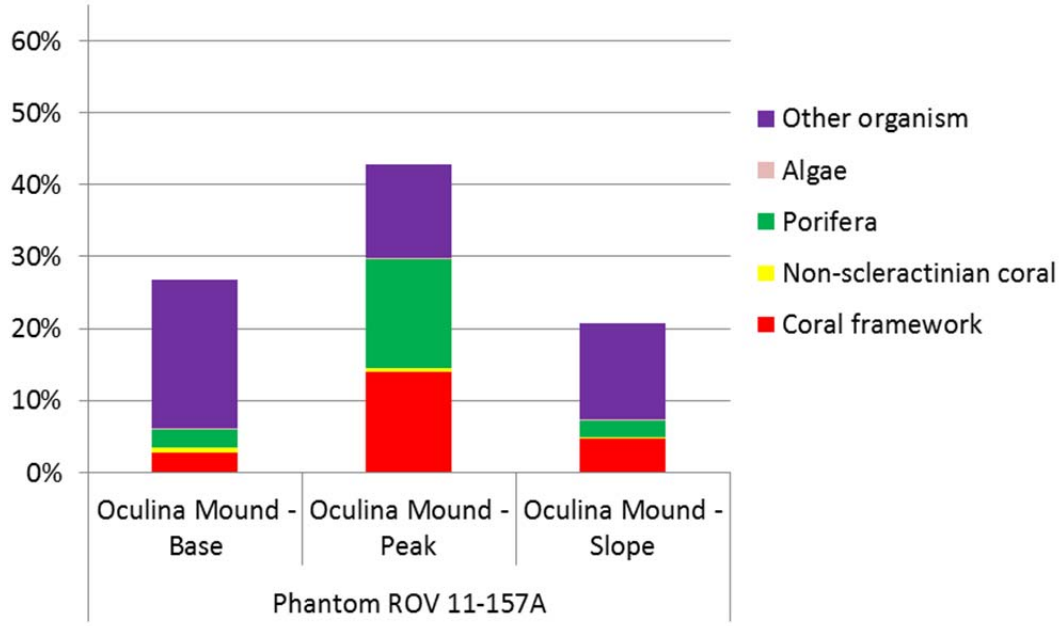


Figure 4. Percent cover of benthic macro-biota for each habitat zone at dive site 11-157A.

The percent cover of biota by habitat type shows the greatest cover of biota was on the *Oculina* mound peaks (42.87% cover). Coral framework was greatest on the peaks (13.89% cover) although 2.7% cover also was on the flat areas between the mounds. Sponge cover ranged from 15.2% cover on the mound peaks to 2.5% on the slopes and base.

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge" or "unidentified Demospongiae", which could consist of numerous species. These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different Classes.

Dive site 11-157A had a total of 43 benthic macro-fauna taxa, consisting of 18 Cnidaria and 3 Porifera (Table 2). Overall density of all benthic macro-fauna was 26.4 organisms/m^2. Cnidaria contributed to 33.5% of the total density at this site and Porifera 6.6%. Cnidaria and demosponges dominated with densities of 8.8 and 1.7 colonies/m^2, respectively. Antipatharia had 0.3 colonies/m^2 and Alcyonacea had 0.97. Scleractinia overall had 1.2 colonies/m^2, with standing *Oculina* colonies at 0.8. Of the sponges an unidentified *Chondosia*? sp. had a density of 0.2 colonies/m^2.

Table 2. Density of benthic macro-biota at site 11-157A (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**125**	**1.73**	**6.58%**
Demospongiae	**125**	**1.73**	**6.58%**

Chondrosida	17	0.24	0.89%
Chondrosia sp.	17	0.24	0.89%
Demospongiae	108	1.50	5.68%
Demospongiae	102	1.42	5.37%
Demospongiae- orange sphere	6	0.08	0.32%
Cnidaria	**638**	**8.85**	**33.56%**
Anthozoa	**431**	**5.98**	**22.67%**
Actiniaria	72	1.00	3.79%
Actiniaria	72	1.00	3.79%
Alcyonacea	70	0.97	3.68%
Alcyonacea	1	0.01	0.05%
Ellisellidae	20	0.28	1.05%
Eunicella sp.	6	0.08	0.32%
Gorgonacea (accepted as Alcyonacea)	7	0.10	0.37%
Nidalia occidentalis	23	0.32	1.21%
Telesto sp.	13	0.18	0.68%
Antipatharia	21	0.29	1.10%
Antipathidae	8	0.11	0.42%
Stichopathes lutkeni	7	0.10	0.37%
Tanacetipathes hirta	6	0.08	0.32%
Ceriantharia	49	0.68	2.58%
Cerianthidae	49	0.68	2.58%
Corallimorpharia	3	0.04	0.16%
Corallimorphus sp.	3	0.04	0.16%
Scleractinia	86	1.19	4.52%
Cladocora sp.	16	0.22	0.84%
Oculina varicosa	10	0.14	0.53%
Oculina varicosa- dead standing	49	0.68	2.58%
Scleractinia- unid cup	11	0.15	0.58%
Zoanthidea	130	1.80	6.84%
Zoanthidae	130	1.80	6.84%
Hydrozoa	**207**	**2.87**	**10.89%**
Leptothecata	43	0.60	2.26%
Aglaophenia trifida	43	0.60	2.26%
Hydrozoa	164	2.28	8.63%
Hydroidolina	164	2.28	8.63%
Annelida	**454**	**6.30**	**23.88%**
Polychaeta	**454**	**6.30**	**23.88%**
Amphinomida	1	0.01	0.05%
Hermodice carunculata	1	0.01	0.05%
Sabellida	225	3.12	11.84%
Sabellidae	214	2.97	11.26%
Serpulidae	11	0.15	0.58%

Dive Number: Phantom ROV 11-157A **Location:** USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

Polychaeta	228	3.16	11.99%
Mollusca	**4**	**0.06**	**0.21%**
Gastropoda	**4**	**0.06**	**0.21%**
Gastropoda	4	0.06	0.21%
Gastropoda	4	0.06	0.21%
Arthropoda	**234**	**3.25**	**12.31%**
Malacostraca	**215**	**2.98**	**11.31%**
Amphipoda	200	2.78	10.52%
Corophiidea	200	2.78	10.52%
Decapoda	15	0.21	0.79%
Majidae	1	0.01	0.05%
Paguroidea	12	0.17	0.63%
Stenorhynchus seticornis	2	0.03	0.11%
Maxillopoda	**6**	**0.08**	**0.32%**
Maxillopoda	6	0.08	0.32%
Cirripedia	6	0.08	0.32%
Pycnogonida	**13**	**0.18**	**0.68%**
Pantopoda	13	0.18	0.68%
Anoplodactylus lentus	13	0.18	0.68%
Echinodermata	**402**	**5.58**	**21.15%**
Asteroidea	**16**	**0.22**	**0.84%**
Valvatida	9	0.12	0.47%
Goniasteridae	9	0.12	0.47%
Asteroidea	7	0.10	0.37%
Asteroidea	7	0.10	0.37%
Crinoidea	**1**	**0.01**	**0.05%**
Comatulida	1	0.01	0.05%
Comatulida	1	0.01	0.05%
Echinoidea	**365**	**5.07**	**19.20%**
Arbacioda	205	2.85	10.78%
Arbacia punctulata	205	2.85	10.78%
Cidaroida	154	2.14	8.10%
Cidaroida	9	0.12	0.47%
Eucidaris tribuloides	145	2.01	7.63%
Diadematoida	6	0.08	0.32%
Centrostephanus longispinus	6	0.08	0.32%
Ophiuroidea	**20**	**0.28**	**1.05%**
Euryalida	4	0.06	0.21%
Asteroporpa annulata	4	0.06	0.21%
Ophiurida	16	0.22	0.84%
Ophioderma devaneyi	16	0.22	0.84%
Chordata	**16**	**0.22**	**0.84%**

Dive Number: Phantom ROV 11-157A **Location:** USA, Florida, Cape Canaveral, North Canaveral Oculina Mounds, Site 1, Reed Site DR14

Ascidiacea	**16**	**0.22**	**0.84%**
Aplousobranchia	14	0.19	0.74%
Didemnidae	10	0.14	0.53%
Trididemnum sp.	4	0.06	0.21%
Ascidiacea	2	0.03	0.11%
Ascidiacea	2	0.03	0.11%
Rhodophyta	**26**	**0.36**	**1.37%**
Florideophyceae	**1**	**0.01**	**0.05%**
Rhodymeniales	1	0.01	0.05%
Rhodymenia sp.	1	0.01	0.05%
Rhodophyta	**25**	**0.35**	**1.32%**
Rhodophyta	25	0.35	1.32%
Corallinales or Peyssonneliaceae	25	0.35	1.32%
Human debris	**2**	**0.03**	**0.11%**
Human debris	**2**	**0.03**	**0.11%**
Human debris	2	0.03	0.11%
Human debris- fish line/gear	1	0.01	0.05%
Human debris- unid.	1	0.01	0.05%
Grand Total	**1901**	**26.38**	**100.00%**

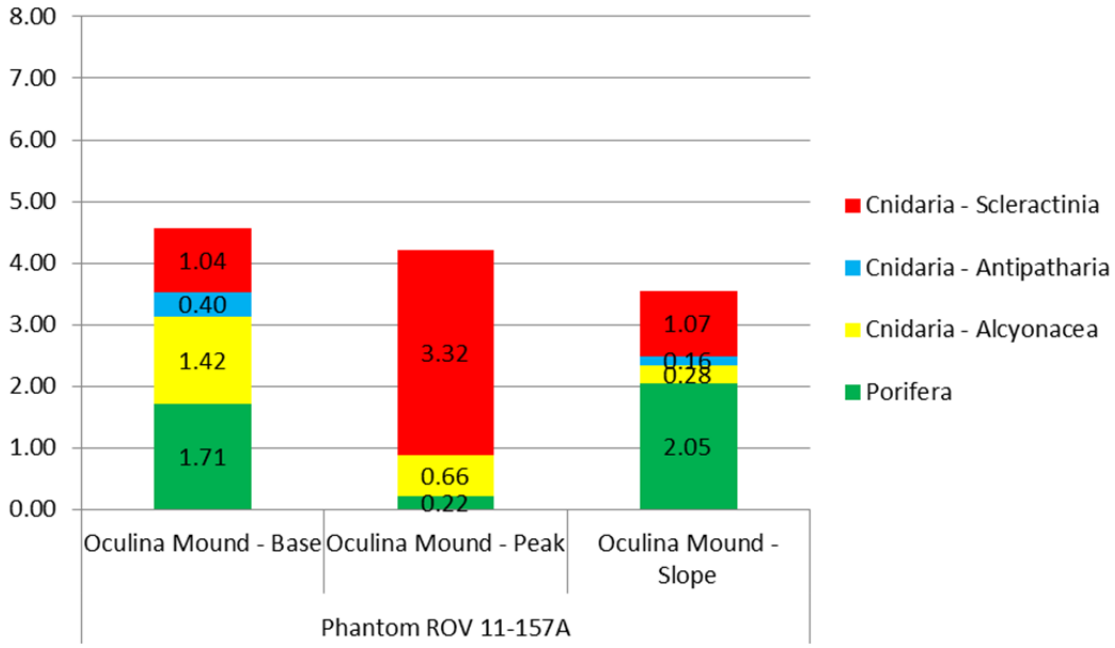


Figure 5. Density (number colonies/m^2) of Porifera, hard coral (Stylasteridae, Scleractinia), Antipatharia, and Alcyonacea (Gorgonacea) for each habitat zone at dive site 11-157A.

Figure 5 shows the density of Porifera and coral for each of the habitats at dive site 11-157A. Coral is defined as hard coral (Scleractinia), Antipatharia, and Gorgonacea. The *Oculina* peaks had the greatest density of Scleractinia coral (3.3 colonies/m^2) and Alcyonacea density was 0.7. Coral density was 1.0 colonies/m^2 in the flat areas between the mounds (base) and Alcyonacea were denser at the base. Sponge cover was 2.0

colonies/m^2 on the slopes, 1.7 at the base, and 0.2 on the peaks. In addition to these analyses of the digital still photo transects, a total count of live standing *Oculina* coral colonies was made from the forward-looking video camera for the entire dive. For this dive, 34 colonies were counted in the video and ranged in size from ~10 to 40 cm, which is equivalent to possibly 10-25 years old. Since the actual video field-of-view is just a small portion of the total mound area, we calculated the estimated field-of-view area for the dive [field-of-view width (~10 m) x transect length = area of the video transect]. From this we estimated the total number of live *Oculina* corals that may occur over the entire mound area at the dive site. In ArcGis we calculated the total planar surface area of the coral mounds that were transected during the dive which was 123,895 m^2. We then multiplied the density of coral in the video by the total mound surface area. We estimate a total of 114 live coral colonies may occur on these nine *Oculina* mounds.

Fish Data Analysis:

Video transects were used to analyze the fish populations and densities. Protocol for the fish analyses was to divide the continuous video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. A total of 26 taxa of fish were identified from dive site 11-157A for a total density of 812 individuals/km (Table 3). These were dominated by *Centropristes* spp (499 individuals/km; either black sea bass and/or bank sea bass but were too far away to distinguish), black sea bass (165), roughtongue bass (45) and bank sea bass (43). Managed and fished species included black sea bass (165 individuals/km), amberjack (5), red porgy (5), snowy grouper (3), and scamp (0.8).

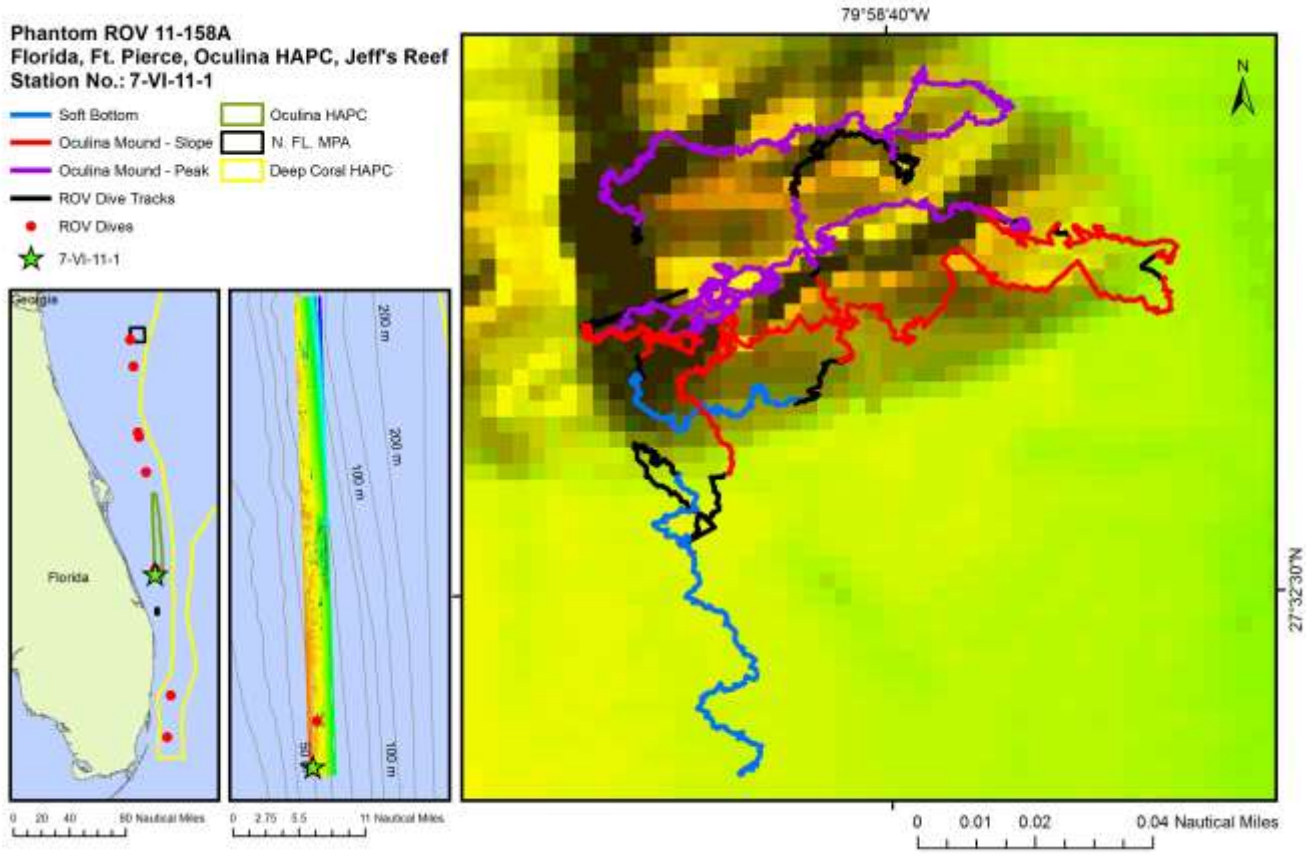
Table 3. Density of fish for all transects at dive site 11-157A (number individuals/km).

Common Name	Species Name	Density (#/km)
sea bass	*Centropristis sp.*	499.3
black sea bass	*Centropristis striata*	164.9
roughtongue bass	*Pronotogrammus martinicensis*	45.1
bank sea bass	*Centropristis aya*	43.5
tattler	*Serranus phoebe*	17.3
bank butterflyfish	*Prognathodes aya*	8.3
amberjack	*Seriola sp.*	4.8
red porgy	*Pagrus pagrus*	4.8
yellowtail reeffish	*Chromis enchrysurus*	4.5
snowy grouper	*Epinephelus niveatus*	2.9
short bigeye	*Pristigenys alta*	2.4
batfish	*Ogcocephalus sp.*	2.1
scorpionfish	Scorpaenidae	2.1
wrasse	*Halichoeres sp.*	2.1
wrasse bass	*Liopropoma eukrines*	1.9
flounder	Bothidae	1.1
red hogfish	*Decodon puellaris*	0.8
scamp	*Mycteroperca phenax*	0.8
toadfish	*Opsanus sp.*	0.8
anthiid	Anthiinae	0.5

blackbar drum	*Paraques iwamotoi*	0.3
blue angelfish	*Holacanthus bermudensis*	0.3
conger eel	Congridae	0.3
cusk eel	Ophidiidae	0.3
moray eel	Muraenidae	0.3
snake eel	Ophichthidae	0.3

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

General Location and Dive Track:



Site Overview:

Project:	2011 Extreme Corals, NOAA DSCP
Principal Investator:	Andrew W. David
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408
Website:	http://coralreef.noaa.gov/deepseacorals
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington
Data Management:	Access Database, Excel Spreadsheet, WinFrog
ROV Navigation Data:	WinFrog
Ship Position System:	DGPS
Report Analyst:	John Reed, Stephanie Farrington

Dive Overview:

Vessel:	NOAA Ship *Pisces*
Sonar Data:	
Purpose:	Map and characterize DSCE off SE USA
ROV:	NOAA SW Fisheries Super Phantom ROV
Sensors Used:	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Date of Dive:	6/7/2011
Specimens:	0
Digital Photos:	743
DVD:	4
Hard Drive:	2
Date Compiled:	2/20/2013

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

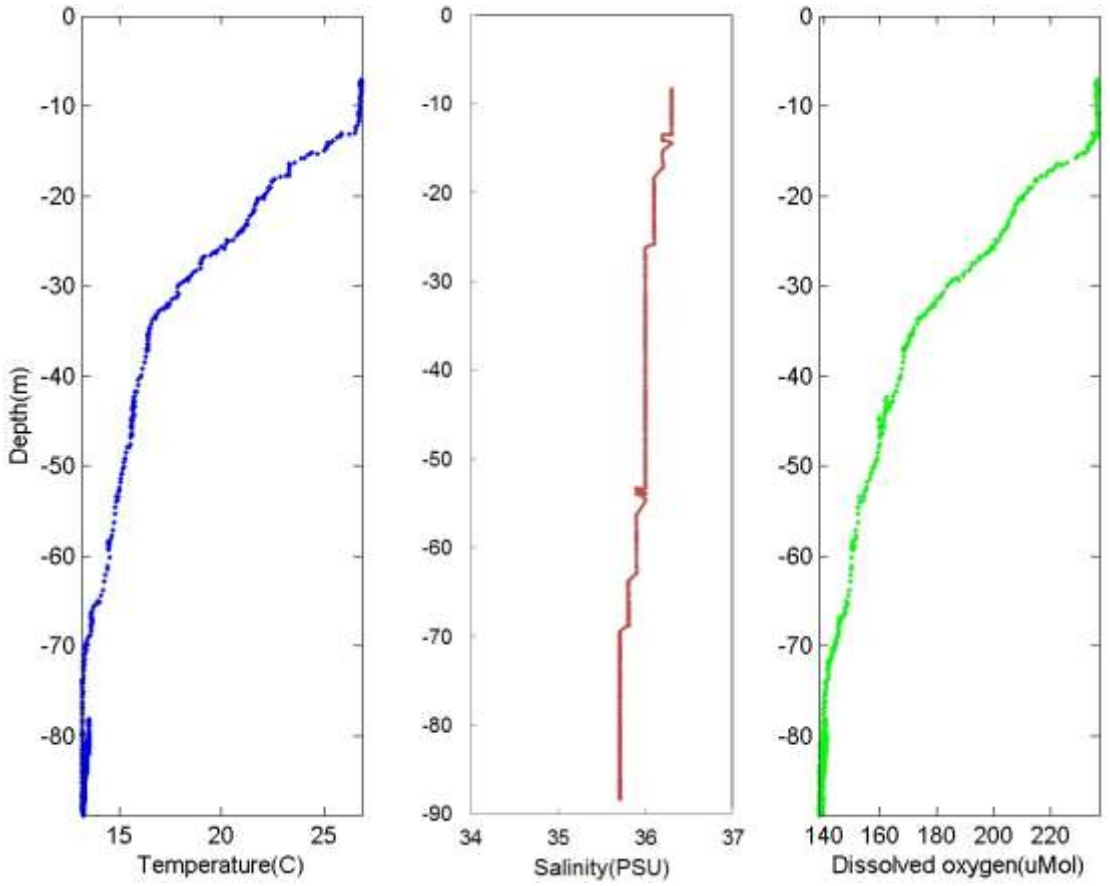
Dive Data:

Minimum Bottom Depth (m):	68	**Total Transect Length (km):**	1.733
Maximum Bottom Depth (m):	88	**Surface Current (kn):**	0.5
On Bottom (Time- GMT):	13:22	**On Bottom (Lat/Long):**	27°31.0853'N; 79°58.1966'W
Off Bottom (Time- GMT):	17:02	**Off Bottom (Lat/Long):**	27°32.5617'N; 79°58.7164'W

Physical (bottom); Temp (°C): 13.20 **Salinity:** 35.70 **Visibility (ft):** 30 **Current (kn):** 0.5

Physical Environment:

CTD Number 11-158A_CTDD



All CTD data were collected with the Super Phantom ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (88.2 m): temperature- 13.2, salinity- 35.7, and dissolved oxygen- 138.8. Surface temperature was 27.1 and there was a thermocline near 12-30 m depth; salinity peaked between 0 and 12 m, dissolved oxygen peaked at 0-13 m. Visibility was estimated at 9-12 m from the ROV video.

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

Dive Imagery:

Figure 1: 27°32.565'N, 79°58.6729'W 70 m

Dense *Oculina varicosa* coral thickets on top ridge of deepwater *Oculina* reef within the OHAPC. Note that the coral is wrapped in fishing line. Lost fishing gear including long lines and trawl nets are not uncommon even within the closed OHAPC.

Figure 2: 27°32.5485'N, 79°58.7082'W 72.5 m

Standing coral framework (Ivory tree coral- *Oculina varicosa*), both living and dead provide habitat to hundreds of species of benthic invertebrates and fish. Sponges (*Geodia* several spp.- flat top sponges, *Erylus*? sp.- grey lobate, Spirastrellidae- red-orange encrusting, Poecilosclerida- orange flabellate), Gorgonacea, and Hydroida. Red barbier (*Hemanthias vivanus*).

Figure 3: 27°32.5496'N, 79°58.7016'W 70.2 m

Scamp (*Mycteroperca phenax*; ~50 cm) on live deepwater *Oculina* coral reef. Ivory tree coral (*Oculina varicosa*), yellow sponge (*Geodia* sp.), grey lobate sponges (*Erylus* sp.), orange encrusters (Spirastrellidae), and spider crab (*Stenorhynchus seticornis*).

Figure 4: 27°32.5561'N, 79°58.6148'W 82.6 m

Snowy grouper (*Epinephelus niveatus*; ~50 cm) with school of red barbier (*Hemanthias vivanus*) on deepwater *Oculina* coral reef within the OHAPC. Large colony of live Ivory tree coral (*Oculina varicosa*) and scattered dead coral framework. Wire coral (*Stichopathes lutkeni*), orange sponge (Poecilosclerida), purple gorgonian (*Diodogorgia* sp.) with spaghetti brittlestar (*Asteroporpa annulata*).

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey *Oculina* coral mound inside the original *Oculina* HAPC (designated 1984). Target site- Jeff's Reef *Oculina* mound: 27° 31'N, 79° 58'W; 68-88 m.

Dive Events: Conducted several video/photo transects over the reef including south slope, peak ridges, and north slope using the multibeam sonar from Reed et al. 2005 (DSC Symp.). [Note- The *Phantom* ROV's top parallel lasers are calibrated at 20 cm, bottom lasers 61 cm. Depth recorded in WinFrog is correct; video overlay display is incorrect.]

Site Description/Habitat/Fauna: Jeff's Reef is an *Oculina* coral bioherm, ~360 m x 165 m diameter at the base, with three ridge peaks oriented E-W; maximum depth at the eastern base is 88 m and minimum peak depth is 68. The southern flank (20-45° slope) and peaks, facing the Florida Current are up to 100% coral cover, with thickets of standing live *Oculina varicosa* coral (azooxanthellate), 30-150 cm tall, standing dead coral and coral rubble. The north slope is less steep and dominated by coral rubble and less live coral. Top south ridge has 80-90% coral cover. Dominant fauna include: Fish- scamp (common, one supermale coloration), gag, black seabass, 50-cm burrows (blueline tilefish in soft sediment off the reef), roughtongue bass, bank seabass, scorpion fish, black drum, blue angel, cubbyu, barbier, wrasse bass, cardinal squirrelfish, moray, bigeye; Sponges- Demospongiae, *Erylus* sp., Theonellidae, Spirastrellidae; Cnidaria- *Oculina varicosa* (Ivory tree coral), *Stichopathes lutkeni*, Plexauridae, *Nidalia occidentalis*, hydroids, Cerianthidae, Antipatharia- *Tanacetipathes*, *Titanideum frauenfeldii*, *Arthropodium* (*Callipodium*), Corallimorpharia, Actiniaria; Echinoderms- *Holothuria lentigenosa enodis*, *Centrostephanus, Isostichopus badionotus*, *Coscinasterias.* Video of cable and fishing line on south base, longline, ball of net, trawl line through the coral.

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

Percent Cover of Benthic Macro-Biota and Substrate:

Phantom ROV 11-158A surveyed Jeff's Reef inside of the *Oculina* HAPC. The dive transects were divided into two habitat types: *Oculina* mound peak and *Oculina* mound slope. Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. Hard bottom in this region may consist of coral framework which is defined as standing colonial hard coral (either live or dead), coral rubble, rock pavement, or rock ledges. Site 11-158A was predominately hard bottom substrate (89.8% cover), consisting primarily of coral framework (37.9%), coral rubble (13.8%), but essentially no exposed rock pavement or ledges (Fig. 2, Table 1). Benthic macro-biota covered 76.4% of the bottom and consisted of 37.9% coral framework (21.2% live *Oculina*, 16.5% standing dead *Oculina*), 24.9% Porifera, 1.8% non-scleractinian coral, and 10.8% other organisms (Fig. 2, Table 1; see Table 2 for complete species list). Figure 3 shows the percent cover of substrate type for each habitat zone of the dive site. Basically there was little difference between the habitat zones. The cover of *Oculina* coral framework ranged from 43.7% on the mound slope to 36.1% at the peak; coral rubble was 11.7% and 14.5%, respectively. Dead coral is typically described as standing dead or coral rubble, however, it is recognized as live-bottom habitat, and is an important component of the habitat. Live coral, coral rubble, and standing dead coral provide habitat for hundreds of species of invertebrates and juvenile fish (e.g., Reed et al., 1982, 1987, 2002; Ross and Quattrini, 2007), in addition to commercially valuable species (e.g., Reed and Farrington, 2010).

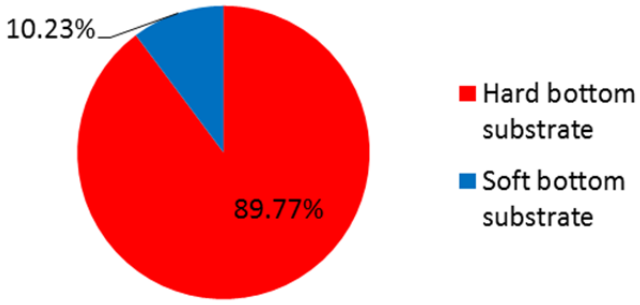


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-158A. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

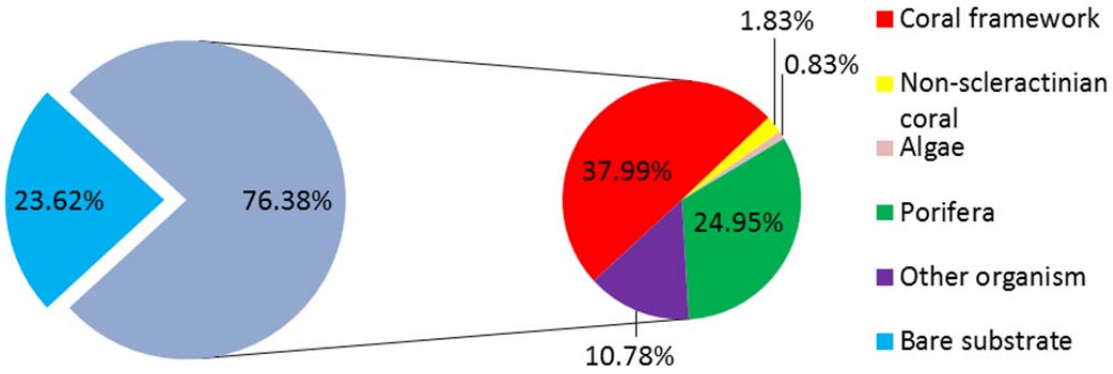


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-158A. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-158A.

Benthic macro-biota and substrate types	% Cover
Coral framework	**37.85%**
Oculina varicosa	21.25%
Scleractinia, unid	0.10%
Standing Dead Coral	16.51%
Non-scleractinian coral	**1.82%**
Alcyonacea	0.10%
Antipatharia	0.19%
Gorgonacea, Unid	1.54%
Porifera	**24.86%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	24.86%
Other organism	**10.74%**
Algae	**0.82%**
Algae- green, brown, red, or cyanobacteria	0.82%
Bare substrate	**23.53%**
Bare Soft Bottom substrate	9.68%
Coral rubble	13.80%
Rock- pavement, boulder, ledge	0.05%
Human debris	**0.38%**
Human debris- Other	0.38%
Grand Total	**100.00%**

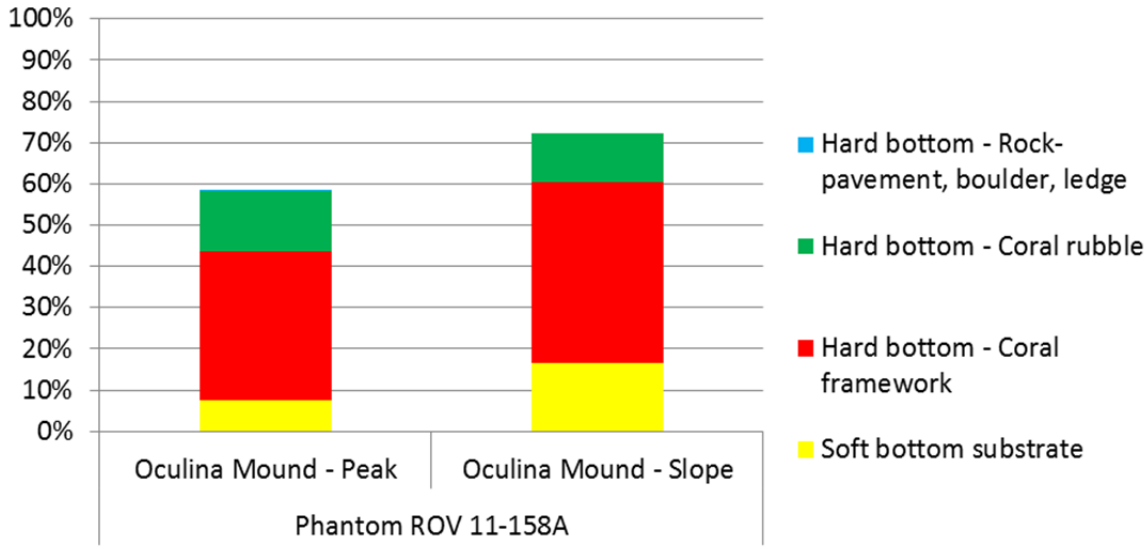


Figure 3. Percent cover of substrate types for each habitat zone at dive site 11-158A.

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

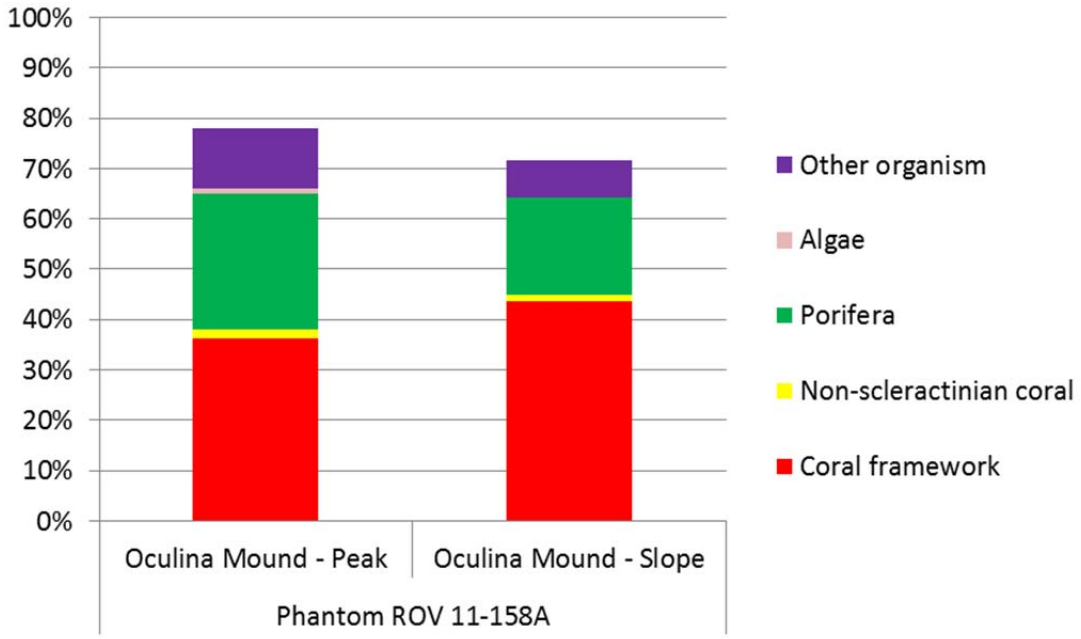


Figure 4. Percent cover of benthic macro-biota for each habitat zone at dive site 11-158A.

The percent cover of biota by habitat zone shows >70% cover for both habitats (Fig. 4). *Oculina* coral framework was the dominant biota on both the slope and peak (43.7 and 36.1 colonies/m^2, respectively), sponges ranged from 19.1 to 26.8, non-scleractinian corals were 1.3-2.0 colonies/m^2.

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge" or "unidentified Demospongiae", which could consist of numerous species. These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different Classes.

Dive site 11-158A had a total of 50 benthic macro-fauna taxa, consisting of 20 Cnidaria and 13 Porifera (Table 2). Overall density of all benthic macro-fauna was 58.9 organisms/m^2. Cnidaria contributed to 37.6% of the total density at this site, and Porifera 58.0%. Cnidaria and demosponges dominated with densities of 22.1 and 34.2 colonies/m^2, respectively. Antipatharia had 0.34 colonies/m^2 and Alcyonacea (primarily Gorgonacea) had 10.7. Scleractinia overall had 7.3 colonies/m^2, with standing live *Oculina* colonies at 6.1. Sponges were dominated by *Erylus* sp. (26.7 colonies/m^2), *Geodia* spp. (2.7), and Spirastrellidae (3.1).

Table 2. Density of benthic macro-biota at site 11-158A (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**3803**	**34.16**	**58.02%**

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

Demospongiae	**3803**	**34.16**	**58.02%**
Astrophorida	3272	29.39	49.92%
Erylus sp.	2968	26.66	45.28%
Geodia- flat top	203	1.82	3.10%
Geodia- flat top red	26	0.23	0.40%
Geodia- flat top yellow	64	0.57	0.98%
Geodia sp.	3	0.03	0.05%
Geodia sp.- tan sp ap pore	8	0.07	0.12%
Chondrosida	3	0.03	0.05%
Chondrosia sp.	3	0.03	0.05%
Hadromerida	351	3.15	5.35%
Spirastrellidae	351	3.15	5.35%
Poecilosclerida	27	0.24	0.41%
Poecilosclerida	27	0.24	0.41%
Verongida	2	0.02	0.03%
Aplysina sp.	2	0.02	0.03%
Demospongiae	148	1.33	2.26%
Demospongiae	127	1.14	1.94%
Demospongiae- am white	6	0.05	0.09%
Demospongiae- ye lobate	15	0.13	0.23%
Cnidaria	**2463**	**22.12**	**37.57%**
Anthozoa	**2298**	**20.64**	**35.06%**
Actiniaria	144	1.29	2.20%
Actiniaria	85	0.76	1.30%
Actiniaria- mat anemone	59	0.53	0.90%
Alcyonacea	1194	10.72	18.22%
Alcyonacea	2	0.02	0.03%
Callipodium rubens (=Anthopodium rubens)	7	0.06	0.11%
Diodogorgia sp.	64	0.57	0.98%
Gorgonacea (accepted as Alcyonacea)	1087	9.76	16.58%
Leptogorgia sp.	1	0.01	0.02%
Nicella sp.	1	0.01	0.02%
Nidalia occidentalis	31	0.28	0.47%
Telesto sp.	1	0.01	0.02%
Antipatharia	38	0.34	0.58%
Antipathidae	3	0.03	0.05%
Stichopathes lutkeni	30	0.27	0.46%
Tanacetipathes hirta	5	0.04	0.08%
Ceriantharia	53	0.48	0.81%
Cerianthidae	53	0.48	0.81%
Corallimorpharia	10	0.09	0.15%
Corallimorphus sp.	10	0.09	0.15%
Scleractinia	814	7.31	12.42%

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

Cladocora sp.	1	0.01	0.02%
Oculina varicosa	681	6.12	10.39%
Oculina varicosa- dead standing	131	1.18	2.00%
Phyllangia americana	1	0.01	0.02%
Zoanthidea	45	0.40	0.69%
Zoanthidae	45	0.40	0.69%
Hydrozoa	**165**	**1.48**	**2.52%**
Hydrozoa	165	1.48	2.52%
Hydroidolina	165	1.48	2.52%
Annelida	**7**	**0.06**	**0.11%**
Polychaeta	**7**	**0.06**	**0.11%**
Sabellida	7	0.06	0.11%
Mollusca	**4**	**0.04**	**0.06%**
Gastropoda	**4**	**0.04**	**0.06%**
Littorinimorpha	4	0.04	0.06%
Cypraea sp.	4	0.04	0.06%
Arthropoda	**66**	**0.59**	**1.01%**
Malacostraca	**54**	**0.49**	**0.82%**
Amphipoda	28	0.25	0.43%
Corophiidea	28	0.25	0.43%
Decapoda	26	0.23	0.40%
Decapoda	17	0.15	0.26%
Paguroidea	1	0.01	0.02%
Stenorhynchus seticornis	8	0.07	0.12%
Pycnogonida	**12**	**0.11**	**0.18%**
Pantopoda	12	0.11	0.18%
Anoplodactylus lentus	12	0.11	0.18%
Echinodermata	**133**	**1.19**	**2.03%**
Asteroidea	**53**	**0.48**	**0.81%**
Forcipulatida	53	0.48	0.81%
Coscinasterias tenuispina	53	0.48	0.81%
Echinoidea	**7**	**0.06**	**0.11%**
Arbacioda	5	0.04	0.08%
Arbacia punctulata	5	0.04	0.08%
Cidaroida	1	0.01	0.02%
Diadematoida	1	0.01	0.02%
Centrostephanus longispinus	1	0.01	0.02%
Holothuroidea	**35**	**0.31**	**0.53%**
Aspidochirotida	35	0.31	0.53%
Holothuria lengtiginosa	34	0.31	0.52%
Isostichopus badionotus	1	0.01	0.02%
Ophiuroidea	**38**	**0.34**	**0.58%**

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

Euryalida	22	0.20	0.34%
Asteroporpa annulata	22	0.20	0.34%
Ophiurida	1	0.01	0.02%
Ophiothrix sp.	1	0.01	0.02%
Ophiuroidea	15	0.13	0.23%
Chordata	**17**	**0.15**	**0.26%**
Ascidiacea	**17**	**0.15**	**0.26%**
Aplousobranchia	2	0.02	0.03%
Didemnidae	2	0.02	0.03%
Ascidiacea	15	0.13	0.23%
Ascidiacea	15	0.13	0.23%
Cyanophyta	**57**	**0.51**	**0.87%**
Cyanophyta	**57**	**0.51**	**0.87%**
Cyanophyta	57	0.51	0.87%
Cyanobacteria	57	0.51	0.87%
Human debris	**5**	**0.04**	**0.08%**
Human debris	**5**	**0.04**	**0.08%**
Human debris	5	0.04	0.08%
Human debris- fish line/gear	4	0.04	0.06%
Human debris- unid.	1	0.01	0.02%
Grand Total	**6555**	**58.88**	**100.00%**

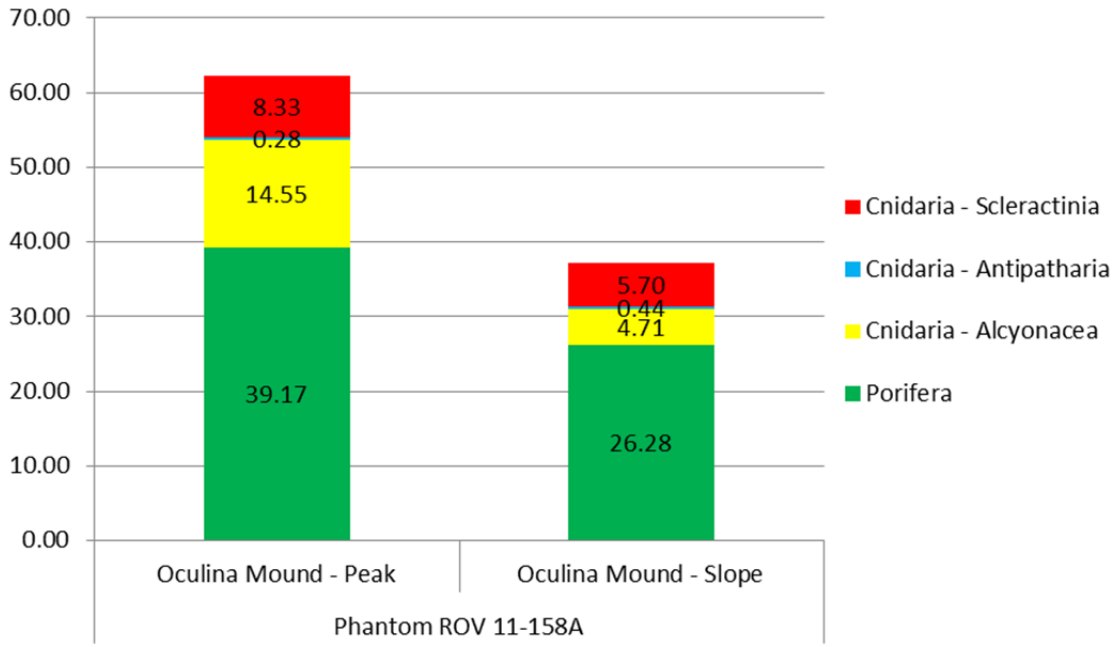


Figure 5. Density (number colonies/m^2) of Porifera, hard coral (Stylasteridae, Scleractinia), Antipatharia, and Alcyonacea (Gorgonacea) for each habitat zone at dive site 11-158A.

Dive Number: Phantom ROV 11-158A **Location:** USA, Florida, Ft. Pierce, Oculina HAPC, Jeff's Reef

Figure 5 shows the density of Porifera and coral for each of the habitats at dive site 11-158A. Coral is defined as hard coral (Scleractinia), Antipatharia, and Gorgonacea. The *Oculina* mound peak had greater overall biota density (60.9 organisms/m^2) than the mound slope (35.9); Scleractinian coral (all species) ranged from 8.3 to 5.7 on the peak and slope, respectively; and sponges were also very dense on the peak and slope (39.2 and 26.3 colonies/m^2, respectively) as were Alcyonacea (primarily Gorgonacea; 14.5 and 4.7, respectively).

Fish Data Analysis:

Video transects were used to analyze the fish populations and densities. Protocol for the fish analyses was to divide the continuous video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. A total of 33 taxa of fish were identified from dive site 11-158A for a total density of 2738 individuals/km (Table 3). These were dominated by anthiids (unidentified Anthiinae, primarily roughtongue bass and red barrier; 2565 individuals/km), roughtongue bass (41), and bank butterflyfish (27). Managed and fished species included scamp (12.7), amberjack spp. (2.9), blueline tilefish (1.2), snowy grouper (1.2), and gag grouper (0.6).

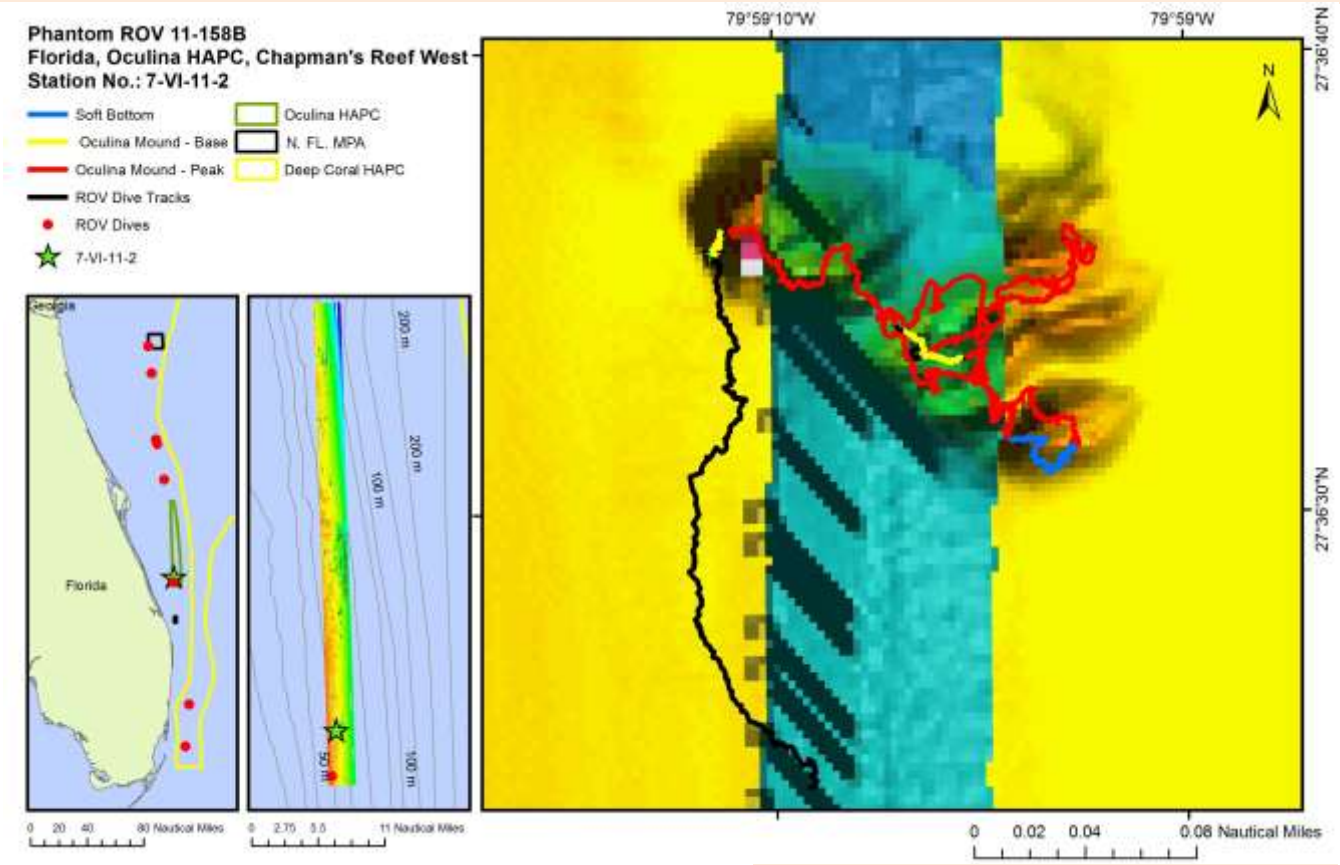
Table 3. Density of fish for all transects at dive site 11-158A (number individuals/km).

Common Name	Species Name	Density (#/km)
anthiids	Anthiinae	2565.5
roughtongue bass	*Pronotogrammus martinicensis*	41.0
bank butterflyfish	*Prognathodes aya*	27.1
sea bass	*Centropristis sp.*	25.4
scamp	*Mycteroperca phenax*	12.7
bank sea bass	*Centropristis ocyurus*	12.1
cubbyu	*Equetus umbrosus*	12.1
short bigeye	*Pristigenys alta*	7.5
tattler	*Serranus phoebe*	4.0
yellowtail reeffish	*Chromis enchrysurus*	3.5
scorpionfish	Scorpaenidae	2.9
amberjack	*Seriola sp.*	2.3
red barbier	*Hemanthias vivanus*	2.3
searobin	Triglidae	2.3
wrasse bass	*Liopropoma eukrines*	2.3
blue angelfish	*Holacanthus bermudensis*	1.7
sea bass	*Serranus sp.*	1.7
batfish	*Ogcocephalus sp.*	1.2
tilefish	*Caulolatilus sp.*	1.2
purple reeffish	*Chromis scotti*	1.2
reticulate moray eel	*Muraena retifera*	1.2
snowy grouper	*Epinephelus niveatus*	1.2
apricot bass	*Plectranthias garrupellus*	0.6
belted sand bass	*Serranus subligarius*	0.6

black sea bass	*Centropristis striata*	0.6
flounder	Bothidae	0.6
gag grouper	*Mycteroperca microlepis*	0.6
greater amberjack	*Seriola dumerili*	0.6
moray eel	Muraenidae	0.6
orangeback bass	*Serranus annularis*	0.6
red hogfish	*Decodon puellaris*	0.6
soldierfish	Holocentridae	0.6
wrasse	*Halichoeres sp.*	0.6

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

General Location and Dive Track:



Site Overview:

Project:	2011 Extreme Corals, NOAA DSCP
Principal Investator:	Andrew W. David
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408
Website:	http://coralreef.noaa.gov/deepseacorals
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington
Data Management:	Access Database, Excel Spreadsheet, WinFrog
ROV Navigation Data:	WinFrog
Ship Position System:	DGPS
Report Analyst:	John Reed, Stephanie Farrington

Dive Overview:

Vessel:	NOAA Ship *Pisces*
Sonar Data:	Chapman test: chapman_S_N.tif
Purpose:	Map and characterize DSCE off SE USA
ROV:	NOAA SW Fisheries Super Phantom ROV
Sensors Used:	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Date of Dive:	6/7/2011
Specimens:	0
Digital Photos:	541
DVD:	4
Hard Drive:	1
Date Compiled:	2/20/2013

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

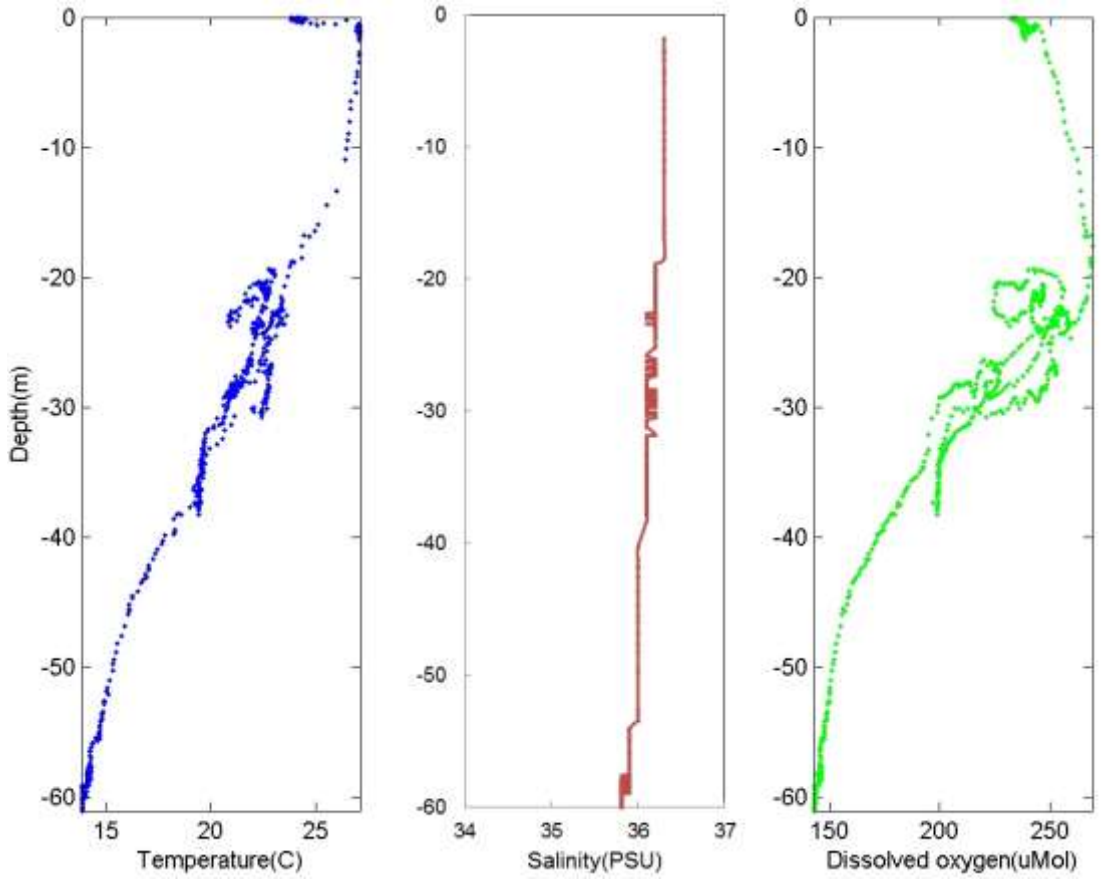
Dive Data:

Minimum Bottom Depth (m):	64	**Total Transect Length (km):**	1.926
Maximum Bottom Depth (m):	74	**Surface Current (kn):**	.25
On Bottom (Time- GMT):	19:12	**On Bottom (Lat/Long):**	27°36.3984'N; 79°59.1549'W
Off Bottom (Time- GMT):	22:05	**Off Bottom (Lat/Long):**	27°36.5555'N; 79°59.1135'W

Physical (bottom); Temp (°C): 13.47 **Salinity:** 35.70 **Visibility (ft):** 60+ **Current (kn):** 0.25

Physical Environment:

CTD Number 11-158B_CTDU



All CTD data were collected with the Super Phantom ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (61 m): temperature- 13.9, salinity- 35.8, and dissolved oxygen- 143.1. Surface temperature was 27.2 and there was no distinct thermocline; salinity peaked between 0 and 18 m, dissolved oxygen peaked at 20 m. Visibility was estimated at 18-21 m from the ROV video.

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

Dive Imagery:

Figure 1: 27°36.571'N, 79°59.1255'W 67.4 m

Thickets of live Ivory tree coral (*Oculina varicosa*) growing on the ridges of the deepwater Oculina coral reef within the OHAPC. Encrusting the dead standing coral are sponges (*Geodia* spp.- flat top sponge, *Erylus* sp.- grey lobate, Spirastrellidae- red-orange), Gorgonacea, and Hydroida. Red barbier (*Hemanthias vivanus*).

Figure 2: 27°36.583'N, 79°59.1513'W 72.9 m

Trawl net wrapped around the Ivory tree coral (*Oculina varicosa*). Unfortunately although protected since 1984 as an OHAPC, lost fishing gear including fishing lines, long lines, and trawl nets are not uncommon on these deepwater reefs.

Figure 3: 27°36.5932'N, 79°59.047'W 68.3 m

The standing dead coral framework and coral rubble still provide habitat for many benthic species. Small live *Oculina varicosa* colonies like these (10-20 cm diameter) are relatively new growth, less than 10-20 years old. The coral rubble provides habitat for other species too, including purple gorgonians (*Diodogorgia* sp)., spaghetti brittlestars (*Asteroporpa annulata*), fire-ball corals (*Nidalia occidentalis*), and sponges (Spirastrellidae and Poecilosclerida).

Figure 4: 27°36.5413'N, 79°59.0642'W 67.1 m

Concrete reef blocks were place within the OHAPC in the late 1990s and early 2000s as an experiment to attract coral settlement and fish, especially in dead rubble areas. This live Ivory tree coral, *Oculina varicosa*, has settled and grown on the block since 1997.

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey *Oculina* coral mound inside the original *Oculina* HAPC (designated 1984). Target site- Chapman's Reef West *Oculina* mound: 27° 35'N, 79° 58'W; 64-74 m.

Dive Events: Conducted several video/photo transects including south slope and along the three peak ridges ground truthing the multibeam sonar from Reed et al. 2005 (DSC Symp.) and *Pisces* multibeam sonar. [Note- The *Phantom* ROV's top parallel lasers are calibrated at 20 cm, bottom lasers 61 cm. Depth recorded in WinFrog is correct; video overlay display is incorrect.]

Site Description/Habitat/Fauna: Chapman's Reef West is an *Oculina* coral bioherm, ~350 x 230 m, oriented NW-SE; maximum depth is 74 m and minimum depth is 64 m. Coral cover is greatest along the south face and along the edges of the three NW-SE ridges where live *Oculina varicosa* coral colonies (azooxanthellate) average 20-50 cm diameter but a few are up to 1 m. The coverage in these areas vary from 10-20% live coral up to 30-50% live along with coral rubble. The ridge tops tend to have greater percentage of coral rubble and few standing corals. At least six artificial reef blocks (~1 m x 1 m aggregates of concrete blocks; deployed in 1996-1998 by C. Koenig) were found; a few live colonies of *O. varicosa* are growing on some. On top of the reef are areas of thick deposits of a grey mud with pudding-like consistency which appears unnatural but similar to that seen on nearshore reefs which had been covered from coastal dredging projects. Dominant fauna include: Fish- scamp, black seabass, scorpaenids, puffer, wrasse bass, short bigeye, bank butterfly, spotted moray, black drum, anthiids, queen angelfish, damselfish; Sponges- demosponges; Cnidaria- *Oculina varicosa* (Ivory tree coral), *Stichopathes*, Plexauridae, Pennatulacea- *Virgularia*, *Anthomastus*, hydroids, Cerianthidae, Antipatharia- *Tanacetipathes*, *Arthropodium* (*Callipodium*), Corallimorpharia, Actiniaria; Echinoderms- *Holothuria lentigenosa*, *Centrostephanus*, *Astroporpa annulata*, *Ophioderma*, *Narcissia trigonaria*. Video of fish net on 1-m *Oculina* colony, trawl net, long lines, and a fish net by a dead coral.

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

Percent Cover of Benthic Macro-Biota and Substrate:

Phantom ROV 11-158B surveyed Chapman's Reef West inside of the *Oculina* HAPC. The dive transects were divided into two habitat types: *Oculina* mound peak (peak and slope were combined as the mound is fairly low relief), and *Oculina* mound base (valleys between the peaks). Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. Hard bottom in this region may consist of coral framework which is defined as standing colonial hard coral (either live or dead), coral rubble, rock pavement, or rock ledges. Site 11-158B was predominately hard bottom substrate (77.8% cover), consisting primarily of coral framework (29.2%), coral rubble (16.6%), but essentially no exposed rock pavement or ledges (Fig. 2, Table 1). Benthic macro-biota covered 62.3% of the bottom and consisted of 29% coral framework (12.5% live *Oculina*, 15.8% standing dead *Oculina*), 20.0% Porifera, 3.3% non-scleractinian coral, and 7.8% other organisms (Fig. 2, Table 1; see Table 2 for complete species list). Figure 3 shows the percent cover of substrate type for each habitat zone of the dive site. Basically there was little difference between the habitat zones. The cover of coral framework ranged from 29.5% on the mound to 26.3% in the valleys between the ridges (base); coral rubble was 16.6% and 16.8%, respectively. Dead coral is typically described as standing dead or coral rubble, however, it is recognized as live-bottom habitat, and is an important component of the habitat. Live coral, coral rubble, and standing dead coral provide habitat for hundreds of species of invertebrates and juvenile fish (e.g., Reed et al., 1982, 1987, 2002; Ross and Quattrini, 2007), in addition to commercially valuable species (e.g., Reed and Farrington, 2010).

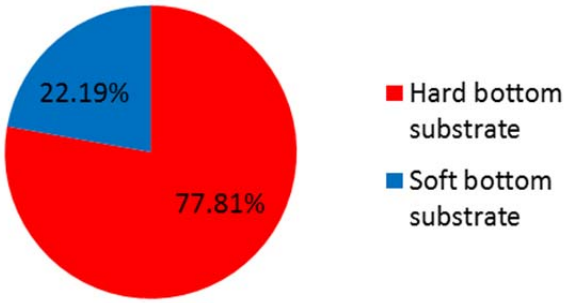


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-158B. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

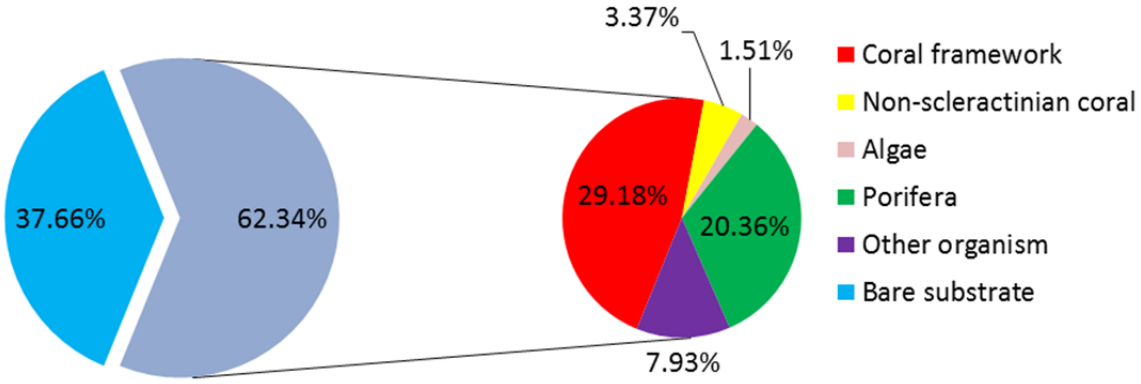


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-158B. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-158B.

Benthic macro-biota and substrate types	% Cover
Coral framework	**28.67%**
Oculina varicosa	12.55%
Scleractinia, unid	0.27%
Standing Dead Coral	15.85%
Non-scleractinian coral	**3.31%**
Alcyonacea	0.64%
Antipatharia	1.11%
Gorgonacea, Unid	1.56%
Porifera	**20.02%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	20.02%
Other organism	**7.80%**
Algae	**1.48%**
Algae- green, brown, red, or cyanobacteria	1.48%
Bare substrate	**37.02%**
Bare Soft Bottom substrate	20.46%
Coral rubble	16.34%
Rock- pavement, boulder, ledge	0.02%
Rubble	0.21%
Human debris	**1.70%**
Fish/crab trap	0.03%
Human debris- Other	1.45%
Trawl gear	0.22%
Grand Total	**100.00%**

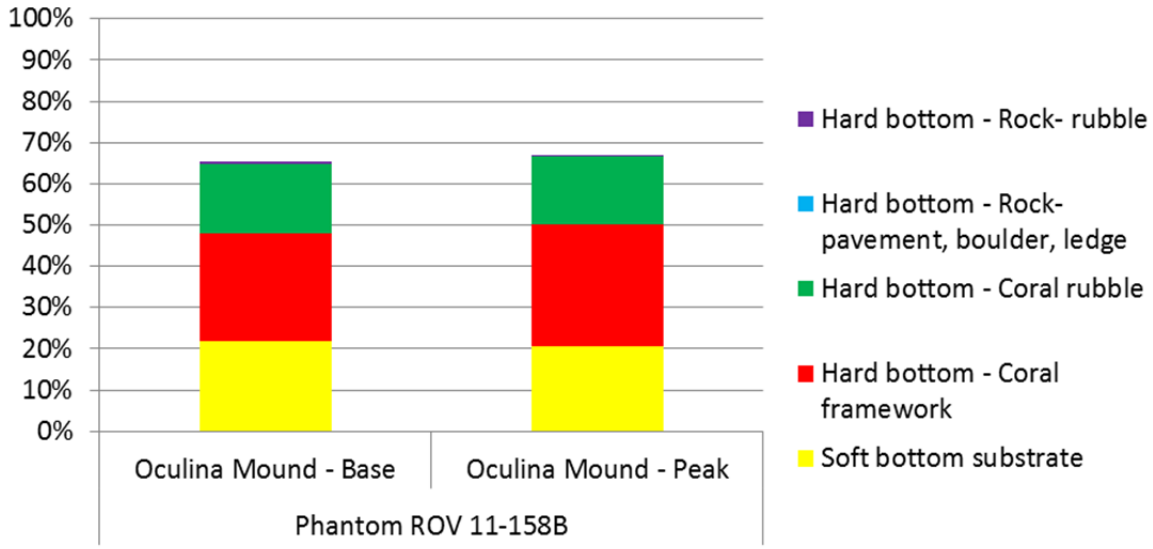


Figure 3. Percent cover of substrate types for each habitat zone at dive site 11-158B.

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

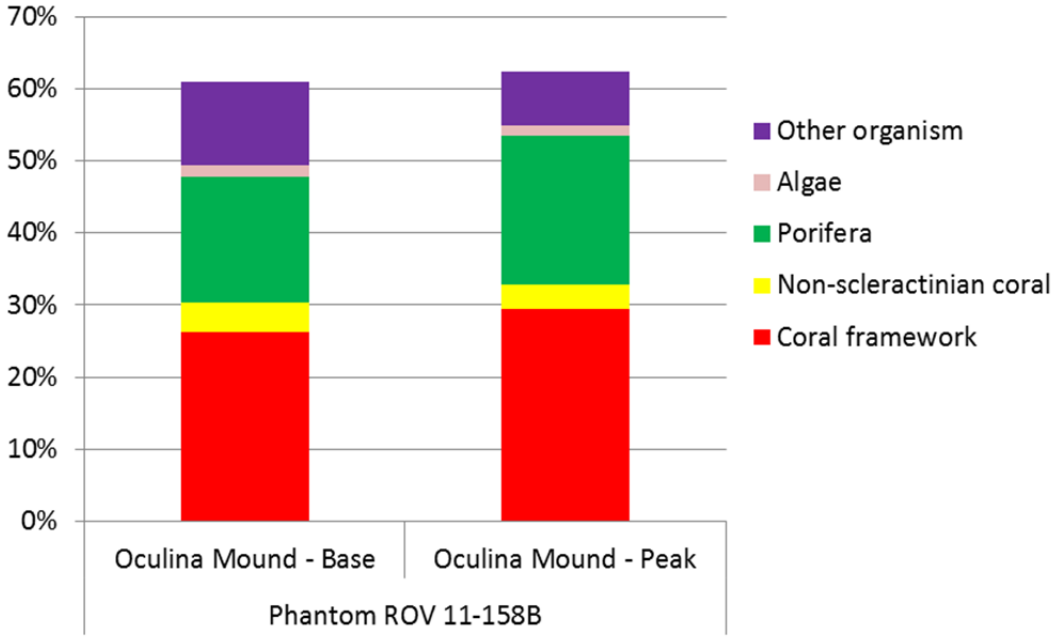


Figure 4. Percent cover of benthic macro-biota for each habitat zone at dive site 11-158B.

The percent cover of biota by habitat type shows >60% cover for both habitats (Fig. 4). *Oculina* coral framework was the dominant biota (26-29% cover), sponges ranged from 20.7% to 17.3%, and other biota were 11.5 to 7.5%.

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge" or "unidentified Demospongiae", which could consist of numerous species. These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different Classes.

Dive site 11-158B had a total of 54 benthic macro-fauna taxa, consisting of 19 Cnidaria and 9 Porifera (Table 2). Overall density of all benthic macro-fauna was 30.4 organisms/m^2. Cnidaria contributed to 56.6% of the total density at this site, and Porifera 32.4%. Cnidaria and demosponges dominated with densities of 17.2 and 9.9 colonies/m^2, respectively. Antipatharia had a density of .68 colonies/m^2 and Alcyonacea had 9.1. Scleractinia overall had 5.5 colonies/m^2, with standing live *Oculina* colonies at 4.1. Sponges were dominated by *Erylus* sp. (5.57 colonies/m2), *Geodia* spp. (0.8), and Spirastrellidae (2.7).

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

Table 2. Density of benthic macro-biota at site 11-158B (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**910**	**9.87**	**32.43%**
Demospongiae	**910**	**9.87**	**32.43%**
Astrophorida	587	6.37	20.92%
Erylus sp.	513	5.57	18.28%
Geodia- flat top	34	0.37	1.21%
Geodia- flat top red	15	0.16	0.53%
Geodia- flat top yellow	24	0.26	0.86%
Geodia sp.	1	0.01	0.04%
Hadromerida	254	2.76	9.05%
Spirastrellidae	254	2.76	9.05%
Poecilosclerida	4	0.04	0.14%
Poecilosclerida	4	0.04	0.14%
Demospongiae	65	0.71	2.32%
Demospongiae	63	0.68	2.25%
Demospongiae- am white	2	0.02	0.07%
Cnidaria	**1589**	**17.24**	**56.63%**
Anthozoa	**1508**	**16.36**	**53.74%**
Actiniaria	13	0.14	0.46%
Actiniaria	13	0.14	0.46%
Alcyonacea	838	9.09	29.86%
Alcyonacea	1	0.01	0.04%
Callipodium rubens (=Anthopodium rubens)	8	0.09	0.29%
Diodogorgia sp.	28	0.30	1.00%
Ellisellidae	1	0.01	0.04%
Gorgonacea (accepted as Alcyonacea)	689	7.48	24.55%
Nicella sp.	1	0.01	0.04%
Nidalia occidentalis	110	1.19	3.92%
Antipatharia	63	0.68	2.25%
Antipathidae	20	0.22	0.71%
Stichopathes lutkeni	37	0.40	1.32%
Tanacetipathes hirta	6	0.07	0.21%
Ceriantharia	19	0.21	0.68%
Cerianthidae	19	0.21	0.68%
Corallimorpharia	21	0.23	0.75%
Corallimorphus sp.	21	0.23	0.75%
Scleractinia	504	5.47	17.96%
Oculina varicosa	381	4.13	13.58%
Oculina varicosa- dead standing	112	1.22	3.99%
Phyllangia americana	9	0.10	0.32%

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

Scleractinia- unid colonial	1	0.01	0.04%
Scleractinia- unid cup	1	0.01	0.04%
Zoanthidea	50	0.54	1.78%
Zoanthidae	50	0.54	1.78%
Hydrozoa	**81**	**0.88**	**2.89%**
Hydrozoa	81	0.88	2.89%
Hydroidolina	81	0.88	2.89%
Annelida	**67**	**0.73**	**2.39%**
Polychaeta	**67**	**0.73**	**2.39%**
Amphinomida	1	0.01	0.04%
Hermodice carunculata	1	0.01	0.04%
Sabellida	25	0.27	0.89%
Sabellidae	25	0.27	0.89%
Polychaeta	41	0.44	1.46%
Mollusca	**2**	**0.02**	**0.07%**
Gastropoda	**2**	**0.02**	**0.07%**
Littorinimorpha	2	0.02	0.07%
Cypraea sp.	2	0.02	0.07%
Arthropoda	**25**	**0.27**	**0.89%**
Malacostraca	**13**	**0.14**	**0.46%**
Amphipoda	1	0.01	0.04%
Corophiidea	1	0.01	0.04%
Chelicerata	5	0.05	0.18%
Pycnogonida	5	0.05	0.18%
Decapoda	7	0.08	0.25%
Decapoda	2	0.02	0.07%
Stenorhynchus seticornis	5	0.05	0.18%
Pycnogonida	**12**	**0.13**	**0.43%**
Pantopoda	12	0.13	0.43%
Anoplodactylus lentus	12	0.13	0.43%
Echinodermata	**158**	**1.71**	**5.63%**
Asteroidea	**121**	**1.31**	**4.31%**
Forcipulatida	100	1.09	3.56%
Coscinasterias tenuispina	100	1.09	3.56%
Valvatida	1	0.01	0.04%
Goniasteridae	1	0.01	0.04%
Asteroidea	20	0.22	0.71%
Asteroidea	17	0.18	0.61%
Asteroidea- red spotted	3	0.03	0.11%
Echinoidea	**17**	**0.18**	**0.61%**
Arbacioda	4	0.04	0.14%
Arbacia punctulata	4	0.04	0.14%

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

Cidaroida	1	0.01	0.04%
Eucidaris tribuloides	1	0.01	0.04%
Diadematoida	12	0.13	0.43%
Centrostephanus longispinus	12	0.13	0.43%
Holothuroidea	**12**	**0.13**	**0.43%**
Aspidochirotida	10	0.11	0.36%
Holothuria lengtiginosa	9	0.10	0.32%
Isostichopus badionotus	1	0.01	0.04%
Holothuroidea	2	0.02	0.07%
Holothuroidea	2	0.02	0.07%
Ophiuroidea	**8**	**0.09**	**0.29%**
Euryalida	5	0.05	0.18%
Asteroporpa annulata	5	0.05	0.18%
Ophiuroidea	3	0.03	0.11%
Chordata	**13**	**0.14**	**0.46%**
Ascidiacea	**13**	**0.14**	**0.46%**
Aplousobranchia	2	0.02	0.07%
Didemnidae	2	0.02	0.07%
Ascidiacea	11	0.12	0.39%
Ascidiacea	11	0.12	0.39%
Cyanophyta	**25**	**0.27**	**0.89%**
Cyanophyta	**25**	**0.27**	**0.89%**
Cyanophyta	25	0.27	0.89%
Cyanobacteria	25	0.27	0.89%
Rhodophyta	**10**	**0.11**	**0.36%**
Rhodophyta	**10**	**0.11**	**0.36%**
Rhodophyta	10	0.11	0.36%
Corallinales or Peyssonneliaceae	6	0.07	0.21%
Rhodophyta- flat oval	4	0.04	0.14%
Human debris	**7**	**0.08**	**0.25%**
Human debris	**7**	**0.08**	**0.25%**
Human debris	7	0.08	0.25%
Human debris- cans/bottles	2	0.02	0.07%
Human debris- net	4	0.04	0.14%
Human debris- unid.	1	0.01	0.04%
Grand Total	**2806**	**30.45**	**100.00%**

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

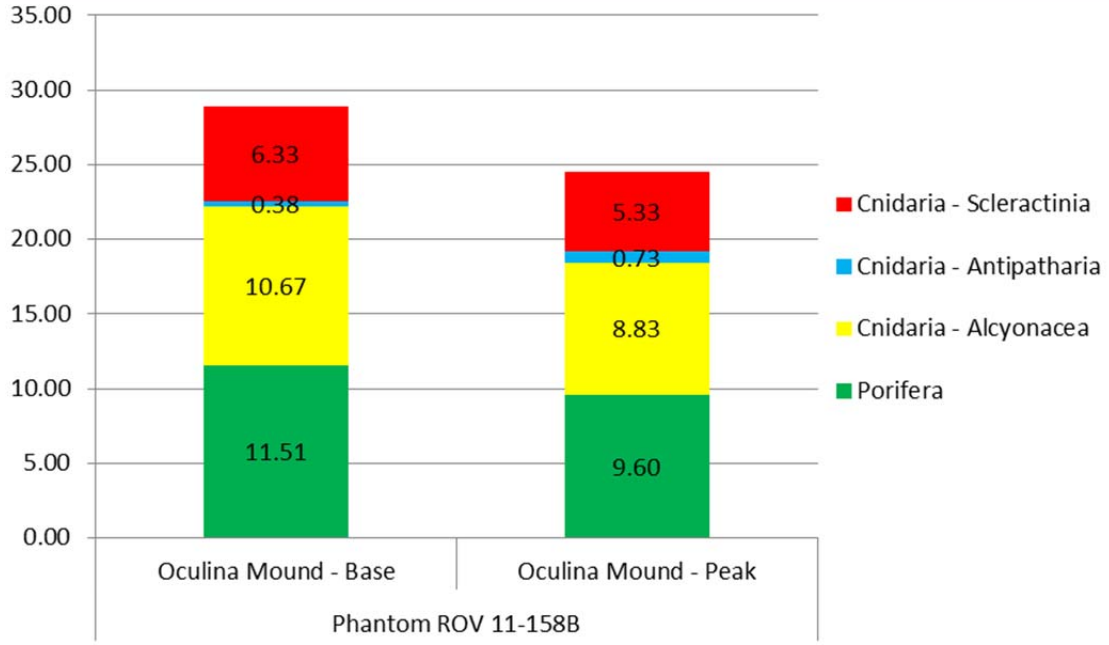


Figure 5. Density (number colonies/m^2) of Porifera, hard coral (Stylasteridae, Scleractinia), Antipatharia, and Alcyonacea (Gorgonacea) for each habitat zone at dive site 11-158B.

Figure 5 shows the density of Porifera and coral for each of the habitats at dive site 11-158B. Coral is defined as hard coral (Scleractinia), Antipatharia, and Gorgonacea. The *Oculina* peaks and base had similar densities of scleractinian corals (5.3 and 6.3 colonies/m^2, respectively), sponges ranged from 9.6 to 11.5, respectively, and Alcyonacea were 8.8 to 10.7.

Fish Data Analysis:

Video transects were used to analyze the fish populations and densities. Protocol for the fish analyses was to divide the continuous video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. A total of 24 taxa of fish were identified from dive site 11-158B for a total density of 1160 individuals/km (Table 3). These were dominated by anthiids (unidentified Anthiinae, primarily roughtongue bass and/or red barbier but were too far away to distinguish; 845 individuals/km), red barbier (103), and *Centropristes* sp. (41 individuals/km; either black sea bass and/or bank sea bass but were too far away to distinguish). Managed and fished species included black sea bass (11 individuals/km), scamp (1.6), amberjack and vermillion snapper (1.5/km each).

Table 3. Density of fish for all transects at dive site 11-158B (number individuals/km).

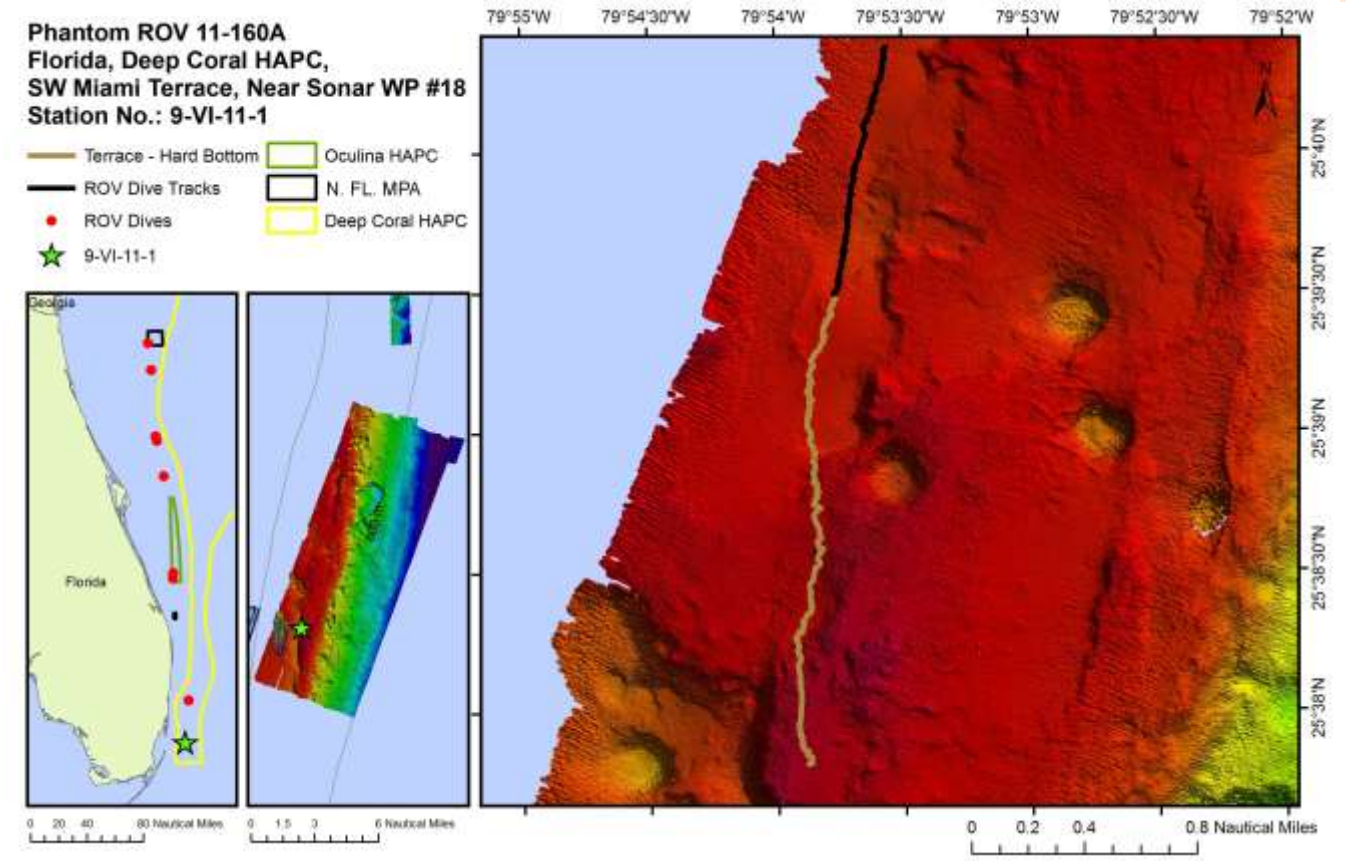
Common Name	Species Name	Density (#/km)
anthiids	Anthiinae	845.3
red barbier	*Hemanthias vivanus*	102.8
sea bass	*Centropristis sp.*	41.5
roughtongue bass	*Pronotogrammus marinicensis*	37.9
bank butterflyfish	*Prognathodes aya*	27.5

Dive Number: Phantom ROV 11-158B **Location:** USA, Florida, Oculina HAPC, Chapman's Reef West

cubbyu	*Equetus umbrosus*	21.3
bank sea bass	*Centropristis ocyurus*	17.1
tattler	*Serranus phoebe*	16.6
black sea bass	*Centropristis striata*	11.4
scorpionfish	Scorpaenidae	8.3
short bigeye	*Pristigenys alta*	8.3
yellowtail reeffish	*Chromis enchrysurus*	6.7
wrasse bass	*Liopropoma eukrines*	4.2
reticulate moray eel	*Muraena retifera*	3.1
scamp	*Mycteroperca phenax*	1.6
blue angelfish	*Holacanthus bermudensis*	1.0
sea bass	*Serranus sp.*	1.0
wrasse	*Halichoeres sp.*	1.0
greater amberjack	*Seriola dumerili*	0.5
lizardfish	*Synodus sp.*	0.5
porcupinefish	*Diodon hystrix*	0.5
red hogfish	*Decodon puellaris*	0.5
sand diver	*Synodus intermedius*	0.5
vermilion snapper	*Rhomboplites aurorubens*	0.5

Dive Number:	Phantom ROV 11-160A	**Location:**	USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

General Location and Dive Track:



Site Overview:		**Dive Overview:**	
Project:	2011 Extreme Corals, NOAA DSCP	**Vessel:**	NOAA Ship *Pisces*
Principal Investator:	Andrew W. David	**Sonar Data:**	Miami Terrace: Miami_terrace_west.tif
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408	**Purpose:**	Map and characterize DSCE off SE USA
Website:	http://coralreef.noaa.gov/deepseacorals	**ROV:**	NOAA SW Fisheries Super Phantom ROV
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington	**Sensors Used:**	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Data Management:	Access Database, Excel Spreadsheet, WinFrog	**Date of Dive:**	6/9/2011
		Specimens:	0
ROV Navigation Data:	WinFrog	**Digital Photos:**	289
Ship Position System:	DGPS	**DVD:**	6
Report Analyst:	John Reed, Stephanie Farrington	**Hard Drive:**	1
		Date Compiled:	2/20/2013

Dive Number:	Phantom ROV 11-160A	**Location:**	USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

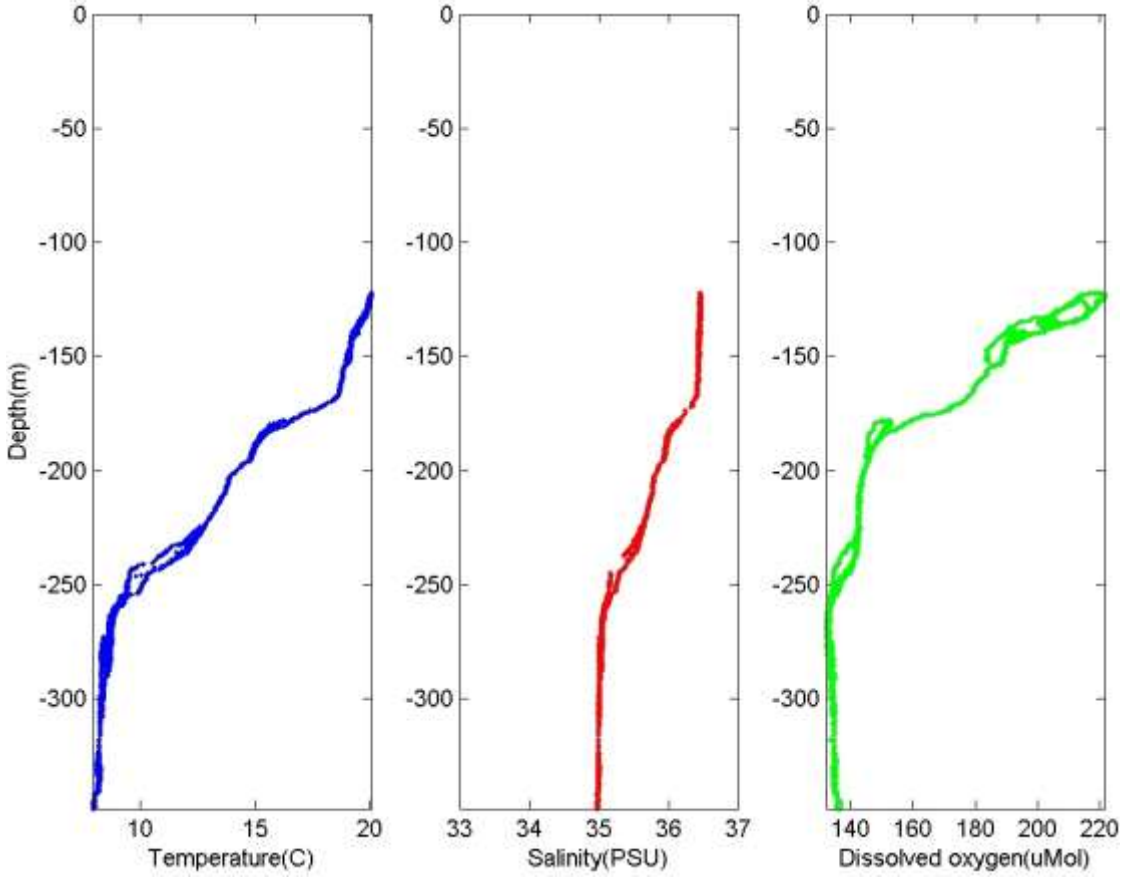
Dive Data:

Minimum Bottom Depth (m):	340	**Total Transect Length (km):**	5.466
Maximum Bottom Depth (m):	375	**Surface Current (kn):**	1.2kts
On Bottom (Time- GMT):	18:53	**On Bottom (Lat/Long):**	25°37.7910'N; 79°53.8740'W
Off Bottom (Time- GMT):	21:31	**Off Bottom (Lat/Long):**	25°40.3702'N; 79°53.5650'W

Physical (bottom); Temp (°C): 7.90 **Salinity:** 34.97 **Visibility (ft):** 60 **Current (kn):**

Physical Environment:

CTD Number 11-160A_CTDD



All CTD data were collected with the Super Phantom ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (348.1 m): temperature- 8.0, salinity- 35.0, and dissolved oxygen- 136.5. The CTD did not start recording until 122 m, at that depth temperature was 17.85 and there was a thermocline near 175 m depth; salinity peaked between 121 and 160 m, dissolved oxygen peaked at 121 m (the shallowest recorded). Visibility was estimated at 18-21 m from the ROV video.

Dive Number: Phantom ROV 11-160A **Location:** USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

Dive Imagery:

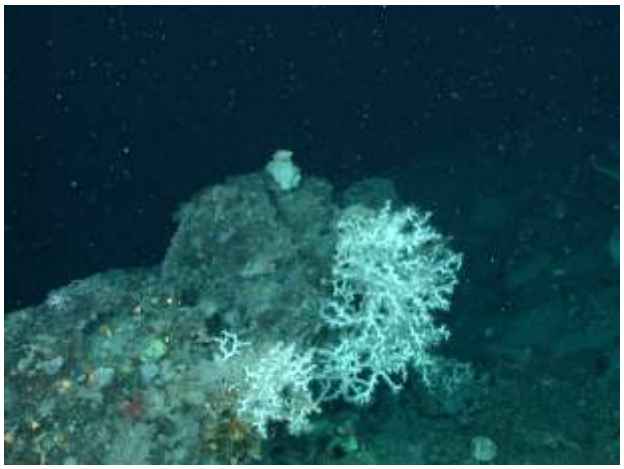


Figure 1: 25°38.1903'N, 79°53.9135'W 345.7 m

Phosphoritic limestone rock slabs, boulders and cobble provide habitat for a variety of benthic species including these corals (*Lophelia pertusa*, unidentified cup Scleractinia, fire-ball coral- *Anthomastus* sp., gorgonacea- *Plumerella* sp.), sponges (Hexactinellida- various spp., yellow sponge- *Hertwigia falcifera*), Asteroidea, and Crinoidea.

Figure 2: 25°38.6752'N, 79°53.8467'W 354.2 m

Phosphoritic limestone rock slabs, boulders and cobble provide habitat for a variety of benthic species including these corals (solitary cup Scleractinia, gorgonacea- *Plumerella* sp.), sponges (Hexactinellida- various spp., *Geodia* sp.), and large anemone (Hormathiidae?).

Figure 3: 25°38.5515'N, 79°53.8412'W 354 m

Fragile glass goblet sponge (*Aphrocallistes beatrix*) is commonly found on the hard bottom habitat. This species is under research for its potent anti-pancreatic cancer properties.

Figure 4: 25°38.0979'N, 79°53.9145'W 343.3 m

These tube sponges (*Petrosia* sp.) are common on the phosphoritic rock slabs. Sponges (Lithistida,- thick wall cup, *Oceanapia* sp.- thin hollow tube).

Dive Number: Phantom ROV 11-160A **Location:** USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey portion of Miami Terrace within the Deep Coral Habitat Area of Particular Concern (CHAPC) that is also within the open Allowable Crab Fishing Area (ACFA) and to ground-truth NOAA regional bathymetric contour maps which show apparent high-relief features that are likely hard-bottom habitat. Target site- SW Miami Terrace: 25° 35.829'N, 79° 54.29'W; 350-410 m.

Dive Events: Difficulty with station keeping and ship's Dynamic Positioning in 2 kn surface current; launched and repositioned three times. ROV pulled off bottom numerous times during transect. Unable to stop ROV or maneuver in current. The ROV dive ended up 2.0 nmi northeast of the target site but within the CHAPC. [Note- The *Phantom* ROV's top parallel lasers are calibrated at 20 cm, bottom lasers 61 cm. Depth recorded in WinFrog is correct; video overlay display is incorrect.]

Site Description/Habitat/Fauna:
Mapped two sites with *Pisces* multibeam inside the ACFA and CHAPC (Miami Terrace south survey): 8 linear nmi and 5 nmi; the second site overlaps with Dave Naar's S. Miami sonar survey (2010). The sonar maps (Fig. 1) show definite high-relief hard bottom features, including individual mounds, steep ridge from 350-400 m with relief up to 60 m, and apparent deepwater sinkholes. The ROV dive site was 100% hard bottom consisting of rock pavement, rock slabs, boulders, cobble, rubble, gravel, sediment veneer over pavement, and low to moderate relief ledges up to 1 m tall. Some pavement has thin, 10-20 cm tall vertical ridges of unknown origin. Dominate fauna: Fish- *Laemonema*, shark, beardfish, catshark, greeneye, black belly rosefish; Sponges- dense fan sponges, plate, vase, barrel, and tube, Demospongiae, Pachastrellidae, Geodiidae, Petrosiidae, *Phakellia*, *Spongosorites*, Hexactinellida- *Vazella*, *Aphrocallistes*; Cnidaria- *Lophelia pertusa* (20-30 cm, sparse), Primnoidae, *Leiopathes*, Actiniaria, white gorgonians, Paramuriceidae (60 cm), Corallimorpharia; Decapoda- *Chaceon fenneri* (golden crab); Echinoderms- *Coronaster*.

Dive Number: Phantom ROV 11-160A **Location:** USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

Percent Cover of Benthic Macro-Biota and Substrate:

Phantom ROV 11-160A surveyed a portion of the Miami Terrace Deep Coral HAPC. Because of difficulty with station keeping in the 2 kn surface current, the ROV landed 2 nmi north of the target site, but still within the HAPC. The photo transect was basically on one type of habitat: rock pavement. Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. Hard bottom in this region may consist of rock pavement, ledges, coral rubble, and coral framework which is defined as standing colonial hard coral (either Stylasteridae or Scleractinia). Site 11-160A was predominately hard bottom substrate (50.4% cover), but much of the apparent soft bottom was likely rock pavement with a thin veneer of sediment. The bare hard bottom substrate consisted of rock pavement (25.1% cover) and rock rubble (16.9%) (Fig. 3). Benthic macro-biota covered 8.3% of the bottom and consisted of 4.6% Porifera (both Hexactinellida and Demospongiae), 0.7 non-scleractinian corals, 0.5% framework corals, and 2.6% other organisms (Fig. 2, Table 1; see Density section for complete species list). Since this dive only had one habitat zone, the data won't be further analyzed by habitat type.

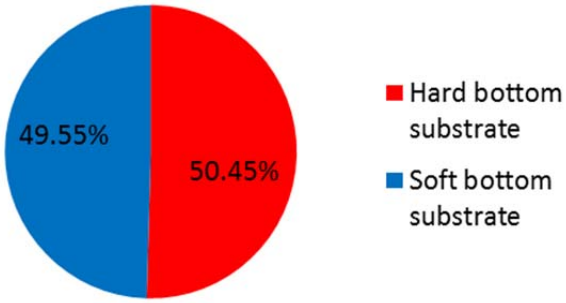


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-160A. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

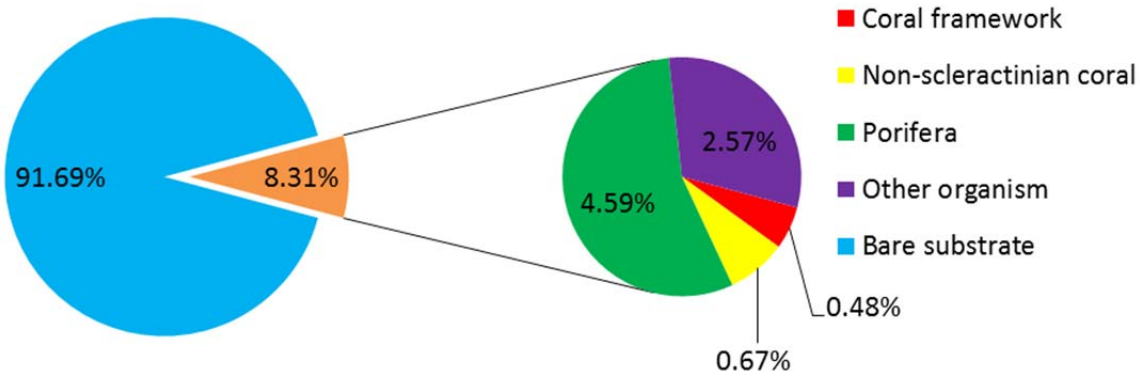


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-160A. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: Phantom ROV 11-160A **Location:** USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-160A.

Benthic macro-biota and substrate types	% Cover
Coral framework	**0.48%**
Lophelia pertusa	0.16%
Scleractinia, unid	0.14%
Standing Dead Coral	0.14%
Stylasteridae	0.05%
Non-scleractinian coral	**0.67%**
Alcyonacea	0.02%
Gorgonacea, Unid	0.65%
Porifera	**4.58%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	4.58%
Other organism	**2.57%**
Bare substrate	**91.59%**
Bare Soft Bottom substrate	48.00%
Coral rubble	1.59%
Rock- pavement, boulder, ledge	25.09%
Rubble	16.92%
Human debris	**0.10%**
Fishing line/long line	0.03%
Human debris- Other	0.07%
Grand Total	**100.00%**

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge". These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different Classes.

Dive site 11-160A had a total of 53 benthic macro-fauna taxa, consisting of 20 Porifera (including 8 Hexactinellida) and 19 Cnidaria (Table 2). Overall density of all benthic macro-fauna was 9.99 organisms/m^2. Cnidaria contributed to 47.1% of the total density at this site and Porifera 36.6%. Demosponges and Cnidaria dominated with densities of 3.6 and 4.7 organisms/m^2, respectively. The density of scleractinian corals was 0.6 colonies/m^2 (live *Lophelia pertusa* coral- 0.1, standing dead *Lophelia*- 1.2); stylaster corals were 1.3 colonies/m^2; Alcyonacea (primarily Gorgonacea) were 1.5 colonies/m^2. Sponges were dominated by the hexactinellid glass sponges *Farrea* sp. (0.6), and demosponges Astrophorida (0.3) and Haplosclerida (0.15). *Aphrocallistes beatrix*, a hexactinellid sponge undergoing research for anti-pancreatic cancer properties, occurred at 0.03 colonies/m^2.

Dive Number: Phantom ROV 11-160A **Location:** USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

Table 2. Density of benthic macro-biota at site 11-160A (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**602**	**3.66**	**36.60%**
Demospongiae	**279**	**1.70**	**16.96%**
Astrophorida	44	0.27	2.67%
Astrophorida	31	0.19	1.88%
Astrophorida- fan	11	0.07	0.67%
Geodia sp.	1	0.01	0.06%
Pachastrellidae	1	0.01	0.06%
Dictyoceratida	1	0.01	0.06%
Ircinia sp.	1	0.01	0.06%
Halichondrida	12	0.07	0.73%
Phakellia sp.	12	0.07	0.73%
Haplosclerida	24	0.15	1.46%
Oceanapia sp.	12	0.07	0.73%
Petrosia sp.	12	0.07	0.73%
Lithistida	17	0.10	1.03%
Lithistida	17	0.10	1.03%
Poecilosclerida	1	0.01	0.06%
Hymedesmia sp.- yellow morph	1	0.01	0.06%
Demospongiae	180	1.09	10.94%
Demospongiae	179	1.09	10.88%
Demospongiae- thin curtain	1	0.01	0.06%
Hexactinellida	**323**	**1.96**	**19.64%**
Hexactinosida	101	0.61	6.14%
Aphrocallistes beatrix	5	0.03	0.30%
Farrea sp.	96	0.58	5.84%
Lyssacinosida	10	0.06	0.61%
Hertwigia falcifera	3	0.02	0.18%
Nodastrella nodastrella	1	0.01	0.06%
Vazella pourtalesii	6	0.04	0.36%
Hexactinellida	212	1.29	12.89%
Hexactinellida	189	1.15	11.49%
Hexactinellida- curtain	20	0.12	1.22%
Hexactinellida- fan	3	0.02	0.18%
Cnidaria	**775**	**4.71**	**47.11%**
Anthozoa	**531**	**3.23**	**32.28%**
Actiniaria	34	0.21	2.07%
Actiniaria	33	0.20	2.01%
Actinoscyphia sp.	1	0.01	0.06%
Alcyonacea	255	1.55	15.50%

Dive Number: Phantom ROV 11-160A **Location:** USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

Alcyonacea	26	0.16	1.58%
Anthomastus sp.	53	0.32	3.22%
Capnella sp.	17	0.10	1.03%
Ellisellidae	29	0.18	1.76%
Eunicella sp.	50	0.30	3.04%
Gorgonacea (accepted as Alcyonacea)	26	0.16	1.58%
Nidalia occidentalis	1	0.01	0.06%
Paramuricea sp.	1	0.01	0.06%
Plumarella sp.	15	0.09	0.91%
Primnoidae	37	0.22	2.25%
Corallimorpharia	6	0.04	0.36%
Corallimorpharia	6	0.04	0.36%
Scleractinia	99	0.60	6.02%
Lophelia pertusa	17	0.10	1.03%
Lophelia- standing dead	20	0.12	1.22%
Scleractinia- unid colonial	10	0.06	0.61%
Scleractinia- unid cup	52	0.32	3.16%
Zoanthidea	137	0.83	8.33%
Zoanthidae	137	0.83	8.33%
Hydrozoa	**244**	**1.48**	**14.83%**
Anthoathecata	222	1.35	13.50%
Stylasteridae	222	1.35	13.50%
Hydrozoa	22	0.13	1.34%
Hydroidolina	22	0.13	1.34%
Mollusca	**7**	**0.04**	**0.43%**
Gastropoda	**7**	**0.04**	**0.43%**
Littorinimorpha	1	0.01	0.06%
Cypraeidae	1	0.01	0.06%
Gastropoda	6	0.04	0.36%
Arthropoda	**9**	**0.05**	**0.55%**
Malacostraca	**8**	**0.05**	**0.49%**
Decapoda	8	0.05	0.49%
Chaceon fenneri	2	0.01	0.12%
Paguroidea	6	0.04	0.36%
Pycnogonida	**1**	**0.01**	**0.06%**
Pantopoda	1	0.01	0.06%
Anoplodactylus lentus	1	0.01	0.06%
Bryozoa	**7**	**0.04**	**0.43%**
Echinodermata	**233**	**1.42**	**14.16%**
Asteroidea	**3**	**0.02**	**0.18%**
Forcipulatida	1	0.01	0.06%
Coronaster briareus	1	0.01	0.06%

Dive Number: Phantom ROV 11-160A **Location:** USA, Florida, Deep Coral HAPC, SW Miami Terrace, Near Sonar WP #18

Asteroidea	2	0.01	0.12%
Asteroidea	2	0.01	0.12%
Crinoidea	**7**	**0.04**	**0.43%**
Comatulida	7	0.04	0.43%
Comatulida	7	0.04	0.43%
Echinoidea	**1**	**0.01**	**0.06%**
Ophiuroidea	**222**	**1.35**	**13.50%**
Ophiurida	2	0.01	0.12%
Ophioderma sp.	1	0.01	0.06%
Ophiothrix sp.	1	0.01	0.06%
Ophiuroidea	220	1.34	13.37%
Chordata	**12**	**0.07**	**0.73%**
Ascidiacea	**12**	**0.07**	**0.73%**
Grand Total	**1645**	**9.99**	**100.00%**

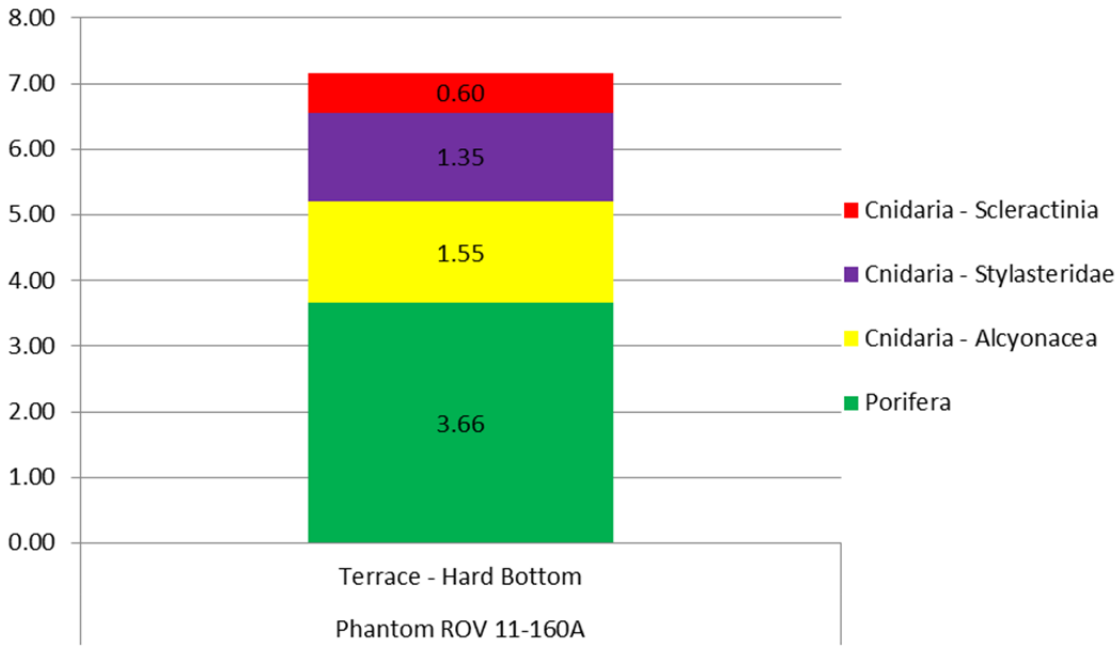


Figure 3. Density (number colonies/m^2) of Porifera, hard coral (Stylasteridae, Scleractinia), Antipatharia, and Alcyonacea (Gorgonacea) at dive site 11-160A.

Figure 3 shows the density of Porifera and coral at dive site 11-160A. Coral is defined as hard coral (Stylasteridae and Scleractinia), Antipatharia, and Gorgonacea. Scleractinian coral density was 0.6 colonies/m^2, stylaster coral- 1.3, Alcyonacea- 1.5, and sponges- 3.7.

Fish Data Analysis:

Video transects were used to analyze the fish populations and densities. A Kongsberg high-definition video camera was used with 10-cm lasers for scale. Protocol for the fish analyses was to divide the continuous HD video into 5 minute segments, or whenever there was a change in habitat type, whichever came first, so each

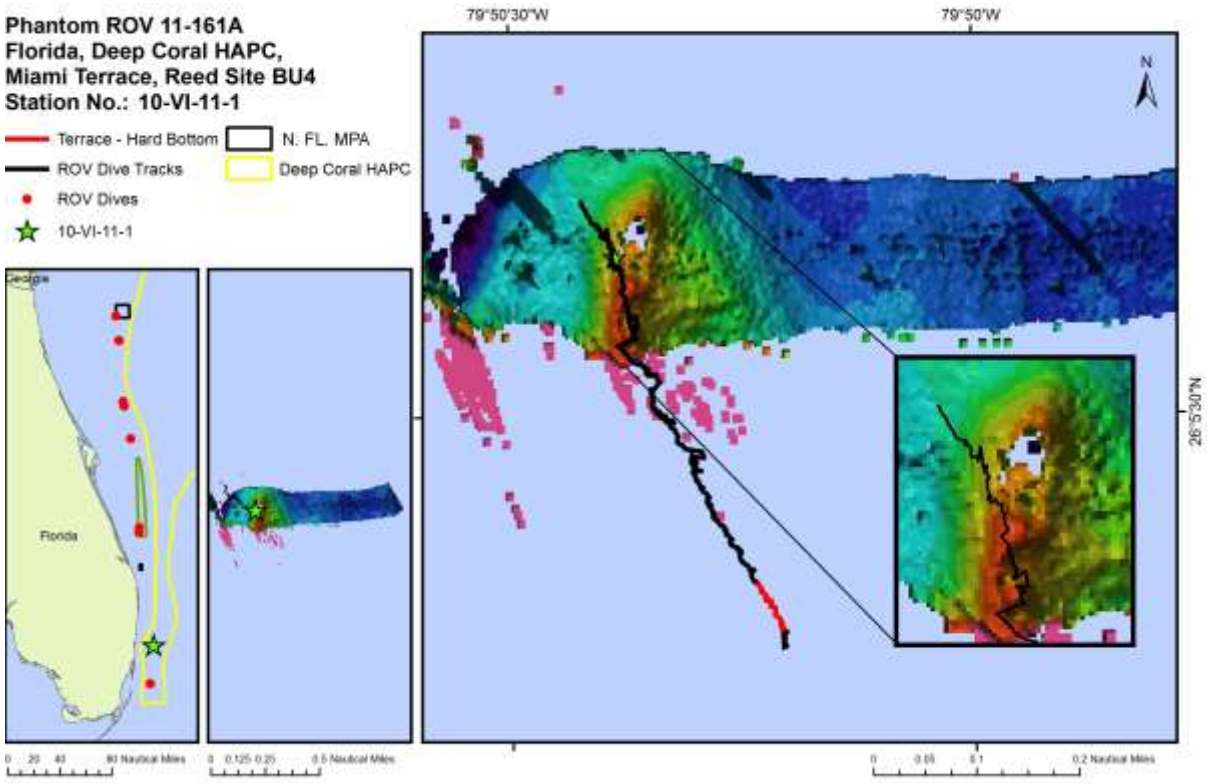
video segment only contained one habitat type (see Methods for details). These were also correlated with the habitat types used for the benthic analyses. All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the density (# individuals/km) of each fish species. Very few fish were seen on the dive; a total of 6 species of fish were identified from dive site 11-160A for a total density of 10 individuals/km (Table 3). These were dominated by *Polymyxia* sp. (7.3 individuals/km), and *Laemonema* spp. (2.2).

Table 3. Density of fish for all transects at dive site 11-160A (number individuals/km).

Common Name	Species Name	Density (#/km)
beardfish	*Polymixia sp.*	7.3
mora	*Laemonema sp.*	1.8
mora	*Laemonema melanurum*	0.4
shortnose greeneye	*Chloropthalmus agassiz*	0.4
blackbelly rosefish	*Helicolenus dactylopterus*	0.2
catshark	*Scyliorhinus sp.*	0.2

Dive Number:	Phantom ROV 11-161A	**Location:**	USA, Florida, Deep Coral HAPC, Miami Terrace, Reed Site BU4

General Location and Dive Track:



Site Overview:		**Dive Overview:**	
Project:	2011 Extreme Corals, NOAA DSCP	**Vessel:**	NOAA Ship *Pisces*
Principal Investator:	Andrew W. David	**Sonar Data:**	Pisces bump1.tif
PI Contact Info:	3500 Delwood Beach Rd. Panama City FL 32408	**Purpose:**	Map and characterize DSCE off SE USA
Website:	http://coralreef.noaa.gov/deepseacorals	**ROV:**	NOAA SW Fisheries Super Phantom ROV
Scientific Observers:	Andrew W. David, Charles Messing, Diego Figueroa, Jana Thoma, John Reed, Stephanie Farrington	**Sensors Used:**	Temperature (°C), Dissolved Oxygen (ml/l), Salinity (PSU), Conductivity
Data Management:	Access Database, Excel Spreadsheet, WinFrog	**Date of Dive:**	6/10/2011
		Specimens:	0
ROV Navigation Data:	WinFrog	**Digital Photos:**	74
Ship Position System:	DGPS	**DVD:**	2
Report Analyst:	John Reed, Stephanie Farrington	**Hard Drive:**	1
		Date Compiled:	2/20/2013

Dive Number:	Phantom ROV 11-161A	**Location:**	USA, Florida, Deep Coral HAPC, Miami Terrace, Reed Site BU4

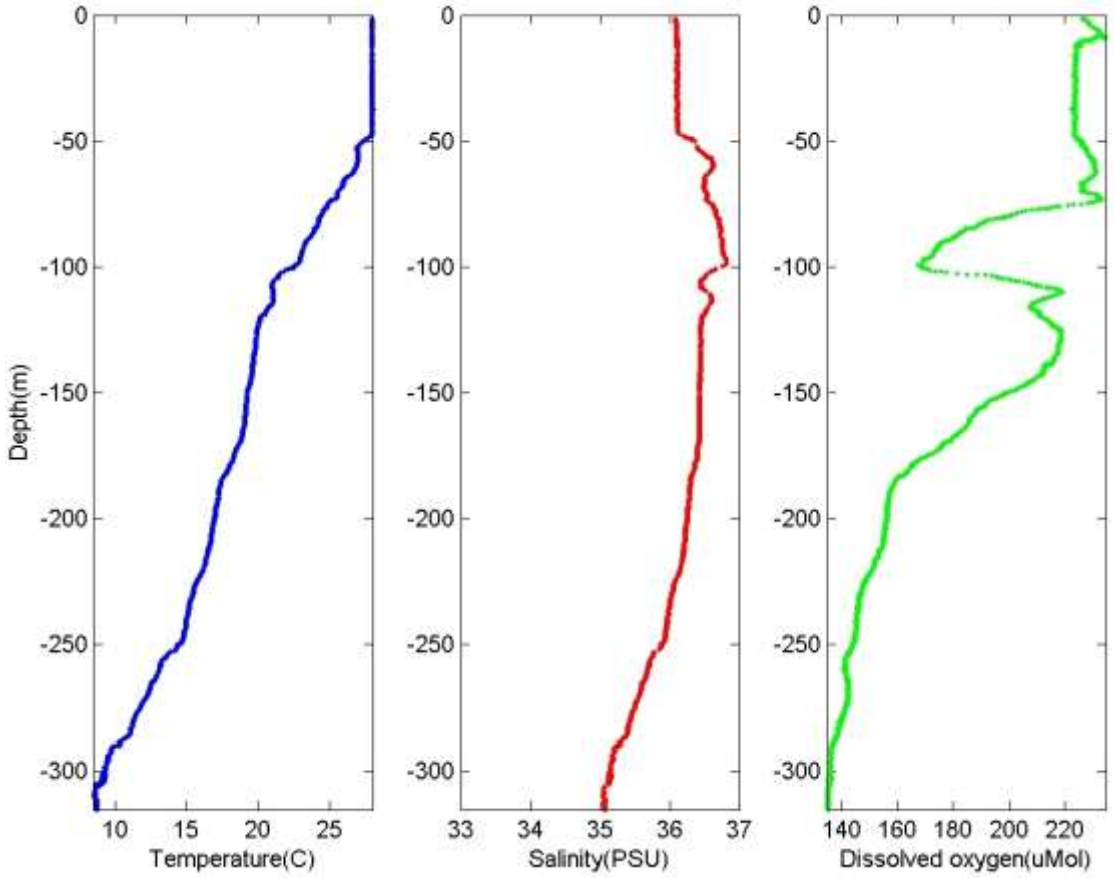
Dive Data:

Minimum Bottom Depth (m):	295	**Total Transect Length (km):**	1.83
Maximum Bottom Depth (m):	316	**Surface Current (kn):**	2 kt
On Bottom (Time- GMT):	13:53	**On Bottom (Lat/Long):**	26°05.2720'N; 79°50.2090'W
Off Bottom (Time- GMT):	14:11	**Off Bottom (Lat/Long):**	26°05.7459'N; 79°50.4240'W

Physical (bottom); Temp (°C): 8.60 **Salinity:** 35.05 **Visibility (ft):** 50 **Current (kn):**

Physical Environment:

CTD Number 11-161A_CTDD



All CTD data were collected with the Super Phantom ROV which recorded depth, temperature (°C), conductivity (salinity, PSU), pressure (mbar), sound velocity (m/sec), oxygen concentration (uMol), and oxygen saturation. These data were used both to support multibeam surveys (sound velocity) and to characterize hydrographic conditions at the dive sites.

The following values were recorded at the maximum depth of this CTD cast (315.4 m): temperature- 8.7, salinity- 35.1, and dissolved oxygen- 135.4. Surface temperature was 28.0 and there was a thermocline at 50 m depth; salinity peaked between 50 and 100 m, dissolved oxygen peaked at 10-70 m. Visibility was estimated at 15-18 m from the ROV video.

Dive Number: Phantom ROV 11-161A **Location:** USA, Florida, Deep Coral HAPC, Miami Terrace, Reed Site BU4

Dive Imagery:

Figure 1: 26°5.2981'N, 79°50.2119'W 320.6 m

Unfortunately, due to strong currents, this ROV dive totally missed the target site, a high relief plateau. Instead we landed on hard rock pavement with a variety of sponges including this mesh fan sponge (*Raspailia* sp.) and pencil sea urchins (Cidaroida, *Cidaris* sp.).

Figure 2: 26°5.3365'N, 79°50.2384'W 318.3 m

Koosh-ball anemone (*Liponema* sp.) is common on the rock pavement habitat along with these small solitary cup corals, white coral (Stylaster sp.), and dense numbers of ophiuroid brittlestars with arms protruding.

Dive Number: Phantom ROV 11-161A **Location:** USA, Florida, Deep Coral HAPC, Miami Terrace, Reed Site BU4

Dive Notes:

Objectives, Site Description, Habitat, Fauna:

Objective: Survey portion of Miami Terrace within the Deep Coral Habitat Area of Particular Concern (CHAPC) and ground truth *Pisces* sonar survey of the site. Target site- Reed Site BU4; 26° 05'N, 79° 50'W; 286 m.

Dive Events: Surface current is 2.0 kn and unable to station keep, or to slow the ROV down to less than 2.0 kn speed over ground. Dive terminated after 18 minutes; only 5 minutes on bottom south and SE of target site, but drifted 20 m above the target site. [Note- The *Phantom* ROV's top parallel lasers are calibrated at 20 cm, bottom lasers 61 cm. Depth recorded in WinFrog is correct; video overlay display is incorrect.]

Site Description/Habitat/Fauna: ROV track ground-truthed Ballard and Uchupi's (1970) bathymetric contour map and the 2011 *Pisces* multibeam sonar; the Ballard Uchupi map appears shifted west by 500 m of BU4 position in new multibeam. The dive was only on bottom south of the target site and consisted of 100% hard bottom with rock pavement and sediment veneer over pavement. Some pavement has thin, 10-20 cm tall vertical ridges of unknown origin. The black rock appears to be Miocene-age phosphoritic limestone. Dominate fauna: dense sponges, Pachastrellidae, Axinellidae, sea urchins, and Ophiuroidea.

Dive Number: Phantom ROV 11-161A	**Location:** USA, Florida, Deep Coral HAPC, Miami Terrace, Reed Site BU4

Percent Cover of Benthic Macro-Biota and Substrate:

Phantom ROV 11-161A attempted to survey a high-relief feature (Reed Site BU4) on the Miami Terrace HAPC. However, the ship and ROV were unable to station-keep in the 2.0 kn surface current and the ROV was traveling 2.0 kn over the bottom during the dive. The dive did not survey the target site but was on flat hard bottom habitat southeast of the feature. Point count (CPCe©) was used to determine percent cover (see methods for details). Figure 1 shows the percent cover of hard bottom and soft bottom substrate; points on biota were scored as the underlying substrate type. Soft bottom substrate is defined as unconsolidated mud or sand. Site 11-161A was predominately soft bottom substrate (68.3% cover), which was probably rock pavement with sediment veneer, and exposed hard bottom (31.6% cover) which was rock pavement and rubble. Benthic macro-biota covered 3.3% of the bottom and consisted of 1.0% coral framework (*Lophelia pertusa* and Stylasteridae), 0.86% Porifera (both Hexactinellida and Demospongiae), and 1.4% other organisms (Fig. 2, Table 1; see Density section for complete species list). Since this dive only had one habitat zone, the data won't be further analyzed by habitat type.

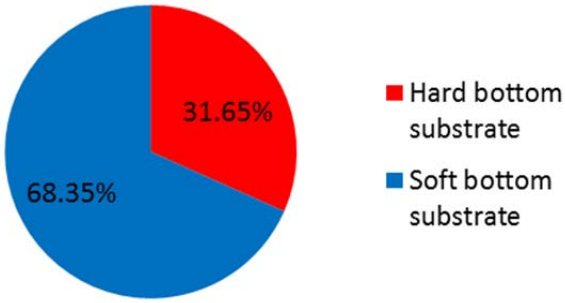


Figure 1. Percent cover of hard and soft bottom substrate at dive site 11-161A. CPCe© points on organisms were scored as the underlying substrate (hard or soft).

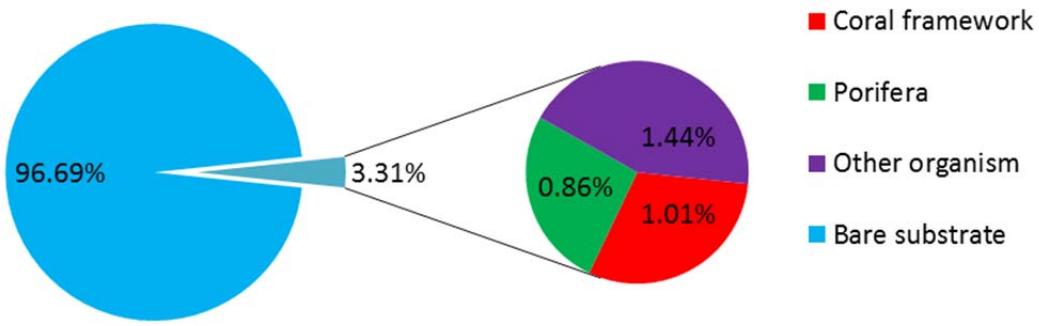


Figure 2. Percent cover of bare substrate and benthic macro-biota at dive site 11-161A. Coral framework is standing, colonial hard coral. Non-scleractinian corals are defined as Gorgonacea, other Alcyonacea, and Antipatharia.

Dive Number: Phantom ROV 11-161A **Location:** USA, Florida, Deep Coral HAPC, Miami Terrace, Reed Site BU4

Table 1. Percent cover of benthic macro-biota and substrate types at dive site 11-161A.

Benthic macro-biota and substrate types	% Cover
Coral framework	**1.01%**
Lophelia pertusa	0.29%
Scleractinia, unid	0.14%
Standing Dead Coral	0.29%
Stylasteridae	0.29%
Porifera	**0.86%**
Porifera- Hexactinellida, Calcarea, or Demospongiae	0.86%
Other organism	**1.44%**
Bare substrate	**96.69%**
Bare Soft Bottom substrate	68.06%
Coral rubble	9.21%
Rock- pavement, boulder, ledge	12.09%
Rubble	7.34%
Grand Total	**100.00%**

Density of Benthic Macro-Biota:

As discussed in the Methods, some common taxa could be identified to genus or species level but many could only be identified to a higher level such as family, class, order or even phylum. Sponges, gorgonians, and black coral are especially difficult to identify without a specimen in hand. In these cases a general descriptive taxa was used, e.g., "brown lobate sponge". These designations should not be considered equivalent to species level and should not be used for diversity (H') indices calculations. Many deepwater species in this region look nearly identical, such as fan sponges which are polyphyletic and actually include different Classes.

Dive site 11-161A had a total of 19 benthic macro-fauna taxa, consisting of 4 Porifera and 11 Cnidaria (Table 2). Overall density of all benthic macro-fauna was 18.9 organisms/m^2. Cnidaria contributed to 27.5% of the total density at this site and Porifera 14.6%. Demosponges and Cnidaria dominated with densities of 2.7 and 5.2 organisms/m^2, respectively; the density of hard corals was 1.9 colonies/m^2 (0.2 *Lophelia*, 0.7 Stylasteridae). Alcyonacea density was 1.8 including bamboo coral (Isididae) at 0.1. Of the sponges, Poecilosclerida were common (2.4/m^2) and Raspailliidae fan sponges had a density of 2.1 colonies/m^2.

Table 2. Density of benthic macro-biota at site 11-161A (# organisms, number/m^2, percent of total density).

Phylum/Class/Order/Scientific Name	# Organisms	#/m2	% of Site
Porifera	**25**	**2.76**	**14.62%**
Demospongiae	**25**	**2.76**	**14.62%**
Astrophorida	1	0.11	0.58%
Astrophorida- fan	1	0.11	0.58%
Poecilosclerida	22	2.43	12.87%
Hymedesmia sp.- blue morph	3	0.33	1.75%
Raspailiidae- fan mesh	19	2.10	11.11%

Dive Number: Phantom ROV 11-161A **Location:** USA, Florida, Deep Coral HAPC, Miami Terrace, Reed Site BU4

Demospongiae	2	0.22	1.17%
Cnidaria	**47**	**5.19**	**27.49%**
Anthozoa	**40**	**4.42**	**23.39%**
Actiniaria	7	0.77	4.09%
Actiniaria	6	0.66	3.51%
Liponema sp.	1	0.11	0.58%
Alcyonacea	16	1.77	9.36%
Alcyonacea- brown sphere	8	0.88	4.68%
Anthomastus sp.	5	0.55	2.92%
Ellisellidae	1	0.11	0.58%
Gorgonacea (accepted as Alcyonacea)	1	0.11	0.58%
Isididae	1	0.11	0.58%
Scleractinia	17	1.88	9.94%
Lophelia pertusa	2	0.22	1.17%
Scleractinia- unid cup	15	1.66	8.77%
Hydrozoa	**7**	**0.77**	**4.09%**
Anthoathecata	6	0.66	3.51%
Stylasteridae	6	0.66	3.51%
Hydrozoa	1	0.11	0.58%
Hydroidolina	1	0.11	0.58%
Arthropoda	**1**	**0.11**	**0.58%**
Malacostraca	**1**	**0.11**	**0.58%**
Decapoda	1	0.11	0.58%
Echinodermata	**98**	**10.83**	**57.31%**
Crinoidea	**2**	**0.22**	**1.17%**
Comatulida	2	0.22	1.17%
Echinoidea	**11**	**1.22**	**6.43%**
Cidaroida	11	1.22	6.43%
Ophiuroidea	**85**	**9.39**	**49.71%**
Ophiuroidea	85	9.39	49.71%
Grand Total	**171**	**18.90**	**100.00%**

Dive Number: Phantom ROV 11-161A **Location:** USA, Florida, Deep Coral HAPC, Miami Terrace, Reed Site BU4

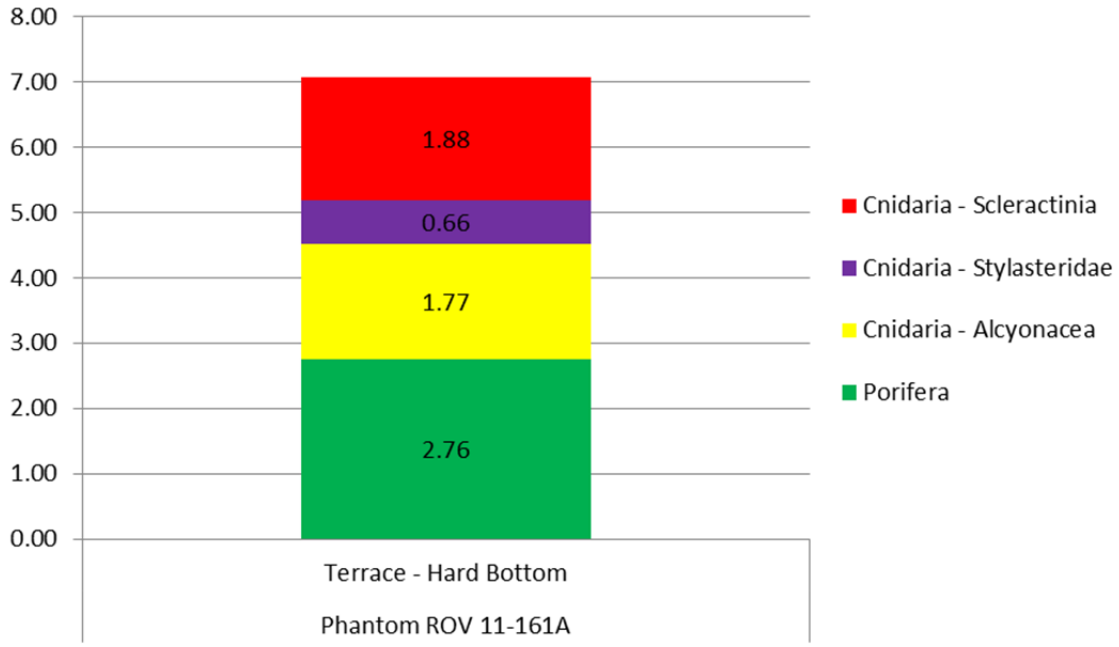


Figure 3. Density (number colonies/m^2) of Porifera, hard coral (Stylasteridae, Scleractinia), Antipatharia, and Alcyonacea (Gorgonacea) at dive site 11-161A.

Figure 3 shows the density of Porifera and coral at dive site 11-161A. Coral is defined as hard coral (Stylasteridae and Scleractinia), Antipatharia, and Gorgonacea. Porifera dominated with 2.7 colonies/m^2, 1.9 scleractinia, 0.7 Stylasteridae, and 1.8 Alcyonacea.

Fish Data Analysis:

Because of the short time the ROV was on bottom the few fish observed were not analyzed.

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Sub-lethal coral stress: Detecting molecular responses of coral populations to environmental conditions over space and time

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ABSTRACT

In order for sessile organisms to survive environmental fluctuations and exposures to pollutants, molecular mechanisms (i.e. stress responses) are elicited. Previously, detrimental effects of natural and anthropogenic stressors on coral health could not be ascertained until significant physiological responses resulted in visible signs of stress (e.g. tissue necrosis, bleaching). In this study, a focused anthozoan holobiont microarray was used to detect early and sub-lethal effects of spatial and temporal environmental changes on gene expression patterns in the scleractinian coral, *Montastraea cavernosa*, on south Florida reefs. Although all colonies appeared healthy (i.e. no visible tissue necrosis or bleaching), corals were differentially physiologically compensating for exposure to stressors that varied over time. Corals near the Port of Miami inlet experienced significant changes in expression of stress responsive and symbiont (zooxanthella)-specific genes after periods of heavy precipitation. In contrast, coral populations did not demonstrate stress responses during periods of increased water temperature (up to 29 °C). Specific acute and long-term localized responses to other stressors were also evident. A correlation between stress response genes and symbiont-specific genes was also observed, possibly indicating early processes involved in the maintenance or disruption of the coral–zooxanthella symbiosis. This is the first study to reveal spatially- and temporally-related variation in gene expression in response to different stressors of in situ coral populations, and demonstrates that microarray technology can be used to detect specific sub-lethal physiological responses to specific environmental conditions that are not visually detectable.

1. Introduction

Over evolutionary time, sessile marine organisms have physiologically adapted to daily and seasonal fluctuations in salinity, temperature and solar radiation, which have been modest relative to the increase in frequency and severity of these environmental conditions in recent decades. In addition to the increases in natural stressors, reef communities are increasingly impacted by a variety of anthropogenic stressors. Altered land use, urban development, chemical pollution and improper waste disposal impact local coral reef communities through point and non-point sources. These recent changes have occurred too rapidly for long-lived species to adapt, resulting in organisms that are physiologically less capable of tolerating extreme environmental conditions. As a result, synergistic effects of global environmental changes and localized stressors on coral reefs have contributed to a steady decline in quality and diversity of coral reef habitats worldwide (Pandolfi et al., 2003; Wilkinson, 2004; Mora, 2008), and will likely cause further degradation of reef systems (Buddemeier et al., 2004; Wilkinson, 2004; Mumby and Steneck, 2008).

Impacts of environmental stressors on coral reefs are often documented by gross community- and population-level characteristics; for example, changes in percent coral cover, percent bleaching and biodiversity (Carpenter et al., 2008; Baker et al., 2008; Knowlton and Jackson, 2008; Hoegh-Guldberg et al., 2007). Physiological decline in individuals, measured as shifts in respiration, photosynthetic efficiency and bleaching (Gleason and Wellington, 1993; Fitt and Warner, 1995; Jones et al., 1999; Anthony and Hoegh-Guldberg, 2003) can also reflect the impact of stress, however such indicators do not identify specific stressor(s) or determine the underlying biological mechanisms causing the observed response.

To survive the challenges associated with environmental fluctuations and contaminant exposures, organisms attempt to acclimate by eliciting different molecular mechanisms (i.e. stress responses). The use of molecular technology, such as DNA microarrays, serves to diagnose these early, sub-lethal responses to stress prior to the onset of gross indicators, such as bleaching and partial mortality.

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Table 1
Montastraea cavernosa collection sites, collection periods and sample sizes. Water temperature (°C) at 20 m depth near Site 1 and mean precipitation (cm) are provided for each collection period. PMI = Port of Miami Inlet. NA indicates the site was not established during this collection period.

Study site	Location		Depth (m)	Position relative to PMI	Coral collection sample sizes (*n*)				
					Feb 2005 23.3 °C; 1.5 cm	Jun 2005 27.8 °C; 18.0 cm	Aug 2005 29.7 °C; 6.0 cm	Oct 2005 28.0 °C; 12.5 cm	Jun 2006 27.1 °C; 5.0 cm
Site 1	25°42.930′N	80°05.385′W	20	6.5 km south	4	4	4	4	4
Site 2	25°43.517′N	80°05.993′W	10	5.0 km south	5	5	5	5	4
Site 3	25°48.696′N	80°05.936′W	10	6.3 km north	5	5	5	5	4
Site 4	25°56.701′N	80°05.334′W	10	20.7 km north	5	5	5	5	4
Site 5	25°57.569′N	80°06.028′W	20	22.0 km north	NA	5	5	5	5

Gene expression profiling uses microarray technology to identify the regulation of specific genes expressed by an organism to protect cellular structures, repair damage and maintain normal cellular functions (Edge et al., 2005; Leggat et al., 2007). Quantifying differential gene expression can elucidate the mechanisms behind a biological response and produce a snapshot of cellular machinery in action (Snape et al., 2004). Gene expression profiling with DNA microarrays has been used to diagnose and quantify the impact of specific stressors on corals in laboratory and field conditions (Edge et al., 2005; Morgan et al., 2005; Forêt et al., 2007; Edge et al., 2008); however, spatial and temporal patterns of molecular responses of corals to stress in situ have not been documented.

Documenting the range of molecular responses corals exhibit over space and time is necessary before the physiological mechanisms involved in stress responses and environmental thresholds triggering these responses in natural populations can be fully understood. Reef environments consist of patchy microhabitats with variable environmental conditions over small spatial scales. At larger geographic scales, environmental influences may affect local or regional levels of habitat quality. Traditional methods of identifying coral responses to stress at these scales involve measuring changes at the community, population and organismal level. Although important, these measurements generally occur after declining health is evident. Evaluation of gene expression may identify coral populations exhibiting stress responses, even when visible signs of stress are not yet obvious.

This study investigates in situ molecular responses of the scleractinian coral, *Montastraea cavernosa*, to temporal environmental changes and spatial influences related to proximity of populations to a documented point source for various contaminants, the Port of Miami inlet and surrounding area (Biscayne Bay and Virginia Key sewage outfall) in south Florida (McArthur, 2001; Long et al., 2002; Gardinali et al., 2004). A focused anthozoan holobiont microarray was used to assess sub-lethal responses of *M. cavernosa* over a period of 16 months in order to test the hypotheses that both temporal and spatial influences differentially affect the gene expression patterns in corals and that gene expression profiling can differentiate molecular responses to specific stressors.

2. Materials and methods

2.1. Study sites and sample collection

Five sites (10–20 m depth) located north and south of the Port of Miami inlet (PMI) were selected in south Florida (Table 1; Fig. 1). At each site, five *M. cavernosa* colonies were permanently marked, mapped and photographed. The same coral colonies were sampled 4–5 times during the 16-month study period (February 2005–June 2006). Coral tissue samples (~1 cm^2) were chipped from the edge of each colony, preserved in TRIzol (Invitrogen) and frozen at −80 °C for RNA processing.

Water temperature, precipitation and storm activity were documented throughout the duration of the collections in order to assess relationships between these conditions and gene expression patterns. Water temperature was recorded daily at site 1 (Fig. 2A) by the Environmental Protection Agency using an acoustic doppler current profiler situated one meter from the bottom at a depth of 20 m. Precipitation and storm data were recorded hourly in Miami by Dade County, Florida by the National Climatic Data Center (station identifier 085663) (Fig. 2B).

2.2. Total RNA isolation

For each coral sample, total RNA was isolated from 2 ml TRIzol aliquots following the manufacturer's protocol (based on Chomezynski and Sacchi, 1987). RNA was purified using RNeasy MiniElute Clean-up Kit (Qiagen). RNA concentration was determined using a Nanodrop ND-1000 spectrophotometer (ThermoScientific). Replicate aliquots of 5 μg of purified total RNA from each sample were reverse transcribed. The resulting cDNA was purified with isopropyl alcohol precipitation (IPA) and quantified. The cDNA was exposed to an excess of an amine-reactive fluorescent dye (ARES Alexa Fluor 546 Amino-allyl Labeling Kit, Invitrogen) and resulting fluorescently labeled cDNA was purified using isopropyl alcohol precipitation and quantified.

2.3. Anthozoan holobiont stress microarray

Custom anthozoan holobiont microarrays (Combimatrix, Inc.) consisting of 2240 features, representing 148 genes from multiple anthozoan and symbiont (*Symbiodinium*) species, were used to measure changes in gene expression. One to five oligonucleotide sequences (35 base probes) from different regions of each gene were incorporated onto the arrays (Edge, 2007; Electronic Supplemental Material, ESM Table S1). More than 50 of the 148 genes were isolated from scleractinian corals, *Acropora cervicornis* or *Montastraea faveolata*, exposed to natural or anthropogenic stressors (Morgan et al., 2001; Morgan and Snell, 2002, 2006; Edge et al., 2005). Additional genes, involved in various cellular functions, were identified using a bioinformatics approach and literature search resulting in an array consisting primarily (73%) of sequences from *Acropora* and *Montastraea* species. In addition, two *Arabidopsis* spike mRNAs were included as positive controls and several phage sequences were included as negative controls.

Array genes were categorized based on their primary cellular activity according to published research and the Gene Ontology database (Ashburner et al., 2000). Categories were further grouped based on primary function to provide a general overview of the coral holobiont response. These functional groups included normal cellular function (NCF), multifunctional response (MF), stress response (SR), unknown function (EST) and symbiont specific response (ZOOX) (Table 2). NCF genes are involved in transcription and translation, cellular respiration, metabolism,

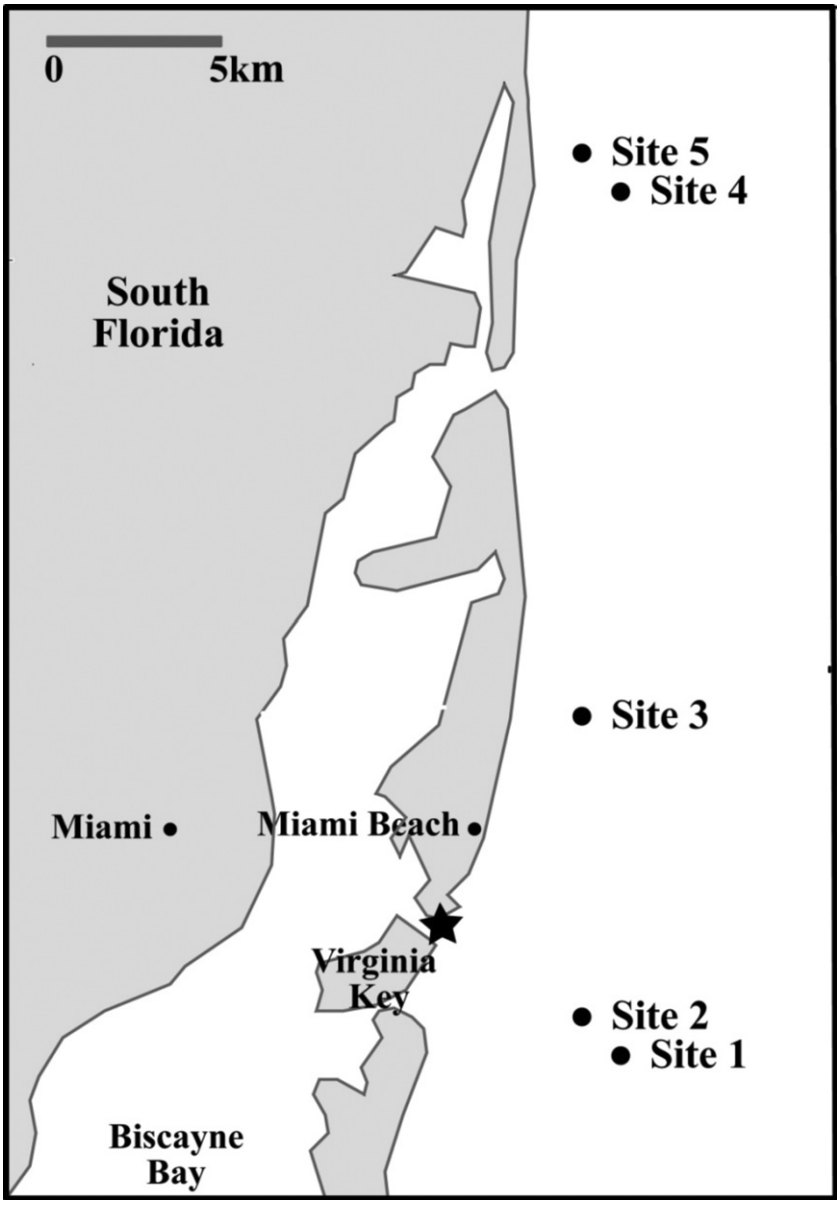

Fig. 1. Map of South Florida illustrating location of collection sites. The star indicates the Port of Miami inlet.

and signal transduction. MF genes include those with both normal cellular and stress response functions, such as molecular chaperones, heat shock elements and genes involved in the regulation of apoptosis, proteolysis and metal ion regulation. SR genes include those involved in DNA repair, wound healing, oxidative stress, and xenobiotic exposure. EST's are nucleotide sequences isolated from coral with uncharacterized functions based on sequence similarity analysis (*National Center for Biotechnology Information*, Basic Local Alignment Search Tool). ZOOX symbiont genes are involved in calcium binding, carbon dioxide fixation, metabolism, growth and development, proteolysis and response to light.

2.4. Microarray hybridization and analysis of microarray data

Approximately 1 μg fluorescently labeled cDNA from each sample was hybridized to two replicate microarrays at 50 °C for 12–16 h and washed according to the manufacturer's protocol (Combimatrix). A Microarray Express scanner (Perkin Elmer) was used to detect the fluorescence of each spot and Microarray Imager software (Combimatrix) was used to quantify signal intensities.

Average background intensity was subtracted from each oligonucleotide feature and resulting feature intensities were averaged to produce a fluorescence measurement for each probe. Data were log base 2 transformed and normalized with a global loess smoothing model. Replicate probes for each gene were averaged and multivariate repeated measures analysis of variance (corresponding to gene by gene comparison) was used to quantify significant differences in gene expression (JMP Genomics, SAS Institute). The model incorporated fixed effects and least squares effects as site ($n = 5$), collection period ($n = 5$) and an interaction between site and collection period (site × collection period; $n = 24$; no collections were made from Site 5 in February 2005). The cut-off value for significance was $p < 0.001$. As an adjustment for multiplicity of testing, the false discovery rate was $Q = 0.05$ (Benjamini and Hochberg, 1995). Hierarchical cluster analysis of significant genes using Ward's method and geometric

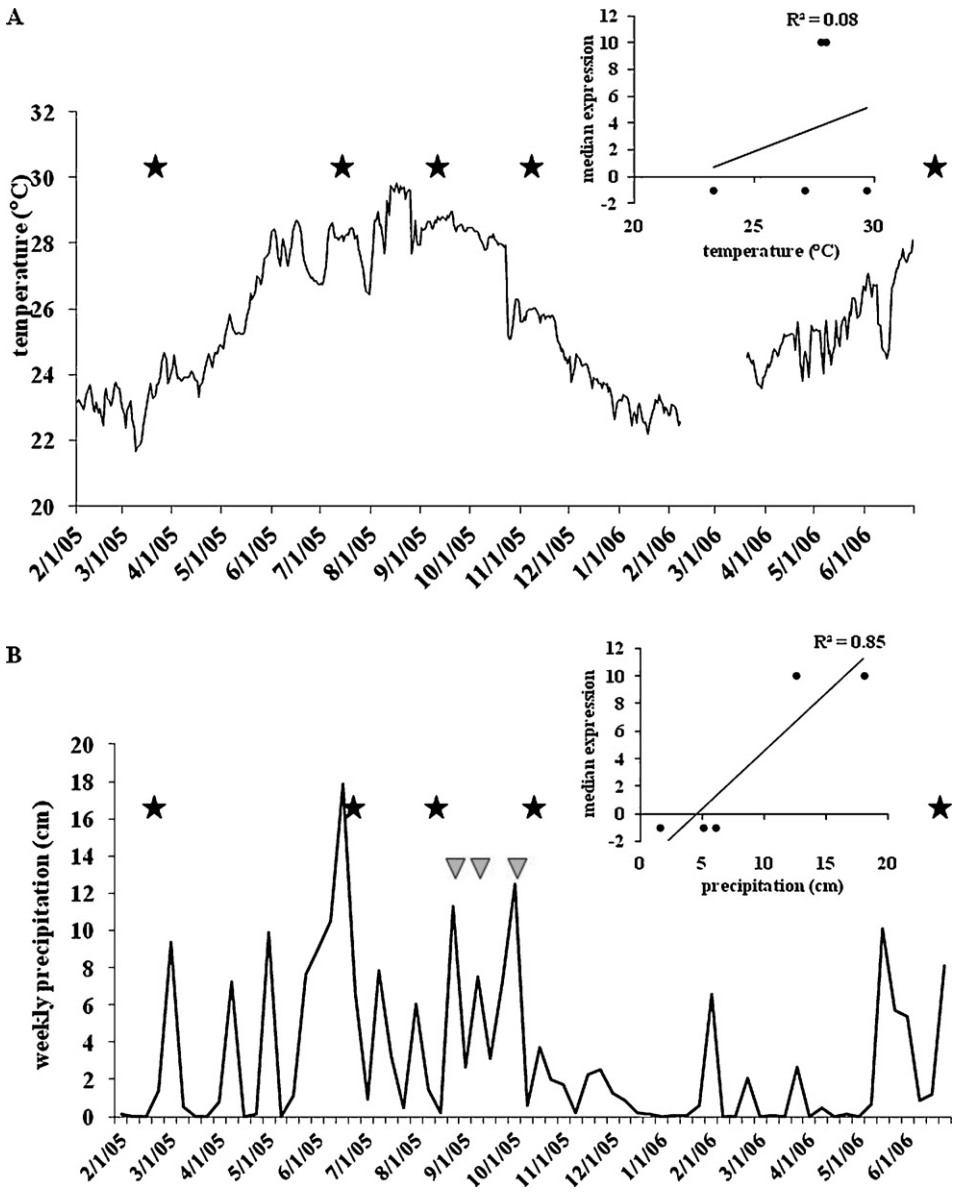

Fig. 2. Environmental data during study period and correlation analysis with gene expression data. Water temperature (A) was collected by the Environmental Protection Agency Region 4 from 20 m depth near Site 1 using an Acoustic Doppler Current Profiler. Precipitation (B) was acquired from the National Oceanographic and Atmospheric Administration National Data Center, recorded hourly at the Miami, Florida Dade County station (COOPID 85663). Data are represented as weekly total precipitation amounts. Stars indicate collection dates. Triangles indicate hurricane Katrina (August), tropical storm Ophelia (September) and hurricane Wilma (October). Inset graphs illustrate correlation analysis of water temperature and precipitation with median expression level of all genes by collection date. Median expression values (as opposed to mean expression) were used to minimize the effects of extreme values at either end of the gene expression distribution.

spacing was performed between sites, collection periods and samples (site × collection period) resulting in hierarchical clustering based on similarities in gene expression patterns (Ward, 1963).

Least squares profiles (corresponding to normalized signal intensities) of significant genes generated by ANOVA were standardized to zero. Deviations from the standardized least squares mean (SLSM) were compared between functional groups. Tukey–Kramer HSD was used to determine which functional groups demonstrated significant variability across samples ($p \leq 0.05$). To evaluate associations among functional groups, correlation analyses were performed on median SLSM expression values for each functional group. Median expression values (as opposed to mean expression) were used to minimize the effects of extreme values at either end of the gene expression distribution.

3. Results

3.1. Spatial variation in gene expression

Significant differences in expression of 43–103 genes were observed within sites (Table 3A). Site 2, the 10 m site closest to the PMI (5.0 km SE), exhibited the greatest number of differentially expressed genes (103 genes), including both highly up- and down-regulated genes (ESM Fig. 1A). Sites 4 and 5, the two sites furthest from the PMI exhibited the fewest number of differentially expressed genes (43 and 45, respectively). Pairwise comparisons between sites (10 comparisons) revealed significant differences in expression of 5–43 genes (Table 3B). Site 2 exhibited the greatest number of differentially expressed genes compared to each site (25.8 ± 6.1). Hierarchical clustering analysis of the deviations from the SLSM produced by the ANOVA supported differentiation of Site

Table 2
Number of genes in each functional category by specific function represented on the coral holobiont array. Accession numbers and probe information for each gene are provided in Supplementary Table 1.

Function	Functional category (FC)				
	NCF	*MF*	*SR*	*ZOOX*	*EST*
Metabolism	11	3	–	–	–
Growth and development	13	–	–	–	–
Molecular chaperones	–	3	8	–	–
Oxidative stress	–	–	11	–	–
Unknown	–	–	–	1	9
Protein modification	2	6	–	–	–
Regulation of transcription	6	1	–	–	–
Cellular respiration	6	1	–	–	–
Response to xenobiotic	–	1	6	–	–
Cellular signaling	3	3	–	–	–
Regulation of apoptosis	–	5	–	–	–
Nucleic acid modification	4	–	–	–	–
Cell migration	3	1	–	–	–
Protein transport	3	1	–	–	–
Translation	3	–	–	–	–
Proteolysis	1	2	–	–	–
Immune response	–	3	–	–	–
DNA repair	–	–	2	–	–
Cytoskeletal organization	–	2	–	–	–
Lipid transport/reproduction	1	–	–	–	–
Bio luminescence	1	–	–	–	–
Inflammation	–	1	–	–	–
Response to light	–	–	–	6	–
CO_2 fixation	–	–	–	2	–
Cell motility	–	–	–	2	–
Cell signaling	–	–	–	1	–
Metabolism	–	–	–	1	–

2 from other study sites, while sites 4 and 5 exhibited the greatest overall similarity in gene expression patterns (Table 3B; ESM Fig. 1A).

3.2. Temporal variation in gene expression

Within sampling date, 51–79 genes were significantly expressed, with June 2005 and 2006 exhibiting the greatest number of differentially expressed genes (79 and 70, respectively; Fig. 3C). Pairwise comparisons of each collection period (10 comparisons) revealed differential expression of 2–30 genes (Fig. 3D). The greatest number of differentially expressed genes (19.8 ± 5.2) was observed from samples collected in February 2005, the collection period with the lowest water temperature (23.3 °C; Fig. 2A) and precipitation in the area (1.5 cm; Fig. 2B). Samples collected during the highest water temperature (August 2005, 29.7 °C) exhibited the lowest number of differentially expressed genes (12.8 ± 3.2) relative to other collection dates. Hierarchical clustering of the SLSM revealed the greatest similarity in gene expression patterns between August 2005 and June 2006, and also between June 2005 and October 2005 (ESM Fig. 1B). There was no correlation between median gene expression and water temperature across sampling dates ($R^2 = 0.08$; Fig. 2A); in fact, the collection periods with the highest and lowest water temperatures exhibited similar gene expression levels. A positive relationship between median gene expression and precipitation was observed ($R^2 = 0.85$; Fig. 2B). Corals collected during June 2005 and October 2005, collection dates preceded by high precipitation and storm activity, demonstrated the highest gene expression levels.

3.3. Interaction between space and time

The interaction of spatial and temporal variability was assessed in a site by collection period interaction analysis with a total of 276 pairwise comparisons. Multivariate ANOVA revealed 49% of the comparisons demonstrated differential expression levels. Of these, 23% revealed 10–85 differentially expressed genes. While eight comparisons demonstrated differential expression of greater than 25% of all genes (Table 4). Principal component analysis indicated that "site" contributed to 18.4% of the total variance, whereas "collection date" and "colony" contributed to 4.5% and 2.2% of the variance, respectively.

Differentiation of Site 2 from other sites was driven by exceptional differential regulation of several genes during February 2005 (ESM Fig. 1C). Highly up-regulated genes included several known to be up-regulated in response to xenobiotic exposure (Morgan et al., 2001; Morgan and Snell, 2002, 2006; Tamura et al., 2006; Table 4). Several multi-functional and symbiont-specific genes are also highly differentially regulated at Site 2 in February 2005 (Table 4), indicating a response to an acute localized stressor.

Table 3
Number of differentially expressed genes determined by ANOVA (A) within collection location, (B) among collection locations, (C) within collection period and (D) among collection periods.

A

Collection location	# of genes
Site 1	50
Site 2	103
Site 3	71
Site 4	43
Site 5	45

B

Collection location	# of genes				
	Site 1	Site 2	Site 3	Site 4	Site 5
Site 1					
Site 2	22				
Site 3	8	43			
Site 4	7	24	7		
Site 5	13	14	13	5	
mean	12.5	25.8	17.8	10.8	11.3

C

Collection period	# of genes
Feb 2005	51
June 2005	79
Aug 2005	62
Oct 2005	54
June 2006	70

D

Collection period	# of genes				
	Feb 2005	June 2005	Aug 2005	Oct 2005	June 2006
Feb 2005					
June 2005	27				
Aug 2005	9	16			
Oct 2005	30	2	20		
June 2006	13	17	6	18	
mean	19.8	15.5	12.8	17.5	13.5

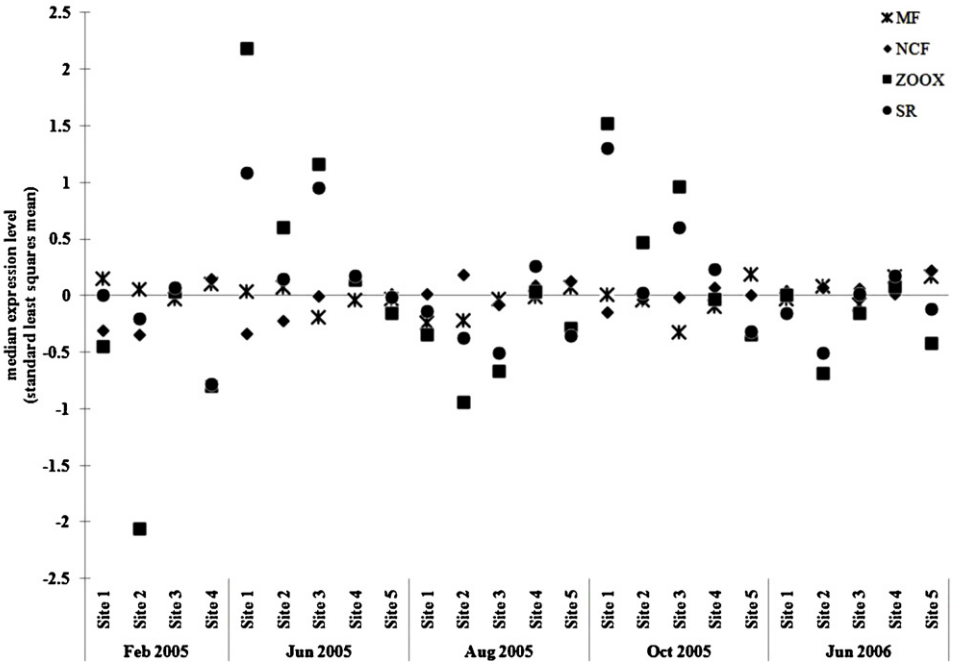

Fig. 3. Deviations from the standardized least squares mean (SLSM) for genes within functional categories (MF = multifunctional, NCF = normal cellular functioning, SR = stress response, ZOOX = symbiont-specific). Least squares profiles (corresponding to normalized signal intensities) were standardized to mean 0 for all genes. The median SLSM value of genes within each functional category is graphed by collection period and site. Correlation analysis revealed a strong association between SR and ZOOX functional groups ($r = 0.90$); however, there were no correlations between MF and NCF ($r = -0.16$) or across all functional groups ($r = -0.32$).

A longer-term localized response was identified at Site 4 in June 2005, August 2005, October 2005 and June 2006, as indicated by consistent significant up-regulation of normal cellular function and multifunctional genes known to be activated under stress conditions (i.e. green fluorescent protein, Palmer et al., 2009; NALP/cryopyrin, Lee, 2001; heat shock protein 70 genes, Parsell and Lindquist, 1993; Eckwert et al., 1997; polyubiquitin, Cheng et al., 1994; Table 4). A DNA repair gene (DNA-3-methyladenine glycosylase) and an oxidative stress indicator gene (selenium binding protein) were also highly up-regulated at Site 4 during these collection dates (Table 4A). Similar gene expression profiles were not observed at other sites over any collection date.

When considering interactions between location and sampling dates, comparisons between Sites 4 and 5 revealed from spatial data alone (ESM Fig. 1A) showed little similarity (Table 4; ESM Fig. 1C). Site 5 expression profiles clustered with Sites 1 and 3 collection dates, while expression exhibited by corals within Site 4 was similar across sampling dates, with the exception of February 2005 (ESM Fig. 1C). On the other hand, similarity between sample dates, June 2005 and October 2005 identified from temporal data alone (ESM Fig. 1B), was retained in the location by sampling date interaction hierarchical cluster analysis, and was supported by similarity within Sites 1, 2, 3 and 4 during these dates (ESM Fig. 1C).

SR and ZOOX groups revealed significant expression variability in site by collection period interactions ($p = 0.0205$ and $p < 0.0001$, respectively; Fig. 3); however, there was no significant variability in sites during the study period in NCF and MF groups ($p = 0.9970$ and $p = 0.8740$, respectively). SR and ZOOX gene expression was highly differentially regulated in June 2005 and October 2005 at Sites 1, 2, and 3 whereas, expression was reduced or equivalent to the SLSM at all other site/collection period comparisons (Table 4B; Fig. 3). Correlation analysis revealed a strong association between SR and ZOOX functional groups ($r = 0.90$); however, there were no correlations between MF and NCF ($r = -0.16$) or across all functional groups ($r = -0.32$).

4. Discussion

Marine communities experience heterogeneous effects of environmental influences due to microhabitat variability and proximity to point sources of pollutants, as well as temporal variation in environmental conditions. In this study, gene expression analysis revealed that coral populations were differentially impacted by location and sampling date.

Water temperature, a common contributor to coral stress (Glynn and D'Croz, 1990; Gates et al., 1992; Bruno et al., 2007), did not correlate with gene expression profiles during any collection date at any location (Fig. 2A) and the fewest number of differentially expressed genes (12.8 ± 3.2) was observed during the highest water temperature (August 2005, ~30 °C). In fact, the highest apparent stress response (based on number and identity of differentially expressed genes) occurred in June 2005 and October 2005 when water temperatures ranged between 27 and 28 °C (ESM Fig. 1C). Cluster analysis also illustrated that corals experiencing similar temperatures do not cluster strongly with each other (ESM Fig. 1C). It was expected that water temperatures of <30 °C would not alter coral gene expression given that previous studies using protein biomarkers have reported that heat shock genes, classic indicators of thermal stress, at temperatures below 33 °C were not differentially expressed (Black et al., 1995; Sharp et al., 1997; Downs et al., 2000).

Gene expression patterns, however, were positively correlated with precipitation (Fig. 2B). During this study, heavy precipitation events occurred in Dade County immediately prior to the June 2005 and October 2005 collections (Fig. 2B). Precipitation in June 2005 was the highest recorded during the study period, followed by hurricane Katrina, tropical storm Ophelia and hurricane Wilma in August, September and October 2005, respectively. Corals collected during June 2005 and October 2005, particularly at sites

Table 4
Genes including accession numbers deviating by at least ±0.80 of the standard least squares mean as determined by ANOVA. Multiple accession numbers of the same gene are differentiated by superscript numbers and indicate multiple versions of this gene represented on the array. Highly significant up-regulation and down-regulation are indicated by "+" and "−", respectively. To highlight spatial and temporal gene expression patterns, the data are presented by site (A) and collection date (B).

A			Site 1					Site 2					Site 3					Site 4					Site 5				
			20m 6.5km S					10m 5.0km SE					10m 6.3km NNE					10m 20.7km NNE					20m 22.0km N				
	Fur	Gene (Accession)	F05	J05	A05	O05	J06	F05	J05	A05	O05	J06	F05	J05	A05	O05	J06	F05	J05	A05	O05	J06	F05	J05	A05	O05	J06
Normal Cellular Function (NCF)		**regulation of transcription**																									
		Coiled-coil domain-containing (EZ042546)		-	-	-			-		-																
		Regulation of nuclear pre-mRNA (EZ013430)		+		+						-													-		
		cellular respiration																									
		cytochrome oxidase 1 (AF013738)		-	+	-			-		-			-		-								+		+
		NADH dehydrogenase (EZ026766[1], DQ351254[2], EZ011273[3])		$-^{123}$		$-^{123}$			$-^{23}$	$-^{3}$	$-^{23}$	$+^{12}$	$+^{23}$	$-^{12}$	$+^{1}$	$-^{12}$	$+^{23}$	$+^{12}$			$+^{2}$			$+^{23}$	$+^{23}$	$+^{3}$
		metabolism																									
		acyl-CoA thioesterase (DQ309537[1], DQ309539[2])	$+^{2}$					$+^{12}$				$-^{1}$		$-^{1}$		$-^{1}$	$-^{1}$	$-^{2}$						$-^{2}$	$+^{2}$		
		bioluminescence																									
		green fluorescent protein (AY181557)		-				-	-	-	-		+					+	+	+	+	+					
Multi-functional (MF)		**regulation of apoptosis**																									
		B-cell lymphoma-2 antagonist/killer (XM_002160789)		-		-		+		+		+		-		-				+							
		B-cell lymphoma-2 apoptosis regulator (EU035762)		-		-		+		+		+		-	+	-		+									
		molecular chaperone																									
		70-kDa heat-shock protein (AY226079)				+		+		-		-		+		+		-	+	+	+						
		Hsp70 interacting, suppression of tumorigenicity (NM_001030757)		-		-		+	-	-								+	+	+	+	+					
		proteolysis																									
		Membrane-bound transcription factor(EZ004852)		+				-		-		-		+		+		-									
		polyubiquitin (JK822200)		+		+		-		-		-							+	+	+	+					-
		metal ion regulation																									
		cytochrome b (AB117374)				-		+										+		-							
		succinate dehydrogenase complex, DHSB (AJ251055)			-			-		-	-	+					-					+					+
		ferritin (JK822205)		+		+		-	+	-	+	-		+		+											-
		metallothionein (CV564390[1], DR681654[2])	$+^{2}$	$-^{12}$		$-^{12}$		$+^{2}$	$-^{12}$		$-^{1}$	$+^{2}$			$+^{2}$			$+^{12}$	$+^{1}$							$+^{12}$	$+^{1}$
Stress Response (SR)		**inflammation**																									
		NALP, leucine-rich repeat ribonuclease inhibitor (JK822215)		-		+		+	-					-				-	+	+	+				+		
		DNA repair																									
		UV excision repair protein RAD23 (XM_002169183)		-			-	+	-		-			+			-		+			+					
		DNA-3-methyladenine glycosylase (EZ033943)		+		+		-		-		-		+		+						+					
		oxidative stress																									
		copper/zinc SOD (DQ309550[1], AY164664[2], U27840[3])		$+^{123}$		$+^{13}$		$+^{12}$	$+^{123}$		$+^{13}$		$-^{13}$	$-^{12}$	$-^{1}$	$-^{12}$		$-^{3}$	$-^{1}$	$-^{1}$	$-^{12}$			$-^{2}$		$-^{2}$	$+^{1}$
		glutaredoxin (EZ030451)		+				-	+	+	+	-					-										
		glutathione peroxidase (AY836663)				+		-		-				+		+	+	-									
		heme binding protein 2 (HEBP2) (DQ213995)		+		+		+	+		+		-		-				+	-					-		+
		response to xenobiotic																									
		selenium binding protein (EZ043132)																	+	+	+	+					
		glutathione-s-transferase (EU747061[1], EZ040771[2])			$+^{1}$			$-^{12}$	$-^{2}$	$+^{2}$		$-^{1}$	$+^{12}$		$+^{1}$	$+^{2}$		$-^{2}$		$+^{12}$					$+^{1}$		$-^{1}$
		response to copper exposure (JG294128[1], JG294126[2])	$+^{12}$	$-^{2}$			$-^{2}$	$+^{12}$						$-^{12}$		$-^{12}$		$+^{2}$							$-^{2}$	$+^{1}$	
		response to dibrome exposure (BI534456)	+	-		-		+		+		+		-											-		
		response to permethrin exposure (JG294127)	+	-		-		+	-		-					-						+				+	
		response to mercury exposure (BI534459)		-				+	-	+	-	+		-		-		+									
		Hephaestin, ceruloplasmin homologue (DN167139)	+			-	-	+								-		+							-		
		wound healing																									
		Ly6/PLAUR (JK822199)		+		+		-	+	-	+	-		+	-	+		-									
		myosin heavy chain 1 (EZ002271)		+		+		-		-		-		+		+		-		+					-		
Symbiont -specific (ZOOX)		**zooxanthella**																									
		actin (AB086828)		+		+		-	+	-		-		+	-												-
		calmodulin (AF007889)		+		+		-	+	-	+	-															
		ferredoxin (EF134003)		+		+		-		-								-							-		-
		glyceraldehyde-3-phosphate dehydrogenase (AB106689)		+		+		-						+	-	+		-									
		RuBisCO (AF299359[1], AF298221[2])		$+^{12}$		$+^{12}$		$-^{12}$	$+^{2}$	$-^{12}$				$+^{12}$		$+^{12}$	$+^{2}$	$-^{12}$									
		peridinin chlorophyll-a binding protein (pcp) (AY149170)		+		+		-	+		+			+				-							-		-
		peridinin chlorophyll-a binding protein (JK822207)	+					+					-	-		-						-					
		pbsA photosystem II protein D1 (AJ884906)		-		-		+	-	+		+		-	-	-										+	
		ultraviolet inducible ribosomal protein (EZ011894)		-		-		+				+		-		-		+		-		-					

Table 4 (*continued*).

B			February 2005					June 2005					August 2005					October 2005					July 2006				
			23.3°C 1.5cm					27.8°C 18.0cm					29.7°C 6.0cm					28.0°C 12.5cm					27.1°C 5.0cm				
	Fur	Gene (Accession)	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Normal Cellular Function (NCF)		**regulation of transcription**																									
		Coiled-coil domain-containing (EZ042546)						-	-				+					-	-								
		Regulation of nuclear pre-mRNA (EZ013430)						+									-	+						-			
		cellular respiration																									
		cytochrome oxidase 1 (AF013738)				+		-	-	-								-	-	-							
		NADH dehydrogenase (EZ026766[1], DQ351254[2], EZ011273[3])			$+^{13}$	$+^{2}$		$-^{123}$	$-^{13}$	$-^{12}$				$-^{3}$	$+^{2}$		$+^{3}$	$-^{23}$	$-^{13}$	$-^{12}$	$+^{1}$	$+^{1}$		$+^{12}$	$+^{13}$	$+^{3}$	$+^{3}$
		metabolism																									
		acyl-CoA thioesterase (DQ309537[1], DQ309539[2])	$+^{2}$	$+^{12}$		$-^{2}$											$-^{2}$					$+^{2}$		$-^{2}$	$-^{2}$		
		bioluminescence																									
		green fluorescent protein (AY181557)		-	+	-		-	-		+			-		+			-		+					+	
Multi-functional (MF)		**regulation of apoptosis**																									
		B-cell lymphoma-2 antagonist/killer (XM_002160789)		+		+		-		-				+				-		-				+			
		B-cell lymphoma-2 apoptosis regulator (EU035762)		+		+		-		-				+	+			-		-				+			
		molecular chaperone																									
		70-kDa heat-shock protein (AY226079)		-	+	-				+	+			-				+		+	+			-		+	
		Hsp70 interacting, suppression of tumorigenicity (NM_001030757)				+		-	-		+			-				-			+					+	
		proteolysis																									
		Membrane-bound transcription factor(EZ004852)		-		-		+	+	+	+			-	-			+		+				-			
		polyubiquitin (JK822200)		-		-		+			+			-				+		+	+			-			-
		metal ion regulation																									
		cytochrome b (AB117374)		+		+												-									
		succinate dehydrogenase complex, DHSB (AJ251055)		+										-										+		+	+
		ferritin (JK822205)		+				+	+	+				-				+	+	+							
		metallothionein (CV564390[1], DR681654[2])	$+^{2}$	$+^{2}$		$+^{1}$		$-^{12}$	$-^{12}$	$-^{2}$					$+^{2}$			$-^{12}$	$-^{1}$	$-^{2}$		$+^{12}$		$+^{2}$			$+^{1}$
Stress Response (SR)		**inflammation**																									
		NALP, leucine-rich repeat ribonuclease inhibitor (JK822215)		-		-			-	-	+					+	+	+			+							
		DNA repair																									
		UV excision repair protein RAD23 (XM_002169183)		+				-	-	+	+								-						-	+	
		DNA-3-methyladenine glycosylase (EZ033943)		-				+		+	+			-				+		+				-		+	
		oxidative stress																									
		copper/zinc SOD (DQ309550[1], AY164664[2], U27840[3])		$+^{12}$	$-^{13}$	$-^{3}$		$+^{123}$	$+^{123}$	$-^{12}$	$-^{1}$	$-^{2}$		$+^{1}$	$-^{3}$	$-^{13}$			$+^{13}$	$+^{13}$	$+^{12}$	$-^{12}$	$-^{2}$					$+^{1}$
		glutaredoxin (EZ030451)		-				+	+		-			+					+					-	-		
		glutathione peroxidase (AY836663)		-		-		+		+				-				+		+					+		
		heme binding protein 2 (HEBP2) (DQ213995)		+	-			+	+		+				-		-	+	+								+
		response to xenobiotic																									
		selenium binding protein (EZ043132)									+					+					+					+	
		glutathione-s-transferase (EU747061[1], EZ040771[2])		$-^{12}$	$+^{12}$	$-^{2}$		$-^{2}$	$-^{2}$				$+^{1}$	$+^{2}$	$+^{1}$	$+^{12}$	$+^{1}$	$-^{1}$	$-^{2}$	$+^{2}$	$+^{2}$	$-^{1}$		$-^{2}$			$-^{1}$
		response to copper exposure (JG294128[1], JG294126[2])	$+^{12}$	$+^{12}$		$+^{2}$		$-^{2}$		$-^{12}$							$-^{2}$			$-^{12}$		$+^{1}$					
		response to dibrome exposure (BI534456)	+	+		+		-		-				+			-	-						+			
		response to permethrin exposure (JG294127)	+	+				-										-	-			+				+	
		response to mercury exposure (BI534459)		+		+		-	-	-				+					-	-				+			
		Hephaestin, ceruloplasmin homologue (DN167139)	+	+		+												-		-							
		wound healing																									
		Ly6/PLAUR (JK822199)		-		-		+	+	+				-	-			+	+	+				-			
		myosin heavy chain 1 (EZ002271)		-		-		+		+				-			-	+		+				-			
Symbiont -specific (ZOOX)		**zooxanthella**																									
		actin (AB086828)		-				+	+	+				-	-			+	+	+				-			-
		calmodulin (AF007889)		-				+	+					-				+	+					-			
		ferredoxin (EF134003)		-		-		+	+	+	+			-			-	+		+							-
		glyceraldehyde-3-phosphate dehydrogenase (AB106689)		-		-		+		+					-			+		+	+						
		RuBisCO (AF299359[1], AF298221[2])		$-^{12}$		$-^{12}$		$+^{12}$		$+^{12}$				$-^{12}$				$+^{12}$		$+^{12}$					$+^{2}$		
		peridinin chlorophyll-a binding protein (pcp) (AY149170)		-		-		+	+	+							-	+	+								-
		peridinin chlorophyll-a binding protein (JK822207)	+	+	-					-										-							
		pbsA photosystem II protein D1 (AJ884906)		+				-	-	-				+	-					-		+		+			
		ultraviolet inducible ribosomal protein (EZ011894)		+		+				-	-							-		-	-	+		+		-	

closest (<6 km) to the PMI area (Sites 1, 2 and 3), demonstrated similar patterns in differential gene expression (Table 4A). The PMI and surrounding areas (Miami River, Biscayne Bay and Virginia Key sewage outfall) are known to be significant sources of freshwater, sediment and contaminants to nearby reefs (McArthur, 2001; Long et al., 2002; Gardinali et al., 2004). Heavy precipitation likely increases the impacts of these point sources through reductions in salinity, increases in terrestrial runoff and overloading of wastewater treatment facilities, potentially exposing nearby reefs to osmotic stress, sedimentation, xenobiotics, and/or increased nutrients, all of which have been implicated in declining coral health (Dubinsky and Stambler, 1996; Kerswell and Jones, 2003;

McLaughlin et al., 2003; Philipp and Fabricius, 2003; Weber et al., 2006).

We suspect that the precipitation events preceding the June 2005 and October 2005 collections acted as regional stressors by exposing corals closest to the PMI to episodes of low salinity. Ambient salinities in the south-Atlantic Florida region generally range from 36 to 37 ppt at the surface and vary little with depth. However, this area experienced a drop in salinity during the 4th quarter of 2005 due to weather related precipitation (Boyer and Briceño, 2006). Surface salinity at Site 2 was 30 ppt in June 2005 during a period of local flooding (Edge, pers. obs; salinities were not measured at other sites or collection dates). Such reductions in salinity are potentially lethal to corals, in part due to corals' limited osmoregulation capacity (Ferrier-Pages et al., 1999; Kerswell and Jones, 2003; Manzello and Lirman, 2003). Decreased salinity affects metabolism, disrupts cellular processes and enzyme kinetics, causes decreases in reproduction and survivorship, negatively impacts photosynthesis and respiration and can result in bleaching (Muthiga and Szmant, 1987; Moberg et al., 1997; Ferrier-Pages et al., 1999; Kerswell and Jones, 2003; Manzello and Lirman, 2003). In this study, alterations in gene expression are consistent with coral physiological responses to low salinity. Genes involved in cellular respiration are significantly decreased in samples collected from Sites 1, 2 and 3 in June 2005 and October 2005 (Table 4). In addition, genes involved in the regulation of apoptosis are decreased, indicating a response associated with cell death (Yu and Choi, 2000). Apoptotic regulation is important in maintaining coral–zooxanthella symbiosis (Perez and Weis, 2006; Rodriguez-Lanetty et al., 2006), and may be indicative of a disturbance to the coral–zooxanthella symbiosis. Genes demonstrating increased expression are involved in, DNA repair, oxidative stress, proteolysis and wound healing, consistent with responses to salinity stress. Significant changes in expression observed in all symbiont genes indicate that either the zooxanthellae are also directly impacted by this stressor, or that the coral–zooxanthella symbiosis is being affected. Genes known to be up-regulated specifically to xenobiotics (Morgan et al., 2001; Morgan and Snell, 2002, 2006) were down-regulated at these sites, suggesting xenobiotic exposure did not contribute to the observed stress response in June 2005 and October 2005.

Gene expression patterns of corals at Site 2 revealed an acute localized stress response during February 2005. Corals sampled from Site 2, the 10 m site closest to the PMI (5.0 km SE), exhibited highly differential expression in photoprotection, molecular chaperones, DNA repair, apoptosis, metabolism, proteolysis, metal ion regulation, xenobiotic-responsive and symbiont genes, indicative of stress responses consistent with sediment stress and xenobiotic exposure (Morgan et al., 2001; Morgan and Snell, 2002, 2006; Tamura et al., 2006). Although corals at Site 2 appeared healthy (i.e. no visual signs of partial mortality or bleaching), sediments had accumulated on corals at this site, a phenomenon that was not observed at any other site (Edge, pers. obs.). Site 2 also exhibited lower species diversity than other sites (Edge, pers. obs.) and was dominated by sediment tolerant scleractinian coral species, including *M. cavernosa* (Bak and Elgershuizen, 1976; Lasker, 1980).

Negative impacts of sediments on corals result from tissue abrasion, light reduction, smothering, energetic costs of removal, and exposure to pathogenic microbes, nutrients, and contaminants bound to the sediments (Rogers, 1990; McLaughlin et al., 2003; Nugues and Roberts, 2003; Weber et al., 2006). Organic xenobiotics and heavy metals can bind to sediments exposing corals to these contaminants for extended periods of time (Bubb and Lester, 1995; Mortimer and Connell, 1995; Dubinsky and Stambler, 1996). Studies investigating coral response to sediment stress have shown reduced chlorophyll-a and zooxanthella concentrations, decreased photosynthesis and increased respiration (Riegl and Branch, 1995; Philipp and Fabricius, 2003; Weber et al., 2006). An induction of molecular chaperones, including *hsp70*, has also been shown to occur in response to sediment stress (Wiens et al., 2000; Hashimoto et al., 2004). Gene expression patterns at Site 2 in February 2005 are consistent with exposure to xenobiotics and sediment stress and are correlated with observations of sediment accumulation on corals at this site.

Expression patterns at Sites 4 and 5, the most geographically distant sites from the PMI area (>20.7 km; Fig. 1), were distinct from those observed at Sites 1, 2 and 3. Moreover, sites 4 and 5 may not experience direct effects from the PMI area. Based on gene expression patterns, Site 5 shows lower levels of stress than any other site across time. Site 4, however, appears to be influenced by a long-term localized stressor since corals from this site were characterized by consistent significant up-regulation of stress-activated genes, unrelated to direct exposure to xenobiotics in June 2005, August 2005, October 2005 and June 2006 (Table 4A). These patterns are unique to this site and the stressors responsible for these patterns are unknown.

During reproductive periods, organisms may redirect energy allocations from other resources to reproductive effort, which may be reflected in gene expression patterns across time; however, it did not appear that reproductive processes contributed significantly to temporal expression patterns of the genes targeted in this study. This species typically begins to develop gametes in November (females) or May (males) and spawns gametes a few days after the full moon in July, August and/or September each year (Szmant, 1991). Expression patterns were not unique in August 2005 or consistent across all sites during this collection period, as might be expected if reproductive processes were influencing regulation of the study genes.

There was a strong, positive correlation between host stress response gene expression and expression of most symbiont genes ($r = 0.9$; Fig. 3). Expression patterns of symbiont genes involved in metabolism, carbon dioxide fixation, and growth (actin, glyceraldehyde-3-phosphate dehydrogenase, ribulose-1,5-bisphosphate carboxylase oxygenase (rubisco), membrane-bound transcription factor, ferredoxin, peridinin chlorophyll-a, and calmodulin 1) demonstrated an opposite pattern of expression than three symbiont genes involved in responses to light and photosynthesis (peridinin chlorophyll-a binding protein apoprotein precursor, a UVB-inducible ribosomal gene, and photosystem II protein D1; Table 4; ESM Fig. 1C). These results are noteworthy regarding insight into the coral–zooxanthella symbiosis and indicate increased metabolic activity and decreased photosynthetic activity by zooxanthellae during periods of host stress.

Exposure of coral holobionts to various stressors is known to disrupt carbon dioxide fixation in zooxanthellae, resulting in a redox imbalance and subsequent damage to the photosystem II complex (Jones et al., 1998; Lesser and Farrell, 2004). In this study, rubisco, the key photosynthetic enzyme that catalyzes the first step of carbon dioxide fixation, exhibits increased expression simultaneous to increased expression of host stress genes. The symbiont may be responding to the mounting redox imbalance by producing more rubisco. In addition, it has been demonstrated that the photosystem II D1 protein decreases with increased exposure to various stressors (Warner et al., 1999; Lesser and Farrell, 2004). Changes in this protein are associated with damage to the photosystem II complex due to oxidative stress (Jones et al., 1998). In this study, the photosystem II D1 gene exhibits significantly decreased expression concomitant with elevated host stress gene expression. Impairment in the ability of the symbionts to photosynthesize may represent a signal initiating the dissociation of the coral–algal symbiosis (Kerswell and Jones, 2003).

5. Conclusions

This study uses gene expression analysis to show specific spatial and temporal responses to different stressors such as xenobiotic exposure and osmotic stress. By monitoring the expression patterns of specific genetic biomarkers, the relative influence of different stressors impacting an organism can be prioritized. Using such a method, this study was able to identify temporal stress in coral associated with heavy precipitation that was localized to a point source input. Additionally, acute stress, localized to a single site, proved to be associated with xenobiotic and sediment stress based on the biomarkers affected. Although the exact stressor(s) may not ultimately be identified, the list can be narrowed substantially, allowing researchers and managers to prioritize their investigation of major factors impacting coral populations at various times and locations. Finally, this study shows that gene expression analysis can be used to investigate the impacts of stress on symbiotic relationships. An unexpected pattern in zooxanthellae gene expression associated with host stress gene expression was revealed and opens new questions and hypotheses regarding coral–zooxanthellae interactions during stress responses.

Risk assessment investigations typically characterize locations by initially performing chemical analyses followed by biological assays to quantify the toxicity of chemicals associated with study sites. Uncertainties in the bioavailability and interactive effects of toxins surrounds environmental risk assessments based on data generated from traditional analytical chemical methods (Frederickson et al., 2001). This study offers an alternative approach by first quantifying and characterizing the expression profiles of the coral populations at 5 different study sites. Biological monitoring and effect-directed analysis are becoming increasingly important tools to characterize environmental contaminations (Blasco and Picó, 2009). Biosensors are capable of converting a biologically induced recognition event (e.g. gene expression) into a usable signal (microarray expression profiles) (Farré et al., 2005). Results of the biosensors presented in this study provide directions for future chemical analyses to focus on those study sites most responsive to xenobiotic-related gene expression. Based on results herein, Site 2 reveals significant expression of xenobiotic-related genes during a time period that significantly corresponds with periods of heavy precipitation. Presently, the possibility cannot be excluded that this response could be linked to sediment stress. However, Site 4 exhibits the expression of a suite of xenobiotic-related genes that are unique compared to all other sites. Concurrently, site 4 had no visible evidence of sedimentation stress. This study presents the development and application of a microarray (i.e. biosensor) to produce gene expression profiles which in turn provide effect-directed results to aid in the identification of sites that should be further investigated for the presence of xenobiotic chemicals. This type of analysis has proven useful as the initial step in identifying adverse effects on organisms and populations (Farré et al., 2005; Schmitt et al., 2011).

The presence of specific contaminants was not investigated in this study, but the results provide evidence of different levels of stress and toxicity responses between sites that change over time. An unidentified chemical stressor (or cocktail of chemical stressors) appears to be impacting coral populations at some of the study sites. It has been documented that these sites are proximate to point sources of contaminants, including copper, lead, mercury, zinc, arsenic, PAHs and PCBs (McArthur, 2001; Long et al., 2002; Gardinali et al., 2004). This study detects spatial and temporal signals that are likely related to variable contamination events across the area of investigation. Additionally, the altered pattern of gene expression at some of the study sites does not strongly correspond to other environmental stressors such as temperature, salinity, and/or sedimentation. This study demonstrates the ability of stress-gene microarrays to identify sub-lethal effects of environmental stressors on natural populations of corals where visual assessments of coral health fail to indicate adverse effects. Gene expression analysis provides insight into the molecular mechanisms elicited in response to different environmental stressors and how corals compensate for a variety of perturbations, which will ultimately aid in the understanding of the causes of coral reef decline. In summary, this study demonstrates an exposure driven assessment that detects adverse effects in natural populations responding to contaminant exposures. The spatial and temporal nature of responses detected in this study offers insight into new directions for future chemical analyses at these study sites.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.aquatox.2012.11.014.

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Assessment of the Impacts of the Oculina Bank Marine Protected Area and In-Depth Ethnographic Profile of the Fort Pierce, Florida Fishing Community

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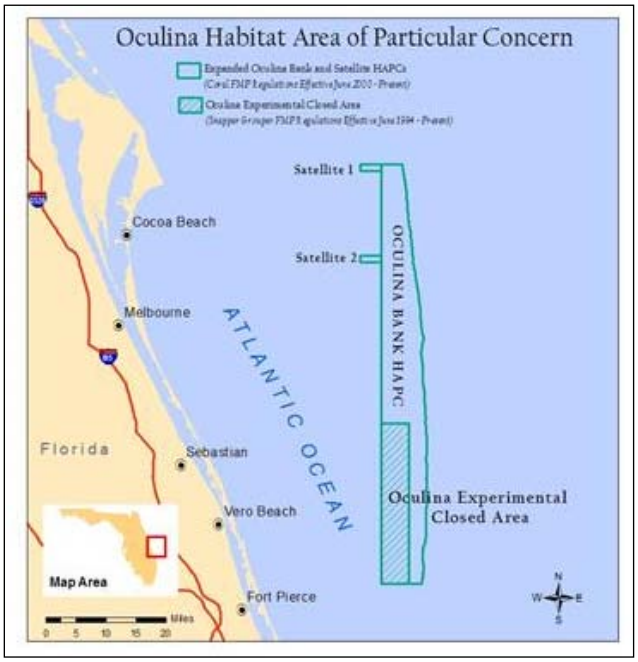
FINAL REPORT



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Title: Assessment of the Impacts of the Oculina Bank Marine Protected Area and In-Depth Ethnographic Profile of the Fort Pierce, Florida Fishing Community

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I. Abstract

This project addressed the problems related to examining the impacts of marine protected areas (MPAs) on the community of Fort Pierce, Florida, in particular the recreational, charter and commercial fishermen. Further, the report provides an in-depth description of the fishing community and the various networks that exist between and among the various fishing sectors: commercial, recreational and charter. Commercial, charter for-hire, and private recreational fishermen participated in a collection of oral histories focused around their experiences regarding the Oculina Bank. In total, 45 oral histories were collected; 15 interviews were completed with each of the three identified fishing sectors under study: commercial, charter/headboat, and recreational fishermen. The interviews were digitally recorded and uploaded to a website from which the recordings were downloaded for transcription by the University of South Florida's Oral History Program. The audio recordings and transcripts are available to the public at [**http://guides.lib.usf.edu/content.php?pid=49131&sid=1429723**], where USF has generously agreed to house the collection. Using the 45 interview responses for analysis, the social networks of these fishermen were examined for transmission of information about fishing regulations. The results of the study rely heavily on the texts from participating fishermen. It is from their perspective and narratives that effects are assessed. The effects from the regulations implementing the Oculina Bank HAPC have been described qualitatively. These impacts were generalized as (a) positive or negative according to the goals of the impacted user group; and (b) direct or indirect correlating roughly with short-term, immediate impacts or long-term, future impacts. This study raises the issue that more data are needed to document the impacts and benefits of MPAs on both the biological and socio-cultural environment.

II. Executive Summary

As concern over the health of marine ecosystems grows, various management agencies in the United States are considering Marine Protected Areas (MPAs) to provide protection for and conservation of valued marine habitats and resources. MPAs can be a valuable tool to balance sustainable use with long-term conservation of the ocean, especially when they are planned, managed and evaluated using reliable natural and social science. While MPAs come in many sizes, shapes and purposes, they share a fundamental characteristic and challenge: providing a higher level of protection to specific places in the ocean (Wahle et al., 2003).

There has been relatively little social impact assessment of the impact of MPAs, at least comprehensively within the United States. In fact, the evaluation plan for the Oculina Bank Experimental Closed Area includes no mention of an assessment of the impacts of the MPA on the community or humans. Yet, an understanding of the human use of natural resources is recognized as a critical component of any ecosystems approach, including the use of MPAs (Curran, 2002). Christie (2004), in a review of MPA social and biological success, points out that: "… a strong linkage exists between social and biological success, with social considerations determining long-term biological success. This finding implies that standards for measuring both biological and social success should be applied equally and that MPAs should be designed to meet multiple social and biological goals" (Christie, 2004:132). While there has been no attempt to understand the social impacts of the Oculina Bank, there have been some studies that examine the impacts of other MPAs in the region. Murray (2005) finds that the original projections of the economic impacts of the Dry Tortugas Ecological Reserve were generally accurate in terms of predicting changes in catch, effort and overall economic activity. Generally, there was consolidation of fishing effort with a landings increase while participation declined. Current perceptions of fishermen seemed to correspond with earlier projections as they perceived the impacts of the reserve to positively affect stocks, but saw no positive effects for themselves.

This study examined the effects of the Oculina Bank HAPC closure and regulations on the fishermen of Fort Pierce, Florida. Commercial, charter for-hire, and private recreational fishermen participated in a collection of oral histories focused around their experiences regarding the Oculina Bank. The results of the study rely heavily on the texts from participating fishermen. It is from their perspective and narratives that effects are assessed. The data collected from field notes, data requests to NOAA's Southeast Science Center, the South Atlantic Fishery Management Council and Florida State agencies, museum archives, academic literature, and news articles were compiled and used to form the ethnographic profile of Fort Pierce. This profile provides descriptive characteristics of the community through time. Data were collected at as fine a scale as possible and the geographic range for landings and trip data are presented below.

Changes in behavior are imposed on fishermen when certain regulations are implemented and these regulations affect fishermen in different ways. Commercial and recreational fishermen may be impacted differently, and perceive the same regulation differently, as well. But even within one sector, there is variation in fishing preferences and activity and thus differential impacts. The effects from the regulations implementing the Oculina Bank HAPC have been described qualitatively. These impacts were generalized as (a) positive or negative according to

the goals of the impacted user group; and (b) direct or indirect correlating roughly with short-term, immediate impacts or long-term, future impacts.

As with many fishery regulations that restrict effort, there were winners and losers as a result of the closure of the Oculina Bank HAPC. An important result of this study found that those who benefited or were negatively impacted cannot be identified by sector alone. Some attest that the closure saved the Port Canaveral area rock shrimp fishery. On the other hand, the commercial bottom fishermen of Fort Pierce were negatively impacted. Today, commercial fishing in Fort Pierce is primarily directed at king mackerel (kingfish) and the actual number of commercial bottom fishers who were impacted by the Oculina Bank closure remains unknown. Although the majority of commercial landings by Fort Pierce fishermen now consist of king mackerel, there are local commercial fishermen with diversified strategies who target snapper grouper outside of the Oculina Bank, as well as tilefish and pelagics.

An important idea that arose frequently during the ethnographic and oral history components of the study concerns fishermen's support for effort-restricting regulations that make sense to the fishermen. For example, fishermen's observations support the need for certain effort restrictions. The need for fish to be able to reproduce is a common theme among effort restrictions fishermen find necessary. Fishermen generally support closed seasons or areas during times of spawning, but resist areas closed as complete no-take zones. There is also broad support for minimum size limits, as fishermen understand the need for fish to grow to reproductive maturity, but the observation of dead discards from throwing back undersized fish is perceived as wasteful. The lesson for fishery managers is to recognize the need to design effort restrictions around fishing behavior, knowledge, and perceptions rather than based on an assemblage of restrictions that will meet a total allowable catch.

Finally, this study raises the issue that more data are needed to document the impacts and benefits of MPAs on both the biological and socio-cultural environment. It is not only important to consider whether potential biological benefits outweigh negative socio-cultural and economic impacts, but to test such assumptions and expectations. If evidence supports such closures, fishery managers should be more pro-active in communicating this information with fishermen in order to help shape an understanding and acceptance of such management measures. If evidence does not provide measurable benefits to the biological or physical environments to support ongoing negative socio-cultural and economic impacts, then such restrictions should be relaxed.

This report summarizes a long-term study of the fishing community of Fort Pierce, Florida to provide a better understanding of the various social and economic networks within a community that pertain to fishing and how they may have changed over time as a result of varying fishing regulations, including the establishment of the Oculina Bank MPA and other socio-economic and demographic transformations.

III. Purpose

Description of Problem:

As concern over the health of the marine ecosystems grows, various management agencies in the United States are considering Marine Protected Areas (MPAs) to provide protection for and conservation of valued marine habitats and resources. MPAs can be a valuable tool to balance sustainable use with long-term conservation of the ocean, especially when they are planned, managed and evaluated using reliable natural and social science. While MPAs come in many sizes, shapes and purposes, they share a fundamental characteristic and challenge: providing a higher level of protection to specific places in the ocean (Wahle et al., 2003).

The official definition of an MPA is "any area of the marine environment that has been reserved by federal, state, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." (Executive Order 13158, May 2000). Practically all of the federal mandates pertinent to MPAs refer to the important role of social and economic factors in policy development and management decisions concerning MPAs (e.g. Sustainable Fisheries Act, National Marine Sanctuaries Act, Coastal Zone Management Act, Presidential Proclamations and Executive Orders). Similar requirements exist in national environmental legislation, such as the National Environmental Policy Act (NEPA) and Executive Order 12044 on improving government regulations. Overall, these mandates refer to the need for interdisciplinary assessment in support of policy and management decisions, including both formal social scientific data and the inclusion of public and stakeholder input (Wahle et al., 2003).

Although there is considerable support for the use of MPAs among fishery management agencies, there have been important differences expressed by stakeholders. One investigation into perceptions of fishermen concerning MPAs found that although these protected areas are promoted as providing increased protection for certain species of fish or crustaceans and/or increased abundance, fishermen may not agree with such estimates of expected results and see little utility in establishing an MPA (Milon et al., 1997). Others have found that predicted results of establishing MPAs will at times be overstated because researchers wrongly predicted harvesting behavior.

These results suggest a need for continued exploration of the social and economic impacts of MPAs. There has been a historic lack of funding for social science research in coastal and marine affairs; furthermore, the network of social scientists outside of the government, working on issues related to MPAs is similarly underdeveloped (NRC, 2001). With this in mind, Wahle et al. (2003) have developed, "The Social Science Research Strategy for Marine Protected Areas." The strategy document identifies high priority needs for social science information that are fundamental to the planning, management and evaluation of MPAs. Among these is the growing need to collect, analyze, synthesize, store and manage social science data of all types. Additionally, the need for baseline data, monitoring programs and evaluation methods are also called for. The national social science strategy identifies the following six priority themes for social science research on MPAs:

- Governance, Institutions and Processes;
- Use Patterns;

• Attitudes, Perceptions and Beliefs;
• Economics of MPAs;
• Communities;
• Cultural Heritage and Resources (Wahle et al., 2003)

Blount and Pitchon (2007) have called for an increased role for anthropology within the multi-disciplinary research on MPAs. They note that issues of social and economic equity are most often at the forefront of concern for stakeholders and the discipline of anthropology is especially suited to document those concerns (Blount and Pitchon, 2007:109).

The following description of management action regarding the Oculina Bank comes from the "Oculina Experimental Closed Area Evaluation Plan" (SAFMC, 2005):

> The Oculina Bank is a 90-mile strip of coral reefs, located near the continental shelf edge off central eastern Florida that gets its name from the presence of banks, thickets, and rubble zones of *Oculina varicosa*. The depth of the western edge of the Oculina Bank is about 180 ft and the eastern boundary, located less than 3 miles east, is 400 ft. The bank narrows at the northern end, towards Cape Canaveral, to less than 2 miles wide. In 1984, the Council designated a 92-nm^2 portion of the Oculina Bank as the Oculina Habitat Area of Particular Concern (HAPC). Additionally, the Council prohibited the use of bottom trawls, bottom longlines, dredges, fish traps, and fish pots within the HAPC to mitigate the threat of fishing gear to Oculina coral. In January of 1996, regulations in Amendment 3 to the Coral FMP (SAFMC, 1995) became effective, which prohibited all fishing vessels from anchoring within the HAPC. Also in 1996, to minimize the impacts of the rock shrimp fishery on essential fish habitat, including the fragile coral species existing in the Oculina Bank, the Council prohibited trawling for rock shrimp east of 80°W longitude, between 27°30'N and 28°30'N latitude, in depths less than 100 fathoms. This action was taken through Amendment 1 to the Shrimp FMP (SAFMC, 1996). The area to which the prohibition applied became known as the rock shrimp closed area. In Amendment 6/Environmental Assessment to the Snapper Grouper FMP (SAFMC, 1993), implemented in 1994, the Council prohibited fishing for and retention of snapper grouper species within the HAPC and prohibited anchoring by vessels fishing for snapper grouper species. The area to which these prohibitions applied became known as the Oculina Experimental Closed Area. The intent of these prohibitions was to enhance stock stability and increase recruitment by providing an area where deep water species can grow and reproduce without being subjected to fishing mortality" (SAFMC, 1993). In 1998, the Council expanded the Oculina HAPC to include the rock shrimp closed area and added two Oculina HAPC satellite areas. This action was accomplished through Amendment 4 to the Coral FMP included in the Council's Comprehensive Habitat Amendment (SAFMC, 1998).

As evidenced by the passage above, over time there have been numerous management actions that may have had significant impacts upon the community and various fishing sectors. Over time, the accumulated effects of this management have undoubtedly influenced fishing behavior and other aspects of the fishing public and perceptions. Indeed, further restrictions may be imposed without any assessment on the cumulative social and economic impacts.

This project addressed many of the priority themes discussed earlier from the strategy for MPA social science assessment by incorporating an analysis of the impacts of the Oculina Bank MPA on the fishing community of Fort Pierce, Florida (with a focus on the three sectors of recreational, charter and commercial fishermen). This was accomplished by developing an in-depth ethnography of the fishing community including an examination of the social networks that exist among the fishing sectors and how they relate to the current MPA and its historical use.

Figure 1: Oculina Bank Experimental Closed Area. (SAFMC, 2005)

Overview of National Standard 8 and the Study of Fishing Communities

Since the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act in 1996, federal fishery management agencies have begun to provide funding in a number of regions to identify fishing communities in order to address National Standard 8 (McCay and Cieri, 2000; Hall-Arber et al., 2001; Jacob et al., 2002). These studies addressed, to varying degrees, the problem of identifying fishing communities and their dependence upon fishing. In each case the number of fishing communities studied covered entire states or regions of the country. These were very large areas which limited the amount of time spent in any particular fishing community. Another factor that makes this research relevant is that definitional

guidelines for identifying fishing communities and their dependence upon fishing have not yet been finalized. That makes this research particularly useful in providing insight into development of future guidelines for meeting National Standard 8.

Recently, efforts to identify fishing communities in the South Atlantic and Gulf of Mexico have been undertaken using secondary data sources, rapid assessment, and a Geographic Information System (GIS) (Impact Assessment, 2004; Jepson et al., 2005); yet this research has addressed only a portion of National Standard 8, the identification of fishing communities. Problems in defining community boundaries, the linkages between the fishing industry and the community, issues of growth and development from other economic activities and the accumulated impacts of regulation over time are just a few of the important problems that have emerged from the previous work in the Gulf of Mexico, South Atlantic region and elsewhere. The problem stems, in part, from the inability to ascertain such information from secondary data analysis and rapid assessment. These previous studies have encompassed large regions and many communities which make it difficult to explore the complex networks, both social and economic, that exist.

To truly understand the importance of fishing to a community, one must understand how the occupation of fishing is woven into the social and cultural fabric of a community through interaction over time. Like many natural resource communities, fishing communities have suffered over the years as they have endured many of the ills affecting so many extractive industries. As there have been declines in extractive and manufacturing employment, many communities have struggled to make the transition to service oriented work and other types of economic endeavors (Jacob et al., 2002). Measuring the strains of such transition requires a closer look at how communities have adapted and changed. This may be especially important in communities which have been affected by MPAs established nearby. Merely noting the change in economic sectors does not explain who struggles or why or how people adapt to such transitions in employment. This is important for fishery managers, as fishermen often switch to other fisheries or change fishing behavior. Furthermore, though often treated as firms, the fishing enterprise is most likely carried out at the household level. Many studies have pointed to the important role that wives and children have in providing support to the father's role as fisherman (Davis, 1986; Binkley, 2000; Smith et al., 2003). Therefore, to fully understand the relationship of the household and how it adapts to the larger socio-economic environment requires more intimate study. In order to answer many of these questions it has become obvious that to do so requires investigation over a longer period of time in a localized area. This report summarizes a long-term study of the fishing community of Fort Pierce, Florida to provide a better understanding of the various social and economic networks within a community that pertain to fishing and how they may have changed over time as a result of varying fishing regulations, including the establishment of the Oculina Bank MPA and other socio-economic and demographic transformations.

Using Ethnography in the Study of Fishing Communities

With the addition of National Standard 8 to the Magnuson-Stevens Act, a new focus on the study of the community and awareness of the need for more comprehensive study of the "fishing community" has been revived. Recent attempts to identify fishing communities and their dependence have had varied success in determining community boundaries, how a community relates to fishing or depends upon it and in some cases have been unable to accurately describe

certain sectors and their involvement within the fishing enterprise or the impact of regulations. Therefore to answer such questions a different methodology is needed.

Ethnography is not a methodology in and of itself. It encompasses the use of many different methodologies. Some of these methods include: participant observation, unobtrusive observation, oral history, unstructured interviews, semi-structured interviews, structured interviews, local archival research, folk taxonomies, cognitive mapping and others. This research utilizes many of these methodologies. The use of several different methods is necessary in conducting qualitative work to provide for validation of data collected. Often times through a process of triangulation, data collected through several methods will be compared to confirm the reliability of information gathered which will enhance its validity and comparability later.

This research is intended to show the interrelationship between reliance upon natural resources (fishing) and community. It provides an understanding of how people determine the boundaries of their community and provide an overview of the social and economic networks that are important to fishing within those boundaries. Furthermore, it provides an indication of how those networks have changed as a result of the historical events within the community, including fishing regulation, demographic and socio-economic transformations. In particular, the impact of situating the Oculina Bank Habitat Area of Particular Concern just offshore Fort Pierce, Florida is the focus.

Coastal communities are subject to many types of change that may include rapidly growing populations, increasing regulations, degradation of local ecosystems and in some cases the decline of important marine resources. Because natural resources are in a continuous state of fluctuation, residents of natural resource-dependent communities are often adapting to resource availability and seasonal variations which make adapting to change part of their daily lives. Through the use of ethnography this research attempts to provide an understanding of how fishermen cope with such transitions and how that affects their perception of their community and work. Because the Oculina Bank was a key fishing location for many fishermen in the area, their past history and present fishing practices are examined to understand how they have changed and what the fishermen perceive the impact to have been on their community. Other secondary quantitative data was also collected to compare to the qualitative discussion of change.

Overview of Fishing Communities Studies

As mentioned above, since the addition of National Standard 8 to the Magnuson Stevens Fishery Management and Conservation Act, there has been a concerted effort by the National Marine Fisheries Service to identify fishing communities throughout all regions of the U.S. including its territories. Initially, research focused on how to identify a fishing community and how to determine its dependence upon fishing (McCay and Cieri, 2000; Hall-Arber et al., 2001; Jacob et al., 2002). Determining boundaries of a fishing community and various criteria for determining dependence were key topics as was the focus on the complexity of fishing infrastructure and the degree of gentrification for individual communities.

Follow-up research, used rapid appraisal as a method to provide cursory indices of dependence as a means of identification for management purposes (Impact Assessment, 2004, 2005a, 2005b, 2006; Langdon-Pollack, 2004; Jepson et al., 2005; Agar and Stoffle, 2006; Griffith et al., 2006). Field visits to conduct key informant interviews and windshield surveys in coastal communities

provided rudimentary descriptions of fishing infrastructure and in some cases provided a ranking of coastal communities in terms of their fishing dependence. Unfortunately, as acknowledged by Griffith et al. (2006:1) "our research suggests that it is difficult to find many communities so heavily dependent on fishing that a decline in fishery resources would result in the entire community's collapse, yet the communities we designate highly dependent on fishing certainly would experience widespread economic dislocation with a substantial decline in fishing resources or activity."

Problems in defining community boundaries, the links to the fishing industry that pertain to the community, issues of growth and development from other economic activities and the accumulated impacts of regulation over time are just a few of the important difficulties that have emerged. Coastal communities are affected by numerous challenges that affect them whether they are heavily fishing dependent or not (Jepson, 2006). This makes it difficult to ascertain specific social impacts that might accrue from changes in fishing regulations and other factors. With communities so embedded in a coastal economy that is often tied to recreational tourism and development, isolating the impacts on the fishing population is complicated.

Under mandates to conduct social impact assessments, Regional Fishery Management Councils and the National Marine Fisheries Service (NMFS) have proceeded to incorporate fishing community profiles into management plans in order to provide some indication of the impacts of fishing regulations. Recent management actions have included summaries of impacts based upon the identification of fishing communities in all regions among most fisheries (NEFMC, 2003; PFMC, 2003; GMFMC, 2005; NOAA, 2006; SAFMC, 2006; WPFMC, 2006). Unfortunately, the collection of information on fishing communities is often not detailed enough to ascertain specific social impacts (Hanna, 2004; Kaplan, 2004). The baseline information that is collected provides the basis for building a social impact assessment, but further data and analysis are required, especially when attempting to ascertain cumulative impacts within an ecosystems approach (Cheuvront et al., 2005).

Although previous guidelines for conducting social impact assessment are available and have provided direction for much of the Social Impact Assessment (SIA) work to date (Bright et al., 2003; IOCGP, 2003), there remain certain issues that require elaboration for definitional and analytical consistency within Fishery Management Plans. Recent attempts to construct indices of vulnerability and resilience have borne out the difficulty in choosing consistent valid and reliable variables to measure such concepts across regional boundaries and research (Hall-Arber et al., 2001; GMFMC, 2004, 2005). Nevertheless, there remains a need to collect baseline information on fishing communities to build valid measures for social impact assessment that can apply to all regions and fisheries.

Fishing communities in the South Atlantic have been profiled (Jepson et al., 2005) using the standard tools of rapid assessment. Like the previous studies, this research covers a broad geographic area and includes numerous communities in each state along the South Atlantic coast. Description is limited to secondary data analysis and rapid appraisal, which as stated before, limits the ability of researchers to describe the complex networks that exist or linkages to other communities, regions and global markets. Furthermore, the effect of long-term changes in regulation and other socio-economic and demographic change is difficult to establish.

This research addresses several of the problems identified in previous research to enhance the assessment of impacts on the community of a MPA closure. Each of the above studies have had some success in attempting to identify communities that have an association with the fishing industry and in some cases were successful in providing some measure of dependence. However, the nature of how the fishing industry is connected to the larger social and economic region has not been accomplished for fishing communities in many areas. It is difficult to establish how certain occupations and industry are connected with the larger community through the "snapshot" approach. It has been difficult to rectify inconsistencies between different data sources which often present conflicting results, i.e., census employment data compared to permit data. With a more in-depth look at how the fishing infrastructure and enterprise intermingle into the larger community and economy, the social impacts of fishery regulation, like MPAs can be better assessed.

Overview of Social Assessment of MPAs

Although Blount and Pitchon (2007) see an important role for anthropology in the development of MPAs, there has been relatively little social impact assessment of the impact of MPAs, at least comprehensively within the United States. In fact, the evaluation plan for the Oculina Bank Experimental Closed Area includes no mention of an assessment of the impacts of the MPA on the community or humans. Yet, an understanding of the human use of natural resources is recognized as a critical component of any ecosystems approach, including the use of MPAs (Curran, 2002). Interestingly, an understanding of the migration of humans and the ensuing impact upon the coastal environment seems to bring together several theoretical approaches that suggest a variety of research methods. Curran (2002) states that understanding social networks of migrants to coastal areas can provide insight into their embededness within the community and thereby is essential to an understanding of their attitudes and perceptions regarding resource use. Social networks of established residents should provide similar insights as well.

Christie (2004), in a review of MPA social and biological success, points out that: "… a strong linkage exists between social and biological success, with social considerations determining long-term biological success. This finding implies that standards for measuring both biological and social success should be applied equally and that MPAs should be designed to meet multiple social and biological goals" (Christie, 2004:132). While there has been no attempt to understand the social impacts of the Oculina Bank, there have been some studies that examine the impacts of other MPAs in the region. Murray (2005) finds that the original projections of the economic impacts of the Dry Tortugas Ecological Reserve were generally accurate in terms of predicting changes in catch, effort and overall economic activity. Generally, there was consolidation of fishing effort with a landings increase while participation declined. Current perceptions of fishermen seemed to correspond with earlier projections as they perceived the impacts of the reserve to positively affect stocks, but saw no positive effects for themselves. This finding is similar to Milon et al.'s (1997) findings in their assessment of Florida Keys fishermen's perceptions of the Keys National Marine Sanctuary. Fishermen in their survey saw few benefits accruing outside the sanctuary with no long term benefit to the economy of the Keys.

These previous studies of the impacts of MPAs have pointed to some important consequences, some beneficial and others not so beneficial. It is important to continue to evaluate the impacts of this management policy as the use of MPAs continues to be promoted as a key component of Ecosystems Management.

Objectives:

Goal I: *Conduct in-depth ethnography of the fishing-dependent community of Fort Pierce, FL and implement protocol for examining the impact of the Oculina Bank Marine Protected Area*

1. Collect data through various ethnographic methods to determine social and economic networks that will help establish criteria for determining dependence upon fishing and the impacts of the establishment of the Oculina Bank and accumulated regulations upon the community of Fort Pierce, Florida;

2. Train local fishermen to conduct oral histories and collect historical information on their fishing community with a focus on the historical use of the Oculina Bank and surrounding area;

3. Ascertain the historical and current use of the MPA and surrounding area through the examination of social and economic networks for recreational, charter and commercial fishermen and others involved in the fishing enterprise. In some cases, cognitive mapping will be used to determine in as fine a scale as possible the use of the MPA and other fishing areas; and

4. Conduct a series of oral histories with key informants from Ft. Pierce to document changes in natural resource patterns and use to understand the impacts of the MPA over time and changes to the community and resource. In addition, certain historical information pertaining to the Oculina Bank and the fishing community will be sought out for the ethnographic profile of the community.

Goal II: *Analyze data collected through the ethnographic fieldwork, in-depth oral histories and compilation of historical data to conduct an assessment of impacts of the MPA and complete report writing*

IV. Approach

Statement of Work:

Planning Meeting:

A planning meeting was held in Tampa, FL on November 17, 2009. Foundation Executive Director Ms. Judy Jamison, Program Director Mr. Frank Helies and Program Specialist Ms. Gwen Hughes attended along with Dr. Ava Lasseter, Dr. Mark Greenberg and Technical Monitor Dr. Michael Jepson. Prior to the meeting, Dr. Lasseter traveled to Fort Pierce and met with several fishermen, eventually selecting two to participate in the project as research assistants. It was decided that Dr. Lasseter and Dr. Greenberg would collaboratively develop the interview instrument to ensure the proper questions were being asked.

Ethnographic Fieldwork:

Data collection began with initial trips to the community to recruit research assistants and to begin ethnographic fieldwork. Monthly visits were made to continue data collection and monitor

the progress of the research assistants. In addition to working with the research assistants Dr. Lasseter collected data from other sources during these monthly trips to Fort Pierce. Using participant observation, she met with fishermen at the fish houses, attended fishing tournaments and fishing club meetings, and interviewed charterboat captains at local marinas. These experiences and interactions provided extensive qualitative data about socio-cultural characteristics of fishing in the community.

Dr. Lasseter also collected historical data from the St. Lucie County Historical Museum archives with the assistance of museum staff. Permit data were acquired from the Florida Fish and Wildlife Institute and landings data from the NOAA Southeast Science Center.

Two research assistants were identified and contracted with for their in-depth knowledge of local fishing and the history of fishing in Fort Pierce. Both are Fort Pierce residents and commercial fishermen. Because both men reside in the community and actively fish, they did not need proper introduction into the community and were already familiar with industry leaders. Thus, their participation in community functions is a normal part of their daily routine.

In attempting to address the impacts of the Oculina Bank MPA, one of the more difficult impacts to ascertain was the long term impacts of the MPA and other influences upon the community. Part of that description came from analyzing changes in the number of fishing permits over time, the enumeration of fishing infrastructure and any alterations and fluctuations in landings for the community prior to and after establishment of the Oculina Bank MPA. Some information on impacts may not be demonstrable through secondary data sources; therefore oral histories with key informants were utilized to reconstruct past use and ensuing changes.

Oral Histories:

The research assistants were trained by Dr. Lasseter in the collection of oral histories and in the use of the digital recording equipment (protocol outlined in Appendix A). She met monthly with each research assistant to review progress on the oral history collection. The utilization of fishermen to interview other fishermen provided a participatory framework to the project.

In contrast to a more traditional form of oral history that collects the life history of the interviewee, the oral histories collected for this study were essentially semi-structured interviews that focused on the interviewee's fishing history, familiarity and experiences with the Oculina Bank. In total, 45 oral histories were collected; 15 interviews were completed with each of the three identified fishing sectors under study: commercial, charter/headboat, and recreational fishermen. The oral history participants were not selected at random, but rather, were selected with the assistance of the research assistants for their recognized experience as fishermen in the community, and familiarity with the Oculina Bank. The oral history participants were presented with the visual reinforcement of a nautical map during their interview in order to prompt further insight about important changes in resource availability for certain areas.

Using key informants as primary data sources is a time honored tradition in ethnography. While oral histories are valuable in their own right, they also constitute one manner with which to link historic events to their causes and consequences. The oral histories focus on changes in marine resources and the ecosystem and expand upon the participant's perception of how those changes occurred. As a result of those changes, participants were be asked to recount whether the MPA

may have changed fishing behavior or how it may have affected stocks and how they reacted to these changes. Finally informants were asked to recount how the community overall may have changed as a result.

The interviews were digitally recorded and uploaded to a website from which the recordings were downloaded for transcription by the University of South Florida's Oral History Program. Dr. Greenberg was responsible for hire students to do the interview transcribing. The interviews were transcribed verbatim, with minor editing. Release forms were filled out by the interviewees, informing them that their interviews were published on the internet. The audio recordings and transcripts are available to the public at [**http://guides.lib.usf.edu/content.php?pid=49131&sid=1429723**], where USF has generously agreed to house the collection.

Social Network Data:

With the help of the research assistants, data on the social networks among fishermen living and working in Fort Pierce was also collected. Social network analysis identifies key nodes of social relationships within a group and facilitates the identification of important geographical and political orientations within a region. Network analysis can also reaffirm established contacts as key informants and help establish others who may reside on the fringes of the network, thereby establishing theirs as an alternate view from outside a network. Through an examination of the network and enhanced with other data, the historical and present day use of the MPA can be further explored.

Using the 45 interview responses for analysis, the social networks of these fishermen were examined for transmission of information about fishing regulations. Each of the participants was asked to name five individuals with whom they talk about fishing regulations. These data were used to create a relational, binary matrix for analysis within the social network analysis software, UCINet (Borgatti et al., 2002).

Data Analysis:

Qualitative Data Analysis

The oral history transcripts were first entered into the text analysis software, MaxQDA. The transcripts were next sorted according to the interviewee's sector (commercial, recreational, charter/headboat). A codebook was developed to guide the analysis.

A codebook assists in managing a large volume of qualitative data. There are two principal types of coding: structural and thematic. Structural coding is used to identify and isolate components of a text. For example, structural codes were created for each of the individual questions in the oral history interviews, irrespective of the answers. Thematic codes isolate text that shares a common idea, or theme. For example, a thematic code was created for "travel further distances to fish." Any time an interviewee mentioned this idea, irrespective of which question he had been asked, the text was coded for this thematic code.

With these two types of codes, the segments of the texts where they were mentioned can be retrieved and analyzed further. With the interviews categorized according to sector in which the

interviewee participates, these codes can also be compared and contrasted for cross-sector themes.

In interpreting and analyzing the texts, it is important to recognize that it is common for an interviewee to not remember correct dates of regulations; rather, they would recall other significant details that served as temporal bookmarks. For example, a fisherman is not as likely to remember that it was the year 1994 when snapper grouper fishing was prohibited within the Oculina Bank, as it was that he would recall that the closure occurred shortly before the net ban (1995). In this way, qualitative analysis is the most appropriate analytically. At this stage, the purpose is to identify impacts; description is a critical step before a more quantitative analysis could be possible.

Compiling Ethnographic Portrait

The data collected from field notes, data requests to NOAA's Southeast Science Center, the South Atlantic Fishery Management Council and Florida State agencies, museum archives, academic literature, and news articles were compiled and used to form the ethnographic profile of Fort Pierce. This profile provides descriptive characteristics of the community through time. Data were collected at as fine a scale as possible and the geographic range for landings and trip data are presented below.

Social Network Analysis

A social network analysis was conducted on data collected, as described above. Data entry and matrix creation necessary for the analysis were accomplished by one of the research assistants after training. The objective of the analysis was to examine the flow of information regarding management regulations within and among the community of fishermen. The analysis and results are detailed under the Findings section.

Project Management:

Principal Investigator:	
Ms. Judy L. Jamison	Executive Director
Foundation Staff:	
Dr. Michael Jepson	Program Director (former)
Mr. Frank C. Helies	Program Director (current)
Ms. Gwen Hughes	Program Specialist
Ms. Charlotte Irsch	Grants/Contracts Specialist Administrative Assistant
Independent Contractors:	
Dr. Ava Lasseter	Social Scientist
Dr. Mark Greenberg	Dir. of the FL Studies Center, University of South Florida
Research Assistants:	
Mr. Robert Cardin	Fort Pierce, FL
Mr. Terry Howard	Fort Pierce, FL
Mr. Cody Cardin	Fort Pierce, FL

Overall project quality control and assurance was assumed by the Gulf & South Atlantic Fisheries Foundation, Inc. through its office in Tampa, FL. The Foundation's Executive Director had ultimate responsibility for all Foundation administrative and programmatic activities, with oversight by the Foundation's Board of Trustees. She ensured timely progress of activities to meet project objectives and confirmed compliance of all activities with NOAA/NMFS. The Foundation's Program Directors had overall responsibility for all technical aspects of Foundation projects and coordinated performance activities of all project personnel, including contractors. The Program Directors prepared all progress reports concerning project performance.

It was the responsibility of the Foundation's Executive and Program Directors to ensure that quality control and assurance were maintained for all aspects of this program. This was accomplished through regular phone and email communications with project Contractors.

The Program Specialist was responsible for tracking programmatic activities, including generating supporting documentation to assist in any and all programmatic audits. She was responsible for auditing and paying all program related invoices. She processed requests for reimbursement to conform with federal guidelines and prepared and maintained all subcontracts and amendments.

The Grant/Contracts Specialist was responsible for maintaining general financial accounting of all Foundation funds including all Cooperative Agreements and contracts, as well as communicating with NOAA Grants Management personnel, and assisting fiscal auditors in their reviews. She conducted/documented internal and program (single and desk) audits, prepared backup documentation for fiscal audits, and drafted award extension requests (as applicable). She provided the Executive and Program Directors with projected budgets concerning program performance and ensured that these budgets adhered to the proposed budget. Finally, she prepared the annual administrative budget, NOAA Financial Reports, and confirmed compliance of all activities with NOAA/NMFS and OMB guidelines.

The Administrative Assistant was responsible for receptionist/clerical duties, word processing, filing correspondence, dissemination of materials to industry (final reports, press releases, newsletters). She was also responsible for creating and organizing meeting files, processing invoices and maintaining cooperative program files.

Dr. Ava Lasseter served as the Ethnographer and conducted the overall project management including monitoring of the research assistants and coordination between the research assistants and the transcription process at the University of South Florida. She conducted the text analysis and writing of the final report.

Mr. Robert Cardin was born in Fort Pierce and is a life-long commercial fisherman. He conducted the oral histories with the commercial fishermen. Mr. Cardin also served as Dr. Lasseter's key informant, introducing her to fishermen at the fishing dock and their homes. His extensive, in-depth knowledge of local fisheries and history of the area was provided over countless hours of interviews and touring Fort Pierce.

Since retiring as a high school geography teacher, Mr. Terry Howard fishes for king mackerel full-time. With a grant from the St. Lucie Historical Society, he independently conducted oral histories with local Fort Pierce king mackerel fishermen, ultimately publishing excerpts in his book, *Great Kingfish Captains of Fort Pierce, Florida, Tell Their Stories* (Howard, 2007). For this project, Mr. Howard conducted the oral histories with charter boat captains and private recreational fishermen.

Mr. Cody Cardin is the son of a commercial fisherman, with whom he occasionally fishes when not in school. Mr. Cardin assisted with data collection on community characteristics, fishing infrastructure, and social network data.

Dr. Mark Greenberg is the Director of the Florida Studies Center at the University of South Florida, also directs the Library's Oral History Program. Dr. Greenberg oversaw the transcription and storage of the oral history interviews. Digital copies of the interviews are now held on their servers and are available for public use through their website.

V. Findings

Actual Accomplishments and Findings:

This section presents the results of the research project including the ethnographic profile of Fort Pierce as a fishing community and the social network analysis. Additionally, themes that arose during analysis of the oral history texts are discussed in terms of the socio-economic impacts on the community's fishermen resulting from the closure of the Oculina Bank HAPC.

Ethnographic Profile of Fort Pierce, FL

History of Fort Pierce, Florida

One of the first sites occupied by Europeans in the area occurred when, in 1565, the Spanish built Fort Santa Lucia on the Jupiter Inlet. It is from here that St Lucie county takes its name. [1] Much later, the brother of US President Pierce, US Army Lt. Col. Benjamin Kendrick Pierce, built a fort in 1837 for use as the Army's headquarters. The area was occupied principally by Native Americans until the Armed Occupation Act of 1842, which ended the Seminole War. The act permitted "any able bodied man or head of a family [to] apply for 160 acres of hitherto unoccupied land lying south of Palatka or Gainesville for which a patent would be issued, provided the land was held continuously for seven years against the Indians" (Hellier, 1965). As the land had yet to be surveyed, this was essentially a way for the federal government to both survey the land and populate the area won from the Native Americans. Hellier (1965) cites one of the founders of Canaveral, shipping turtles and oranges from local groves surrounding the area in 1856. Enormous sawfish were caught and displayed as trophy catches. It was also common for people to eat manatees, green turtles and their eggs (Hellier, 1965).

During the second half of the 19th century, Fort Pierce developed industries for the export of fishery products. There were several wholesale fish companies operating where the City Marina is situated today. The town was first known as "Cantown" for the canning factory that processed and packaged locally caught fish. Only later was the official name made Fort Pierce (Hellier,

[1] www.rootsweb.com/~flstluci/slchistory.htm

1965). By 1894, Fort Pierce was connected by Flagler's railroad to Jacksonville, facilitating export of canned fish to the Eastern Seaboard (Hellier, 1965).

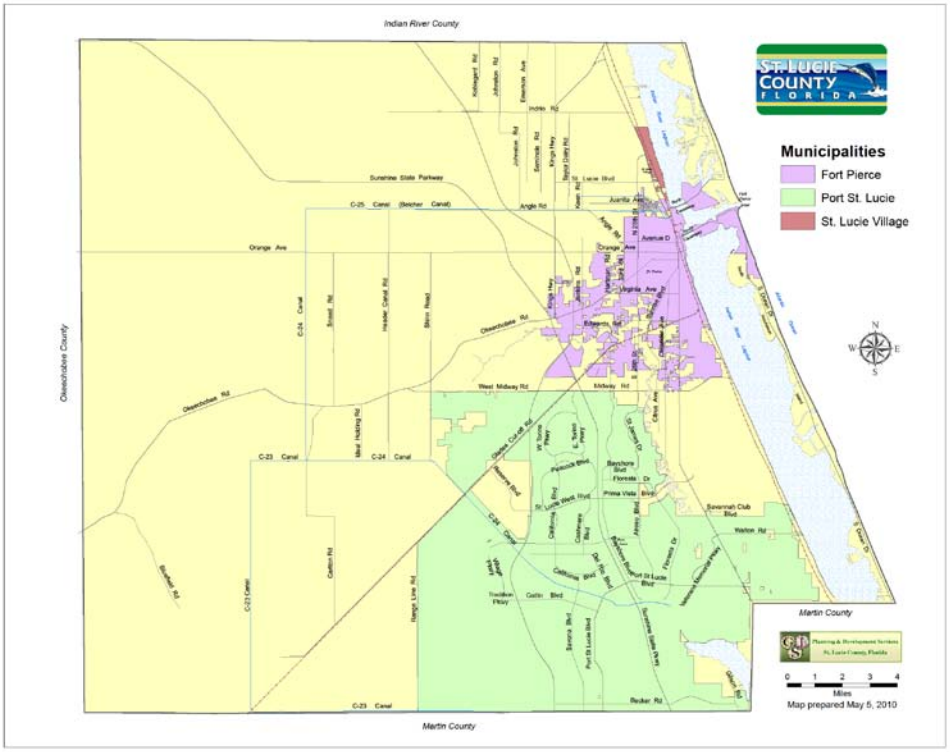


Figure 2: St. Lucie County map showing Fort Pierce on the Indian River Estuary and the constructed inlet permitting the only ocean access in the county.

Fort Pierce was incorporated February 2, 1901 with 66 legal voters in residence. H.B. Summerlin, whose grandson is a fisherman today and is one of the oral history participants in this study, was among the signers of the original documents incorporating the city (Miley, 1980). Fort Pierce's population remained low until World War II when a Navy base was built which served as one of two original training stations (the other in California) for the Navy SEAL program.[2] James "Patches" Watson was a graduate of the first class of Navy SEALS from Fort Pierce. He returned to the area after the war, settled down, and eventually helped start the local National Navy SEAL Museum.

[2] www.cityoffortpierce.com/fp000.html

Figure 3: Photo of Navy SEAL underwater training during World War II. The diver is holding a Hagensen pack filled with explosive that could be quickly draped over an obstacle or target. Photo courtesy of the National Navy SEAL Museum.

Figure 4: Amphibious training on the Fort Pierce jetty during World War II. Photo courtesy of the National Navy SEAL Museum.

Demographics

Although Fort Pierce has seen moderate population growth over the past three decades, the percent of the population in the labor force has remained around 55 percent. Unemployment has dropped from 12.4 percent in 1990 to 8.8 percent in 2000. Average wages and salaries have grown slowly over the past ten years while the number of persons living under the poverty level has risen significantly. The number of people working in farm, fish and forestry has remained

relatively high for both occupation and industry over the years with both categories having over 1000 persons in each sector (Jepson et al., 2005, Pp263). At the time of writing this report, the unemployment rate for St. Lucie County stands at 15.2%, compared with 12% for the state of Florida.[3]

Table 1: Sources for demographic data include St. Lucie County Almanac (1850) and Bureau of Economic and Business Research (1910-2005). Of the 139 people residing in St. Lucie County in 1850, 27 of these were slaves.

Population		
	Fort Pierce	St Lucie County
1850		139
1910	1,333	4,750
1920	2,115	7,886
1930	4,803	7,057
1940	8,040	11,871
1950	13,502	20,180
1960	25,256	39,294
1970	29,721	50,836
1980	33,802	87,182
1990	36,830	151,880
2000	37,516	192,695
2005	38,569	240,039

[3] US Bureau of Labor Statistics http://www.bls.gov/lau/ Accessed on January 29, 2011.

Table 2: Community Demographics for Ft. Pierce. Snapper-Grouper Amendment 13A and the U.S. Census Bureau (2010).

Community Demographics for Fort Pierce, Florida	**1990**	**2000**	**2010**
Total population	36,830	37516	41394
Gender Ratio M/F	92/100	97.4/100	96.1/100
Age (Percent of total population)			
Under 18 years of age	26.2	27.2	26.5
18 to 64 years of age	55.0	55.4	57.4
65 years and over	19.1	17.5	16.1
Ethnicity or Race (Percent)			
White	53.7	49.5	51.8
Black or African American	42.3	40.9	40.3
American Indian and Alaskan Native	0.3	0.3	0.6
Asian	0. 5	0.8	1.6
Native Hawaiian and other Pacific Islander*	n/a	0.08	0.0
Some other race	3.0	0.56	4.8
Two or more races*	n/a	0.03	0.9
Hispanic or Latino (any race)	6.4	15.0	18.7
Educational Attainment (Population 25 and over)			
Percent with less than 9th grade	18.3	17.8	13.8
Percent high school graduate or higher	56.9	59.7	66.0
Percent with a Bachelor's degree or higher	11.3	12.7	14.5
Language Spoken at Home (Population 5 years and over)			
Percent who speak a language other than English at home	11.6	24.8	24.8
Percent who speak English less than very well	77.1	14.8	15.2
Median Household Income	18913	25121	33501
Poverty Status (Percent of population with income below poverty line)	29.2	30.9	26.7
Percent Female Headed Household	6.87	19.3	19.1
Home Ownership			
Owner occupied	53.3	53.2	55.7
Renter occupied	46.7	46.8	44.3
Value Owner-occupied Housing (Median $)	56900	62800	139000
Monthly Rent (Median $)	401	517	864
Employment Status (Population 16 yrs and over)			
Percent in the Labor Force	54.9	55.1	58.7
Percent of Civilian Labor Force Unemployed	12.4	8.8	14.1
Occupation			
Management, professional, and related occupations	n/a	19.9	19.5
Service occupations	15.6	19.3	22.1
Sales and office occupations	n/a	20.5	24.7
Farming, fishing, and forestry occupations	9.4	9	4.3
Construction, extraction, and maintenance occupations*	n/a	15.8	16.5
Production, transportation, and material moving occupations*	n/a	15.5	13.0
Industry			
Agriculture, forestry, fishing and hunting	9.8	7.8	4.5
Manufacturing	7.14	8	5.7
Percent government workers	17.7	11.4	12.2

Table 3: Number of people employed by Industry for Fort Pierce, Florida 1970-2000. (Source: Jepson et al., 2005) The number of people employed in the fishing industry has declined each decade while the overall population of the city has continued to increase.

Industry	**1970**	**1980**	**1990**	**2000**
Agriculture, Fishing, Mining	2460	1838	1324	1119
Construction	885	1258	1100	1803
Business Services	260	467	521	388
Communication/Utilities	315	693	463	365
Manufacturing	846	1149	962	1139
Financial, Insurance & Real Estate	342	485	593	625
Services	440	693	661	6453
Wholesale/Retail Trade	3110	1916	4277	3822
Transportation	2405	3005	3387	433

Hurricanes

As is true in many communities around the southeast U.S. coast, hurricanes have had a serious impact on the community of Fort Pierce. According to Pilkey et al. (1984), 17 hurricanes passed within a 50-mile radius of Fort Pierce between the years of 1900 and 1962 with no additional hurricanes passing nearby between 1962 and 1984. In 1928, two storms severely impacted Fort Pierce, and a third passed further to the south, missing the city. There were an estimated 2,500 fatalities from the storm known as the Okeechobee Hurricane, which made landfall between Jupiter and Boca Raton on September 17. Although this storm is beyond the memory of most active fishermen today, several multi-generation members of the community mentioned the storm in relating stories of their ancestors. The 1949 hurricane is another one that still exists in the memory of local residents, as mentioned by Bud Tillman in his oral history.

More recently, Fort Pierce was severely damaged when two hurricanes struck during the devastating 2004 season. Overall impacts to the state's physical infrastructure were estimated to be in the 20 billion dollar range, not including impacts that the season had on the Florida tourist trade.[4] That year, Hurricane Frances virtually ripped apart Fort Pierce, FL, and Hurricane Jeanne followed close on Frances' heels to send the community reeling from the physical and economic impacts of these two storms. One estimate had bookings for hotels in the area down by as far as 20%.[5] Other impacts to the Fort Pierce area included overwash damage and damage to small boats in the area. Overwash damage pushed beach sand inland, covering or destroying sections of ornamental landscaping as well as depositing the sand in several houses near the beach section of the community. The City Marina was completely destroyed and had to be rebuilt, as were the docks of Inlet Fisheries, the only commercial fish house in operation at the time.

[4] http://news.bbc.co.uk/2/hi/americas/3695518.stm
[5] http://news.bbc.co.uk/2/hi/americas/3695518.stm

Figure 5: Residential storm damage inflicted by Hurricane Frances in 2004.[6]

Figure 6: Overwash deposits near Ft. Pierce. Here waves and storm surge overtopped the crest of the beach and drove sand landward covering vegetation and the road. Overwash deposits like this developed sporadically along the coast.[7]

[6] http://www.noaanews.noaa.gov/stories2004/images/jeanne-ft-pierce-fla-09-2004-27275799b.jpg

[7] http://coastal.er.usgs.gov/hurricanes/frances/

Fishing in Fort Pierce

Fort Pierce's location on the south east coast of Florida provides opportune geography for fishing. Fort Pierce is on the west side of the 155 mile long Indian River Estuary which has only two small natural inlets. The estuary serves as a natural barrier from the Atlantic Ocean, as well as a nursery habitat for many important marine species. The inlet at Fort Pierce was actually constructed early in the 20th century by local residents. Approximately six miles from downtown, Interstate 95 and the Florida Turnpike have exits less than one mile apart. The proximity of these two highways has turned the junction into a popular travel layover spot. There are several hotels and restaurants, representing major national chains that provide additional tourist infrastructure.

Downtown Fort Pierce was the site of many early fish houses that packed fish into barrels and shipped them north by rail. Over time, the importance of commercial fishing has slowly given way to the charter and private recreational sectors. This is apparent at the City Marina, the focal point of downtown Fort Pierce. There are frequent weekend events including boat shows, a weekly farmer's market, and live music.

Commercial fishing was one of the earliest industries in Fort Pierce. In the late 1800s, a man from Titusville helped to create the commercial fishing sector in Ft. Pierce. He would bring fish caught in Fort Pierce to Titusville for shipping to the rest of the east coast. The first icehouse for packaging fish was built in 1900 (Newman, 1953). At this time, several fish houses occupied spots along the waterfront.

After World War II, tourism became more important, and the charterboat industry began in earnest. As private boat ownership became feasible to more people, the private recreational industry also grew. From Fort Pierce's beginnings, however, the line separating commercial, charter, and recreational fishing was never rigid. White's Tackle, a local recreational fishing favorite, has been serving the fishing population in Fort Pierce since 1925. Local commercial fishermen also worked as guides for visiting sportsmen.

In addition to its economic importance, the culture of fishing has been central to the area since its inception. Anecdotes passed down from one generation to the next of Ft. Pierce residents describe the abundance of fish in the area in the late 1800s and early 1900s. One such story, told by Newman (1953) in her book, *Early Life Along the Beautiful Indian River*, tells of a man who bound his shirt at the sleeves and waist and cut a plunging neckline. He would then stand in the water until the shirt was full of fish and then empty it out into a bucket on the shore.

In 1914, there were already fish houses where the City Marina sits today, as a new arrival is described by Miley (1980): "There was a little "tramline" along Avenue A from the railway tracks down Cobb's dock at the foot of the avenue and along over the dock to the several fish houses out over the river along its sides. Hand-pushed carts were propelled along the tramline between the fish houses and the railway tracks to carry the boatloads of fish that were daily brought in by the many fishermen; and to transport the ice from the ice plant to the fish house to ice down the fish in barrels. There was a barrel factory out over the river, too—two of them for some years, in fact."

"Fish were shipped out by the carload daily; some days when the run was heavy, several carloads. It was the same all up and down the river and sometimes when the run was heavy there might be a solid trainload of fish by the time the train reached Cocoa or Titusville." (Miley, 1980).

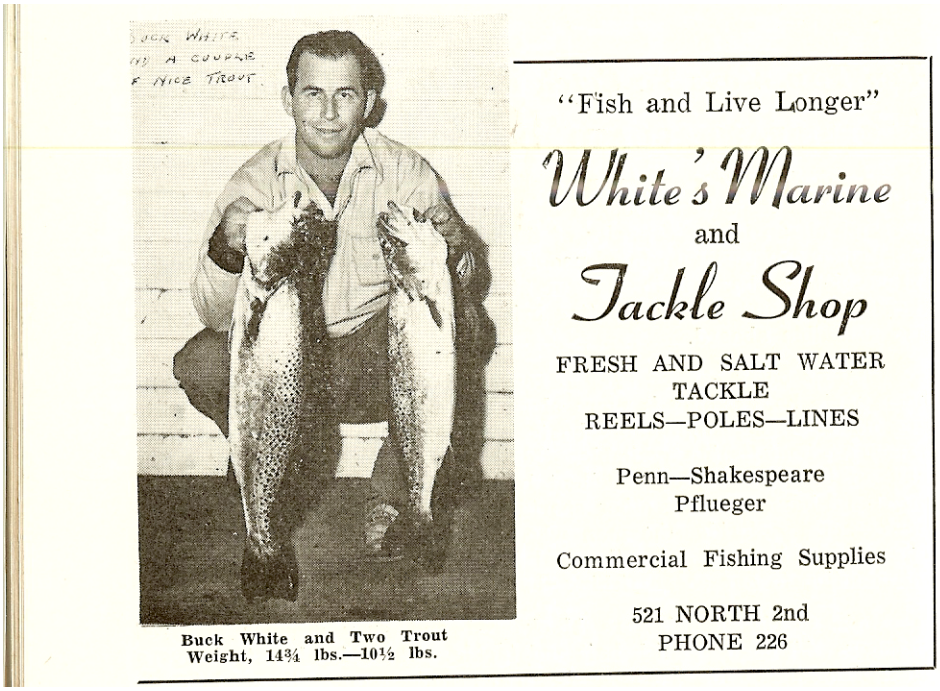


Figure 7: An advertisement for White's Marine and Tackle Shop, used throughout the 1950s in the Chamber of Commerce's Fishing and Visitor's Guides. Buck White, shown in the photo, was the original owner of the still popular bait and tackle store.

Figure 8: Early photos of Fort Pierce's commercial fishing industry. The top photos show the "tramline", described above. Photos courtesy of the St. Lucie County Regional History Center archives.

Figure 9: Early fishermen of Fort Pierce with their catches. Photos courtesy of the St. Lucie County Regional History Center archives.

The presence of Spanish galleons sunk off the St. Lucie and Martin Counties coastline has given this area the nickname, the Treasure Coast. These artificial reefs have created excellent fishing and diving spots, thereby stimulating a local tourist economy. The reefs attract spiny lobsters, marlin, snook, flounder, and grouper. Some of the more popular fish in the St. Lucie River include channel bass, snook, ladyfish, jack crevalle, and trout. Black bass is another popular catch in the area. There are many charter fishing boats in the area which offer half, three-quarter, and full-day trips for dolphin, sailfish, wahoo, amberjack, tuna, kingfish, snapper, and grouper (Jepson et al., 2005). Fishing in Fort Pierce is diverse and includes shore and bridge fishing, fishing in the river, and offshore. Each requires different gear and access, and targets different species.

The Fort Pierce Chamber of Commerce has produced a *Fishing and Visitors' Guide* since the early 1950s. These publications include information on local charter boats and fishing species, including descriptions of where and how the most popular species can be caught.

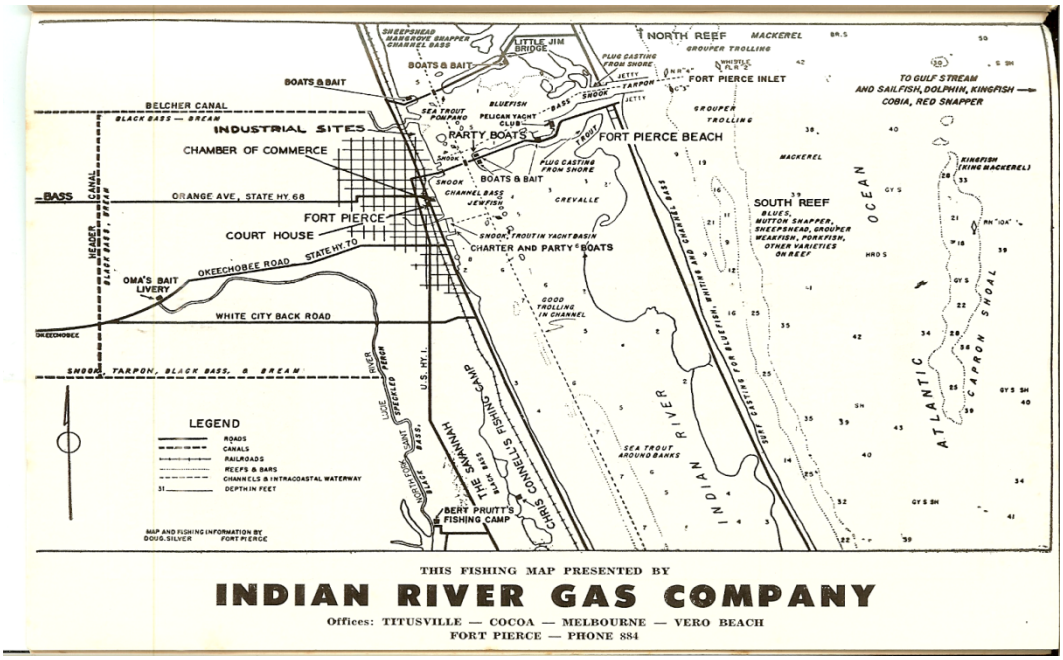


Figure 10: Map of fishing areas that was an advertisement in the Chamber of Commerce's annual Fishing and Visitor's Guide.

One of the most important commercial fisheries in Fort Pierce, historically and remains true today, is mackerel. While the shrimp processors are located in the Cape Canaveral area, Fort Pierce fish houses have mostly processed mackerel. King mackerel, pelagic and migratory, often feed over live reefs so there is a possible relationship between the deep water Oculina coral reefs and where king mackerel are caught. However, mackerel are mid-water to surface fish and the fishing of mackerel has not been impacted by the closures of the Oculina Bank.

The larger impact to the king mackerel fishery came from gill nets (banned in the 1980s) and the Florida net ban, implemented in 1995. Although some Fort Pierce fishermen did use large nets to land huge catches of king mackerel (with the assistance of spotter planes to locate schools of fish), most local fishermen trolled for kingfish using hook and line, even when nets were legal. In fact, one local fisherman noted in his interview that netted mackerel were valued less on the

market than were line caught mackerel, as the nets often damaged the fish. Ultimately, local fishermen targeting king mackerel were not as directly impacted by the net ban as were other net fishers who targeted mullet and other species inshore. However, the net ban caused indirect impacts as netters were forced to shift effort into other fisheries in which they were not engaged previously.

Because king mackerel are pelagic and migratory, the fishery does not interact directly with the Oculina Bank, which is the focus of this study. However, the timing of the net ban (implemented in 1995) occurred immediately after bottom fishing within the Oculina Bank HAPC was prohibited in 1994. The temporal proximity of these events, each of which implemented dramatic changes to fishing behavior, make it more difficult to identify and isolate socio-economic impacts on fishermen.

Fishing Oculina Bank

The early fishing in Fort Pierce was principally done in the estuary or inshore. Due to a lack of motorization, vessels did not venture to the offshore areas, and the gear used at the time would not have allowed fishermen to reach the depths of the Oculina Bank. It was not until the motorization of fishing fleets, and the encouragement by the Federal government to expand fishing production, that fisherman began targeting the offshore fishing grounds and deeper depths for bottomfish.

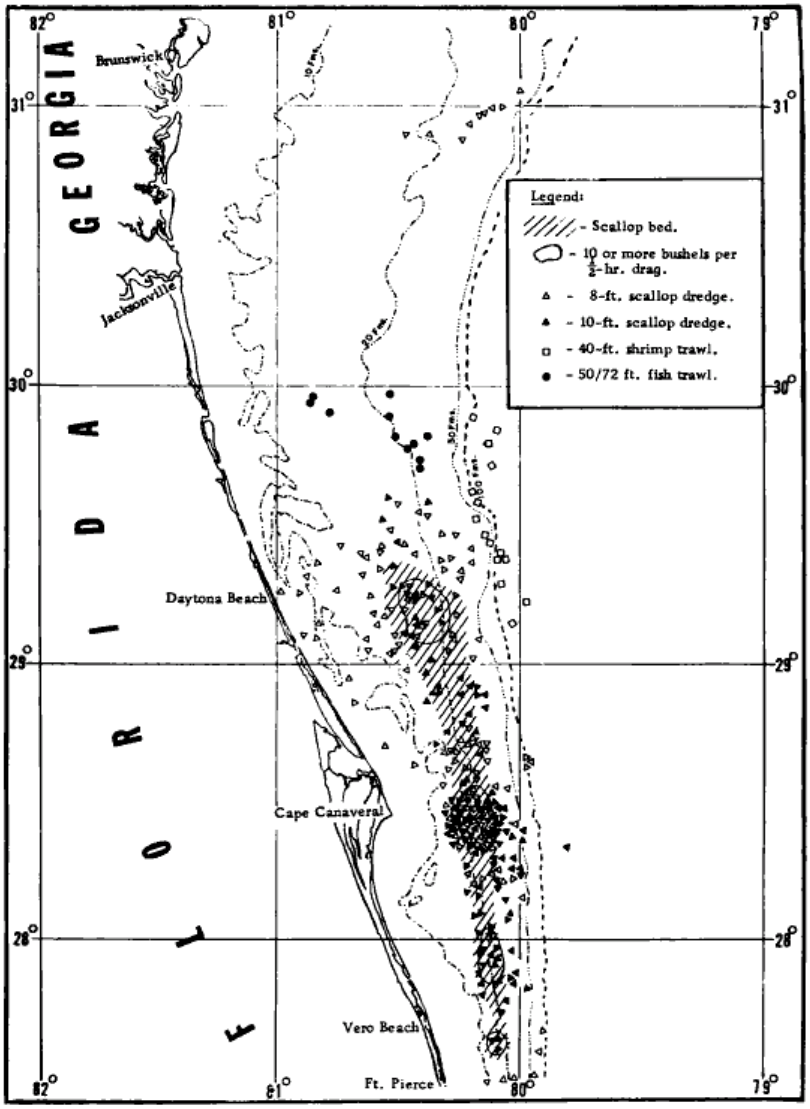
During the second half of the 20th century, however, multiple user groups have targeted multiple species in the area of the Oculina Bank. Fort Pierce, at the southern end of the closed area of the Oculina Bank HAPC, was not as involved in the scallop and rock shrimp trawling fisheries, as were fishermen further north. Thus, much of this history of fishing was centered outside of Fort Pierce, in Cape Canaveral and Titusville, where the rock shrimp and calico scallop processors were based. It is also from this area that the original push for the closure of the Oculina Bank and designation of the HAPC originated.

Calico Scallops and Rock Shrimp

In the oral history transcripts, rock shrimp trawlers receive most of the blame for the damages to the Oculina Bank pinnacles and coral. However, it was actually at the Federal government's direction, and instruction, that trawling began in the area. In 1960, the Federal Bureau of Commercial Fisheries published an account of the calico scallop beds located in the vicinity of the then unidentified Oculina Bank:

> "A total of 252 dredging stations were made during the cruise using 8- and 10- foot modified Georges Bank scallop dredges with 2" rings and 1 ½" mesh liners. A total of 177 drags within the confines of the bed yielded approximately 664 bushels of scallops (an average of 3 ¾ bushels per half-hour tow), and 126 of these drags were within the apparent areas of heaviest concentration (15 to 25 fathoms) and accounted for 659 bushels of the catch (average of 5.2 bushels per tow)."
>
> "During the week of May 30 to June 5 the Silver Bay conducted daily trips to the Cape Canaveral scallop bed off the Florida Atlantic Coast to demonstrate use of commercial scallop dredges to interested fishermen."

The industry, with the backing of the federal government, was encouraged to grow and to take full advantage of the available resource. This speaks to the perspective on fishery management at the time. Management was not about controlling or restricting access to abundant resources. Rather, federal policy aimed to expand domestic fisheries. This expansion was not only designed to maximize economic growth, but also make a national claim to resources in offshore waters, in the face of extensive foreign fishing near US coastlines. This early management paradigm is discussed further in the section below.



M/V Silver Bay Cruise 23 (April 12-May 6, 1960).

Figure 11: The Bureau of Commercial Fisheries published the above map in 1960 showing the recently identified calico scallop beds. Fort Pierce is at the southern end of the range shown in the map. Scallop beds were in depths of 10-32 fathoms.

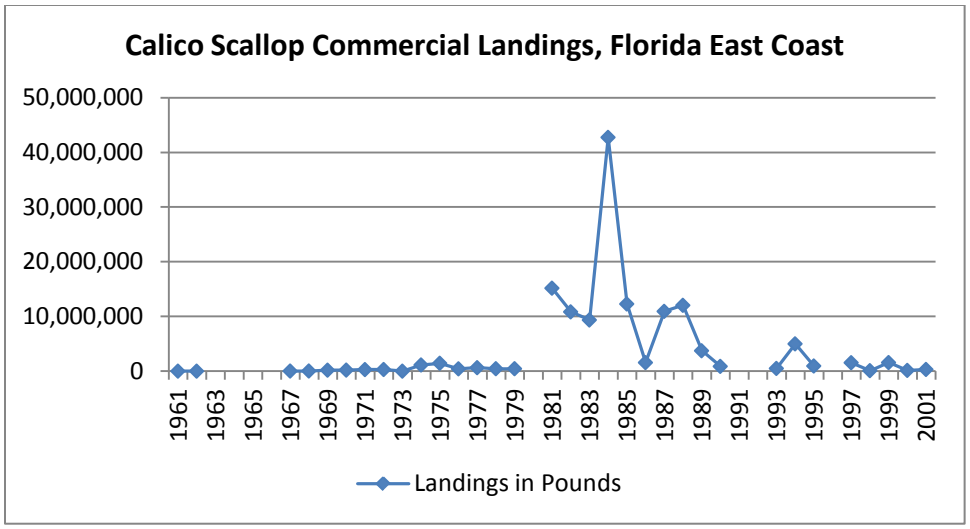


Figure 12: History of calico scallop landings for the entire east coast of Florida. The Oculina Bank HAPC was closed to trawling in 1984. Data source: http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html

Rock shrimp are still an important resource to the east coast of Florida, but it was the heavy trawling pressure from this fleet that initiated the implementation of the Oculina Bank closure. As neither the fishermen nor processors of rock shrimp and calico scallops were based in Fort Pierce, these fisheries are largely outside the purview of this report. Nevertheless, a summary of this history is important as it was in response to the impacts from these fisheries that the movement to implement the Oculina Bank closure occurred. Both the rock shrimp fishery and the calico scallop fishery were of far greater socio-economic importance to the Cape Canaveral area, where the processors have been based throughout the history of the fishery.

According to Rodney Thompson, the rock shrimp fishery began in 1969 when he built a boat to begin harvesting brown shrimp out of Titusville. At that time, rock shrimp "couldn't even be given away, never mind eaten." [8] Not having luck with brown shrimp, Captain Barrett of the NOAA research vessel, Oregon II, directed Rodney to an area 20 miles east of Melbourne. There, dropping nets to trawl at sun down, they landed over 1,000 pounds of rock shrimp, locally known as "peanuts," "trash" or "hardheads," in under an hour.

There was no market for rock shrimp as their hard shells made them extremely difficult to clean. It was Rodney's daughter, Laurilee Thompson (a captain and fisherman, herself), who figured out how to split the hard shells like a lobster. Together, they invented a machine to split open the shells, permitting removal of the large sand vein, as well. With the ease of opening them, a new market quickly developed for rock shrimp. Rodney Thompson established a processing plant at Port Canaveral, and opened a restaurant, Dixie Crossroads, in 1983 in Titusville, Florida. Captain Sam Vona and his sons operated a fleet of shrimp-boats that produced nearly all of the rock shrimp processed at Thompson's plant, Ponce Seafood, Inc.

[8] http://www.dixiecrossroads.com/ShrimpLore/Index.asp

With the new market for rock shrimp, demand increased, as did the number of trawlers targeting offshore in the Oculina Bank.[9] Many of these boats came from the Gulf of Mexico and were much larger than the east coast trawlers. Some were quite large, 110 feet long and capable of dragging four 60' flat nets at one time. According to Laurilee Thompson, the nets were weighted with heavy chains which when dragged, created paths the fishermen called "goat trails." The bigger boats could catch and freeze more than 7,000 pounds of shrimp per night. The industry peaked in 1991, when more than 40 million pounds of rock shrimp landed at Florida's docks. In 2000, less than three million pounds of rock shrimp were offloaded in Florida.

By that time, Rodney Thompson had already begun a campaign to stop bottom-trawling in the Oculina coral reefs, recognizing the area as an important nursery ground for rock shrimp. Initially, he was met with major resistance from captains, boat-owners and owners of fish-houses. As catch rates crashed at an alarming rate, the people who depend on rock shrimp became more supportive. His campaign led to the implementation of a management plan for rock shrimp, in 1984, which closed a 92-nm2 area of abundant Oculina pinnacles as the Oculina Habitat Area of Particular Concern (HAPC). Within this area, the use of bottom trawls, bottom longlines, dredges, fish traps, and fish pots were prohibited (SAFMC and GMFMC, Coral Fishery Management Plan, 1982).

Through the series of regulations detailed below, the rock shrimp trawlers were prohibited from trawling in a larger area between Cape Canaveral and Fort Pierce. Since October, 2003, rock shrimp boats are now required to use a vessel monitoring system on their boats. Their movements are tracked by the NOAA Office of Law Enforcement, in the Southeast Regional Office. Visualizations of the movements of the trawlers, today, show the trawlers heavily working the western edge of the Oculina Bank HAPC.

What is important to note about Rodney Thompson's movement to close the Oculina Bank to rock shrimp trawling, is that while it saved the local rock shrimp fishery, other fisheries along the coast were also impacted. Ultimately, all bottom fishing would be prohibited within the large protected area, although the closure was originally designed to prevent the trawling for scallops and rock shrimp. Thus, the specific goals of the closure were realized and rock shrimp remains a viable industry for the Cape Canaveral-Titusville area, located at the northern end of the Oculina Bank HAPC. However, fishermen from the southern end of the Oculina Bank, specifically Fort Pierce, have incurred unintentional consequences when the area was closed to all bottom fishing in 1994.

Shark and Bottom Fishing

Another fishery that was initially instigated with Federal government support was the shark longlining fishery. During the early 1980s, the government was encouraging growth of the fishery, leading many fishermen to invest in the capital needed to target sharks. "But scientists soon realized that sharks were too slow to mature and reproduce to sustain heavy harvesting. So federal laws changed and squeezed most local commercial shark fishermen, including Colket, out of the business by the mid-1990s" (Kirley, 2010). Later, the restrictions became so strict and

[9] The area was not known then as the Oculina Bank. Rather, local names included the Cones, Steeples, and Humps.

ultimately, shark fishing became largely stigmatized. This relatively rapid shift in government policy and public perceptions is difficult for fishermen, who view themselves as food providers, to understand.

Figure 13: Tris Colket, shown in this 1985 photo, is one of the oral history participants in this study.[10]

Bottom fishing for snapper and grouper species was also an important fishery in the Oculina Bank area prior to its closure. This was the only fishery in that area in which all three sectors, commercial, charter for-hire, and private recreational fishermen participated. This is also the group whose stories and experiences are detailed in the section on Impacts from the closure of the Oculina Bank, below.

Participation and Effort

The number of charter boat operations at a given time is difficult to determine. Many operations open and close within a short time, and many operate on a part-time basis only. There are many small operations that conduct fishing trips in the river, while fewer venture offshore. Nevertheless, the 15 oral histories conducted with charter boat captains represent the majority of

[10] http://blogs.tcpalm.com/coastal_zone/2010/04/once-thriving-shark-fishery-now-largely-a-memory.html Accessed on May 14, 2010.

the active charter fishing operators and include all of those that operate offshore trips. The sample includes a small number of captains that restrict their operations to the river.

In order to examine the importance of fishing to Fort Pierce, currently, two principal types of data are available: fishing permits and landings. With these data, we can consider the relationship local fishing has with the area designated as the Oculina Bank HAPC. It is important to note, however, that permits and landings data cannot inform as to the causes of effort shifts. Also, it is not possible to determine the reason for a decrease in the number of commercial permits, or to locate those individuals who no longer hold a particular permit. Without this information, it is difficult to make conclusions about whether the various regulations implementing closures in the Oculina Bank impacted fishermen directly or indirectly.

Permits

Fishing permits are one way to examine the number of people participating in commercial and recreational fishing. However, it is difficult to make conclusions about fishing effort from permit data alone. For example, permits are sorted according to the address given by the permit holder. A permit holder may have a permanent address outside of Fort Pierce, and thus not be counted in the tallies below, even if he departs and lands fish locally. The opposite may also be true, where a resident permit holder of Fort Pierce travels to Sebastian or elsewhere to fish.

Commercial Permits:

Thus, it is important to note that the tallies of permits given below reflect those with a Fort Pierce address. There are over 100 vessels with federal permits home ported in Fort Pierce and most of those have coastal pelagic permits (Table 4). The majority of these target mackerels, principally. Since 2001, the permit system has become more complex. The number of permits listed for 2011 reflects new categories of permits. It is also important to note that the number of permits is listed for permit holders with a Fort Pierce address.

Table 4: Number of Federal Permits by type for Fort Pierce, Florida. Data source: Southeast Permits Database, NOAA Fisheries Southeast Region, published in SAFMC Snapper-Grouper Amendment 13A, page 118. Current permits (2011) from the Southeast Permits online database, http://sero.nmfs.noaa.gov/foia/readingrm.htm

Type of Permit	**1998**	**1999**	**2000**	**2001**	**2011**
Total Permitted Vessels	88	64	81	100	
Commercial King Mackerel	54	52	62	71	46
Commercial Spanish Mackerel	63	59	72	73	59
Commercial Spiny Lobster	10	8	9	11	3/6[1]
Charter/Headboat for Coastal Pelagics	1	0	0	7	6
Charter/Headboat for Snapper-Grouper	1	0	0	6	6
Snapper Grouper Class 1	5	13	17	18	4[2]
Snapper Grouper Class 2	2	6	7	7	4[2]
Swordfish	18	8	8	11	5/0/1[3]
Shark	46	18	18	24	6/5[4]
Rock Shrimp	0	0	0	0	0
Federal Dealers	3	3	3	5	3

[1] Whole Commercial Spiny Lobster: 3; Spiny Lobster tailing: 6.
[2] Snapper Grouper unlimited trip limit and 225 pound trip limit, respectively.
[3] Swordfish: Directed (5); Handgear (0); Incidental (1).
[4] Shark Directed: 6; Shark Incidental: 5.

Figure 14: Trends in possession of FWCC State of Florida Permits for St. Lucie County residents, by year and type of permit (Saltwater products, left-side y-axis; wholesale dealers, right-side y-axis). Data source: http://research.myfwc.com/features/view_article.asp?id=19224

Recreational Permits:

It is difficult to determine the size of the local recreational fishing population. According to permit data provided by the Fish and Wildlife Research Institute, approximately 2,700 residents of Fort Pierce currently hold a Florida saltwater recreational fishing license. The frequency with which permit holders fish and their target species is unknown. However, recreational fishing is extremely popular in Fort Pierce (see Fishing Infrastructure section below).

Table 5: State Recreational Fishing Licenses (2010). Data source: Joe Ohop, Research Scientist, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission.

City	#SFL
Fort Pierce	2,687
Hutchinson Island	7
Port St Lucie	6,219
St Lucie West	1
County Total	8,914

Landings

Landings are a way to look at fishing activity. However, variations in landings may not accurately reflect species abundance. Other factors often contribute to changes in effort including fuel prices, environmental phenomenon such as hurricanes, and implementation of new fishery regulations.

Commercial Landings:

There are more data for commercial landings than for recreational landings. The following figure (Figure 15) shows recent landings trends for Fort Pierce, for the years 2000 – 2008. Due to the small number of dealers in the community, the actual weight in pounds is considered confidential and not included. Rather, the figure shows how local landings have varied in relation to each other in recent years. Following the landings trend graph is another representation of the most important commercial species (Figure 16), defined according to a "local quotient" (lq). The local quotient is derived from the overall value of local commercial landings divided by the value of each particular species. This is a measure of determining the relative importance of landed species to the community. As seen in the graph, king and Spanish mackerels are the most important commercial species landed in St. Lucie County. The figure is based on landings data from 2008.

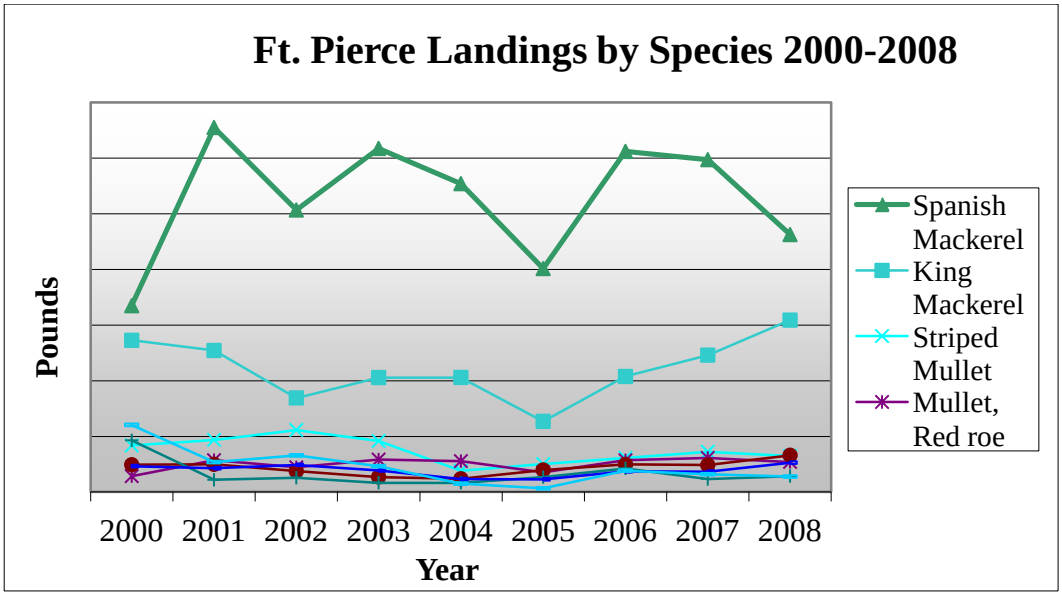


Figure 15: Landings trend for the community of Fort Pierce, Florida. (SERO 2011)

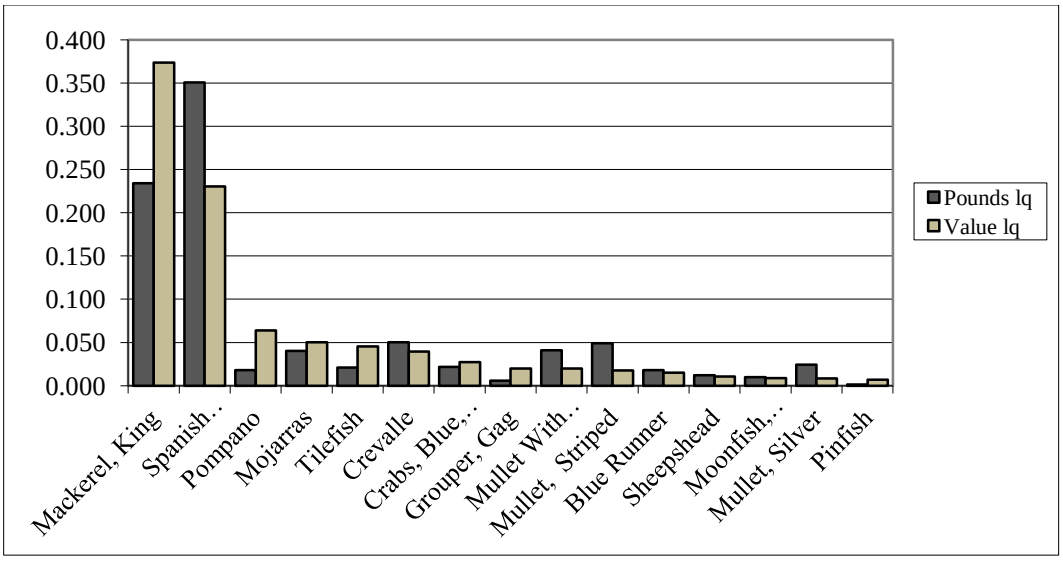


Figure 16: Landings and Value Local Quotient for Top Fifteen Species in Fort Pierce, Florida (SERO 2011)

The following Figure 17 shows the historical landings for grouper species in St. Lucie County. There is a dramatic decline in landings evident for snowy grouper, a deep water species, which coincides with the 1994 closure of the Oculina Bank HAPC to all bottom fishing. Scamp also decreased at the same time. Again, it is difficult to draw conclusions from landings data alone. Furthermore, because data were not available as far back as the original closure in 1984 to bottom longlining, it remains unknown how the closure affected the total weight of bottom fish landings in the area.

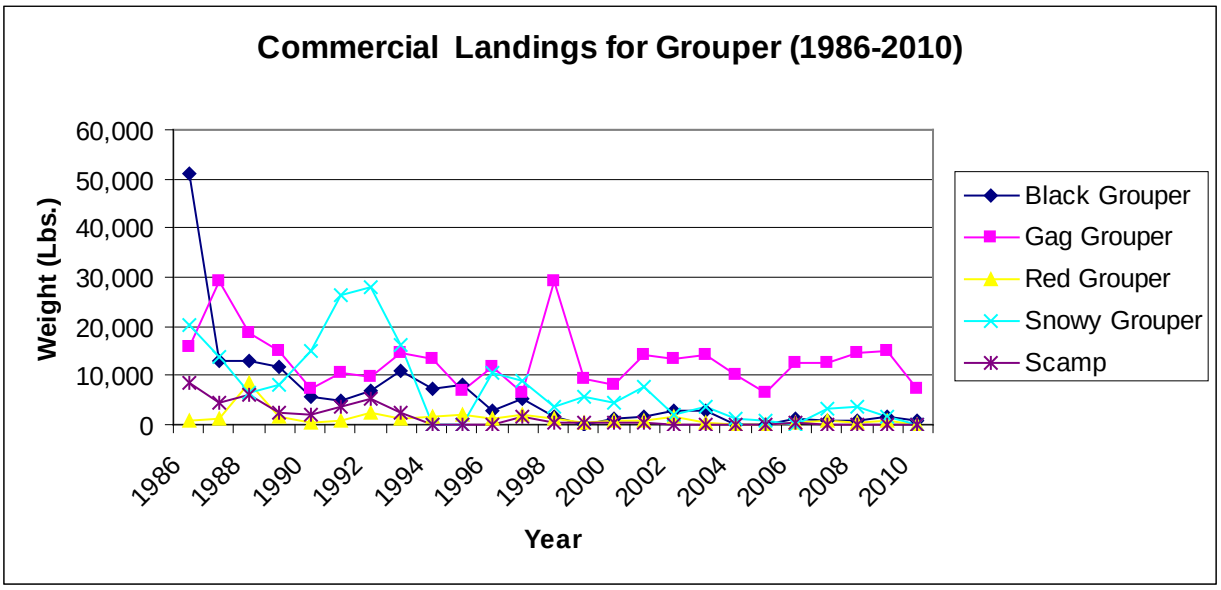


Figure 17: Commercial Landings of Groupers, for St. Lucie County, during the period of 1986 thru 2010. Data provided by the NOAA Southeast Science Center.

Charterboat and Private Recreational Landings Estimates:

The recreational fishing population is even more difficult to define. Fort Pierce offers diverse fishing opportunities and those that venture offshore to the Oculina Bank area likely represent a small minority of the total recreational fishing population. It is equally difficult to estimate landings for the recreational sector. The following figures are based on data provided by the NOAA Southeast Science Center, from MRFSS estimates. The data are given in number of individual fish, not weight of fish, as are the data from commercial landings. The data were also only available for the entire east coast of Florida, making it even more difficult to interpret fluctuations in landings. The figures provide three data series: estimates for charter/for hire operations, private recreational vessel landings, and landings from shore based fishing.

Headboat data are collected and displayed separately from the private recreational and charter/for hire boats, by the NOAA through MRFSS estimates. The following figures display the number of trips for the region between Fort Pierce and Miami, Florida, plus the estimated landings for several important species.

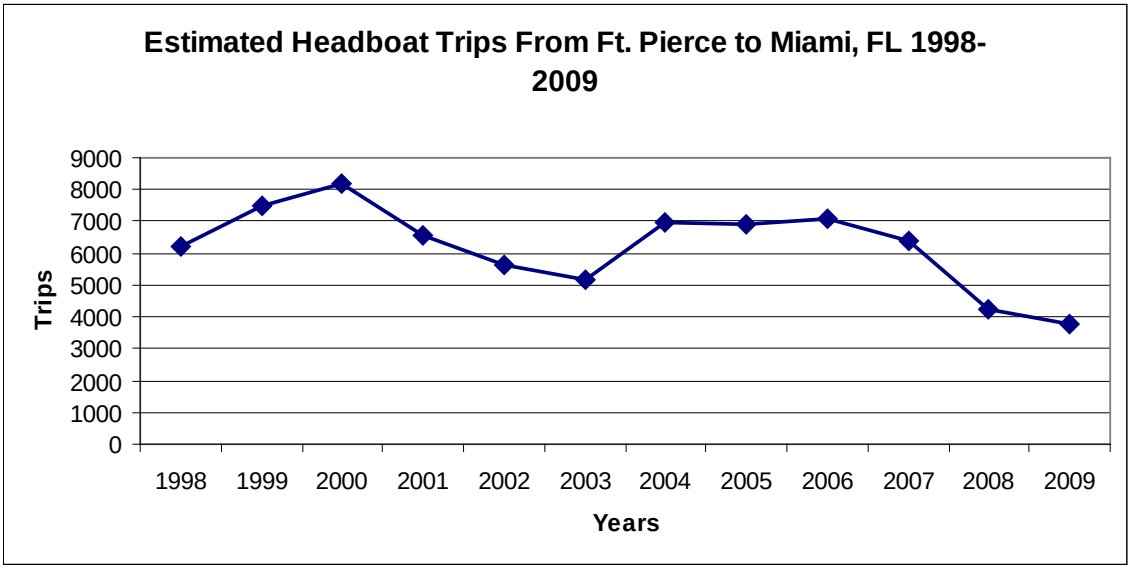


Figure 18: Estimated number of headboat trips from Fort Pierce to Miami, Florida, during the period 1998 to 2009. Data were not available for the local area alone making it difficult to identify trends that may have occurred in Fort Pierce. Data from MRFSS estimates, the NOAA Southeast Science Center.

Fishing Infrastructure

In addition to permits and landings, fishing infrastructure can assist with describing the importance of fishing to a community. This section provides data on the current context of the local fishing economy, infrastructure, and available fishing activities in the Fort Pierce area. Many people claim that the fishing infrastructure has been severely impacted by excessive Federal regulations. However, it is difficult to determine (a) to what extent such regulatory impacts have affected local businesses, and (b) that regulations are the direct cause. Without

baseline data as to the number of marine related businesses in the past, it is hard to track down those who have been put out of business. Also, it is difficult to determine singular causality in the current economic decline which has affected all sectors and industries across the country. Nevertheless, the following data help describe the importance of fishing to the local community.

Employment in the fishing industry, shown in the following tables and graphs, provides socio-economic data on the importance of fishing to the local economy. For example, there are over 260 persons employed in the boat building sector of fishing related employment (Table 6).

Table 6: Number of people employed in different sectors of the fishing industry for the year 2008. Data source: US Census Bureau, St. Lucie Employment County Business Patterns.

Category	**Number Employed**
Fish harvesters	136
Seafood Retail	2
Marina	49
Scenic Water	9
Boat Building	502
Shipping Support	7
Shipping	38
Total Fishing Employment	743

Marinas:

The public spaces occupied by the commercial and recreational fishing sectors have changed over time. In the early days of Fort Pierce's history, when commercial fishing was a cornerstone of the community's economy, the fish houses occupied the central part of town. Today, the City Marina occupies that central space. The public space is now very different compared to the original commercial fishing dock. Today, recreational fishing, both private and for-hire charters, occupy the central space and play a larger part in the local economy.

The marinas listed in the table and figure below are used by private recreational and charter/headboat vessels. Commercial boats principally dock at the two fish houses (Inlet Fisheries and Dayboat) which are located next door to one another on the northwest side of the North Bridge, a couple of miles from the city center. Some commercial fishermen dock at their personal residence. At Inlet Fisheries, there are approximately 20 boats that are homed at the fish house dock.

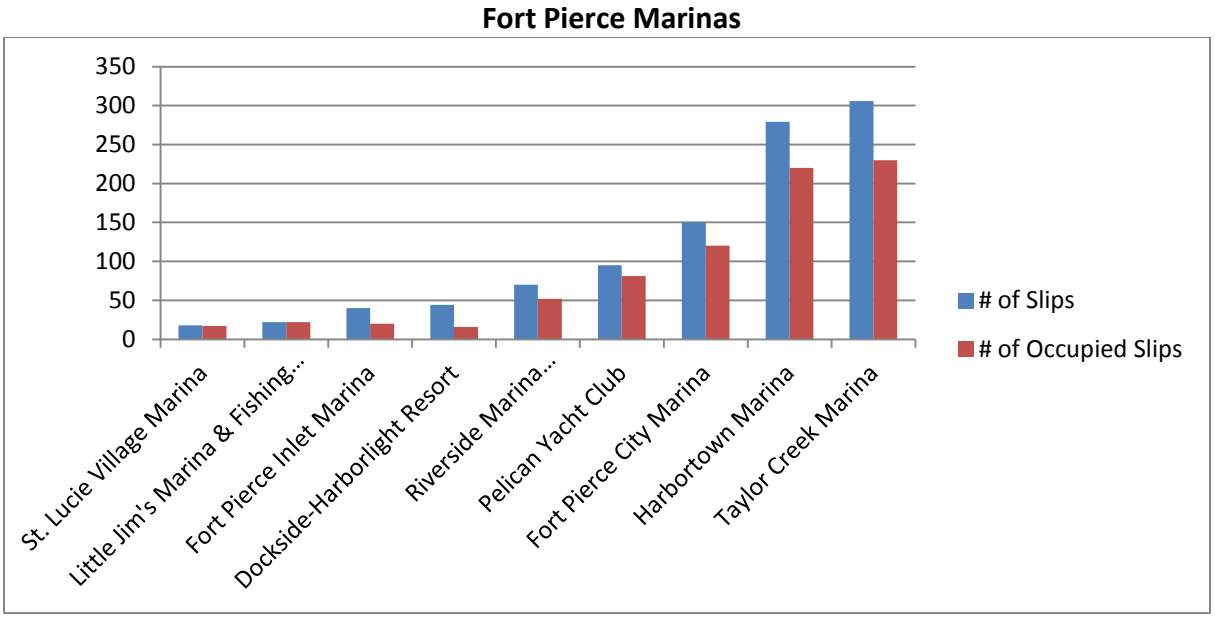


Figure 19: Fort Pierce has numerous marinas available for vessel storage. The figure shows the number of total slips available and the number that were full as of winter 2010-2011. Data source: rapid appraisal and key informant interviews.

Table 7: Marinas of Fort Pierce. Data source: rapid appraisal and key informant interviews.

Marinas of Fort Pierce	**Year Opened**	**Number of Slips**	**Number of Slips Occupied**
Fort Pierce City Marina	1938	150	120
Harbortown Marina	1988	342	205
Little Jim's Marina & Fishing Bridge	1940s	25	21
Riverside Marina	1940	70	52
Fort Pierce Inlet Marina	1987	40	20
Pelican Yacht Club	1946	95	81
Taylor Creek Marina	1979	306*	230
Dockside-Harborlight Resort**	?	44	16
*only six are wet slips. **principally a hotel.			

Bait & Tackle Shops:

Fort Pierce has numerous bait and tackle shops. These shops are social places for fishermen and provide space for the exchange of information about regulations.

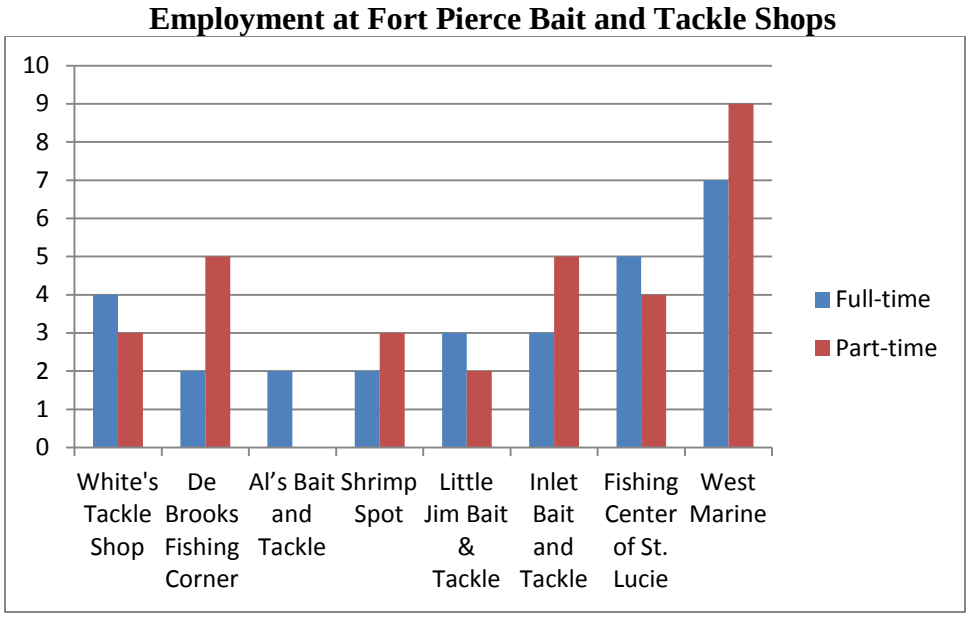


Figure 20: Fort Pierce has numerous bait and tackle shops. The figure shows the number of full and part-time employees at each of the local bait and tackle shops as of winter 2010-2011. Data source: rapid appraisal and key informant interviews.

Restaurants:

Fort Pierce also has numerous restaurants that designate seafood as a focal point of their business. The names of the restaurants reflect this focus. Through informal conversations with wait staff in these restaurants, the origin of marine-based items on the menu is not necessarily local. At least two restaurants buy from local fishermen (who have dealer permits) or local dealers, and others buy from regional dealers who operate along the south eastern Florida coast. However for the most part, restaurants profit more from the image of fishing and the desire of tourists to eat fish and seafood when visiting coastal communities, rather than being directly engaged with the fishing community.

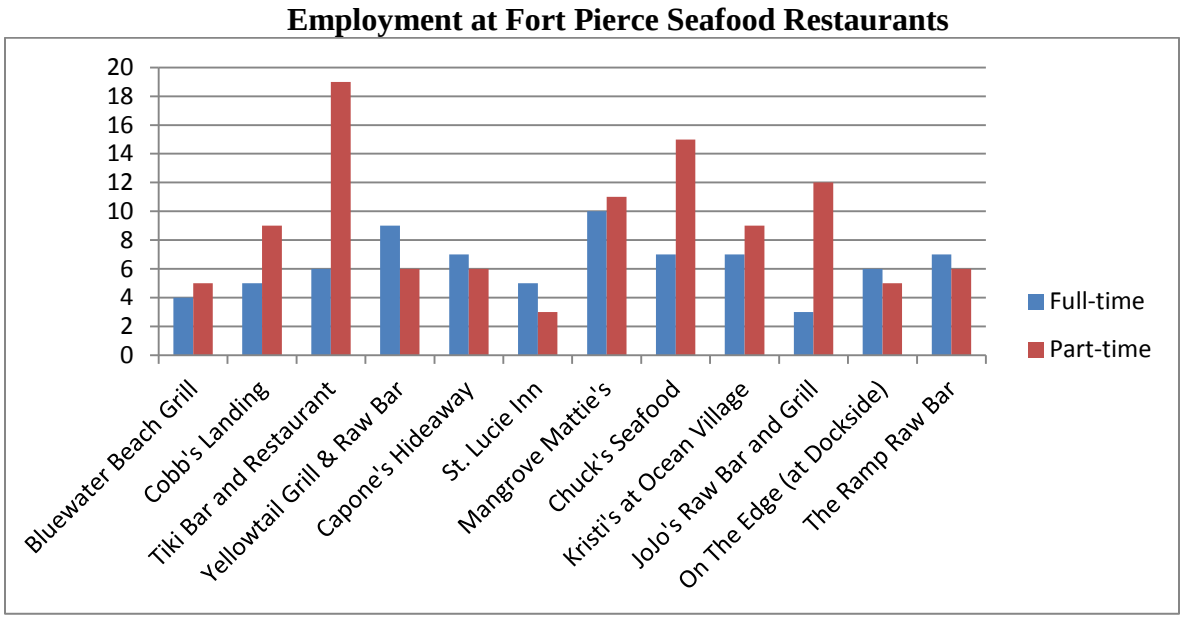


Figure 21: The figure shows the number of full and part-time employees at each of the local restaurants as of winter 2010-2011. Data source: rapid appraisal and key informant interviews.

Fishing Tournaments:

Fort Pierce is an important center for recreational fishing tournaments. Private recreational vessels and charter for-hire boats with paying customers participate in the tournaments. Numerous tournaments are held throughout the year for different target species. Each tournament charges an entry fee and participants include local and regional residents.

Table 8: A list of many of the recreational fishing tournaments that are held in Fort Pierce. Data source: rapid appraisal and key informant interviews.

Fishing Tournaments in Fort Pierce	Years in Operation
Ft. Pierce Pink Ladies Tournament	4
Pelican Yacht Club Billfish Tournament	31
FLW Outdoors Professional Kingfish Tour	2
SKA Tournament/Yellowfin Boats Kingfish Classic	14
Florida Gators Club Fishing Tournament	3
Offshore Big 3 (OB3) Fishing Tournament, Hibiscus Children's Center	9
Fort Pierce Open	26
Bluewater Open Dolphin Mania	14
St Lucie County Chamber of Commerce, Fishing Frenzy	16
Boldwater Wahoo & Dolphin Slamathon	5
St. Lucie County Sheriffs Explorers Tournament	14
Fort Pierce Sportfishing Club Tournament	24
Fort Pierce Saltwater Classic	?
4-H Club Fishing Tournament	?
*Number of years in operation as of 2010.	

Table 9: Number of entrants for each given year and participants' residence. Data were not available for all years in operation, but the following table shows the origin of participants for one of Fort Pierce's most popular tournaments, the Fishing Frenzy. Data source: rapid appraisal and key informant interviews.

St Lucie County Chamber of Commerce Fishing Frenzy							
	Total	Number of Tournament Entrants from:					
Year*	#Entrants	Port St Lucie	Fort Pierce	Martin County	Vero / Sebastian	Orlando	Other
2010	71	20	20	9	9	2	11
2009	99	21	29	11	21	3	14
2008	102	29	35	9	12	2	14
2007	114	33	42	10	15	1	13
2006	115	28	40	9	13	1	24
2005	134	30	45	12	24	3	22
2004	149	33	55	14	22	2	24
*Data available only for the years listed. Tournament has been in operation for 16 years.							

Figure 22: A fishing tournament participant showing off his prize dolphin for the crowd.

Figure 23: A crowd waiting for the next tournament entrant to return for weigh-in.

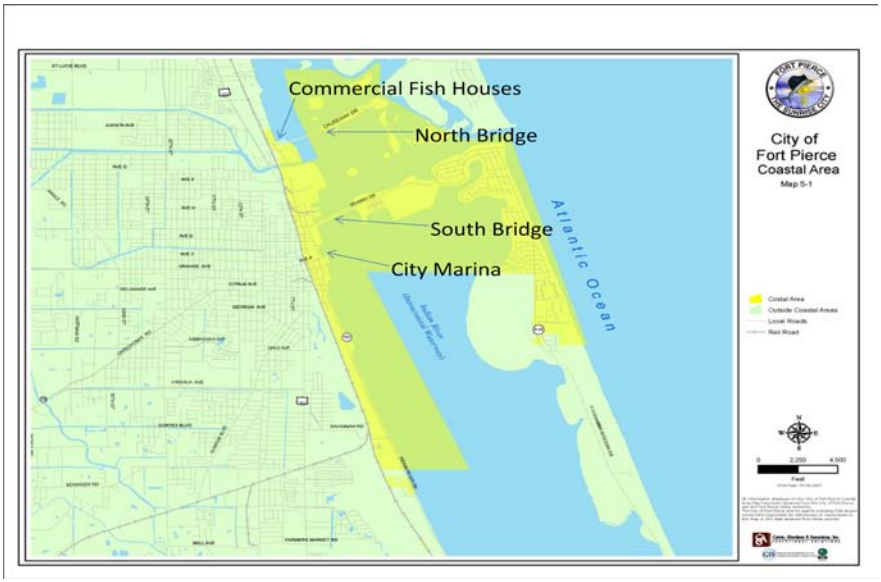


Figure 24: Map of City Marina, in downtown Fort Pierce and location of the longest running charterboat operations along with many private recreational vessels. The City Marina is near the South Bridge. At the North Bridge are found the two commercial fish houses and docks.

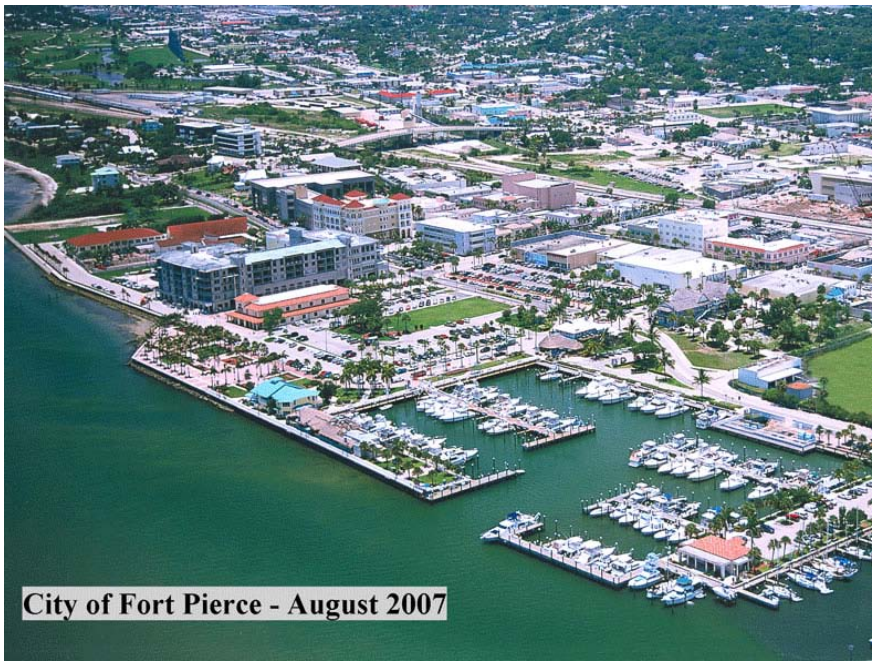


Figure 25: View of City Marina. (City of Fort Pierce website)

Figure 26: View of Inlet Fisheries fish house from the commercial dock.

Figure 27, 28: Commercial fishing boats docked at Inlet Fisheries, Fort Pierce. Commercial fishing boat of one of the oral history participants, at Inlet Fisheries (right).

Social Network Analysis

Social network data were collected with the 45 oral history participants in order to examine social relationships around the exchange of fishing information. Each of the oral history participants was asked the following question: "Please name five people with whom you talk about fishing regulations." The aim is to look at the movement of information concerning fishing. With the answers to this question, a relational data matrix was created and imported into UCINet, a social network analysis software (Borgatti et al., 2002).

The matrix was symmetrized and centrality measures were calculated using Freeman's degree. This is a simple measure of centrality which examines the number of mentions, or ties, indicated from all other actors in a network. One fisherman, in the commercial sector, clearly stood out as the most central in this particular network: CM1 in the figures below.

Next, the data were visualized using NetDraw, a program within UCINet. In order to interpret the figure, some background definitions are required. Each of the squares in the visualization represents an individual and is called a 'node.' The lines between nodes are 'ties' and represent an actor's, represented by the node, mention of another actor's node. Each node is identified with a code. If a code is represented by a pair of letters and a number, the node represents one of the oral history participants. These nodes were also color coded according to the participant's fishing sector: RC for Recreational, CM for commercial, and CH for charter/headboat. The numbers following the letter codes are a unique identifier for each interviewee. There are an additional 88 nodes that are coded by a number only. These nodes represent individuals mentioned by the oral history participants who were not, themselves, interviewed. Their nodes remain uncolored.

The size of the nodes is coded for Freeman's degree centrality. The larger a node, the more often that actor was mentioned by other interviewees as someone who is consulted about fishing regulations. Again, the node CM1 clearly stands out as the most important individual that the other actors in this network consult for information on fishing regulations.

Locally, the commercial fishermen population is a relatively small group. There are only two fish houses now, one of which is relatively new to its location. The recreational community, on the other hand, is quite large based on the number of recreational fishing licenses (Table 5), and tournament participants (Tables 7 and 8). This makes it difficult to identify boundaries of the community, and posed sampling problems as well. For the network represented, the commercial and charterboat interviewees represent a far larger proportion of the total population of their sector, locally, than those recreational fishermen interviewed. Thus, the likelihood that the commercial and charterboat individuals know each other is higher than for the recreational fishermen. However, many of the recreational fishermen know each other, as many are members of the Fort Pierce Sportfishing Club, or are owners of local marine related businesses, so are prominent in the local recreational fishing community.

Based on the ethnographic research collected prior to the network analysis, it was hypothesized that charterboat captains were most likely to be the social brokers between the commercial and recreational sectors. Upon analysis, however, a single recreational fisherman (among the interviewees) appeared as the only direct link between the sectors, thereby providing a link between the commercial and recreational sectors (RC3). This individual is the owner of a local

bait and tackle store, a favored place for informal discussion of fishing and fishery management. Another individual who was not interviewed (17) was the only other connection between the commercial and charter sectors.

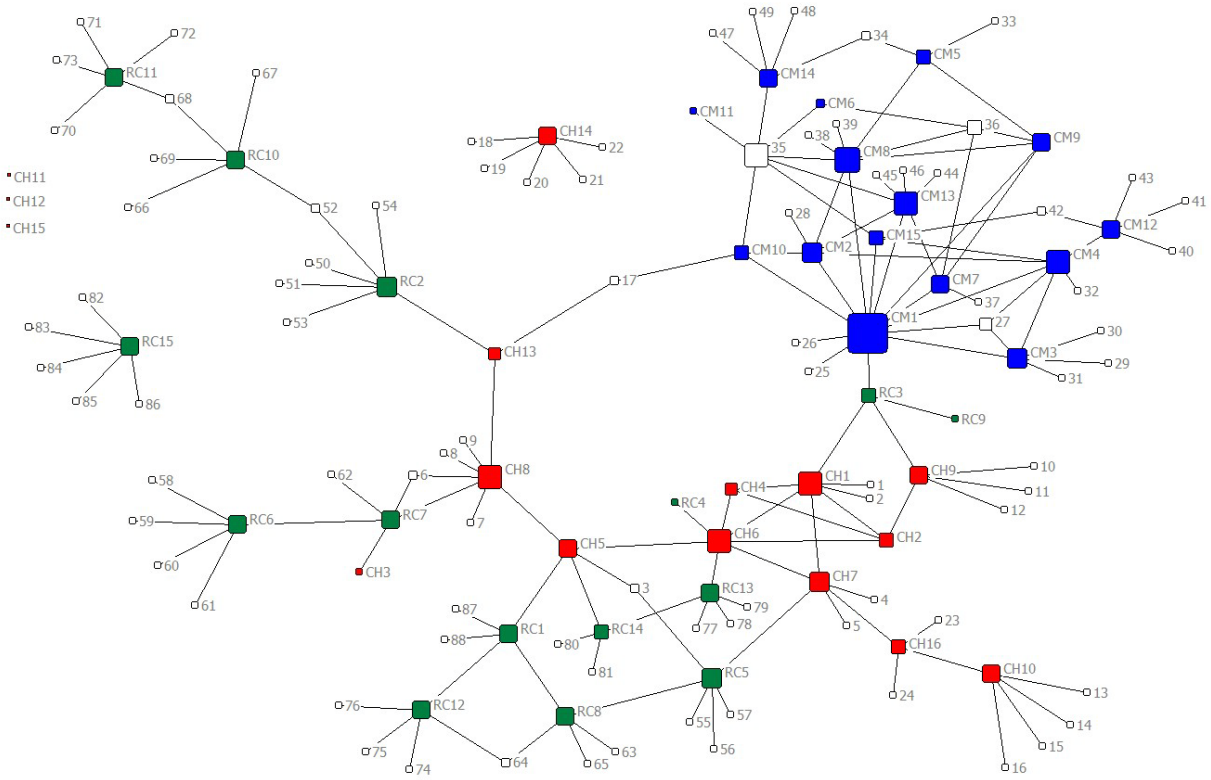


Figure 29: The social network of the 45 oral history participants for the question "Who do you talk to about fishery regulations?" All individuals mentioned by interviewees are included; those not interviewed are represented by colorless squares.

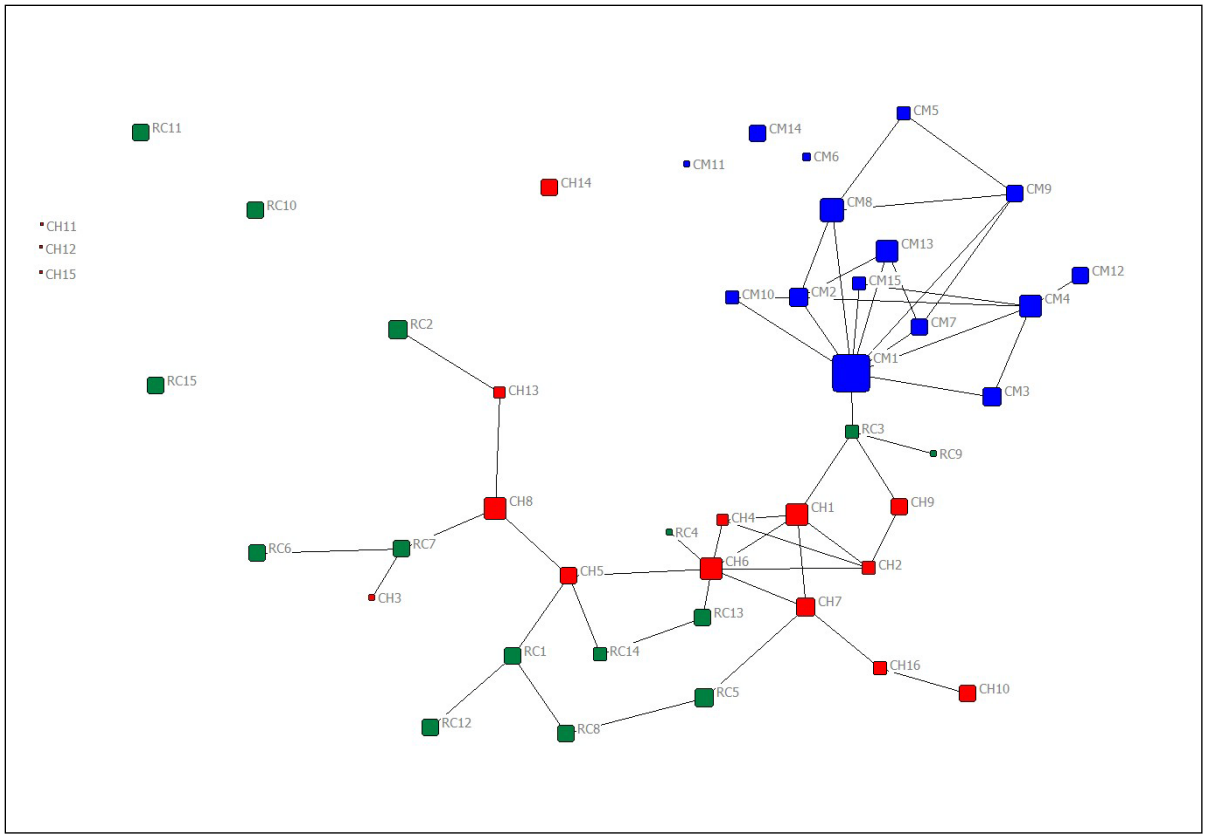


Figure 30: The social network of the 45 oral history participants for the question "Who do you talk to about fishery regulations?" Those individuals named by oral history participants who were not themselves interviewed, have been removed for ease of viewing.

For the most part, the social spaces of the commercial and recreational sectors do not overlap. The two groups do not share the same docks. The vessels of charterboat captains, on the other hand, are mostly docked in marinas which are also occupied by private recreational vessels. These two groups, then, have a greater chance of social interaction.

Bait and tackle shops, as mentioned above, are another social space that can provide for inter-sector interaction. From ethnographic observations, however, these social spaces are used mostly by recreational fishermen. The lack of social interaction likely contributes to perceptions and misconceptions that individuals of different sectors have about one another. In the oral histories, frequent comments were made by commercial and recreational fishermen about members of the other sector, and vice versa. This is akin to stereotypes that are commonly held by all human social groups about "the other."

Although the three sectors are identified as distinct, in reality, these groups are not delineated with such precision. One of the charterboat captains interviewed was formerly a full-time commercial fisherman. He ultimately moved into the charter business as the fishery regulations became ever more difficult for him to make a living in commercial fishing. A local comment made by many commercial fishermen is: "that the only difference between a recreational and commercial fisherman is that the recreational fisherman takes a picture of his fish before he sells

it," alluding to the practice of recreational fishermen being part-time commercial fishermen. Furthermore, commercial and charterboat fishermen love to fish and will usually consider themselves recreational fishermen as well.

Impacts from the closure of the Oculina Bank HAPC

The discussion that follows arose from the qualitative text analysis in terms of the impacts of the closure of the Oculina Bank HAPC and the themes that emerged.

It is important to note that there are multiple groups with a history of fishing the area of the Oculina Bank. Principally, these are rock shrimp trawlers, calico scallop trawlers, commercial bottom longliners (for snapper-grouper, and for a short time, sharks), and recreational bottom fishers. On the eastern side, in deeper water, bottom longline for tilefish is also a commercial target species. Additionally, both commercial and recreational fishers troll within the area for coastal pelagic species including king mackerel, dolphin, and wahoo.

Also, fishermen from many coastal communities have fished in the area of the Oculina Bank. Fort Pierce is located at the southern end of the current boundaries of the HAPC, while Cape Canaveral is located approximately at the north end. Other communities are found between. Fishing effort varies among these communities. Historically, the rock shrimpers and calico scallopers, both vessels and processing facilities, were located in Cape Canaveral. Today, Cape Canaveral remains the principal off-loading site for rock shrimp; there are no longer any commercial trawlers for calico scallops.

The boundaries of the Oculina Bank were established in a series of regulatory actions, implemented within different Fishery Management Plans for different management units under the jurisdiction of the South Atlantic Fishery Management Council. Below, a brief summary of each regulatory action with its date of implementation is followed by a summary of the impacts on the different fishing sectors, selected from the oral history participants' narratives.

It is difficult to isolate a specific cause that incurs social and economic impacts. Multiple factors may contribute to change and impacts. The closure of the Oculina Bank HAPC and its subsequent regulations are just one set of factors that contributed to change in the community. Many locals in Fort Pierce do not remember details of the original closure, owing to the length of time that has passed. One marina dockmaster said that while the economic downturn has hit their business hard, he feels that the South Atlantic Council's regulations on snapper-grouper fishing is what has really hurt the charterboat fleet that used to use the marina. The closure of the Oculina Bank HAPC to bottom fishing is only one regulation affecting snapper-grouper fishing, making it complicated to determine the impact of the marine protected area on fishing, compared with other regulations. Notably, this particular marina has seen the number of charterboats using their facility decrease from approximately one dozen, down to two. A charterboat captain summed up his understanding of the impacts as affecting all fishing sectors:

> *"Well, it's bad enough like it is. If they make any more closures, it's gonna be to the point where you're gonna have forty charter boats to thirty to twenty to ten to just a handful. And they bring tourists that stay in the hotels that eat in the restaurants. There's a — it used to be major, you know, and it's not as big as it was already because of the regulation change. And, I mean, you're gonna lose the few party boats. There*

used to be three party boats, to two, to one, then there'll be no party boats. It affects commercial boats. The amount of commercial boats is way down from the heyday. Hudgins and North Bridge and all that had docks full all the way to the end. Now, it's like a ghost town. There's boats there, but they're not leaving that much. Only the true George Kauls[11] and the hardcores are still doing it, and they're still, you know, the ones that are still doing it are doing okay. But, I mean, there's a definite impact if you do any more closures."

[11] George Kaul is locally known as one of the best commercial king mackerel fishermen.

1984: Implementation of the Oculina Bank HAPC

In 1984, a 92-nm^2 area of *Oculina* pinnacles was designated as the Oculina Bank Habitat Area of Particular Concern (HAPC). Regulations were implemented that prohibited the use of bottom trawls, bottom longlines, dredges, fish traps, and fish pots within the HAPC to mitigate the threat of fishing gear to *Oculina* coral (SAFMC and GMFMC, Coral Fishery Management Plan, 1982).

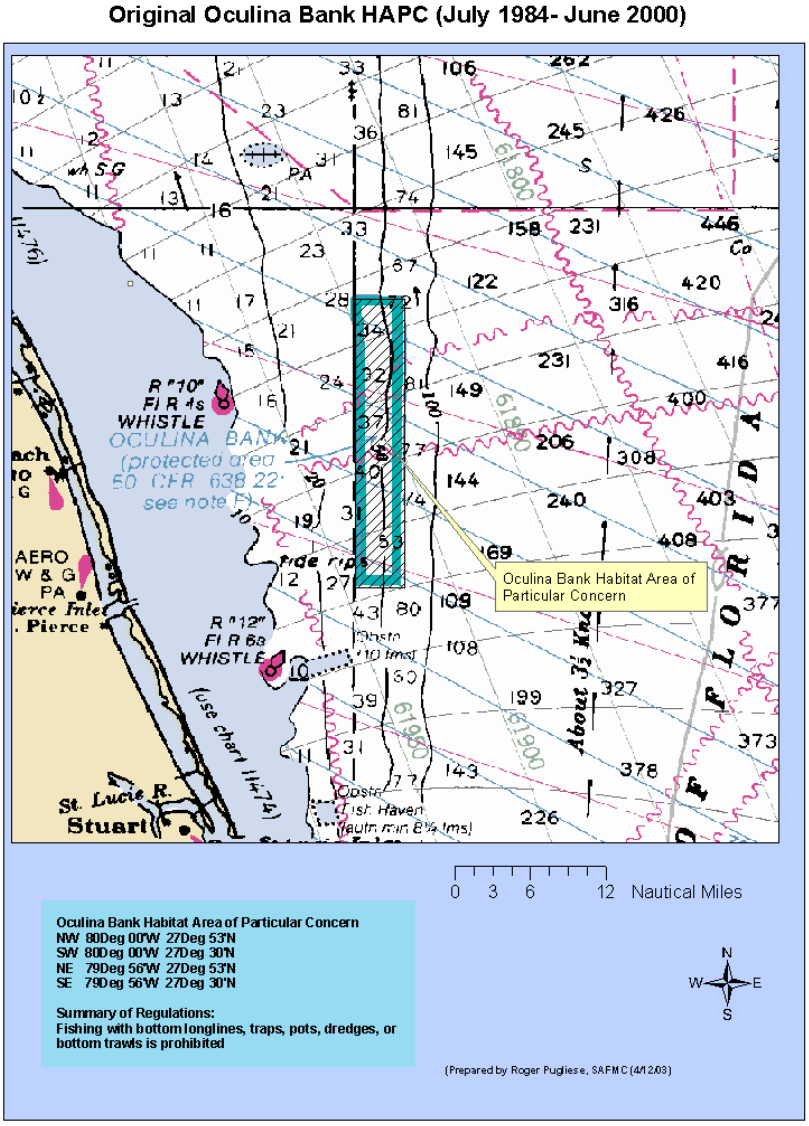


Figure 31: Original Oculina Bank HAPC. SAFMC Snapper-Grouper Amendment 13A. (SAFMC, 2005)

Impacts from the 1984 closure

The original implementation of the protected area affected the effort of bottom trawlers, both scallopers and shrimpers. Because this industry was based out of Port Canaveral, the principal impacts from the regulation occurred there. In Fort Pierce, the restriction on bottom longlines impacted commercial longline fishermen, especially those who targeted sharks. The number of longline fishermen based out of Fort Pierce at that time remains unknown, thus it is difficult to assess the full social impact of this regulation over 25 years after implementation. It is also difficult to isolate impacts from the closure, alone, as separate regulations further restricted the shark fishery.

Few interviewees cited negative impacts from this closure and all of those were commercial fishermen. Again, because the initial closure occurred so long ago, most of the interviewed fishermen would have been quite young at the time. Shark fishers were impacted, as detailed in the following passages:

Commercial Fisherman: Well, yeah, because that's when everybody went to shark fishing, where we had the best catches of our sandbar sharks, which were our money making sharks, was like 400 feet out. And that's right there in the Bank.
Interviewer: So, you got your legs clipped on the sharks in eighty-four?
Commercial Fisherman: No doubt about that.

Another commercial fisherman owned a fish house at the time. He cited an indirect economic impact on his fish house from the closure, due to the restriction on catches. Additionally, impacts were realized in a spatial effort shift due to the closure, resulting in additional fuel costs and travel time to fishing grounds.

Commercial Fisherman: I had to go fish other areas. I had to fish further south or further north or further inshore or further offshore to adjust for it.

Among the charterboat and recreational interviewees, most stated that they were either not in the area or did not fish the Oculina Bank area at that time, or that this particular closure did not affect them. Some were not aware of the particular restrictions put in place when the Oculina Bank HAPC was implemented. Because this closure did not prohibit all bottom fishing, only bottom fishing with a longline, it would follow that non-commercial groups would not be impacted as were commercial fishermen.

In fact, a couple of fishermen claimed to notice positive impacts from the closure to bottom trawling. A charterboat captain stated, "actually, I felt like the fishing actually got better on the Oculina Bank for a number of years once they stopped that [shrimp trawling]." His sentiments were echoed by a recreational fisherman who said, "I didn't see too many draggers other than the rock shrimp fishermen, but when they quit doing that, I think it helped the Oculina Bank's fishing." One recreational fisherman who did fish there, recalls the fishing as the best bottom fishing in the area. Although he did not anchor there because of the depth ("It was a pain in the butt."), he continued to bottom fish there until the next regulation put an end to the practice for fishermen of all sectors.

1994: Bottom fishing prohibited within Oculina Bank HAPC

This regulation prohibited fishing for and retention of snapper-grouper species within the HAPC and prohibited anchoring by vessels fishing for snapper-grouper species.[12] The area to which these prohibitions applied became known as the Oculina Experimental Closed Area and occupied the same 92-nm^2 area of the HAPC. The intent of the regulation was to "enhance stock stability and increase recruitment by providing an area where deep water species can grow and reproduce without being subjected to fishing mortality" (SAFMC, Snapper-Grouper Amendment 6A, 1993).

Impacts from the 1994 closure

This regulation had the greatest impact on the fishermen of Fort Pierce of all the Oculina Bank closures. Commercial, charterboat, and private recreational fishermen were all affected. Although the Oculina Bank was initially implemented under the Coral FMP for the purpose of protecting the deep water *Oculina* coral, this regulation was implemented under a Snapper-Grouper Amendment, with the intention of protecting deepwater bottom fish stocks. Fishermen questioned this change in the intent of the closure after the initial closure was put in place. Some have also questioned the efficacy of the closure and whether studies are being done to assess the stated goal of the closure, given the regulation's impact on their livelihood and recreational opportunities.

Commercial fishermen expressed that they were greatly impacted economically by this regulation. Several fishermen made statements about the closure such as:

> *"That put me totally out of business."*
>
> *"It shut me down totally. It took away at least 60 percent of my income."*
>
> *"I couldn't go in there and catch my amberjacks, which was a new fishery for me. It looked like a good fishery until they did that."*

Other fishermen noted that the closure forced them to travel further to avoid the boundaries of the Oculina Bank HAPC. Even if snapper grouper complex species were caught outside the boundaries of the Oculina Bank closed area, transit through the closed area was not permitted. The closed area is narrow but long, meaning that fishermen often had to travel long distances to go avoid the closed area.

> *"That's messed up the tilefish and messed up the transit—messed up having to drive around it, took away the snowy grouper and the yellowedge grouper fishery."*
>
> *"If you had a mixed catch from somewhere else, or if you're fishing somewhere else you can't—you either got to go around it, you know, but you can't cross over."*

[12] Snapper-grouper species refer to those managed by the Snapper Grouper Fishery Management Plan of the South Atlantic Fishery Management Council.

Fishermen noted that the closure forced an effort shift away from bottom fishing and toward king mackerel trolling. Fishing for kingfish has a long established history in Fort Pierce and the greatest number of participants. Thus, the effort shift added to the fishing population that targets the species.

For example, "now, I'm pretty much 90 percent a kingfisherman; do very little bottom fishing."

Another impact was expressed by a couple of fishermen, noting that the closure affected their ability to keep particular commercial permits. The prohibition on bottom fishing in the highest producing local fishing grounds affected the ability of local fishermen to obtain the amount of landings required for the snapper grouper permit renewal requirement. This affects fishermen's flexibility later as they are restricted from reentering the fishery once other stocks, to which they switched after the closure, experienced pressure and catch declines or increased regulations.

> *"I probably would have kept my unlimited [snapper grouper permit] if that was open."*
>
> *"I had an unlimited snapper-grouper permit, and then I was demoted down to a 225, the non-transferrable permit that I still have. … I would obviously have been fishing in the Oculina Bank and got the thousand pounds that I needed to qualify for the unlimited permit [if the Oculina Bank had not been closed]."*

A commercial fisherman noted that the closure affected capital investment, explaining that, "you can't put your gear in there inside of 600 feet. So, it did take away some grouper fishery, cut back on my golden tilefishing, cut back on me going bigger. Me and Donny had bought a bigger boat."

The charterboat industry experienced economic impacts from the bottom closure. As one charterboat captain expressed, "how it impacted me was it shut me out of 98 percent of my deeper water bottom fishing capability. Yes, it impacted me horribly." Another charterboat captain concurred, "we couldn't go do bottom fishing anymore, and again, that's a tremendous part of my business or every charter boat's business."

As a result of economic impacts, charterboat captains reported an effort shift into other areas.

> *"We just had to adapt. I would say it affected some of our customers that only wanted pure grouper, but I had to learn how to catch other fish to supplement the difference, because yeah, it did [affect us]. There was an effect on it. We had to completely change our style of fishing: we had to go to a shallower fishing technique, which took a different — you know, you don't drift on the shallow like you do, you had to anchor when you fish inshore. Just because there wasn't as much current, you didn't move as much. So I started anchoring more inshore after I had to leave the Bank. They closed the Bank, literally."*

The closure of the Oculina Bank to bottom fishing was perceived as unfairly restrictive on local fishermen. While the closed area was offshore of Fort Pierce, other communities to the north and south were not prohibited from fishing in their local waters.

> *"It was a big part of our fishery at the time, and it basically took us out of the — took that fishery out of us and left it for the guys on either end of us to fish that same waters above and below us. … So, basically, what they did is they took the Fort Pierce fishermen off the map as far as the fishing in forty fathoms."*

Fishermen frequently expressed frustration at the change in goals of the regulations, from protecting the Oculina coral to protecting fish stocks. A recreational fisherman explained this as, "see, they're saying they closed it because of the fish [in 1994]. That's changed. Isn't that correct? They closed it [originally] because they want to protect the coral, not the fish. Now they're all into shutting everything down because of the fish." The frustration with changing goals was often expressed in tandem with the feeling that regulations were being forced on local fishermen unfairly. This was a common theme among all fishing sectors, but is expressed well in the words of the following charterboat captain.

> *"You know, we had to suffer through the original MPA. When I was going to the [Council] meetings, I never heard one good thing said about it. Nobody was for it, but yet, it was still shoved down our throat. I felt like when we went to the meeting, they already had their mind made up and they were going through the motions of listening to us plead our case. So, basically, when they made that, they took the Fort Pierce fishermen and took them off the map for fishing in forty fathoms for what they said was a decade, which, obviously, became more than that. We were the guinea pigs."*

As mentioned by commercial fishermen above, the prohibition on transit through the closed area when in possession of snapper grouper species impacted charterboat and private recreational fishermen as well. They expressed an impact felt through an increase in fuel costs, operating expenses, and fishing practices. Because the shape of the closure consisted of a long narrow stretch of ocean, it affected the spatial fishing patterns of fishermen. The prohibition on transit through the area with fish caught outside its boundaries was especially frustrating to fishermen. As one charterboat captain stated:

> *"I had to go around the Oculina Bank and not have a single bottom fish on it. And the fact is, it covers—I can't even catch a grouper or snapper on my way out on a legal rock and then continue off to catch dolphin, which I can, because I have to cross the Oculina Bank. So, it costs—it's extremely—it costs me fuel and it costs me how I would normally fish. I can't catch a legal grouper in the morning, when they would bite, for fear of being caught on the Oculina Bank looking for dolphin later. That's how it affects me now."*

Another recreational fisherman echoed the issue of management goals not making sense to local fishermen. "It really took our best grouper spots away that we really liked to fish. And I really got to say this: the grouper fishery continued to decline anyway, even though they shut it off."

Economic impacts were felt by those whose business catered to the recreational fishing community. One of the interviewed recreational fishermen who previously owned a tackle store noted, "we saw the sales of bottom fishing tackle changing slowly, you know, not selling as much tackle. ... Our sales were impacted even further at that point [the 1994 closure], because there were smaller areas for people to go bottom fishing. And that was a popular spot for bottom fishing."

Of all the interviewed fishermen, the only support for the 1994 closure came from the private recreational sector, as seen in the following passage. "We fished there many, many times and the fishing was always good. But, I approve of what they did. I like what they've done out there. It is what keeps our reef populated."

In addition to the comments made by fishermen recalling how they were impacted by the 1994 bottom closure, impacts are also suggested by the area's landings. Table 10 and Figure 32 show the catches from the years before and after the 1994 closure for several species. It is difficult to determine how the Oculina Bank closure affected landings on its own, as other factors certainly contribute to fluctuations in landings. Also, no data are available to determine landings before and after the closure for Fort Pierce alone. It is further unknown how many fishermen targeted bottom fish within the protected area's boundaries prior to the closure, and where these fishermen were homeported. Nevertheless, for bottom fish species listed in the table, and aggregated into grouper and snappers in Figure 32, landings dropped dramatically after 1994.

Table 10: Landings (pounds) for the years just before and after the 1994 closure of the Oculina Bank to all bottom fishing and possession of snapper-grouper species within the boundaries of the HAPC. Data source: SAFMC Snapper-Grouper Amendment 13A, Table 13b; NOAA Fisheries, Southeast Science Center. (SAFMC, 2005)

	South Atlantic		**FL East Coast (excluding Keys)**	
	Average of Years		Average of Years	
Species Name	**1991-1993**	**1995-1997**	**1991-1993**	**1995-1997**
Wreckfish	1,364,259	465,462	621,443	154,506
Tilefish	1,072,373	502,574	673,458	315,467
Crevalle	578,872	333,582	569,340	325,549
Sheepshead	417,540	267,980	362,887	189,538
Amberjack	1,173,157	1,033,700	832,213	663,780
Scups or Porgies*	276,296	93,019	160,272	79,821
Snappers*	82,607	15,664	63,386	13,023
Groupers*	192,244	49,168	52,443	11,038
Snapper,Yellowtail	169,926	127,303	168,145	127,226
Snapper, Mutton	113,281	74,335	110,098	71,181
Grouper, Black	81,402	44,794	73,728	43,827
Triggerfishes	311,622	513,467	89,322	71,135
Grouper,Warsaw	18,507	1,566	16,463	618
Sea Basses	1,028,636	855,821	29,240	14,780
Grouper,Yellowedge	35,229	18,549	26,332	14,798
Grouper,Snowy	471,489	381,824	135,663	151,842
Snapper,Red	151,531	137,033	70,259	86,921
Blue Runner	52,833	77,314	50,320	75,170
Grunts	275,356	251,649	53,468	93,420
Porgy,Red	389,196	356,673	0	43,089
Total Landings	11,037,440	8,419,259	4,915,492	3,323,681
Total Value	$14,849,635	$12,769,103	$5,791,034	$4,798,478
Total Real Value ($2001)	$18,777,694	$14,461,334	$7,323,861	$5,441,165

*Unclassified species

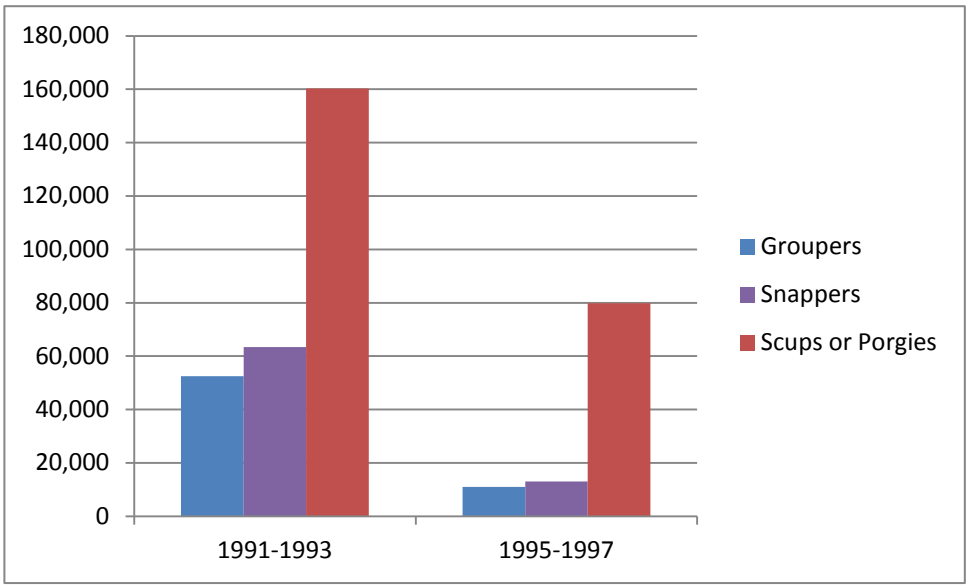


Figure 32: Change in landings for the years prior to and after the closure of Oculina Bank for bottom fishing. The landings are in pounds for the entire east coast of Florida, excluding the Florida Keys. The categories include multiple species of each fish family. Data source: SAFMC Snapper-Grouper Amendment 13A, Table 13b; NOAA Fisheries, Southeast Science Center. (SAFMC, 2005)

1996: All anchoring within Oculina Bank HAPC prohibited

The regulation implemented in 1996 prohibited all fishing vessels from anchoring within the boundaries of the original HAPC, now designated as the Experimental Closed Area (ECA) (SAFMC, Coral Amendment 3, 1995). The regulation also expanded the area of the HAPC north and eastward, and trawling was prohibited east of 80°W longitude, between 27°30'N and 28°30'N latitude, in depths less than 100 fathoms (SAFMC, Shrimp Amendment 1, 1996).

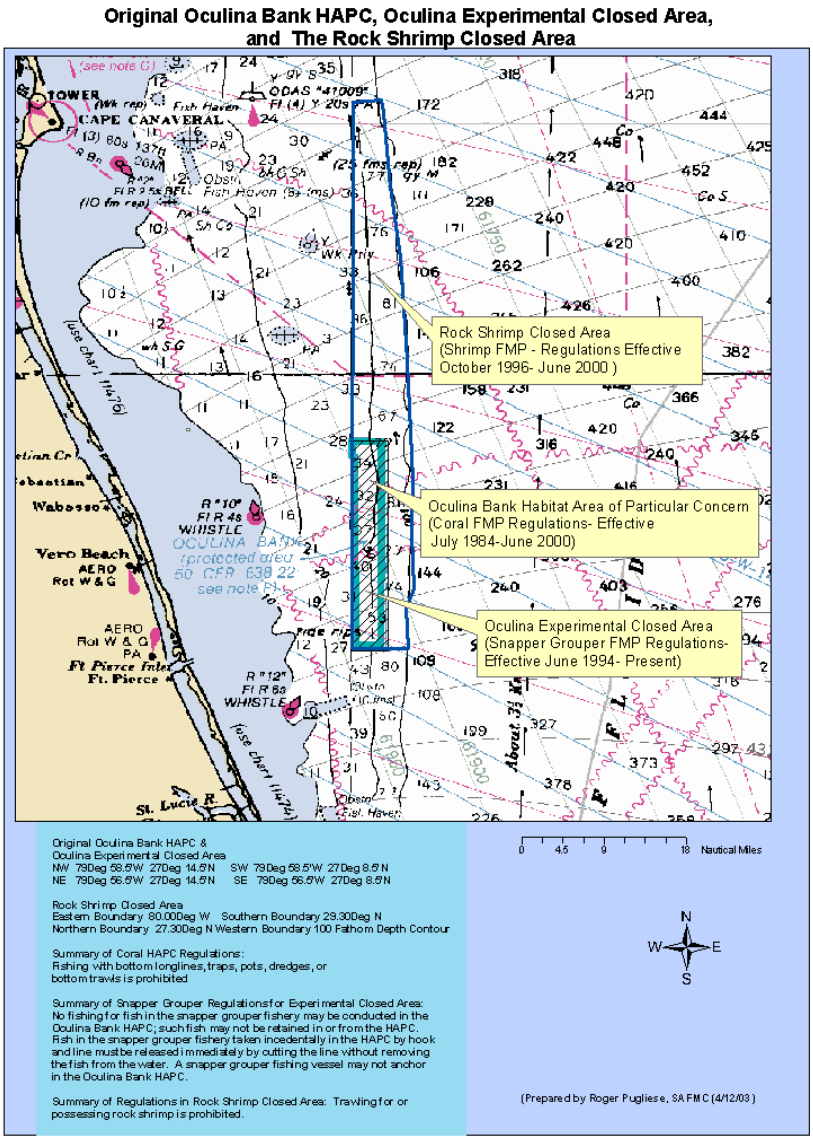


Figure 33: Map from SAFMC Snapper-Grouper Amendment 13A. (SAFMC, 2005)

Impacts from the 1996 regulation

This regulation created further logistic impacts in banning all anchoring within the Oculina Bank Experimental Closed Area (the former Oculina Bank HAPC). Because bottom fishing was already prohibited in this area, however, it did not create direct economic impacts on fishermen as they had already been pushed out of the area. The expansion of the closed area to the north and east under this regulation directly affected commercial trawlers only. As mentioned previously, this population of fishermen was largely based out of Cape Canaveral, north of Fort Pierce. Thus, commercial fishermen of Fort Pierce, for the most part, were not impacted.

Some local fishermen on multi-day trips incurred a logistical impact from the prohibition on anchoring within the marine protected area. Many stated they never anchored at those depths, even when bottom fishing was permitted; rather, they powerfished by using the boat's motor power to maintain position over fishing spots. But there were also some who had anchored within the area while on multi-day fishing trips east of the Oculina Bank HAPC. This practice served to conserve fuel costs which were already increased when fishing east of the Oculina Bank since transit through the protected area was prohibited while in possession of snapper-grouper species, including tilefish. The prohibition on transit necessitated longer travel distances to avoid the closed area. A commercial fisherman described his reasons for anchoring in the area. "I used to anchor up at about 160. I'd be anchored up out there a tilefish day or a grouper day you usually go in there and get out of the tide." While the Oculina Bank pinnacles are concentrated in the closed area, there are large spaces with no pinnacles, within the closed boundary. Those fishermen who anchored or bottom fished within the area noted the care they took to avoid anchoring on the pinnacles, recognizing the damage that the coral would in turn cause to their gear.

This also points to the multiple groups of resource users of the Oculina Bank area who are affected by each regulation: shrimp trawlers whose effort was directly impacted by the regulation, and commercial fishermen who could no longer anchor to get out of the tide. Recreational fishermen also consisted of those who powerfished and those who anchored. There was variation in the regulatory effects both within a sector (shrimp trawlers and displaced longline anchorers) and across sectors, such as when a recreational fisherman perceives an improved fish stock following the curbing of commercial shrimper's access to resources within a newly protected area. This variation points to the complexity of impacts from the regulations which have both direct and indirect effects. Fishermen of different sectors or using different gear types may be affected directly but differently; one may benefit by seeing improvements in the stock and another bears the cost of through the loss of fishing grounds. An indirect impact resulted with the prohibition on transit through the area as fishermen incurred additional fuel and time expenses as they had to go around the protected area. Yet others were impacted since the closure shut them out of a zone that could be used for safety and comfort at sea.

Further indirect effects were reported as fishermen perceived that the regulations were going to continue expanding, rather than providing relief once management goals were realized. One commercial fisherman expressed this when asked about the 1996 closure. "Yeah, it impacted [me] because I knew some more laws were coming out and I was hoping they'd give us some transit provisions. … Then that basically—it didn't directly impact my fishing, but it made me give up any hope of keeping up any deepwater fishery. So, I changed the way I fished a little bit more." Many fishermen expressed this frustration, feeling that the regulations were presented to

them as ways to improve the fishery, but they never receive benefits from their reduced effort; instead, additional regulations continue to be implemented.

Overall, fishermen reiterated that the previous set of regulations in 1994 had had the greatest impact on their fishing. This was expressed by commercial fishermen ("Well, by then, we're done. We're done in ninety-four, so whatever they do after that, no, it didn't affect us at all. Once you're done, you're done."); charterboat captains ("Well, as of eighty-four — ninety-four — we couldn't anchor anyhow. So, there wasn't really much of a difference there.); and recreational fishermen, alike ("Well, we were already out of there, so.").

Thus, the succession of regulations of increasing restrictions on fishermen, without relieving some of the hardships created by previous regulations, contributed to frustration among fishermen. Regulations that do not make sense to fishermen do not foster compliance. As one commercial fisherman put it:

> *"generally speaking, we pretty much were done with this grouper fishing. We still tilefished and we always pushed the limit crossing the zone with product on the boat. I mean we did it. There's no question about it. I mean over, and over, and over, but you can't hardly fish out here and expect us to run [around the protected area boundary]."*

1998: Expansion of Oculina Bank

In 1998, the HAPC was expanded to include the rock shrimp closed area that was established in 1996. Within the expanded HAPC, fishing with a bottom longline, bottom trawl, dredge, fish pot, or fish trap was prohibited, as well as anchoring by a fishing vessel (SAFMC, Coral Amendment 4, included in Comprehensive Habitat Amendment, 1998).

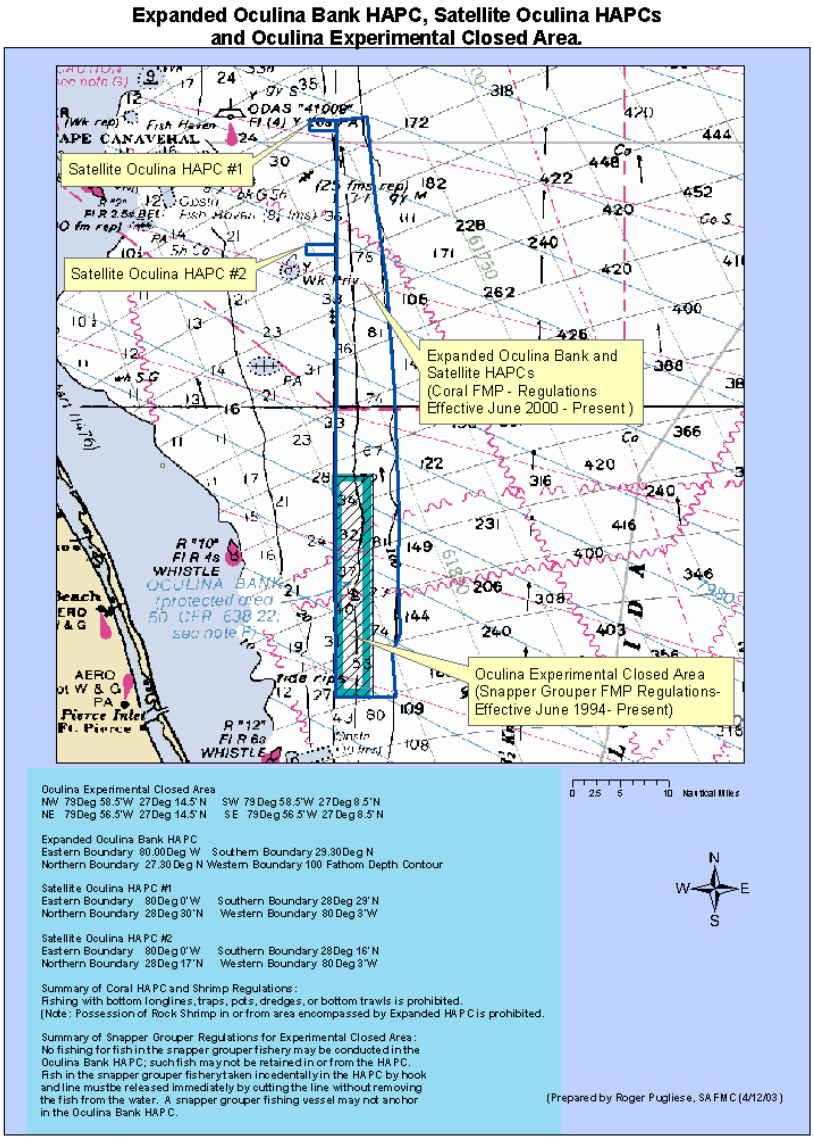


Figure 34: Map from SAFMC Snapper-Grouper Amendment 13A. (SAFMC, 2005)

Impacts from the 1998 regulation

The 1996 regulation that expanded the area in which trawling was prohibited was now officially integrated into the Oculina Bank HAPC. Within this larger area, bottom longlining was now prohibited as well. The expansion under the 1998 regulation extended the protected area north and east from Fort Pierce, stretching away from the local area which likely helped mitigate negative perceptions and impacts from this closure. As explained by a charterboat captain:

> *"Oh, they went north. That didn't affect me because that was north of the area that I fished, and I didn't really fish deeper than that. So personally, with my charter boat, that ruling didn't affect me 'cause I didn't really — once they closed it, I didn't go out there. I couldn't anchor, I couldn't fish it. It became a closed zone. It was a no-no, so we kind of quit going there. So being east and north of it didn't affect me, personally."*

Recreational fishermen made similar statements.

> *"I rarely fish north of Sebastian, yeah north of Sebastian or on the outside; it's just too deep on the outside edge of that Oculina Bank."*
>
> *"Right. So, it really didn't impact me because I don't travel that far to fish, that's all."*
>
> *"I remember that. Doesn't go all the way up to Sebastian now, which the reef does go that far. But that new closed area, no, that didn't affect us at all. We don't go that far north."*
>
> *"No. I was already out of the fishery, and I wasn't gonna run that far north, anyway."*

Because the area was closed to gear principally used by commercial fishermen, negative impacts were largely limited to this sector. For commercial fishermen, direct negative impacts were incurred.

> *"It just decreased the amount of deepwater groupers that I caught, and sharks."*
>
> *"Yeah. Further, it reduced the availability of snowy grouper."*

One charterboat captain cited a perceived impact on the restaurant industry; however, this might have been a short-term impact. He said, "What really was impacted was Dixie Crossroads up in Titusville. Rock shrimp became very expensive. … They used to be delicious and cheap." Laurilee Thompson, co-owner of Dixie Crossroads in Titusville, was interviewed for this project. Ms. Thompson feels that the series of regulations closing the Oculina Bank actually helped save the local rock shrimp fishery. Her father, Rodney Thompson, was one of the early proponents of the closure and, according to Ms. Thompson, felt that the immediate economic impacts on restricting the rock shrimpers were necessary to make the fishery sustainable in the long-term. She feels that the closure helped steer away rock shrimp trawlers from the Gulf of Mexico region. The rock shrimp trawler fleet is now a mostly local fleet. This adds to the point in the previous section about the multiple user groups, targeting different species with different gear types, from home ports up and down the coast, all of whom may experience impacts differently:

positive or negative; direct or indirect; short-term or long-term. Thus, fishermen were impacted in complex ways by the assemblage of regulations and closures that were often coupled with other regulations not related to the Oculina Bank, i.e., the 1995 net ban. Some groups perceived benefits while others experienced severe economic hardships.

Summary of Impacts

Table 11 summarizes the regulations that pertain to the Oculina Bank and the effects on the three fishing groups who participated in this study. What becomes apparent is that there were multiple groups who used the spatial area designated as the Oculina Bank in different ways. These user groups were affected differently, in both direct and indirect ways. Also, each subsequent regulation was implemented within a different management unit of the South Atlantic Fishery Management Council. Although the regulations involved restrictions on effort within the same marine space, they were implemented for the conservation of different managed species and thus, had different purposes and goals, i.e., protection of the coral followed by protection and enhancement of reef fish stock stability and recruitment. Within each regulatory action, a different process of analysis was carried out on the impacts of the proposed regulation, focused around the goals at hand. This might have been a contributing factor to the unintended consequences on user groups whose effort was not directly impacted.

Another impact arises from the design of policy to assist enforcement. The prohibition on transit through the ECA with snapper-grouper species aboard is not permitted, even if gear is stowed. Transit does not directly affect the protected environment. Rather, the prohibition on transit serves to make legible a difficult area to enforce. The HAPC is far from shore and there are no physical markers of its coordinates, i.e. an island or buoy.

For the recreational fishing community, the original closure was widely seen as a positive thing; curtailing commercial shrimp trawlers and longliners. The regulation that impacted them the greatest was the prohibition on snapper grouper fishing, in 1994. Over time, the Oculina Bank peaks had become known locally for really good bottom fishing. The prohibition was, obviously, very unpopular. It was also regarded widely as unnecessary and unfair. Recreational fishermen generally do not see their fishing as more than minimally damaging. They often questioned whether there is evidence or results of studies that can attribute their fishing to negative impacts on the *Oculina* coral or grouper stocks. There was general agreement that regulations were warranted for trawlers, which they identified as utilizing destructive practices. But each angler in his own boat strongly objected to no longer being able to fish in the best local snapper grouper spot.

Table 11: Comparison of regulations and impacts managing the Oculina Banks. Some of the impacts reported by the commercial, charter for-hire, and private recreational fishermen are coded by highlighted color according to their positive or negative, direct or indirect effects from each of the implemented regulation.

Oculina Bank: History and Summary of Regulations and Impacts					
Year (Document)	**Regulatory Action**	**Type of Action**	**Commercial Fishing Impacts**	**Charter Fishing Impacts**	**Recreational Fishing Impacts**
1984 (Coral Fishery Management Plan)	Designated 92-nm^2 area of *Oculina* pinnacles a Habitat Area of Particular Concern (HAPC) and prohibited bottom trawlers, dredges, longlines.	Spatial closure to select gear types	Fort Pierce longliners. Port Canaveral rock shrimpers (Long-term Positive and short-term negative).	Perceived positive results from closure to other (sector) gear types.	Perceived positive results from closure to other (sector) gear types.
1994 (Snapper Grouper Amendment 6A)	Prohibited possession of bottom fish within closed area, renamed Experimental Closed Area (ECA).	Spatial closure to particular species.	Eliminated all bottom fishing in best fishing spot.	Eliminated all bottom fishing in best fishing spot.	Eliminated all bottom fishing in best fishing spot.
1996 (Shrimp Amendment 1)	Prohibit anchoring in ECA; expanded area where trawling prohibited to north and east.	Expand spatial closure to select gear types; Spatial closure to anchors.	Some who anchored for safety and rest; not for fishing. Port Canaveral rock shrimpers.	None (targeting species for which anchor is necessary was already prohibited)	None (targeting species for which anchor is necessary was already prohibited)
1998 (Coral Amendment 4)	HAPC incorporates areas closed to trawling under 1996 regulation. Bottom longlining now prohibited.	Spatial closure to particular gear types within expanded area.	Further reduced fishing grounds for longliners.	Expanded away from their fishing areas, so no impact.	Expanded away from their fishing areas, so no impact.

Summary of Impacts reported by Fort Pierce fishermen		
No Impact		
Direct Impacts	Positive	Negative
Indirect Impacts	Positive	Negative
Impacts on other places		

Additionally, some themes arose from the texts provided by the fishermen. Two of these will be addressed here, cross-sector blame and the issue of trust.

Cross-sector blame:

For the most part, support for the regulations and closure of the Oculina Bank, when offered, primarily came from the charter and private recreational fishermen. This support, however, was usually offered in tandem with assigning blame for benthic damage to participants of other fishing sectors. For example, a recreational fisherman said, "I certainly support limiting the trawlers and that kind of thing. Just from what I've read, they can be fairly destructive on that bottom habitat, not to mention the by-catch and everything else." Negative cross-sector comments appeared as a common theme in the oral histories and occurred among all three sectors.

One charterboat captain who earlier in the interview, stated that their business does not involve offshore fishing, said, "I remember when they did that [closed the area to trawlers and longliners], and all I could think of was, "This is a good thing." A recreational fisherman who uses vertical line for bottom fishing specifically cited longlines as creating negative impacts.

> *"The longline was probably—it impacted the grouper fishing more than anything else. And even though we did very well with our fishery, there would be a handful of boats that would go out maybe twice a month that caught that kind of fish—fifteen to twenty fish a day. Well, twelve to fifteen a day on an average. But the longliners were thousands of pounds, and they were laying down two, three miles of longline, right on the—typically on the twenty-seven fathom line, because that would be just inside the current from the Bank—and then they would pick it back up. That's when you noticeably—I mean, absolutely noticed that the fishing changed, and became worse."*

Commercial fishermen also have their views on the private recreational sector, as expressed by this man.

> *"I don't believe there'll be any [future of fishing], unless they help the commercial fishermen out in some type of way, which I don't have an answer for that one. But the sport boats are still catching the fish in that area that we've been talking about, and nobody's checking 'em. So, if there's a decline in fish, in my opinion, it's from the sport boats. It has nothing to do with the commercial boats."*

Had the regulations targeted stakeholder's preferred fishing grounds, gear type, or target species, a different opinion was usually the result. Fishermen readily recalled statements of support for their own fishing activities that were shut down, such as anchoring. For example, a recreational fisherman said, "the guy [scientist] from Harbor Branch said that anchoring in the Oculina Bank by recreational fisherman was of little impact, and that expanding it for recreational fishing anchoring was really sort of useless and just an exercise in trying to police the area, because it was just not of any value to their studies." However, when other user groups were impacted, the regulations were likely necessary. As mentioned, this was generally expressed by all groups

toward others, but the strongest language was used by recreational fishermen against commercial fishermen. However, this was not true for all charter and private recreational fishermen by any means, many of whom value the commercial sector. A charterboat captain expressed well this pattern of blaming other groups and his hesitancy to do so, saying "I mean, I don't want to put somebody else out of business, you know. It's always easy to kick the can down the road."

Fishery Management and Trust:

Another theme that arose throughout the oral histories concerned the relationship between the fishing population and those who are involved in making regulations. This latter group was generally lumped together under a category called "them", and included scientists, regional Council staff and members, and NMFS employees at the regional and national level. This section provides many of the participants' responses about marine protected areas with closures on fishing, and the relationship between those who make the rules and those who must comply with those rules. Components of this theme are reflected in the problems of enforcement, changing goals of regulations, and suspicion of a misunderstood relationship between science and policy. This suspicion of how data (as information) translates into policy was prominent among the texts from all sectors. As a commercial fisherman explained:

> *"I mean, I've seen scientists say, "Well, golly gee, look! The catch ratio's gone way down." Well, yeah, you've closed our fishery! What the hell did you expect it to do?! You expect it to go up? I mean, so many times they come up with — I hate to say they're just asinine theories, but they're asinine theories, you know? They look at this data and they've done something major to change the data and then they say, "Oh, this fishery's in trouble. Look, the catches just went down to nothing."*

This passage reflects the man's belief that fishery dependent data (landings data) is the basis for managers' determination of the health of a fish stock, and thus, subsequent management restrictions. As he points out, he feels that decreases in landings are not a result of overfishing, but rather the effort restrictions themselves. Essentially, the fish are still there. This reveals not only the gap between managers and fishers, but the understanding (and disconnect) of how landings data is used in the management process. Stock assessments conducted by biologists do not rely principally on fisheries dependent data, including landings, in determining stock abundance; rather, fishery independent data plays a far larger role. The fisherman also recognizes this difference between fishery dependent and independent data, and knows that landings reflect effort and include factors that influence effort such as fuel prices, environmental conditions, and effort restricting regulations. Rather, what is important from the passage is the fisherman's underlying perspective. He is frustrated at being prohibited from fishing where he previously could fish. As an individual, he has not been able to fish there for many years (his effort was restricted), yet the regulations have continued to expand. However, at a broader scale, other factors have continued to affect and change the fishery. His personal fishing effort restrictions should ultimately be rewarded through a future benefit, such as the relaxation of effort restrictions. When this does not happen, he perceives management to be targeted against him.

Generally, fishermen objected to spatial areas that are off limits to fishing. There was broad acceptance of the need for effort reducing regulations, and fishermen supported effort restrictions perceived as partial, i.e. closed seasons or minimum size limits. These management tools were

temporary or still allowed you to fish and maybe fish longer. The complete closure of an area at all times, however, was not only frustrating; it just did not make sense to fishermen. The negative impacts of being completely, and indefinitely, prohibited from any bottom fishing within the area of the best nearby bottom fishing spots was not reciprocated with any apparent positive benefits. On the other hand, fishermen understood that closed seasons allow fish stocks to rest or spawn. Minimum sizes allow small fish to grow and be caught later. But a closed area did not permit fishermen to realize a future positive benefit from their compliance. Fishermen from all sectors expressed their preference for closed seasons and minimum catch sizes over closed areas. For example, one commercial fisherman said, "I think quotas and closed seasons are much better. Closed areas are — they're running crazy with these closed areas, and pretty soon we're going have nowhere else fish."

Charterboat fishermen expressed similar sentiments about closing marine areas to fishing.

> *"I don't agree with closed areas. I don't believe that any part of the ocean should be closed to any kind of hook and line fishing. That does nothing to the fish stock. And because the scientist say so, that doesn't hold any water with me. I mean scientists are wrong all the time."*

> *"MPAs don't work; they haven't worked. As an example, Oculina was supposed to help the snapper and grouper populations. I've seen no difference in the snapper-grouper catches for the time that we've been here. So, if it was gonna work, it would've worked in eleven years. In my opinion, the best management is quotas, size, and bag limits, no closed area. When you reach your quota, you stop fishing."*

And recreational fishermen expressed this, too.

> *"The Oculina Bank, to me, has proven that a closed area doesn't work. The kingfishery in this state was dead, out of control, overfished by net fishermen. You didn't close an area, but you managed the fishing stock. And today, the fishing stock is as healthy as it can be, and it's not in danger in any way. Not by closed fishing, but by managing the breeding stock, we have a strong kingfishery."*

Fishermen are generally suspicious of the purpose behind entirely closing an area to fishing. According to the following commercial fishermen,

> *"To me, the scientists say, "Oh, well, let's close this area because great things will happen." The main thing that happens is that the scientists just create their own little private fishing area, 'cause they're the only ones who get to fish it after that. They go out and get the fish, they can say, "Oh, this is what's happening," and nobody else gets to fish it, so we don't know what's happening. And I can guarantee a scientist doesn't know whether there's enough out there to sell, or anything else, you know?"*

A recreational fisherman expressed the same concept of a closed area being like a garden from which they do not benefit. He then connects this to the issue of enforcement.

"Well, first of all, closing an area to fishing and calling it a tool is a misnomer. It's not a tool. It's an avoidance of addressing the real problem. By closing it off to everybody, all you're doing is trying to make a garden out there, one that's not gonna have any kind of stewardship whatsoever. If there is a problem, then you're not gonna have anybody out there keeping an eye on it. But the main thing is that it's not a tool at all. All it does is prohibit people from being able to do anything. It's punishing the wrong people that didn't have anything to do anything for the wrong reason."

This issue of enforcement and compliance is crucial as fishery management is essentially about managing people, not fish. A charterboat captain pointed out a commonly expressed frustration that is at the root of the open access resource problem, the tragedy of the commons. Just as in an Hardin's parable of the open access scenario (1968), everyone will act in self-interest until a resource is overexploited, in an area where people are accustomed to using a resource, compliance may not come easily especially in a place one is not likely to get caught, such as the Oculina Bank which is far from shore and not bounded by physical markers. The captain explained,

"MPAs are too hard to enforce. And then you also — you take that, you take the honest person will not fish that, and you'll take another fisherman, will use that as his private fishery. It's because it's an enforcement nightmare. These people get away with fishing like a pirate in a closed area, because they know that it's unenforceable."

Issue of compliance affects commercial fishermen, too, as this one put it.

"The problem is you have winners and losers with that because there's not much law enforcement. You got people that are gonna follow the law and those that don't. And you're gonna have aggressive fishermen that cross the lines and you're gonna have honest fishermen that don't. Now, you're coming into a thing where you're talking about IFQs and catch histories and stuff like that. The people who cross the lines and do fish illegal are gonna be the ones rewarded in perpetuity through these IFQ systems and stuff. So from that aspect, closed areas without enforcement don't sound very good, no."

This issue of enforcement was expressed by the recreational sector as well,

"Another part of this thing that I've always wondered about is, you know, the actual enforcement of the closed area, and how well they actually work on the enforcement. They keep adding regulations in closed areas rather than working on the enforcement. I know that's an issue that's been brought up before."

> *"I'm not in favor of closing areas because I think it's a little difficult for them to police those areas in the first place, and expanding it even further is gonna make it even more impossible to do that."*

Charterboat captains expressed similar sentiments.

> *"I feel that they're setting themselves up for failure, because they've created an enforcement nightmare. They've taken hundreds of square miles of ocean that has to be patrolled in order to manage that fishery, which they — it's not economically feasible to enforce the rules that they're creating. I feel that the bag limits and quotas far exceed any kind of MPA management, especially on the basis of enforcement. I feel that the quotas and bag limits have worked in the past, and are very much more enforceable than an MPA."*

The protected area where snapper grouper fishing was prohibited was supposed to incur benefits over the long-term as fish stocks strengthened from the reduction in effort among fishermen. However, after almost two decades, the fishermen do not see benefits realized from their sacrifice in fishing areas. A commercial fisherman pointed out his feelings of unfulfilled promises of management, saying "that was gonna be the sanctuary and if there were gonna be so many fish, they were gonna come inshore." Another said, "there was a hope that once things got better there that we would be able to fish in a limited ability in that area. And it just remains closed, period, the end."

Once a closure is in place, despite suggestions at the time of a temporary term, fishermen feel that benefits will never return. One commercial fisherman said, "it started out as a ten year closure, and how many years is it now? Sixteen years now, it's been." And another said "well, it seems like once the area's closed, it's a done deal. You're just not going back there anymore in your future fishing."

And a charterboat captain complained about the failure to assess the goals of the closure, feeling that goals must be achieved or the closure should be rescinded.

> *"I would like to see a check on the abundance of fish on this closed Oculina Bank to see if it's noticeably more fish there than it was before the closure fifteen or sixteen years ago. If they can't show that this area is spawning an awful lot of fish and sending them to other places, I say open the thing back up to sport and commercial fishing. I agree with no anchoring henceforth and forever more, because that could damage the coral. But I don't believe that sport fishermen dropping a jig or a twenty ounce lead down there are gonna destroy this coral that is two hundred and thirty feet down."*

Another aspect of the closed area can be examined in terms of the fishing behaviors affected. In order to address a management goal, such as to protect the grouper stock of the Oculina Bank, the actual behavior that is affected by the regulatory action may be broader, or indirectly affected. Not only was there a prohibition on using the space to catch desired stocks, the

protection extended to fishermen transiting through the area with those species aboard. Due to its distance from shore, enforcement of the Oculina Bank prohibition on bottom fishing is difficult to enforce. While this was the reason for transit of any grouper aboard a vessel to be prohibited through the Oculina Bank, the impact this had on fishermen was extreme. When fishermen complied and ceased fishing within the boundaries, not only were they forced to move into deeper waters, they had to add distance to their travel time to circumnavigate and avoid the long, narrow protected area. While the transit prohibition is a tool to assist enforcement, a focus on how to promote compliance is missing. Fishermen were left feeling that those that make the regulations were unaware of the reality of what compliance entails. As two commercial fishermen said,

> *"They make these laws, and zones, and rules, and stuff, and they don't ever take into consideration the effects—that kind of effect on it, you know? I mean it's easy for somebody to sit there and draw these lines all over this chart and say you can't fish there. It's another thing entirely to have to deal with it."*
>
> *"There's a lot of things that they got to take into consideration when they make these laws, and I don't think they do a very good job of it."*

Changes in the Fishery Management Paradigms:

An important component of the trust theme requires an understanding of the historical process of change within fishery management. The changes in the goals and perspective of management over time have contributed to disengagement between resource users and policymakers. An underlying component of the trust theme concerns changes in the federal approach to management. That is, the historical perspective of fishery management is important to understand the origin of mistrust. There have been changes in priorities over time, yet the history of the damage to the Bank is viewed through the lens of the present paradigm: that past fishing was destructive and thus, fishers are, by nature, destroyers of the resource. We must remember that just as the management paradigm changes, so do fishermen's perceptions.

Prior to the 1950s, fisheries in the U.S. focused on development rather than conservation and management, owing to the perception of limitless quantities of marine resources (Abbott-Jamieson and Clay, 2010). Social impacts were not a focus of research. This is seen in how people talk about the damage done to the Oculina Bank: in Fort Pierce, which did not have a rock shrimp industry, trawlers are blamed. That is the narrative they get from Harbor Branch. But, there was more to the history. Early on, fishing development was encouraged and it is only under the new conservation paradigm, where megafauna such as sea turtles and manatees get sympathy, are trawlers and other fishery producers cast as villains.

The fact that it was a government initiative that encouraged the entry of fishermen into the practice of dredging is important. Federal fisheries management has undergone multiple paradigm shifts. Prior to the 1990s, Federal policy encouraged the growth and development of fisheries and it was within this paradigm that the early fisheries in and around the Oculina Bank took part. A paradigm shift occurred from one of growth and development, where fishery maximization was emphasized, to the next phase of sustainability, to the current paradigm of conservation.

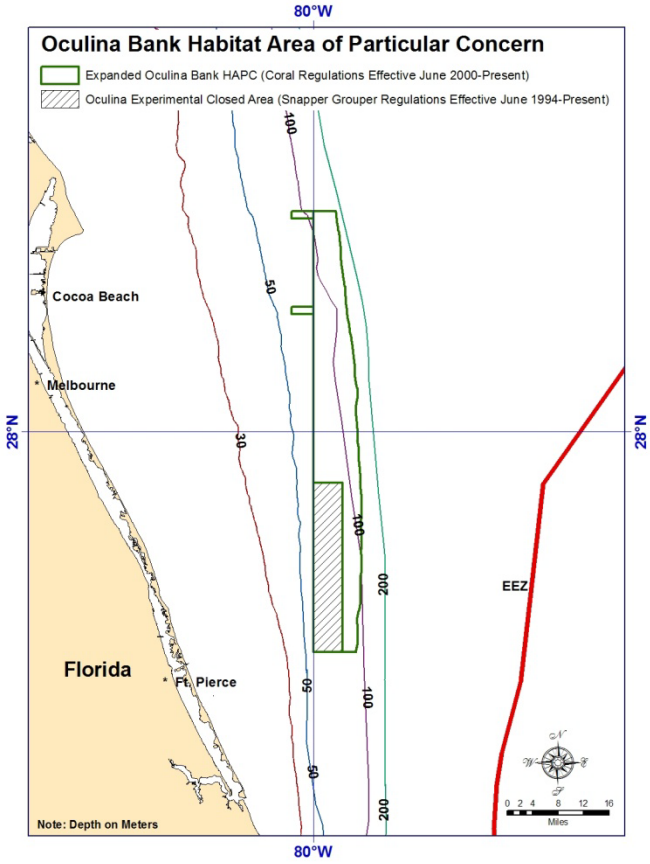


Figure 35: Map of the Oculina Bank provided by the Senior Fishery Biologist/Habitat Coordinator of the South Atlantic Fishery Management Council, showing the boundaries of the HAPC and respective depth contours. However, the map inaccurately shows the eastern boundary of the Oculina Bank as extending well beyond the 100 fathom curve line. In the oral histories, several fishermen complained about the arbitrariness of lines being drawn across the ocean and the difficulty in accurately identifying its boundaries. This map provides a good example for their frustrations.

Future of fishing in Fort Pierce

The Oculina Bank Experimental Closed Area has been closed to bottom fishing for over 15 years. Looking to the future, some fishermen believe that the fishing must get better due to the rules that restrict their effort. Others are less confident. This section describes the sector responses to the question, "what do you think fishing in Fort Pierce will be like in 10 years?" The responses are divided between a positive and negative view of the future, including some other relevant issues that were raised.

Although a positive view was often expressed, such outlooks for the future of fishing was often underscored by the restrictions under which fishermen currently operate. This was expressed by all sectors including these commercial fishermen.

"I think it's gonna keep getting better. I mean, we're putting more and more restrictions on people that aren't necessary. The fishing is already improving due to the restrictions already in force right now. So it should be getting better and better, even though the science doesn't say so."

Well, I'm optimistic. A lot of these management measures that are really cutting our throats and are hurting a lot of us, if people follow some of these limits and some of these closures we have, I'm optimistic. I don't see how it can do anything but get better."

A charterboat captain ("If they stick with the size limits, the amount, the trip catch, you know, what you're allowed to catch per person — we're speaking recreational part now — I think it'll be great.") and a private recreational fisherman ("In Ft. Pierce—I think it's so regulated now, that I don't think there's gonna be a problem in ten years. I just think it's just regulated to the point where it's hard to catch fish, so I don't see a problem. I think fishing will be fine.") expressed similar views.

A negative view of the future of fishing was also expressed in relation to the management regulations. These statements came from commercial fishermen.

"Well, if they keep passing more laws against us, we'll be totally out of business; which right now, only the strongest survive, which is a very few."

"There won't be any. … The laws will be closing it down. They keep limiting and regulating it and regulating it and regulating it more all the time. They can only stand that much. You can't just keep closing down."

Charterboat captains also see the regulations as contributing to a negative future for fishing in Fort Pierce.

"The cost of the license and permits will increase dramatically. What you're able to keep will decrease dramatically, and there's gonna be a loss of money in the sport from the license and permits to the tackle to the hotels and motels that fishing brings to this area. It's gonna affect this area in a negative way as the cost of fishing goes up and what you can keep goes down. Financially, we're gonna have a negative effect in this area because of that."

"There won't be any if the regulations go the way they are."

"I think charter businesses won't be alive in ten years, because there's nothing you can keep and catch."

"Well, I'm afraid that the — I think the fishing will be okay, but the regulations are gonna be more and more imposing on us. I hope I'm wrong, but if it goes to an extreme, I can see where they outlaw fishing almost altogether. I really don't think

that that should happen, but if you look at history, it's been creeping up and up and up, and becoming more and more difficult."

Recreational fishermen also express their feelings that the future of fishing in Fort Pierce will not be good due to excessive regulations.

"I didn't think I'd see the kind of closures that we're having now ten years ago. So, if there's an agenda, I certainly don't know where we're gonna go from here, other than more restrictions. More restrictions are gonna make it more difficult for people to earn their living here in Florida, especially here, which this is a fishing community."

An impact on the process of continually implementing tighter regulations is expressed by the following commercial fisherman who is concerned that regulations merely shift effort, and thus pressure, onto less regulated species.

"*I think the king and Spanish mackerel fishery will be strong, it's just the matter of — the amount of permit holders in it. Like, as you well know, they've shut down snapper; they've got so many restrictions on tilefish now; the shark fishery's like nonexistent, almost. Every time one of these fisheries goes downhill, here come some more people into the king mackerel and Spanish mackerel fishery. So, there's more pressure, more fish on the market, lower prices. The more fisheries they shut down — the people are going to find a job somewhere catching something."*

There was also a negative view of the future of fishing expressed by commercial fishermen who see the process of increasing regulations as contributing to the end of their livelihood.

"I do not think there will be any commercial fishing at all. It'll all be sport fishing."

"At the rate we're going, I don't think we're going to have much fishing in ten years. With the National Marine Fisheries proposals that are on the plate right now, and everything that's going, I just don't see it. I don't know where we are going with this. … The commercial fishery takes the blunt of the blow for both sides, where the recreational sector is left to fish unregulated, basically, is what it boils down to."

Problems Encountered:

The objective of this study was to examine the impacts from the implementation of a marine protected area on a fishing community. However, the particular context of this MPA needs to be considered in terms of its location and history. The fishing conditions within the closed area are regarded as tough even by experienced fishermen; this was never a target area for the average recreational angler. Furthermore, king mackerel fishing is currently the most important commercial fishery to the community and trolling for king mackerel within the Oculina Bank HAPC is permitted. Thus, at present the closure does not impact this important fishery. However, without baseline data on the number of bottom fishermen at the time of the closure, it

is not possible to determine the size of the population impacted by the closure, nor quantify how the closure contributed toward shaping the future of the fishery, including the increase in effort and importance of king mackerel.

Second, the initial closure to longlining took place 36 years ago, meaning that identification of many of the social impacts have been lost. A significant result, then, is that the impacts of any regulation will be directly related to the resources existent within such a closure. Bottom fishers were negatively impacted by the closure of the HAPC, but those fishermen who were put out of business are now retired or have moved on to other fisheries. Baseline data on these fishers is not available.

Logistically, this project faced the following obstacles. Fishermen are busy and despite the economic recession and high local unemployment rate, it was difficult to find people who had the time and skills necessary to assist in the data collection tasks of the study. As far as the project managers are aware, this is the first time fishermen have been hired to conduct interviews with other fishermen, making it an example of true participatory research. However, fishermen do not approach the systematic collection of data from the same perspective and with the experience of a trained social scientist and this becomes evident at times in the interviews. For example, the interviewer may not realize when an issue is raised by a participant relevant to the objectives of the study, and know to probe for further information. Or, the interviewer's personal interests in talking about fishing in general become apparent, at the expense of the purpose of the interviews, which were meant to focus on the impacts and benefits of the closure of the Oculina Bank to fishing. Nevertheless, the end product became not only a collection of oral history interviews, but recorded dialogues between fishermen, which are interesting for further analysis.

Finally, the process of transcribing the oral histories was more lengthy than expected. The corrections for proper name spellings and consistency of industry terms and vocabulary consumed a large proportion of the project. Analysis began prior to the completion of the final edits of the audio recordings, making the already time-intensive process of data coding even more demanding.

Further Research:

In order to better understand local level impacts from federal regulations, this study could be replicated in other communities. The budget and scope of this project was limited and did not allow for the time needed to more thoroughly analyze the oral history texts. These texts are now publicly available for further qualitative analysis.

Another future direction for this research would be to expand the social network analysis to incorporate and code for sub-groups of fishermen. For example, the research design of this project did not entail crew as a group of interviewees, but their social role became apparent during ethnographic research and analysis of social network data. A potential research question could investigate the role of crew in the exchange of information between the commercial and recreational sectors. The results of the social network analysis presented above showed the charter boat captains to be the brokers between the commercial and recreational sectors. It would be interesting to understand the social position of crew and mates, many of whom any of them experiment with different marine-based livelihoods, play in the broader network.

VI. Conclusions

This study examined the effects of the Oculina Bank HAPC closure and regulations on the fishermen of Fort Pierce, Florida. Commercial, charter for-hire, and private recreational fishermen participated in a collection of oral histories focused around their experiences regarding the Oculina Bank. The results of the study rely heavily on the texts from participating fishermen. It is from their perspective and narratives that effects are assessed. Changes in behavior are imposed on fishermen when certain regulations are implemented and these regulations affect fishermen in different ways. Commercial and recreational fishermen may be impacted differently, and perceive the same regulation differently, as well. But even within one sector, there is variation in fishing preferences and activity and thus differential impacts. In fact, sometimes, fishermen of different sectors may have more in common than those within the same sector, as far as sharing an impact from a regulation is concerned.

The effects from the regulations implementing the Oculina Bank HAPC have been described qualitatively. These impacts were generalized as (a) positive or negative according to the goals of the impacted user group; and (b) direct or indirect correlating roughly with short-term, immediate impacts or long-term, future impacts. This is an important first step: through description, patterns can be identified and generalized, and ultimately tested systematically for reliability. Thus, qualitative analysis is the most appropriate analytically.

Although it is now accepted as a truism that fishery management is about managing people, not fish (Jentoft, 1999), fishery management continues to emphasize a bioeconomic approach at the expense of community social concerns. There is more to managing people than implementing ever tightening restrictions. What is needed, as Jentoft pointed out over ten years ago, is to shift the starting point of management from the species to the people. As the idea of ecosystem management moves forward, this may be an opportunity to refocus management around people.

This issue can be evidenced in the frustration expressed by fishermen over the changing regulations governing the Oculina Bank HAPC. The current regulations of the Oculina Bank are the result of a series of changes implemented over several years. The current protected area is not the result of a cohesive original plan, implemented over time for the purpose of mitigating socio-economic and cultural impacts. Rather, the closure was implemented piece by piece, as amendments to fishery management plans for separate management units (coral in 1984, snapper grouper in 1994, shrimp in 1996). With each one of these rules, a new justification for management was written. To fishermen, this type of management appears to be a moving target. Coupled with the lack of studies being undertaken to assess whether the goals of management were being achieved, fishermen's frustrations are understandable. To fishermen, it appears that an agenda was in place since the first closure to trawling which aimed to incrementally restrict them from accessing favorite fishing grounds.

This does not mean that some fishermen do not see positive results from the closure. Indeed, individuals from the rock shrimp industry were both the most impacted by the initial closure to trawling, and the ones who pushed for said closure. Many other fishermen believe in the need to protect spawning grounds of important species and trust that the closure is serving that purpose. However, the underlying issue remains fishermen's feelings of marginalization from the management process. To many, the changing goals of the closed area under the different management plans appear to be a conspiracy to keep them from fishing. Those in fishery

management should interpret this as a need for improved outreach and involvement of fishermen in the management process.

As with many fishery regulations that restrict effort, there were winners and losers as a result of the closure of the Oculina Bank HAPC. An important result of this study found that those who benefited or were negatively impacted cannot be identified by sector alone. Laurilee Thompson, whose father was one of the champions for the closure, attests that the closure saved the Port Canaveral area rock shrimp fishery. On the other hand, the commercial bottom fishermen of Fort Pierce were negatively impacted. Not only were their principal fishing grounds closed, but the closure necessitated longer travel times in order to avoid the boundaries of the HAPC, as possession of any snapper grouper species is prohibited within the area. Thus, impacts on commercial fishermen varied by geography and gear type. Today, commercial fishing in Fort Pierce is primarily directed at king mackerel (kingfish) and the actual number of commercial bottom fishers who were impacted by the Oculina Bank closure remains unknown. Although the majority of commercial landings by Fort Pierce fishermen now consist of king mackerel, there are local commercial fishermen with diversified strategies who target snapper grouper outside of the Oculina Bank, as well as tilefish and pelagics.

Each subsequent regulation also impacted different fishermen in multiple ways. The original closure in 1984 prohibited certain types of commercial gear (primarily trawlers and bottom longliners), thus only commercial fishermen experienced negative impacts. As one recreational fisherman explained, their sector saw this closure as a good thing. However, the subsequent closure to all bottom fishing in 1994 impacted commercial and recreational fishermen alike. In hindsight, this same fisherman felt that the 1994 regulatory expansion was easier to implement since the earlier closure and corresponding gear restrictions were already in place. He noted the irony that inter-sector conflict may have facilitated the closure which ultimately prohibited commercial and recreational fishermen alike from bottom fishing within the Oculina Bank. Each sector primarily occupies different social spaces in the community (e.g. separate marinas, tackle stores). This may contribute to inter-sector tensions as different user groups do not encounter, and so do not interact, frequently with one another in social places. The example above reinforces that the sectors may have common interests that could foster cooperation, rather than competition.

Impacts also vary according to temporal scale where negative impacts incurred in the immediate, short term are mitigated by (assumed) long-term positive benefits. This temporal variance of impacts is exemplified in the negative impacts incurred by fishermen upon implementation of the Oculina Bank closure to bottom fishermen, while long-term benefits are expected to result from the protection of the Oculina Bank HAPC. This is a common rationalization of regulatory impacts, where short-term cuts are justified for long-term growth. What is missing, however, are data that document biological benefits predicted to occur from restricting fishing effort. MPAs are increasingly being used for marine management based on assumptions about their effectiveness. Fishermen expressed frustration with the lack of evidence showing that their restricted effort has realized any benefits to the stocks of bottom fish.

An important idea that arose frequently during the ethnographic and oral history components of the study concerns fishermen's support for effort-restricting regulations that make sense to the fishermen. For example, fishermen's observations support the need for certain effort restrictions. The need for fish to be able to reproduce is a common theme among effort restrictions fishermen

find necessary. Fishermen generally support closed seasons or areas during times of spawning, but resist areas closed as complete no-take zones. There is also broad support for minimum size limits, as fishermen understand the need for fish to grow to reproductive maturity, but the observation of dead discards from throwing back undersized fish is perceived as wasteful. The lesson for fishery managers is to recognize the need to design effort restrictions around fishing behavior, knowledge, and perceptions rather than based on an assemblage of restrictions that will meet a total allowable catch.

Finally, this study raises the issue that more data are needed to document the impacts and benefits of MPAs on both the biological and socio-cultural environment. It is not only important to consider whether potential biological benefits outweigh negative socio-cultural and economic impacts, but to test such assumptions and expectations. If evidence supports such closures, fishery managers should be more pro-active in communicating this information with fishermen in order to help shape an understanding and acceptance of such management measures. If evidence does not provide measurable benefits to the biological or physical environments to support ongoing negative socio-cultural and economic impacts, then such restrictions should be relaxed.

Dissemination of project results:

Copies of this project's Final Report will be published and distributed to various federal and state fishery agencies, university extension/Sea Grant offices, and industry associations. In addition, PDF copies of the Final Report will be made available for download from the Foundation's website under Foundation Research.

Summary reports of the project's findings were published as part of the "Foundation Project Update" section of the "Gulf and South Atlantic News," a publication of the Gulf & South Atlantic Fisheries Foundation, Inc. This newsletter was distributed to over 700 organizations and individuals throughout the region. An electronic version of this newsletter (PDF) was also included in the regular updates to the Foundation's website (www.gulfsouthfoundation.org).

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Appendix A

Oral History Protocol

Training Guide

1. Explain project goals, work, supervision, timeline, etc.
2. Listen to some sample oral histories at USF: ohp.lib.usf.edu
3. Our agreement: Getting paid, invoices, sending me the files, etc.
    - W-9
    - Letter of Agreement
4. Review protocol questions. Edit language as appropriate.
5. Practice with equipment:
    - File type; emailing files (create gmail accounts or usendit)
    - Load program software on their computers and organize a directory
6. Using the maps: distance from shore, direction, depths.
    - Relation to Oculina Bank. (Numbering history of area fishing, in order).
7. Practice interviewing each other with protocol.
    - Go slow, prompting, changing tense of questions, asking more questions.
    - Keeping interviewee on topic!
    - Want consistent interviews!
    - Maintaining (approx) 60 minute interviews!
8. Review recordings; edit interview protocol accordingly.
9. Create list of fishers to be interviewed and assigning other data collection tasks.
    - Collect data on history of fish houses in Fort Pierce from city records, etc.
        - Name of fish house – Years of operation (19xx-19xx) – Owner, species processed, location, any other information you can gather about the operation.
    - Interviews with Jim Busse, rock shrimper and calico shrimper.
    - Find and digitize old photos of fish houses, fishing equipment, etc.

Procedural Guide for Conducting Oral Histories

1. Before the Interview:

- Prepare equipment including recorder, batteries, and microphone. Make sure the recorder is set at LCPM (p29 of instruction manual) to create .wav files. (These are large files that will store approximately 90 minutes of recording.)
- Have copies of: Release Form, Interview, Map, and Survey.
- Camera
- If you have any problems, call Dr. Lasseter at (xxx-xxx-xxxx).

2. Conduct interview in quiet setting with minimum of noise.

3. Go over release forms for interviews. (Let interviewee know that the recording will be made available via the internet. The recordings get cleaned up a bit; pauses and mistakes will be edited out.)

4. Take photograph of interviewee for archive purposes.

5. Begin Recording: Make sure microphone is ON and attached. Keep interview to approximately ONE HOUR.

- Use interview protocol to guide interview. Take notes while listening to remember points to clarify or return to.
- Make sure interviewee speaks in the first person. (e.g. I saw…) and try to avoid their recollections that are not first hand observations.
- Try to promote neutrality in the way you suggest questions.
- Use map as tool to ask about where they used to fish and where fish now. Let them write on the map.
- At end of interview, thank the participant and turn OFF the recorder.

6. Ask participant to complete the one page survey.

7. After each interview:

- Download interview from the recorder to your computer, save the file in .wav format, and name the file with the LAST NAME of the interviewee. Make sure that you can play the interview on your computer!
- Send digital file to Dr. Lasseter via gmail or usendit.com.
- Remember to keep track of your time and mileage to the interviews, and send invoice to Dr. Lasseter.

Oral History Protocol: Commercial

Photograph of participant.
Oral history signed release form.

[Turn on recorder.]
What is your full name?
When and where were you born?
[If not born in Fort Pierce:] When did you move to Fort Pierce?
What brought you to Fort Pierce?
Are you married? [If yes:] How old were you when you got married?
Do you have children? How many? How old are they?
How much schooling do you have?
Do you have another job besides fishing? Have you had other jobs besides fishing? What jobs?
Do you currently own a boat? What kind(s)? [length]

Now, I'd like to talk about your history and experiences with fishing. First, I'm going to ask some general questions about fishing in this area, then I will ask about your specific experiences.
How familiar are you with the Oculina Bank?
Why was the Oculina Bank designated as an area to protect?
Is there anything else you can tell me about the Oculina Bank? [What do you know about it?]
What do you think about the closure of the Oculina Bank to bottom fishing?
Has the closure of the Oculina Bank affected your fishing? How?
If the Oculina Bank was not closed to fishing, would you fish there? How/For what?
Overall, how has fishing changed since you began fishing in the Fort Pierce area?

Now I want to talk about your fishing history specifically.
What is your earliest memory of fishing and how old were you?
How did you learn how to fish? (Who taught you?)
How did you decide to become a fisherman?

When did you start to work as a fisherman in the Fort Pierce area? [age, year]
Where were you living then?
What did you fish for? How did you fish for _____? [gear, bait]
Who did you fish with? Who owned the boat? How were you related to this person?
[If his boat] What kind of boat [length]?
Where did you go to fish when you began fishing? Can you show me on this map? [note beginning of their fishing, depth]
During what months of the year did you fish for _____?
How long did a fishing trip last?
How much was an average trip's catch?
For how many years did you fish for _____?
Why did you stop fishing for _____?
What did you do next?

So you fished for _____ from _____ to _____. [clarify previous experience]
What did you do next? [If not fishing, let him talk. Then, repeat question until returns to fishing.]

[Repeat above questions]
Where were you living then?
How did you fish for _____? [gear, bait]
Who did you fish with? Who owned the boat? How were you related to this person?
[If his boat] What kind of boat [length]?
Where did you go to fish for _____? [use map, note next place for fishing, depth]
During what months of the year did you fish for _____?
How long did a fishing trip last?
How much was an average trip's catch?
For how many years did you fish for _____?
Why did you stop fishing for _____?
What did you do next? [If not fishing, let him talk. Then, repeat question until returns to fishing.]

[Repeat above questions]
Where were you living then?
How did you fish for _____? [gear, bait]
Who did you fish with? Who owned the boat? How were you related to this person?
[If his boat] What kind of boat [length]?
Where did you go to fish for _____? [use map, note next place for fishing, depth]
During what months of the year did you fish for _____?
How long did a fishing trip last?
How much was an average trip's catch?
For how many years did you fish for _____?
Why did you stop fishing for _____?
What did you do next? [If not fishing, let him talk. Then, repeat question until returns to fishing.]

[Repeat above questions]
Where were you living then?
How did you fish for _____? [gear, bait]
Who did you fish with? Who owned the boat? How were you related to this person?
[If his boat] What kind of boat [length]?
Where did you go to fish for _____? [use map, note next place for fishing, depth]
During what months of the year did you fish for _____?
How long did a fishing trip last?
How much was an average trip's catch?
For how many years did you fish for _____?
Why did you stop fishing for _____?
What did you do next?

What are you fishing for now?
How do you fish for _____? [gear, bait]
[If his boat] What kind of boat [length]?
Who do you fish with? Who owns the boat? How are you related to this person?
Where do you go to fish for _____? [use map, note next place for fishing, depth]

On average, how far do you go offshore to fish?
During what months of the year do you fish for _____?
How long did a fishing trip last?
How much was an average trip's catch?
For how many years have you fished for _____?

Finally, I would like to talk about how your fishing has changed over time. [use map to review where they have fished over time and the changes in species and gear, bait, depth]
In what ways does your livelihood depend on fishing?
How has that changed over time?
[If he fished prior to 1984] Has the initial closure of the Oculina Bank to shrimping affected your fishing? How?

[If he fished prior to 1994] In 1994, the Oculina Bank area was closed to bottom fishing and anchoring. Has this affected your fishing or livelihood? How?

In 2000, the Oculina Bank closed area was expanded to the north. Have you been affected by this closure? How?

The closure of marine areas to fishing is being used more frequently as a fishery management tool. What do you think about the implementation of closed areas to fishing compared to other types of management regulations?

What do you think fishing in Fort Pierce will be like in 10 years?

Thank you very much for sharing your fishing history with us.
[Turn off recorder.]

Oral History Protocol: Charterboat

Photograph of participant.
Oral history signed release form.

[Turn on recorder.]
What is your full name?
When and where were you born?
[If not born in Fort Pierce:] When did you move to Fort Pierce?
What brought you to Fort Pierce?
Are you married? [If yes:] How old were you when you got married?
Do you have children? How many? How old are they?
How much schooling do you have?
Do you have another job besides the charterboat? What other jobs have you had?
Do you currently own a boat(s)? What kind(s)? [length]

Now, I'd like to talk about your history and experiences with fishing. First, I'm going to ask some general questions about fishing in this area, then I will ask about your specific experiences.
How familiar are you with the Oculina Bank?
Why was the Oculina Bank designated as an area to protect?
Is there anything else you can tell me about the Oculina Bank? [What do you know about it?]
What do you think about the closure of the Oculina Bank to bottom fishing?
Has the closure of the Oculina Bank affected your fishing? How?
If the Oculina Bank was not closed to fishing, would you fish there? How/For what?
Overall, how has fishing changed since you began fishing in the Fort Pierce area?

Now I want to talk about your fishing history specifically.
What is your earliest memory of fishing and how old were you?
How did you learn how to fish? (Who taught you?)
How did you decide to become a charterboat captain?

When did you start fishing in the Fort Pierce area? [age, year]
Where were you living then?
Were you fishing commercially, recreationally, or working in the charterboat sector?
What did you fish for? How did you fish for _____? [gear, bait]
Who did you fish with? Who owned the boat? How were you related to this person?
Where did you go to fish when you began fishing? Can you show me on this map? [note beginning of their fishing, depth]
During what months of the year did you fish for _____?
How long did a fishing trip last?
How much was an average trip's catch?
For how many years did you fish for _____?
Why did you stop fishing for _____?
What did you do next?

[If above was not about being a charterboat captain: Repeat above questions]

When did you start working as a charterboat captain in the Fort Pierce area? [age, year]
Where were you living then?
What do you fish for and how? [gear, bait]
Who do you work with? Who owns the boat? [If not self:] How are you related to this person?
Where do you go to fish for _____? [use map, note area for fishing, depth]
On average, how far do you go offshore to fish?
How do you decide where you will fish?
During what months of the year do you fish for _____?
How long does a fishing trip last?
How much is an average trip's catch?
For how many years have you been a charterboat captain?

Finally, I would like to talk about how your fishing has changed over time. [use map to review where they have fished over time and the changes in species and gear, bait, depth]
In what ways does your livelihood depend on fishing?
How has that changed over time?

[If he fished prior to 1984] Has the initial closure of the Oculina Bank to shrimping affected your fishing? How?

[If he fished prior to 1994] In 1994, the Oculina Bank area was closed to bottom fishing and anchoring. Has this affected your fishing or livelihood? How?

In 2000, the Oculina Bank closed area was expanded to the north. Have you been affected by this closure? How?

The closure of marine areas to fishing is being used more frequently as a fishery management tool. What do you think about the implementation of closed areas to fishing compared to other types of management regulations?

What do you think fishing in Fort Pierce will be like in 10 years?

Thank you very much for sharing your fishing history with us.
[Turn off recorder.]

Oral History Protocol: Recreational

Photograph of participant.
Oral history signed release form.

[Turn on recorder.]
What is your full name?
When and where were you born?
[If not born in Fort Pierce:] When did you move to Fort Pierce?
What brought you to Fort Pierce?
Are you married? [If yes:] How old were you when you got married?
Do you have children? How many? How old are they?
How much schooling do you have?
What do you do for a living?
What other jobs have you had?
Have you worked in the fishing industry? [How? Commercial, charter industry?]
Do you currently own a boat? What kind(s)? [length]

Now, I'd like to talk about your history and experiences with fishing. First, I'm going to ask some general questions about fishing in this area, then I will ask about your specific experiences.
How familiar are you with the Oculina Bank?
Why was the Oculina Bank designated as an area to protect?
Is there anything else you can tell me about the Oculina Bank? [What do you know about it?]
What do you think about the closure of the Oculina Bank to bottom fishing?
Has the closure of the Oculina Bank affected your fishing? How?
If the Oculina Bank was not closed to fishing, would you fish there? How/For what?
Overall, how has fishing changed since you began fishing in the Fort Pierce area?

Now I want to talk about your fishing history specifically.
What is your earliest memory of fishing and how old were you?
How did you learn how to fish? Who taught you?

When did you start fishing in the Fort Pierce area? [age, year]
Where were you living then?
What did you fish for? How did you fish for _____? [gear, bait]
Where did you go to fish when you began fishing? Can you show me on this map? [note beginning of their fishing, depth]
Did you mostly go fishing in your own boat or the boats of others?
Who did you fish with?
During what months of the year did you fish for _____?
How long did a fishing trip last?
How much would you catch on an average trip?
For how many years did you/have you fish for _____?
Are you still fishing for _____? [If not] Why?

Where else do you go fishing in the Fort Pierce area? [on map, depths]

What do you fish for? What gear, bait do you use?
Do you usually go in your own boat or the boats of others?
Who do you usually fish with?
During what months of the year do you fish there?
How much would you catch on an average trip?
For how many years did you/have you fish for ____?
Are you still fishing for ____? [If not] Why?
[Repeat as necessary for all offshore fishing]

Now, how often do you go offshore fishing?
How many times a week? How many times a month?
Are there some months you go fishing more frequently?
Are there some months you never or rarely go fishing?
On average, how far do you go offshore to fish?
What do you fish for and how? [gear, bait]
Who do you fish with? Who owns the boat? [If not self:] How are you related to this person?
Where do you go to fish for _____? [use map, note area for fishing, depth]
How do you decide where you will fish?
During what months of the year do you fish for _____?
How long does a fishing trip last?
How much do you catch on an average trip?

Finally, I would like to talk about how your fishing has changed over time. [use map to review where they have fished over time and the changes in species and gear, bait, depth]
In what ways does your livelihood depend on fishing?
How has that changed over time?

[If he fished prior to 1984] Has the initial closure of the Oculina Bank to shrimping affected your fishing? How?

[If he fished prior to 1994] In 1994, the Oculina Bank area was closed to bottom fishing and anchoring. Has this affected your fishing or livelihood? How?

In 2000, the Oculina Bank closed area was expanded to the north. Have you been affected by this closure? How?

The closure of marine areas to fishing is being used more frequently as a fishery management tool. What do you think about the implementation of closed areas to fishing compared to other types of management regulations?

What do you think fishing in Fort Pierce will be like in 10 years?

Thank you very much for sharing your fishing history with us.
[Turn off recorder.]

Written Survey for each Oral History Participant

Name: _____

1. Could you describe the history of the boats you have owned?

Name of Boat Year bought Year Sold Type Length

_____
_____
_____
_____
_____
_____

(use back of sheet for additional boats)

Where do you currently keep your boat? _____

Where do you get your information about fishing regulations? _____
_____

Are you a member of any fishing organizations? _____
_____

Who do you talk to about fishing regulations? [Please name 5 people and describe their relationship to you.]

_____
_____
_____
_____
_____

On average, how many days and during what months do you fish? (or last fished)
What species do you target each month? How far do you travel from shore?

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
#Days Fishing												
Species Targeted												
Distance from Shore												

Appendix B

Commercial Fishery Landings

The following tables provide data on commercial fishery landings for St. Lucie County, for locally important species. Because Fort Pierce has the only inlet for the entire county, it is likely that the majority of landings occurred in Fort Pierce. However, dealers in other parts of the county may also have dealer permits and thus their landings are included as well. Data were not available for years prior to 1986, thus the landings at the time of the original Oculina Bank HAPC closure to bottom longlining remain unknown.

Figure B-6 shows that virtually no landings for shrimp species occur in St. Lucie County. However, for two species, there is one year for which landings not only occur, they are abundant: brown shrimp in 1994, and rock shrimp in 1995. As there was no local processor in Fort Pierce, and these are the only years for which there are landings, it is possible that this reflects an error in the data.

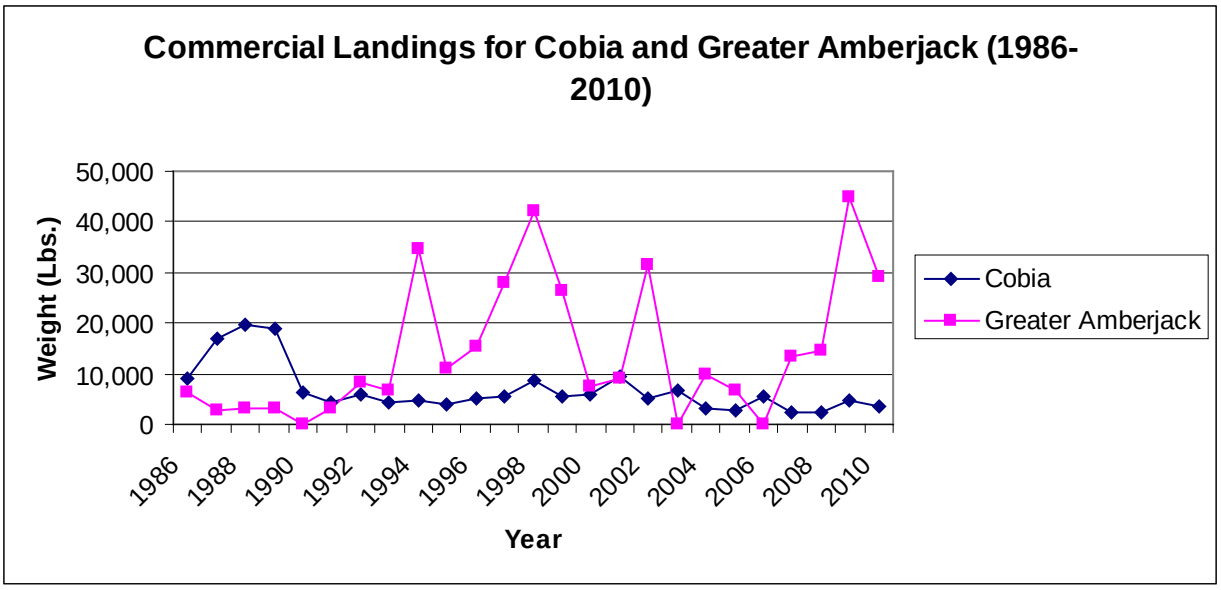

Figure B-1: Commercial Landings of Cobia and Greater Amberjack, for St. Lucie County, during the period of 1986 thru 2010. Data provided by the NOAA Southeast Science Center.

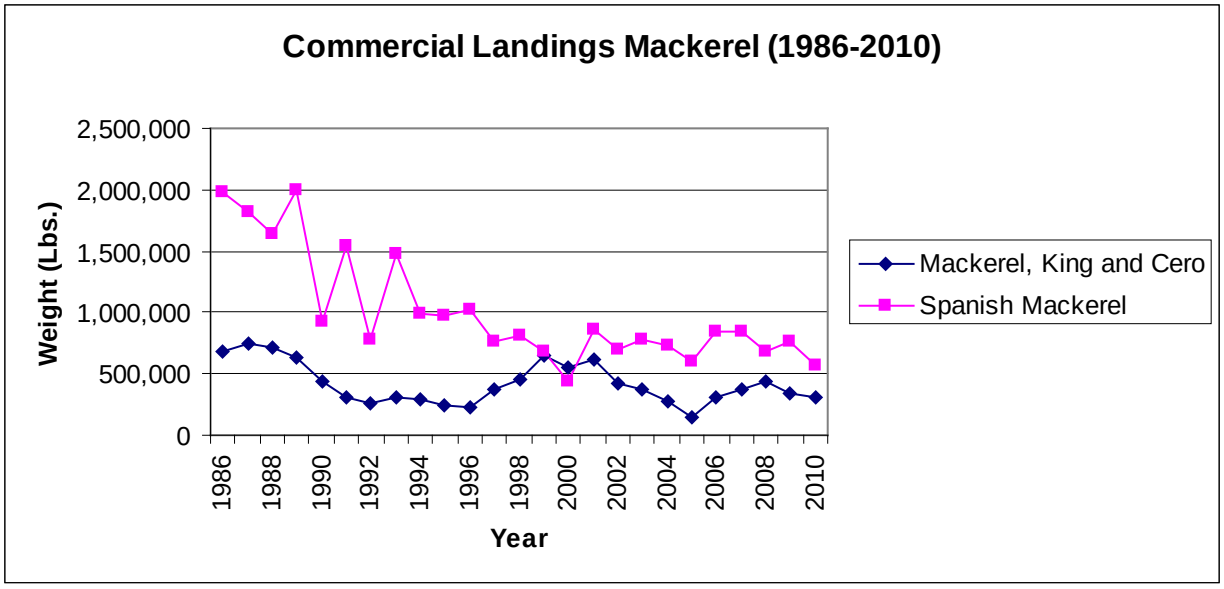

Figure B-2: Commercial Landings of Mackerels, for St. Lucie County, during the period of 1986 thru 2010. Data provided by the NOAA Southeast Science Center.

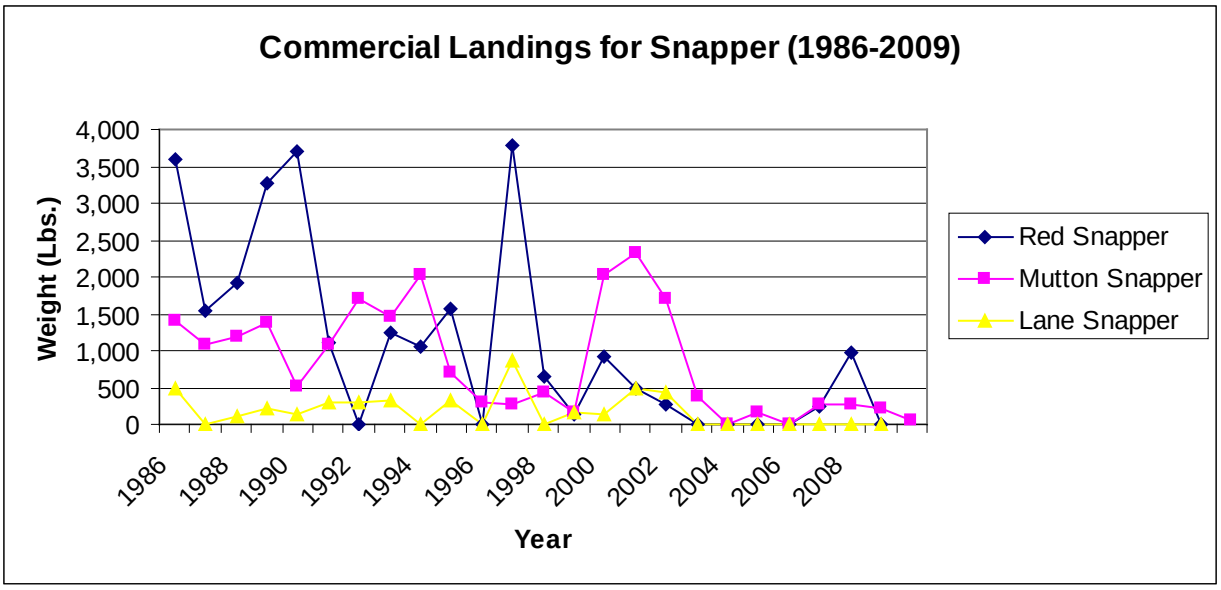

Figure B-3: Commercial Landings of Snappers, for St. Lucie County, during the period of 1986 thru 2009. Data provided by the NOAA Southeast Science Center.

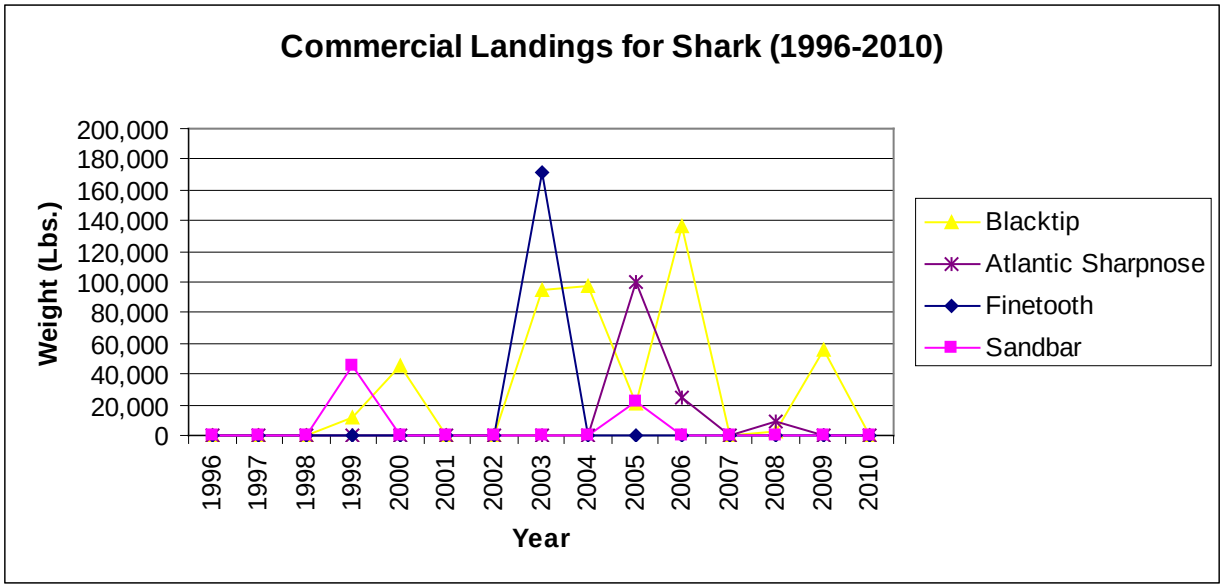

Figure B-4: Commercial Landings of four species of shark, for St. Lucie County, during the period of 1986 thru 2009. Data provided by the NOAA Southeast Science Center.

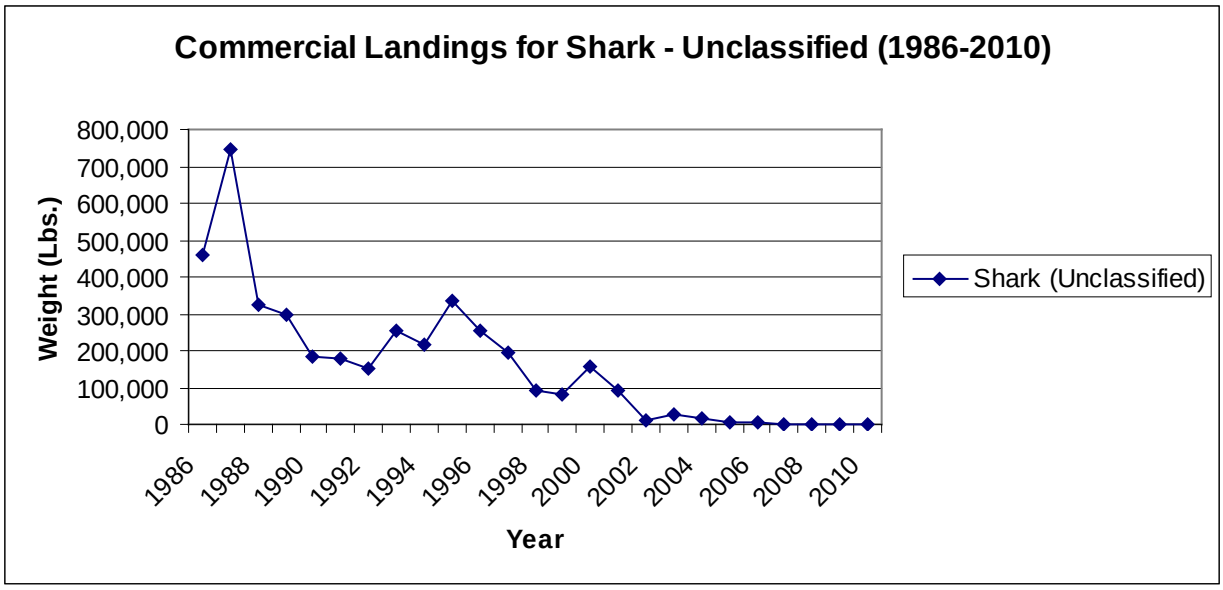

Figure B-5: Commercial Landings of unclassified species of shark, for St. Lucie County, during the period of 1986 thru 2009. Data provided by the NOAA Southeast Science Center.

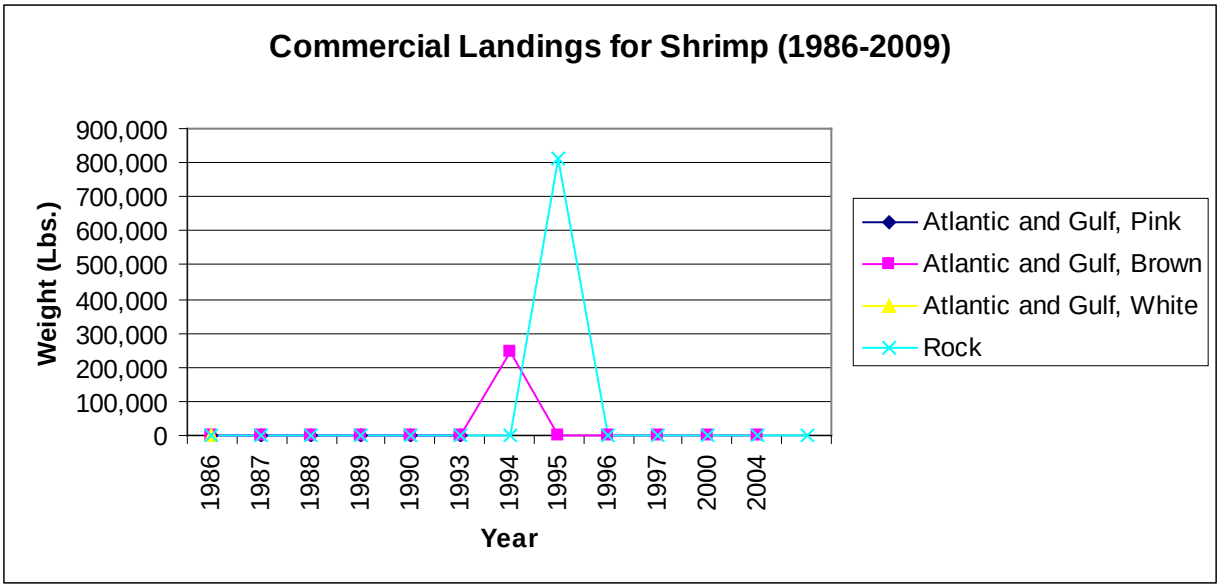

Figure B-6: Commercial Landings of Shrimp, for St. Lucie County, during the period of 1986 thru 2009. Data provided by the NOAA Southeast Science Center.

Appendix C

Charterboat and Private Recreational Fishery Landings Estimates

Landings data are much less precise for the recreational sector. First, the estimates are given in number of fish caught, rather than in weight, as the commercial landings are measured. Second, the system for estimating recreational landings is currently undergoing an extensive redesign in order to address the problems identified in the data collection method. The following graphs show the data that are available for the recreational sector for species recognized as important to Fort Pierce fishermen. Although headboats are required to report landings, these data were not available owing to confidentiality laws due to the small number of vessels.

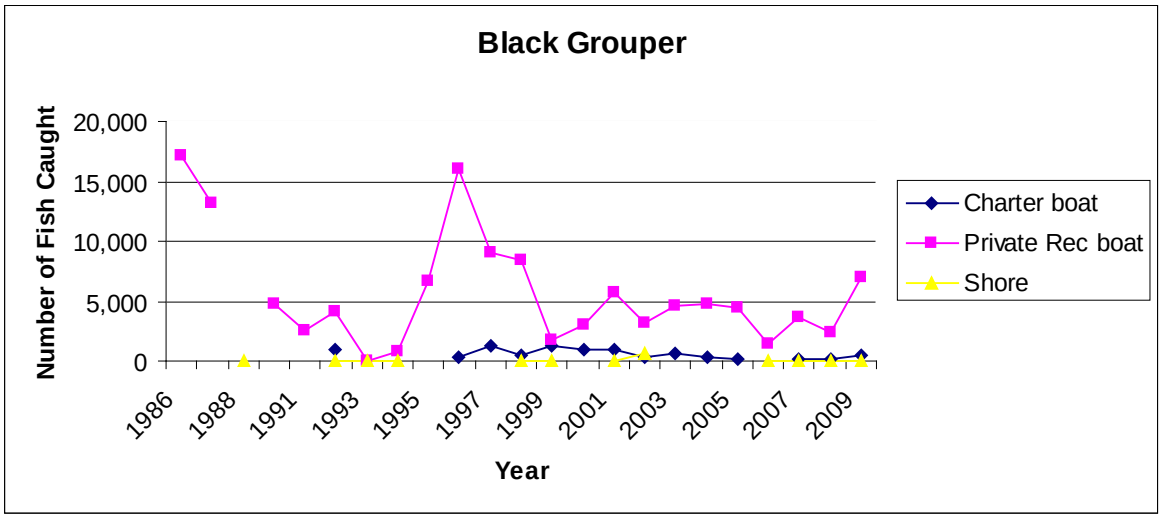

Figure C-1: Number of Black Grouper caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

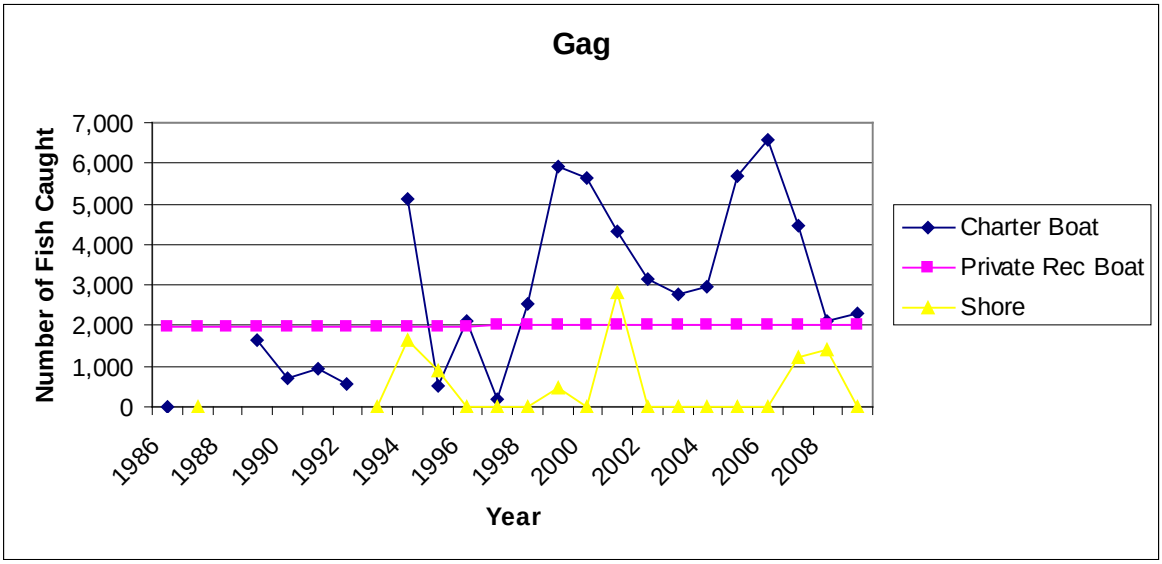

Figure C-2: Number of Gag caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

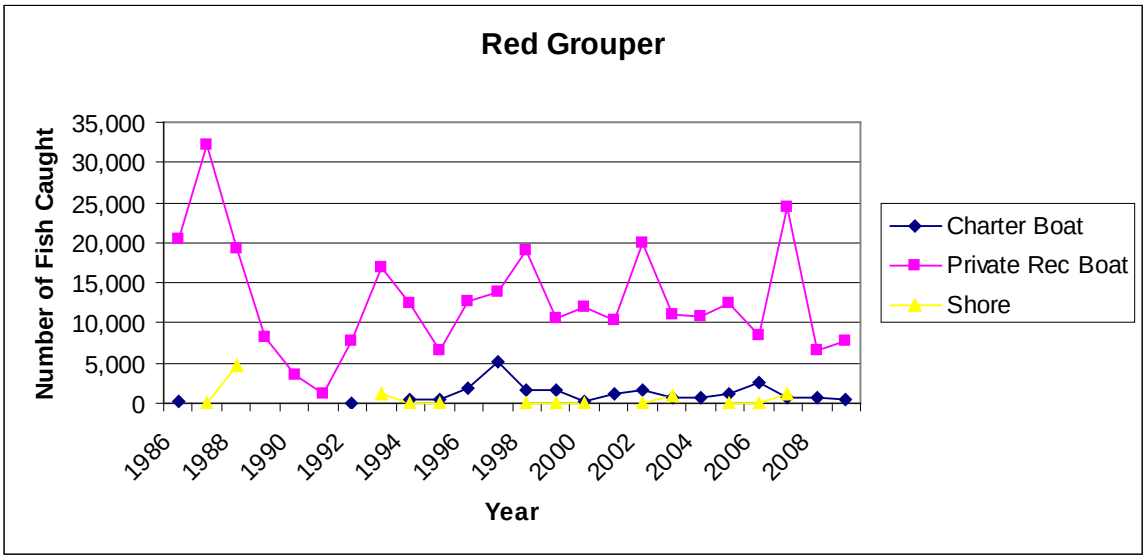

Figure C-3: Number of Red Grouper caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

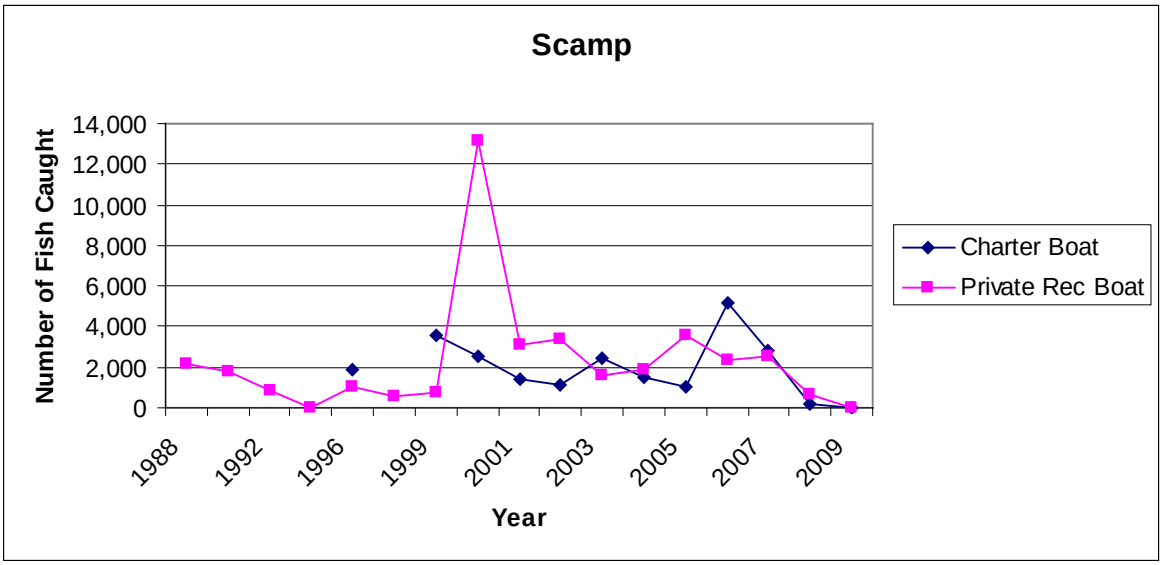

Figure C-4: Number of Scamp caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

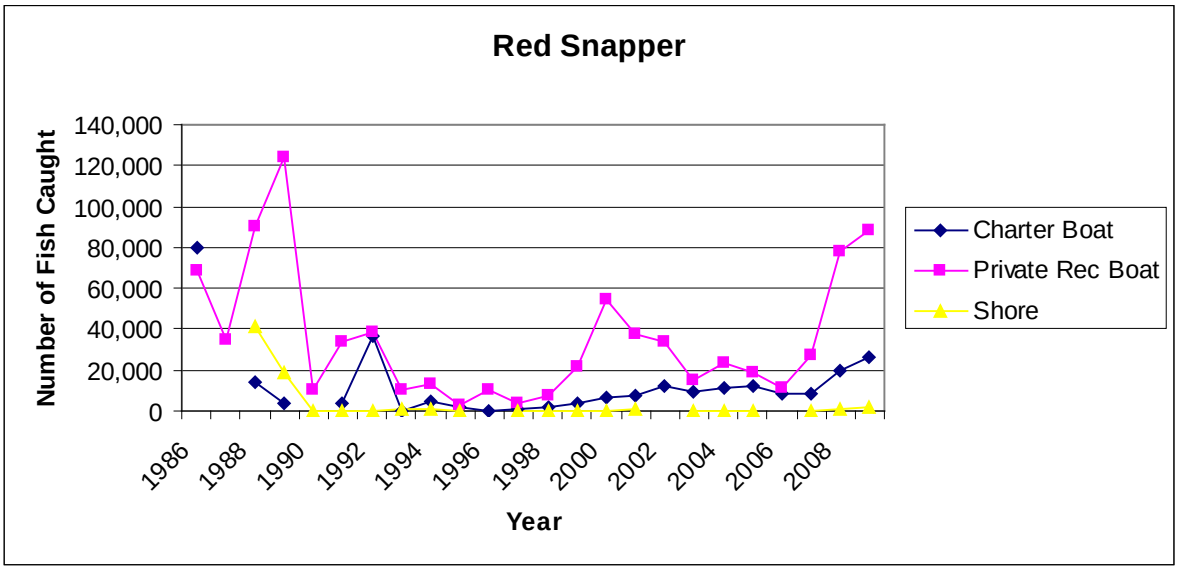

Figure C-5: Number of Red Snapper caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

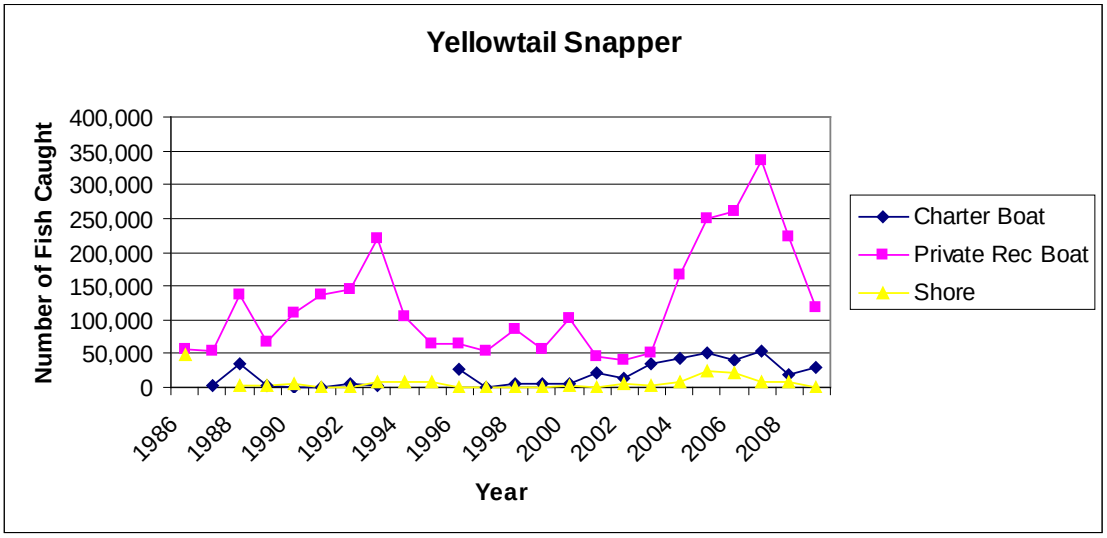

Figure C-6: Number of Yellowtail Snapper caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

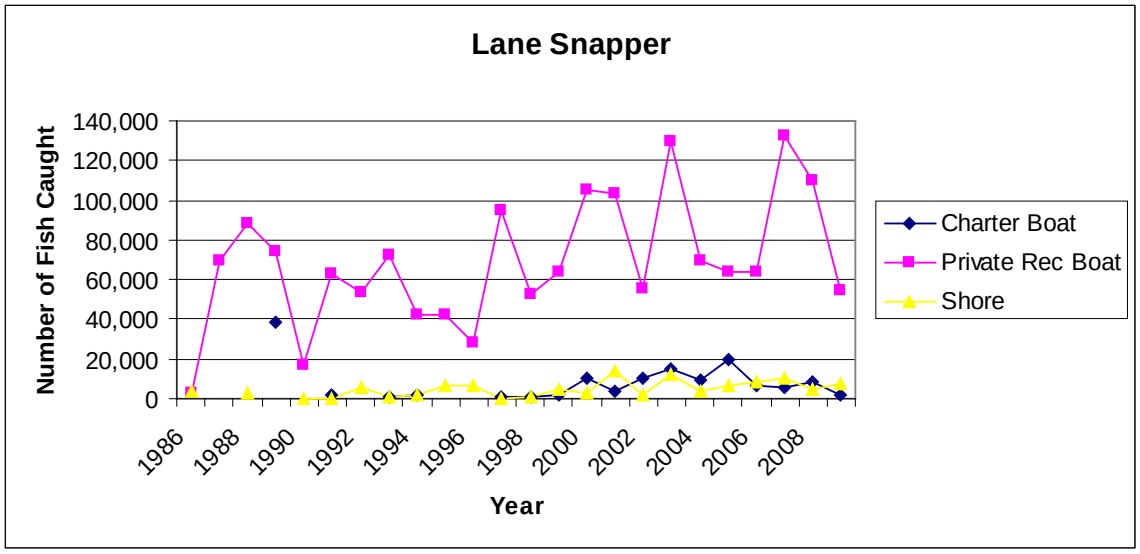

Figure C-7: Number of Lane Snapper caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

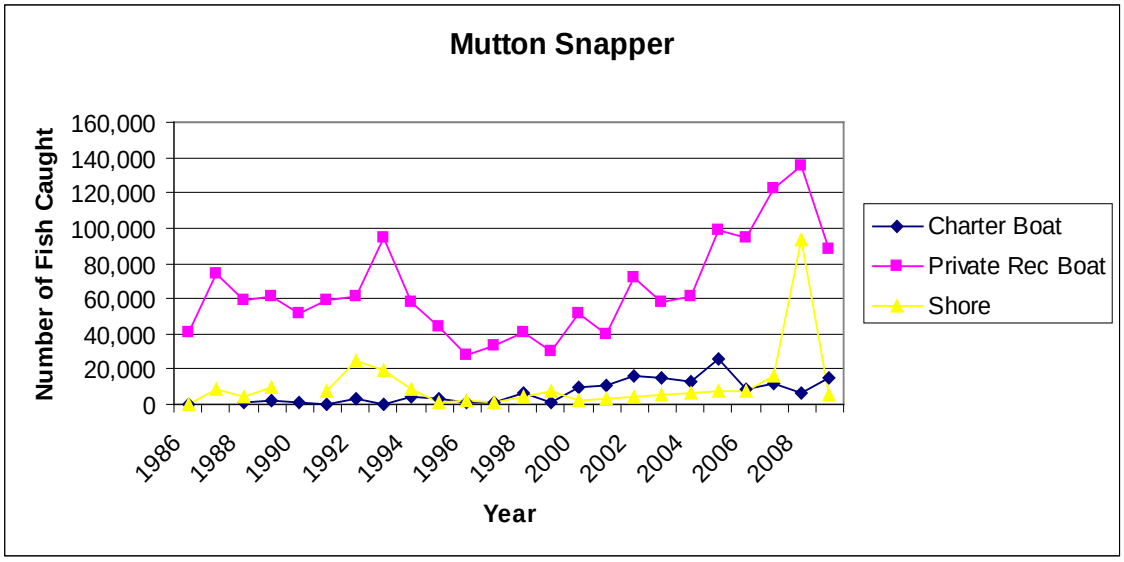

Figure C-8: Number of Mutton Snapper caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

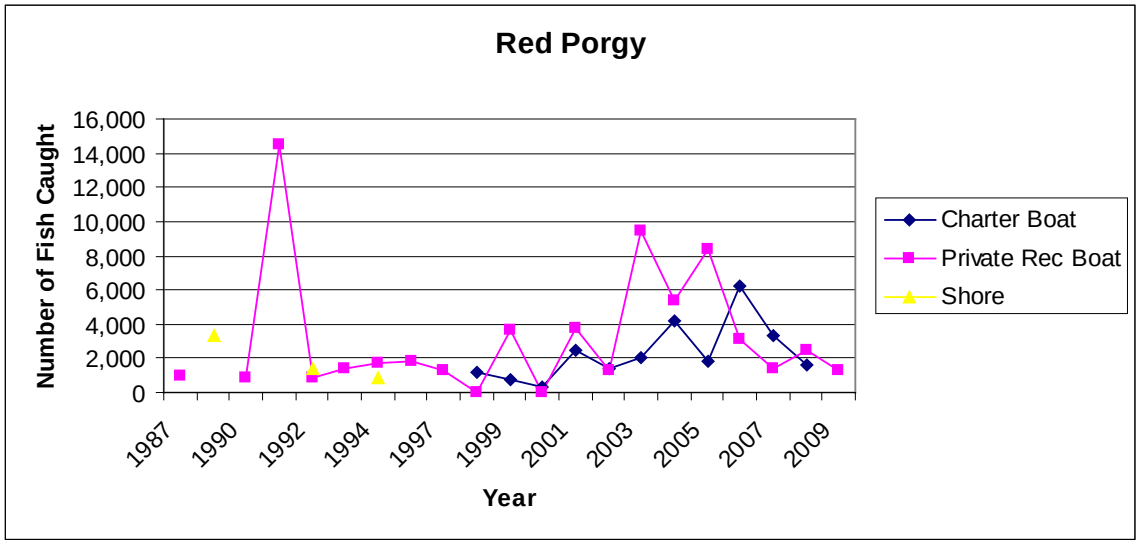

Figure C-9: Number of Red Porgy caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

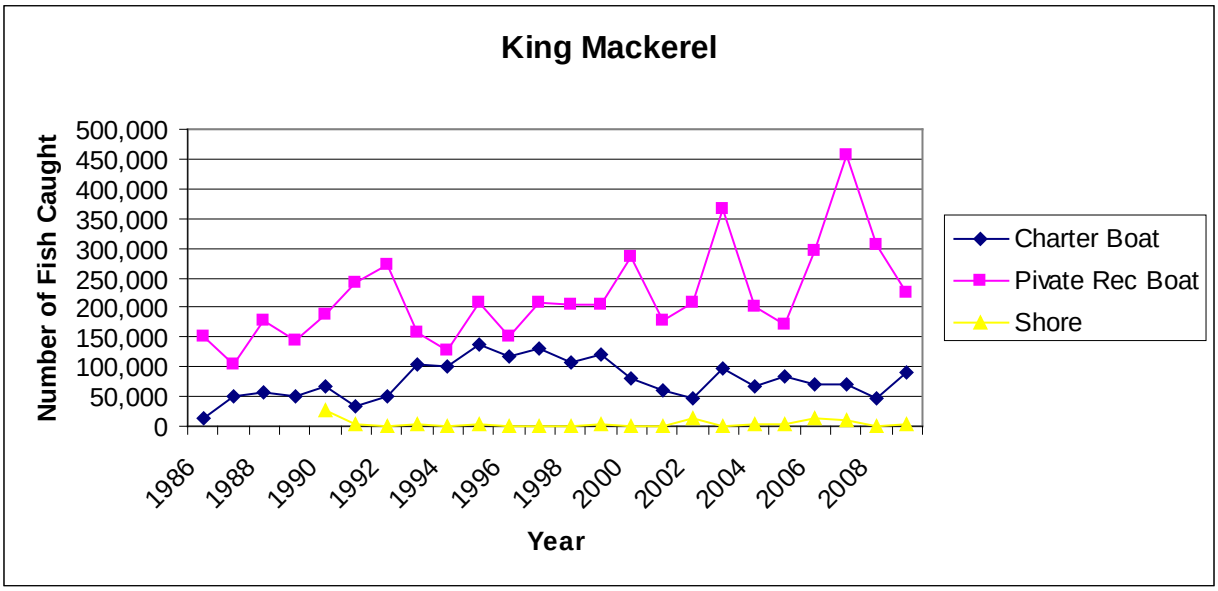

Figure C-10: Number of King Mackerel caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

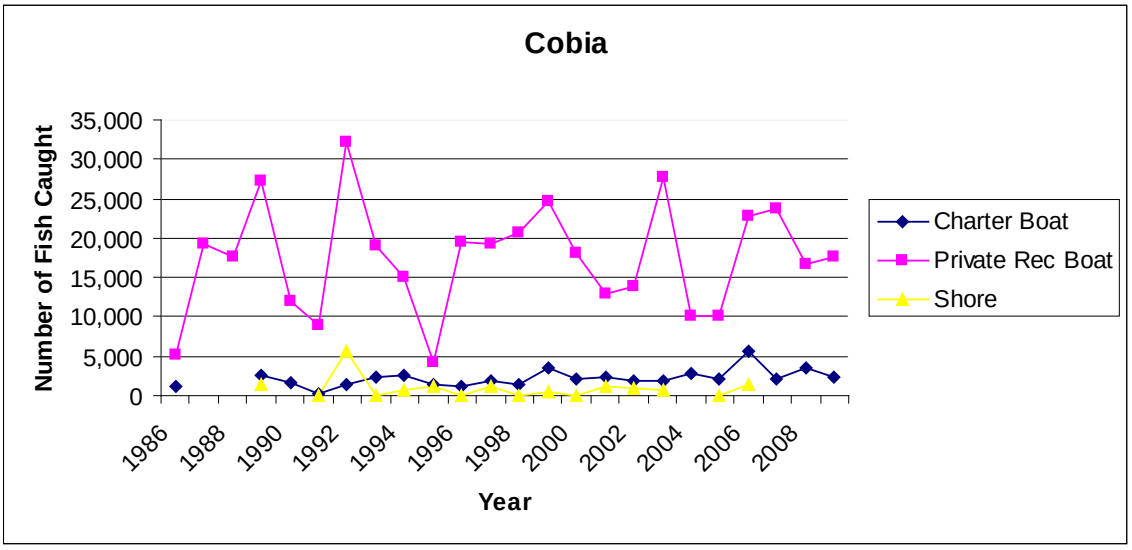

Figure C-11: Number of Cobia caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

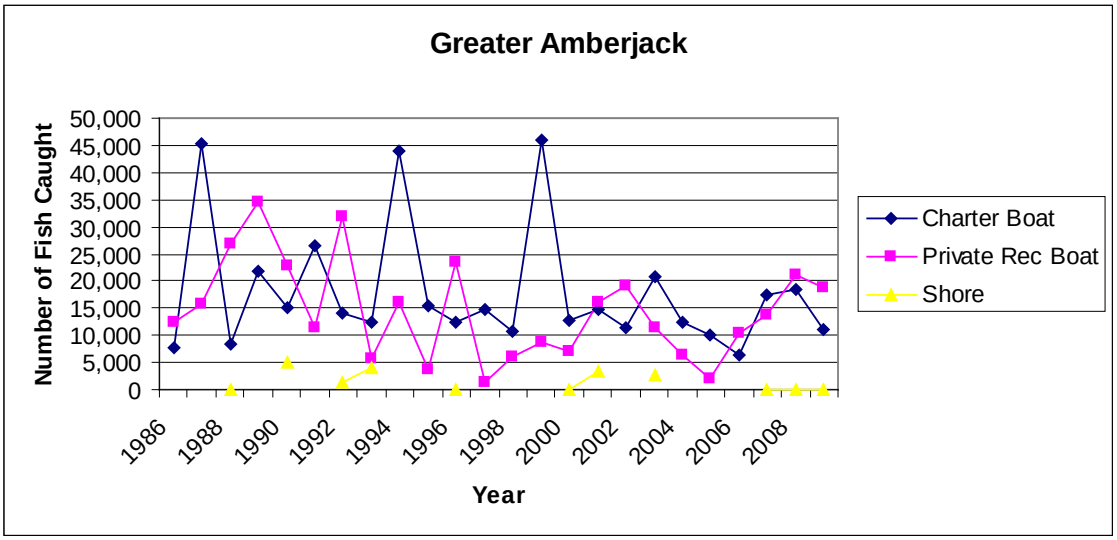

Figure C-12: Number of Greater Amberjack caught during the period 1986 thru 2009 for the east coast of Florida. Data from MRFSS estimates, the NOAA Southeast Science Center.

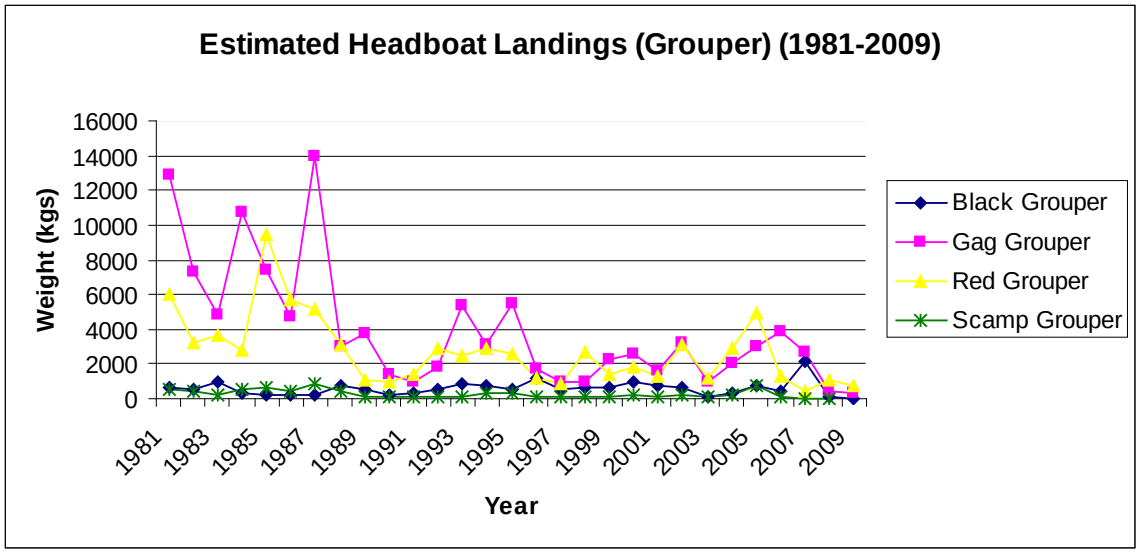

Figure C-13: Estimated Headboat Landings for Grouper from Fort Pierce to Miami, Florida, during the period of 1981 thru 2009. Data were not available for the local area alone making it difficult to identify trends that may have occurred in Fort Pierce. Data from MRFSS estimates, the NOAA Southeast Science Center.

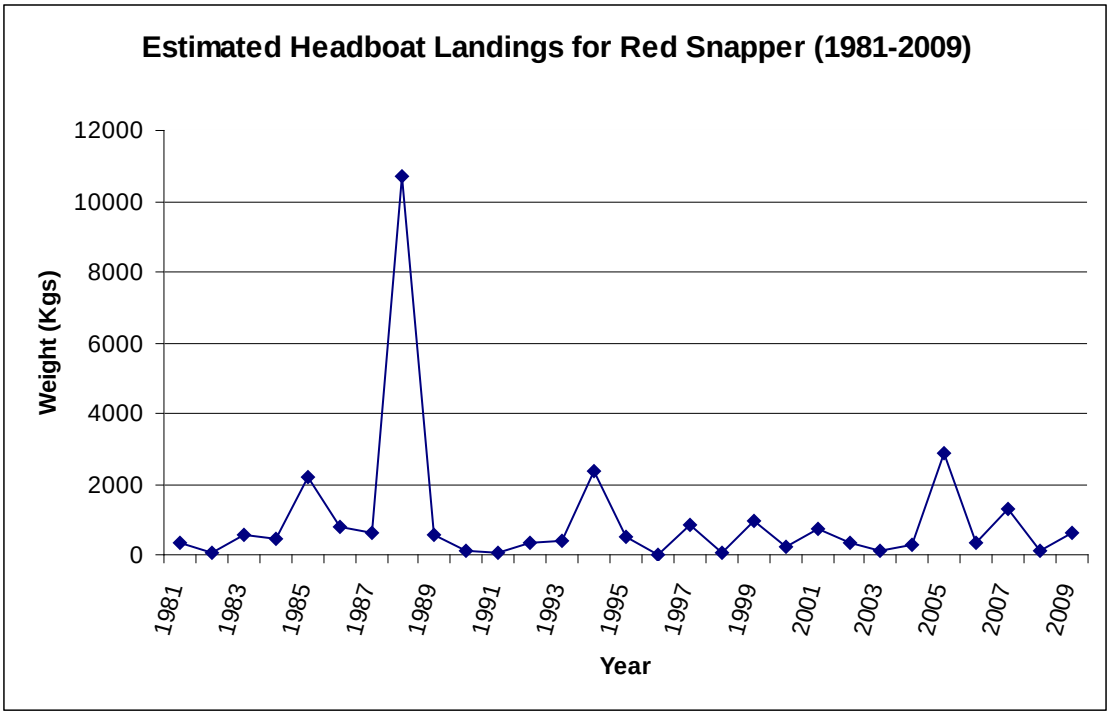

Figure C-14: Estimated Headboat Landings for Red Snapper from Fort Pierce to Miami, Florida, during the period of 1981 thru 2009. Data were not available for the local area alone making it difficult to identify trends that may have occurred in Fort Pierce. Data from MRFSS estimates, the NOAA Southeast Science Center.

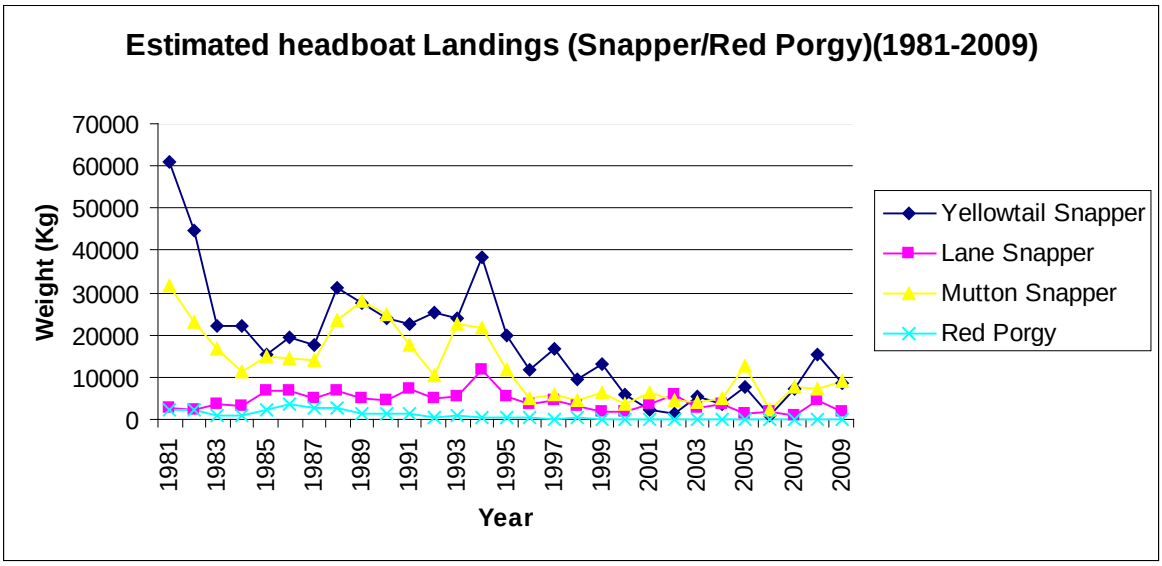

Figure C-15: Estimated Headboat Landings for Yellowtail Snapper, Lane Snapper, Mutton Snapper, and Red Porgy from Fort Pierce to Miami, Florida, during the period of 1981 thru 2009. Data were not available for the local area alone making it difficult to identify trends that may have occurred in Fort Pierce. Data from MRFSS estimates, the NOAA Southeast Science Center.

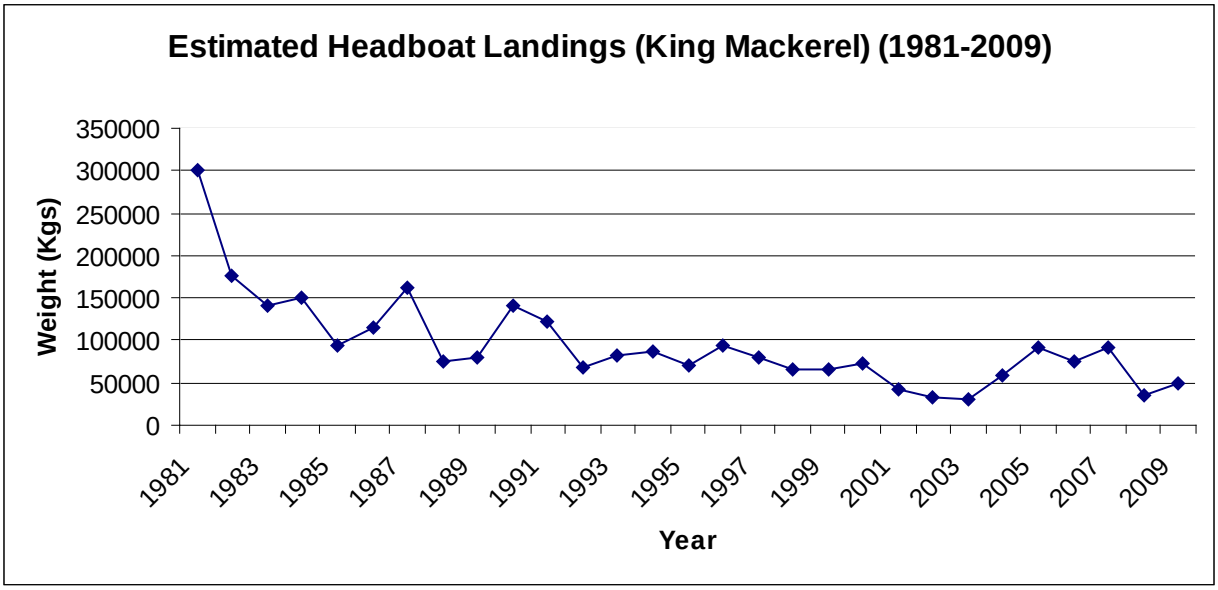

Figure C-16: Estimated Headboat Landings for King Mackerel from Fort Pierce to Miami, Florida, during the period of 1981 thru 2009. Data were not available for the local area alone making it difficult to identify trends that may have occurred in Fort Pierce. Data from the NOAA Southeast Science Center.

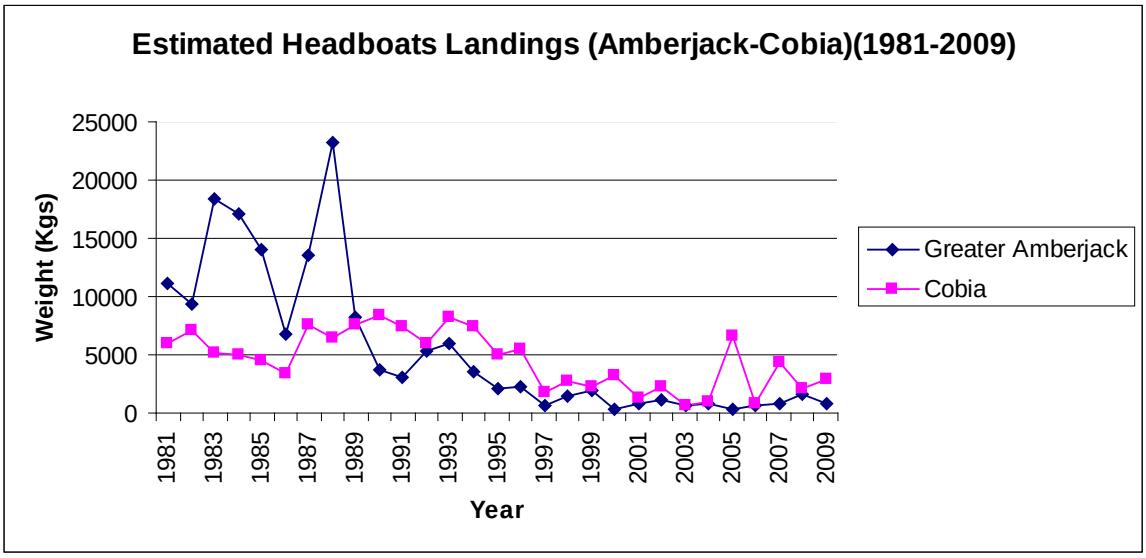

Figure C-17: Estimated Headboat Landings for Amberjack and Cobia from Fort Pierce to Miami, Florida, during the period of 1981 thru 2009. Data were not available for the local area alone making it difficult to identify trends that may have occurred in Fort Pierce. Data from the NOAA Southeast Science Center.

Assessment of fish populations and habitat on Oculina Bank, a deep-sea coral marine protected area off eastern Florida

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Abstract—A portion of the Oculina Bank located off eastern Florida is a marine protected area (MPA) preserved for its dense populations of the ivory tree coral (*Oculina varicosa*), which provides important habitat for fish. Surveys of fish assemblages and benthic habitat were conducted inside and outside the MPA in 2003 and 2005 by using remotely operated vehicle video transects and digital still imagery. Fish species composition, biodiversity, and grouper densities were used to determine whether *O. varicosa* forms an essential habitat compared to other structure-forming habitats and to examine the effectiveness of the MPA. Multivariate analyses indicated no differences in fish assemblages or biodiversity among hardbottom habitat types and grouper densities were highest among the most complex habitats; however the higher densities were not exclusive to coral habitat. Therefore, we conclude that *O. varicosa* was functionally equivalent to other hardbottom habitats. Even though fish assemblages were not different among management areas, biodiversity and grouper densities were higher inside the MPA compared to outside. The percentage of intact coral was also higher inside the MPA. These results provide initial evidence demonstrating effectiveness of the MPA for restoring reef fish and their habitat. This is the first study to compare reef fish populations on *O. varicosa* with other structure-forming reef habitats and also the first to examine the effectiveness of the MPA for restoring fish populations and live reef cover.

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Like shallow tropical coral reefs, deep-sea coral habitats support important ecosystem functions, for example, as hotspots for biodiversity and biomass production (Husebo et al., 2002; Jonsson et al., 2004; George et al., 2007) and as important fish habitat (Gilmore and Jones, 1992; Fosså et al., 2002; Ross and Quattrini, 2007). Like their shallow-water counterparts, deep-sea coral ecosystems are affected by human activities. As harvests have declined in shallow ecosystems, fishing pressure has moved further offshore (Watling and Norse, 1998; Koslow et al., 2000; Roberts, 2002), thus raising interest in deep-sea coral ecosystem protection. With the passage of the Magnuson-Stevens Fishery Management and Conservation Act of 1996, an ecosystem approach to fishery management in the United States has been encouraged by linking the preservation of essential fish habitat with protection of fishery resources. Reauthorization of the Act in 2006 mandated the conservation and studies of deep-sea coral ecosystems. These mandates are expected to lead to the increasing use of marine protected areas (MPAs) as a fishery management tool (Allison et al., 1998; Bohnsack, 1998; Guenette et al., 1998).

One of the world's first deep-sea coral ecosystems to be designated a marine protected area is located approximately 37 km off Florida's east coast in depths of 60–120 m. This area is known as the Oculina Bank, a series of reefs and high-relief bioherms (thickets of live coral, capping mounds of sediment and coral rubble, built upon an underlying lithified base structure) constructed by the scleractinian ivory tree coral (*Oculina varicosa*). This species lives in water depths of 49 to 152 m without zooxanthellae and may form extensive thickets 1 m tall, which over thousands of years have built up mounds and ridges extending as much as 200 m laterally and 35 m above the surrounding seafloor (Reed, 1980). These *O. varicosa* bioherms are known to exist only off the east coast of Florida from Ft. Pierce to St. Augustine, a stretch of almost 150 km along the edge of the Florida-Hatteras slope and beneath the western edge of the Gulf Stream. Surface water currents may exceed 150 cm/sec and bottom currents may exceed 50 cm/sec (Reed, 2002a). Intact, live *O. varicosa* sup-

ports a diverse and dense assemblage of invertebrates and fishes (Avent et al., 1977; Reed, 2002a, 2002b; Koenig et al., 2005), and it may serve as spawning grounds for a number of economically important or threatened reef fish species (Gilmore and Jones, 1992; Koenig et al., 2005).

A portion of the Oculina Bank known as the Oculina Habitat Area of Particular Concern (OHAPC) first received protection in 1984 (Koenig et al., 2005; Reed et al., 2005). Current management regulations established by the South Atlantic Fishery Management Council include a 1029 km² (300 nm²) OHAPC (Fig. 1), within which bottom-fishing gear such as trawls, dredges, longlines, traps, and anchors are not permitted, in order to protect the fragile coral. Within the OHAPC, the 315 km² (92 nm²) Oculina Experimental Closed Area (OECA) (Fig. 1) was designated in 1994 in response to the rapidly diminishing grouper (*Mycteroperca* and *Epinephelus* spp.) populations and excludes all bottom fishing, including fishing with hook-and-line gear, in order to assess the use of a MPA for recovering over-fished reef fish populations, especially those of grouper.

Management requirements to protect many deep-sea coral ecosystems have been delayed owing to the difficulty in quantifying, monitoring, and restoring damaged reefs (Pyle, 2000). Despite efforts to understand and protect the Oculina Bank, extensive damage to the fragile coral had already occurred from fishing gear prior to the implementation of management regulations (Koenig et al., 2000; Reed et al., 2007). When the first management action was taken in 1984, only about 30% of the reef system was afforded protection (Reed et al., 2005). Fishing, including shrimp trawling, was allowed to continue in the northern section of the Oculina Bank until the OHAPC was expanded in 2000. Decades of shrimp trawling and scallop dredging before protection had reduced most of the 150-km stretch of healthy reefs to coral rubble (Reed et al., 2007). Remotely operated vehicle (ROV) transects and multi-beam mapping surveys since 2000, however, have indicated that Jeff's Reef and Chapman's Reef, both located in the southern portion of the OECA, still contain a large amount of intact live *O. varicosa* (Fig. 1) (Reed et al., 2005).

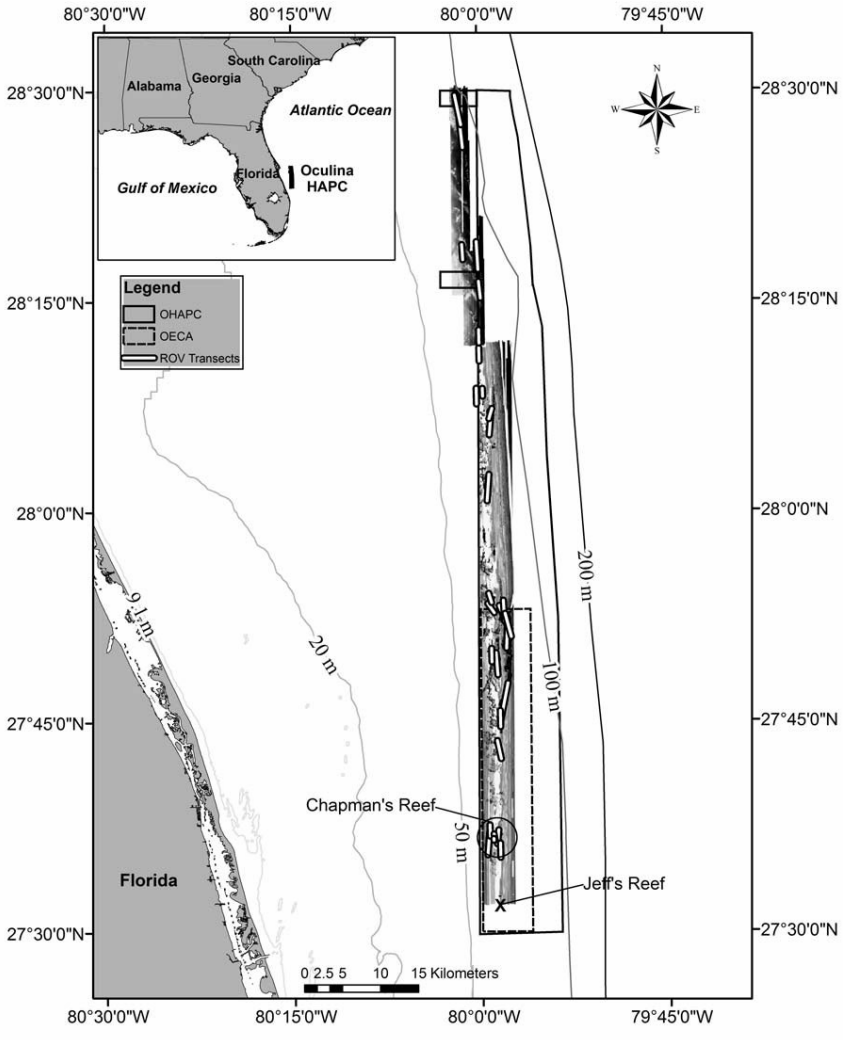

Figure 1

Remotely operated vehicle (ROV) transects overlain on the multibeam map of the Oculina marine protected area (MPA) off eastern Florida. Location of the OHAPC and OECA (OHAPC=areas where all bottom gear except hook and line are restricted, i.e., excluding the OECA, and OECA=inside the MPA where all bottom gear, including hook and line fishing, are restricted) are shown along with Chapman's and Jeff's Reefs. ROV transects were conducted during April–May 2003 and October 2005.

Over-fishing has significantly diminished populations of reef fishes, especially those of groupers (Koenig et al., 2000, 2005). Historical observations made during the 1970s and 1980s indicate that *O. varicosa* reefs were once dominated by large groupers, but later surveys found grouper populations greatly diminished and the reefs dominated by small, non-fishery species like small sea basses (*Serranus* and *Centropristis* spp.), butterflyfishes (*Chaetodon* spp.), and damselfishes (*Chromis* spp.) (Koenig et al., 2005).

A current topic of discussion regarding deep water corals is whether they serve as essential habitat for some fish species or whether any type of 3-dimensional structure (e.g., rock ledges) is important. Auster (2005) proposed that examination of the distribution of fish in relation to all available habitats is one method to assess the "essential"

role of deep water corals. Several studies have concluded that deep water corals were no more important to fishes than other reef structures (Auster, 2005; Tissot et al., 2006) suggesting an opportunistic fish association with deep corals. Ross and Quattrini (2007), however, found that deep reef habitats along the southeast United States slope contain a unique and possibly obligate assemblage of fish. No previous studies have examined whether *O. varicosa* supports a distinct assemblage of fish compared to other structure-forming, hardbottom habitats.

In 2014, the South Atlantic Fishery Management Council will re-evaluate the effectiveness of the OECA. To aid the Council in making future management decisions, our goals for this project were to (1) compare fish assemblage composition, biodiversity, and grouper densities among hardbottom reef habitat types to examine whether *O. varicosa* is an essential habitat structure compared to other structure-forming reef habitats; (2) compare fish assemblage composition, biodiversity, and grouper densities inside and outside managed areas to assess the effectiveness of the MPA; and (3) quantify the percent cover of all hardbottom habitat types.

Materials and methods

Sampling design

In 2002 and 2005, multibeam maps (3-m resolution) were produced for a portion of the Oculina Bank. Coverage included 90% of *O. varicosa* bioherms thought to occur inside the OHAPC, and a portion of bioherms outside the OHAPC between the two satellite areas (Fig. 1). These maps were used to select remotely operated vehicle (ROV) transect stations (April–May 2003, October 2005) so that all habitat types and management areas were examined. Management areas sampled included open (any area outside the OHAPC open to fishing), OHAPC (areas where all bottom gear except hook and line are restricted, i.e., excluding the OECA), and OECA (inside the MPA where all bottom gear, including hook and line fishing, are restricted).

Locations of ROV dive transects were non-random and were based on conducting an equal number of dives in each management area. Due to high current speeds, all dives were conducted in a northerly direction (drifting with prevailing Gulf Stream current with minimal east-west maneuvering). The starting points were chosen *a priori* in order to have each dive cover a range of the major substrate types (described below) as indicated from the multibeam maps. Dives ranged from 0.5 to 3.5 hours.

In addition to management area, fish assemblages were analyzed among five major hardbottom habitat types. Habitat types used were a subset of the Southeast Area Monitoring and Assessment Program (SEAMAP) habitat classification scheme and included pavement, rubble, rock outcrops, standing dead *O. varicosa* coral, and live *O. varicosa* coral. One difference between our habitat classification and that of SEAMAP is that we distinguished between live and dead coral. Pavement habitat was fairly flat rock pavement often with small cracks or crevices present. Rubble habitat consisted of small coral fragments exhibiting little to no relief. Rock outcrop habitat was small rock outcrops approximately 0.3–0.9 m relief, occasionally 1.2–1.8 m relief. *O. varicosa* existed mostly as small individual heads (about 0.3–0.9 m relief), but occasionally as larger mounds and thickets.

Collection methods

The *Phantom Spectrum II* ROV (National Undersea Research Center, University of North Carolina at Wilmington) was used to conduct video and digital still transects to estimate fish densities and characterize habitat. A downweight (~145 kg) was tethered to the umbilical cable of the ROV and the ROV was tethered to a 30-m leash, which allowed it to run just above the seafloor (<1 m) at a controlled over-the-ground speed of approximately 0.39 m/s (range 0.26 to 0.77 m/s). The geographic position of the ROV was constantly recorded throughout each dive using a slant range positioning system linked to the ship's Global Positioning System (GPS). The ROV was equipped with lights, lasers, forward-looking video camera, and down-looking still camera. Lasers projected parallel beams 10 cm apart for measuring fish and habitat features. The forward-looking color video camera provided continuous video while the down-looking high-resolution digital still camera captured images of fish and habitat.

Fish population analyses

Fishes were identified to the lowest discernable taxonomic level and counted and the habitat types were classified from video covering 50-m (±2.5 m) transects. Excluded from the analysis were sections of video recorded when the ROV was in non-hardbottom habitats, video clouded by stirred up sediment, video that zoomed in on a species of interest, or video recorded when the camera was elevated in the water column.

Fish densities (numbers/hectare) were determined by estimating the area viewed during video transects from transect length (L) and width (W). Transect length was calculated from latitude and longitude recorded by the ROV tracking system. Width of each transect was calculated using the following equation:

$$W = 2(\tan(1/2A))D, \quad (1)$$

where A = horizontal angle of view (a constant property of the video camera); and
D = distance from the camera at which fishes could be identified with certainty.

D was usually 5 m except for some dives in 2005 where visibility was reduced to 2–3 m. In 2003, a set of three lasers was mounted to the ROV. The lasers were set up

so that when they were projecting out at a distance of 5 m, two of the lasers overlapped. The third laser was spaced 10 cm apart from the two overlapping lasers, which allowed measurements to be made. This was initially used to train the eye to determine the distance at which fishes could be identified. Distance was then estimated on subsequent dives in 2005. Transect area (*TA*) was then calculated as:

$$TA = (LW) - {}^{1}/_{2}\,(WD) \quad \text{(Koenig et al., 2005).} \qquad (2)$$

Mean *TA* was 372.9 m^2 ±1.8 m^2. Density of all observed fish species was calculated for each transect in 2003 and 2005. Initial analyses demonstrated that no statistical differences were evident between years, so data from both years were combined for all analyses.

Multivariate ecological analyses were conducted using PRIMER 5.0 (Primer–E Ltd, Plymouth, U.K.) to examine fish assemblage composition among habitat types and management areas. A non-metric multi-dimensional scaling (MDS) ordination of ROV transects was constructed from a Bray-Curtis similarity matrix of square root transformed fish densities. A square root transformation was used to reduce the disparity between uncommon and abundant species by downweighting abundant species relative to uncommon species (Clarke, 1993). Prior to analyses, transects in which no fishes were observed were deleted, as the same reason may not apply to why two samples are devoid of species. Species comprising <0.01% of the total abundance of fish were also removed to minimize rare species confounding the cluster analysis. All pelagic species were removed from PRIMER analyses because we wanted to focus on benthic fish species associated with reef habitat. A two-way crossed analysis of similarity (ANOSIM) and pairwise comparisons were used to detect significant differences in fish assemblages among habitat types and management areas.

PRIMER was also used to examine biodiversity among habitats and management areas by calculating average taxonomic distinctness (Δ^+). This statistic uses the taxonomic distance between every pair of species in a given assemblage as the basis for determining relative diversity (Clarke and Warwick, 1998). Unlike conventional diversity indices such as the Shannon-Weiner Index, Δ^+ is independent of sampling effort. To calculate Δ^+, a total list of species observed from ROV transects was used. The following taxonomic categories were utilized: species, genus, family, order, class, and phylum. Each of these represents a node in determining taxonomic distances between species pairs. This list along with fish density data were used to run a TAXDTEST which produces funnel plots where Δ^+ is plotted in comparison with the mean and 95% confidence limits.

Densities of grouper were singled out for analysis because their declining abundances led the South Atlantic Fishery Management Council to establish the OECA. A generalized linear model (GLM) (Minitab 13.32, State College, PA) was used to test for significant differences in grouper densities among management areas and habitat types. Individual species of grouper were not abundant enough to analyze separately, so all grouper species were combined. One-way analysis of variance (ANOVA) was used to test for significant differences in grouper densities among management areas within each habitat type. A significance level of $P \leq 0.05$ was applied to all analyses, and log transformations were applied to correct for unequal variances. Pairwise comparisons were performed using Tukey's honestly significant differences (HSD).

Habitat quantification analyses

A digital still image of the seafloor (taken pointing straight down from the ROV, perpendicular to the seafloor) was taken every 1–3 min during ROV transects to quantify habitat type among management areas. These images were imported into an image analysis program written at the University of North Carolina-Wilmington, emulating the area/length analysis tool of Coral Point Count software (CPCe, Dania Beach, FL) (Kohler and Gill, 2006). Within each image, a polygon was drawn around each distinctive hardbottom area and a habitat type assigned to it. Habitat types were the same as those used for video analyses with the addition of human artifacts (e.g., fishing line, bottles) and shadow, where all or part of an image was blurred, usually from sand being stirred up by the ROV. The program then calculates the percentage of each habitat type within an image based on the number of pixels in each polygon. The area of each habitat type was calculated using paired lasers (set at a known distance of 10 cm apart) on each image. Mean area of still images was 1.2 m^2 ±0.05 m^2. One-way ANOVAs were then used to test for significant differences in habitat type percentages among management areas.

Results

Fish assessment

Forty-two ROV dives (65 hours of video footage) were completed in 2003 and 2005, resulting in 512 hardbottom 50-m transects: 236 in the OECA, 184 in the OHAPC, and 92 in the open area. Among habitat types, 72 transects were in pavement, 186 in rubble, 210 in rock outcrops, 11 in standing dead *O. varicosa*, and 33 in live *O. varicosa*. A total of 62 fish species were observed (Table 1). The previously unexplored bioherms discovered outside the OHAPC between the two satellite areas turned out to be comprised mostly of coral rubble, therefore, even though some live and standing dead *O. varicosa* were observed in the open areas, there wasn't enough of it to produce any 50-m transects to be used in the analyses. No fish species were exclusive to *O. varicosa* coral (live or standing dead). No grouper species were found on pavement except scamp (*Mycteroperca phenax*), the most abundant grouper. Tattlers (*Serranus phoebe*), one of the most abundant small sea basses were

Table 1

Relative abundance (%) of all fish species observed from remotely operated vehicle (ROV) transects on the Oculina Bank during April/May 2003 and October 2005. Species are listed by management area (open= any area outside the OHAPC open to fishing, OHAPC=areas where all bottom gear except hook and line are restricted, i.e., excluding the OECA, and OECA= inside the MPA where all bottom gear, including hook and line fishing, are restricted) and habitat (PAV=pavement, RUB=rubble, OUT=rock outcrops, SD=standing dead *Oculina*, LO=live *Oculina*). There were no SD or LO transects in the open area. A dash indicates 0.00% relative abundance.

	open			OHAPC					OECA				
	PAV	RUB	OUT	PAV	RUB	OUT	SD	LO	PAV	RUB	OUT	SD	LO
Muraenidae													
Gymnothorax spp.	—	—	—	—	—	—	—	—	—	0.07	—	—	—
Undetermined	—	—	—	—	—	—	—	—	—	0.15	—	—	—
Ophicithidae													
Undetermined	—	—	—	—	—	—	—	—	—	—	0.10	—	0.14
Engraulidae													
Anchoa spp.	—	—	—	—	—	—	—	—	—	7.14	—	—	0.28
Synodontidae													
Synodus intermedius	—	—	—	—	0.13	—	—	—	1.49	—	—	—	0.15
Synodus spp.	—	—	—	—	0.14	0.15	—	—	0.76	—	—	—	—
Ogcocephalidae													
Ogcocephalus corniger	—	—	0.12	—	—	—	—	—	—	0.07	—	—	—
Ogcocephalus spp.	—	0.20	—	—	—	—	—	—	—	—	—	—	—
Holocentridae													
Holocentrus rufus	—	—	0.27	—	—	0.38	—	—	—	—	—	—	—
Holocentrus spp.	—	—	—	—	—	—	—	—	—	0.07	0.50	—	—
Myripristis jacobus	—	—	0.13	—	—	—	—	—	—	—	—	—	—
Syngnathidae													
Hippocampus spp.	—	—	—	—	0.14	0.15	—	—	2.34	—	0.50	—	—
Scorpaenidae													
Helicolenus dactylopterus	—	—	0.39	—	—	0.46	—	—	—	0.56	—	—	—
Undetermined	—	0.81	0.39	—	—	0.23	—	—	—	1.60	—	—	1.13
Triglidae													
Prionotus spp.	—	—	—	—	—	—	—	—	—	0.07	—	—	—
Serranidae													
Anthiinae	—	—	3.30	—	11.24	9.06	30.85	25.22	—	16.80	45.22	—	43.79
Centropristis ocyurus	6.63	4.06	8.95	20.91	2.18	8.21	8.29	1.18	16.92	4.13	1.62	7.98	5.16
Centropristis spp.	—	39.93	11.68	38.02	4.52	14.04	4.97	1.19	9.70	3.53	3.15	14.27	5.76
Centropristis striata	—	—	0.12	5.91	—	—	0.83	—	12.26	1.03	0.80	—	0.43
Epinephelus adscensionis	—	—	—	—	—	—	—	—	—	0.07	—	—	—
Epinephelus drummondhayi	—	—	—	—	—	—	—	—	—	—	0.09	—	0.14
Epinephelus morio	—	—	—	—	0.14	0.31	—	—	—	0.07	0.10	2.23	0.28
Epinephelus niveatus	—	—	0.13	—	—	0.15	—	—	—	—	0.19	—	0.14
Hemanthias vivanus	—	5.13	6.69	—	3.00	5.26	3.31	3.41	—	2.21	4.81	—	—
Liopropoma eukrines	—	—	1.93	—	0.42	0.76	0.81	—	—	0.14	1.35	—	1.16
Pronotogrammus martinicensis	—	8.02	31.47	—	17.49	18.74	15.53	13.33	—	4.92	8.55	—	0.14
Mycteroperca microlepis	—	—	—	—	—	0.08	—	—	—	—	—	—	—
Mycteroperca phenax	—	0.20	0.90	2.97	0.13	1.13	4.89	1.76	0.46	0.58	1.59	2.16	1.70
Mycteroperca spp.	—	0.20	—	—	—	—	—	—	—	—	—	—	—
Rypticus maculatus	—	—	—	—	—	—	—	—	—	0.14	—	—	—
Serranus annularis	—	0.20	0.25	—	0.28	—	—	—	—	0.07	—	—	—
Serranus notospilus	—	5.16	0.64	1.00	1.67	1.37	3.30	0.57	1.24	0.40	—	—	0.86
Serranus phoebe	60.57	13.16	10.17	17.74	13.51	16.92	7.53	1.79	27.14	14.91	8.67	14.33	5.16

continued

Table 1 (continued)

	open			OHAPC					OECA				
	PAV	RUB	OUT	PAV	RUB	OUT	SD	LO	PAV	RUB	OUT	SD	LO
Anthiinae (cont.)													
Serranus spp.	—	0.42	0.12	—	—	0.22	—	—	—	0.36	—	—	—
Serranus subligarius	—	—	—	—	—	—	—	—	—	0.36	—	—	0.71
Undetermined grouper	—	—	—	—	—	0.08	—	0.59	0.93	—	0.20	—	0.15
Undetermined small sea bass	—	0.60	0.13	1.02	0.97	0.29	4.19	1.17	2.54	0.11	—	—	—
Priacanthidae													
Priacanthus arenatus	—	—	0.26	—	—	0.74	—	—	—	—	0.57	—	—
Pristigenys alta	13.20	0.20	1.93	3.93	—	4.27	—	—	6.79	0.60	4.47	1.15	0.28
Undetermined	—	—	—	—	—	0.23	—	—	—	—	—	—	—
Apogonidae													
Apogon pseudomaculatus	—	—	—	0.94	—	0.43	—	—	0.94	0.07	0.10	1.09	1.32
Apogon spp.	—	—	0.39	—	—	1.28	—	—	—	0.36	1.07	1.17	0.86
Rachycentridae													
Rachycentron canadum	—	—	—	—	—	0.15	—	—	—	—	—	—	—
Carangidae													
Seriola dumerili	—	—	0.50	—	—	0.79	1.62	—	0.93	0.42	0.29	—	—
Seriola rivoliana	—	—	—	—	0.27	—	—	—	—	—	—	—	—
Seriola spp.	6.91	—	0.13	—	0.41	0.40	—	—	0.47	0.29	0.40	—	0.14
Seriola zonata	—	—	0.13	—	—	—	—	—	0.49	0.14	—	—	—
Lutjanidae													
Lutjanus campechanus	—	—	—	—	—	0.08	—	—	—	—	—	—	—
Lutjanus spp.	—	—	0.13	—	—	—	—	—	—	—	—	—	—
Ocyurus chrysurus	—	—	—	—	—	—	—	—	—	0.08	—	—	—
Haemulidae													
Haemulon aurolineatum	—	—	—	—	—	—	—	—	—	5.03	—	—	—
Haemulon spp.	—	—	—	—	—	—	—	—	—	1.43	—	—	—
Sparidae													
Pagrus pagrus	—	—	0.37	—	—	—	—	—	—	0.14	0.10	—	—
Undetermined	12.69	—	0.13	—	—	0.12	—	—	1.43	0.36	0.39	—	0.42
Sciaenidae													
Equetus acuminatus	—	—	—	0.98	0.14	—	—	—	—	0.49	—	—	—
Equetus spp.	—	—	0.13	—	—	—	—	—	—	—	—	—	—
Equetus umbrosus	—	—	—	—	—	—	—	—	—	—	0.10	—	3.56
Micropogonias undulatus	—	—	—	—	—	—	—	—	—	0.18	—	—	—
Pareques iwamotoi	—	—	—	1.97	—	0.30	—	—	—	—	—	—	—
Chaetondontidae													
Prognathodes aya	—	1.43	2.95	—	2.49	1.66	4.95	2.96	—	7.53	4.02	3.22	10.06
Chaetodon ocellatus	—	—	0.27	—	—	0.15	—	1.74	—	0.07	0.49	—	—
Chaetodon sedentarius	—	0.39	1.04	—	1.65	0.90	—	1.00	—	1.66	1.27	—	0.56
Chaetodon spp.	—	—	0.25	—	0.27	0.08	—	0.59	—	0.79	—	—	—
Pomacanthidae													
Holacanthus bermudensis	—	—	0.66	—	—	0.22	2.44	2.34	—	0.43	1.00	2.13	0.70
Holacanthus ciliaris	—	—	—	—	—	0.07	—	—	—	—	—	—	—
Holacanthus spp.	—	—	—	—	—	—	—	—	—	0.07	—	—	—
Pomacentridae													
Chromis enchrysurus	—	12.32	7.60	—	36.71	5.66	5.68	29.27	8.01	17.56	5.93	44.43	12.55
Chromis scotti	—	0.85	—	—	—	—	—	—	—	0.14	—	—	—
Chromis spp.	—	0.20	0.14	—	0.14	—	—	0.61	—	0.08	—	—	—
Microspathodon chrysurus	—	—	—	—	—	—	—	—	—	0.37	—	—	—
Labridae													
Bodianus pulchellus	—	—	—	—	—	0.15	—	—	—	0.07	0.19	—	—
Bodianus rufus	—	—	—	—	—	—	—	—	—	0.14	—	—	—
Decodon puellaris	—	—	0.12	—	—	0.15	—	—	—	0.07	0.26	5.83	0.14
Halichoeres bathyphilus	—	0.21	—	—	—	—	—	—	—	0.30	—	—	—
Halichoeres spp.	—	3.22	4.45	—	1.54	3.06	—	2.29	—	0.28	1.29	—	0.70

continued

Table 1 (continued)

	open			OHAPC					OECA				
	PAV	RUB	OUT	PAV	RUB	OUT	SD	LO	PAV	RUB	OUT	SD	LO
Sphyraenidae													
Sphyraena barracuda	—	—	—	—	—	—	—	—	—	0.07	—	—	—
Bothidae													
Cyclopsetta fimbriata	—	—	—	—	—	—	—	—	—	—	—	—	0.14
Undetermined	—	—	0.14	0.98	—	—	0.83	—	2.44	—	0.10	—	0.29
Balistidae													
Balistes capriscus	—	—	—	—	—	—	—	—	—	—	0.10	—	—
Monacanthidae													
Aluterus monoceros	—	—	—	—	—	—	—	—	—	0.07	—	—	—
Stephanolepis hispidus	—	—	—	—	—	0.07	—	—	—	—	0.10	—	—
Monacanthus spp.	—	—	—	—	—	0.19	—	—	—	0.07	—	—	—
Ostraciidae													
Lactophrys quadricornis	—	—	—	—	—	—	—	—	—	0.21	—	—	—
Lactophrys spp.	—	—	—	—	—	—	—	—	—	—	0.17	—	—
Tetraodontidae													
Sphoeroides spengleri	—	2.88	0.51	3.62	0.41	0.42	—	—	2.72	0.83	0.16	—	0.44
Sphoeroides spp.	—	—	—	—	—	0.34	—	—	—	0.07	—	—	0.57
Diodontidae													
Chilomycterus spp.	—	0.20	—	—	—	—	—	—	—	—	—	—	—

found in every habitat and management area. Rock hind (*Epinephelus adscensionis*), speckled hind (*E. drummondhayi*), grey triggerfish (*Balistes capriscus*), and grunts (family Haemulidae) were only observed in the OECA.

Multivariate analyses based on 39 fish species across 473 transects indicated no differences in fish assemblages among hardbottom habitat types or management areas. MDS ordination portrayed a potentially useful representation of relationships among ROV transects in two-dimensional space (stress=0.2; see Clarke and Warwick, 2001) and showed no distinct groupings (Fig. 2). ANOSIM results confirmed these conclusions, fish assemblages were not significantly different among hardbottom habitat types (ANOSIM, Global R=0.128, P=0.001) or management areas (ANOSIM, global R=0.061, P=0.002). For ANOSIM, the P value is highly sensitive to sample number and, therefore, the likelihood of committing a type-I error is high. For that reason, the R value is more important than the P value. R equals 0 when groups are the same and R equals 1 when groups are different (Clarke and Warwick, 2001).

Among habitat types, species richness was highest on rock outcrops and lowest for standing dead *O. varicosa* (Fig. 3). Average taxonomic distinctness (Δ^+) was

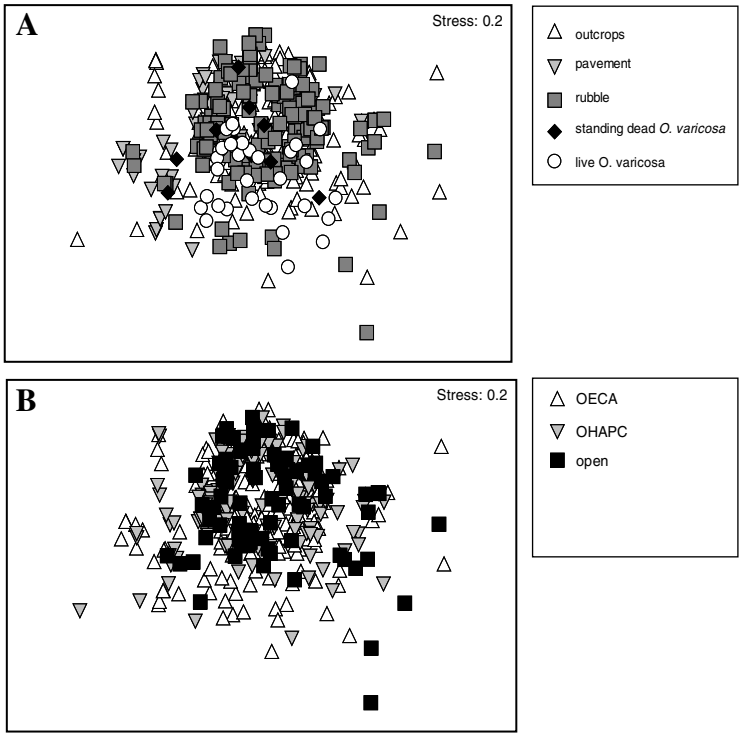

Figure 2

Multidimensional scaling (MDS) ordination of habitats (**A**) and management areas (**B**) based on the Bray-Curtis similarity matrix calculated from square root transformed fish densities (39 species). Data were collected from remotely operated vehicle (ROV) transects conducted on the Oculina Bank during April-May 2003 and October 2005.

highest for rock outcrops followed by pavement, rubble, and live *O. varicosa*, all of which were within the 95% confidence limits. Species richness (Δ^+) for standing dead habitat, however, was less than expected and fell below the 95% confidence limits. Among management areas, species richness was higher in the OECA and OHAPC compared to the open management area (Figure 3). Average taxonomic distinctness (Δ^+) for the OECA and OHAPC were within the 95% confidence limits, however, Δ^+ for the open area was less than expected falling below the 95% confidence limits.

Grouper densities were significantly different among habitat types (GLM, $P<0.001$) and management areas (GLM, $P=0.033$) (Fig. 4). Observed grouper species include speckled hind, red grouper (*E. morio*), snowy grouper (*E. niveatus*), scamp, gag (*M. microlepis*), and rock hind (*E. adscensionis*). Pairwise comparisons revealed that grouper densities were significantly higher ($P<0.05$) on live *O. varicosa*, rock outcrops, and standing dead *O. varicosa* compared to pavement and rubble. Grouper densities were also higher in the OECA compared to both the OHAPC and open management areas. When compared within each single habitat, grouper densities were significantly different on rock outcrops (One-way ANOVA, $P=0.023$) and pairwise comparisons revealed that densities were higher in the OECA compared to both the OHAPC and open areas ($P<0.05$). Grouper densities among management areas were not significantly different ($P>0.05$) for any of the other habitat types.

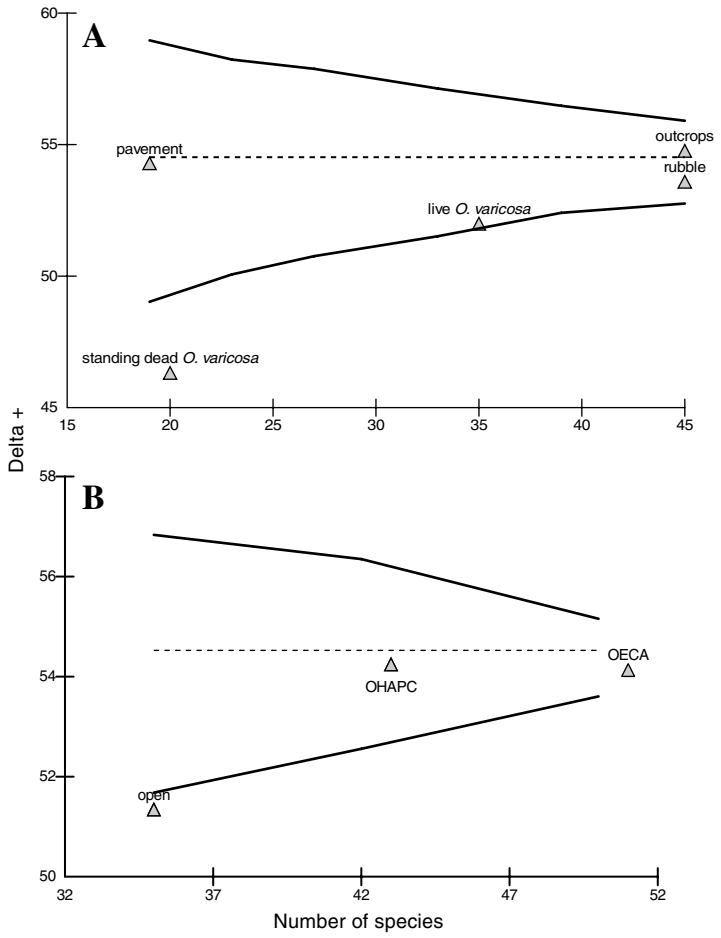

Figure 3

Average taxonomic distinctness (Δ^+) of fish assemblages relative to the mean Δ^+ (dashed line) and the 95% confidence intervals (solid lines) by habitat (**A**) and management area (open = any area outside the OHAPC open to fishing, OHAPC = areas where all bottom gear except hook and line are restricted, i.e., excluding the OECA, and OECA = inside the MPA where all bottom gear, including hook and line fishing, are restricted) (**B**) from remotely operated vehicle (ROV) transects conducted on the Oculina Bank during April–May 2003 and October 2005.

Habitat assessment

Analysis of digital stills revealed the highest percentage of live coral habitat was found in the OECA making up only 1.9% of the total habitat observed (Fig. 5). A total of 1307 digital still images were taken in 2003 and 2005 and used for analysis. There was significantly more live *O. varicosa* located within the OECA compared to the OHAPC and open (One-way ANOVA, $P=0.025$). The percentage of rock outcrops was significantly higher in the OHAPC compared to the open and OECA as well as in the open compared to the OECA (One-way ANOVA, $P<0.001$). Significantly more rubble was found in the OECA and open compared to the OHAPC (One-way ANOVA, $P<0.001$). The percentage of pavement was significantly higher in the OECA and OHAPC compared to the open area (One-way ANOVA, $P=0.003$) and, finally, there was significantly more standing dead *O. varicosa* in the OECA than the open (One-way ANOVA, $P=0.032$). Location of video transects and digital still images containing live *O. varicosa* are shown in Figure 6.

Discussion

This is the first study to address the functionality of coral habitat and to compare fish assemblages among areas with different management levels on the Oculina Bank. Prior to this study, the last survey conducted on the Oculina Bank was in 2001 (Koenig et al., 2005), however, several differences exist between the two and new findings have emerged from the current survey. Koenig et al. (2005) targeted high relief sites within the OECA, used side-scan sonar to locate sites, and compared fish densities among three general habitat types (no coral, sparse live and dead *O. varicosa*, and dense live and dead *O. varicosa*). The current study had updated multibeam maps to target sites,

compared areas not only within the OECA but also included the OHAPC and open areas, and examined an expanded range of habitats.

While it is well known that deep coral habitat supports a high diversity and densities of fish species (Costello et al., 2005; Koenig et al., 2005; Parrish, 2006; Stone, 2006; Ross and Quattrini, 2007), it is unclear whether fish are attracted to live coral or just structure made by corals. Our study addressed this question by comparing fish assemblages, densities, and diversity among several structure-forming habitat types including coral. We found no significant difference in the composition of fish assemblages or diversity among all hardbottom habitat types. Grouper densities were significantly higher on the most structurally complex habitats (live *O. varicosa*, standing dead *O. varicosa*, and rock outcrops) compared to the less complex ones (pavement and rubble). Therefore, higher grouper densities were not exclusive to coral habitats. According to Auster (2005), one of the ways to define functionally equivalent habitats is those that support a similar density of fishes, therefore, we conclude that *O. varicosa* was functionally equivalent to the other hardbottom habitats on the Oculina Bank. Similar results were found in the Gulf of Maine (Auster, 2005). No difference in fish communities was found between habitats dominated by dense corals and those dominated by dense epifauna with or without corals. In addition, Tissot et al. (2006) concluded that fishes in southern California were associated with sponges and corals, but no functional relationship was present. In Hawaii, fish densities were higher in areas with deep-water corals, but when bottom relief and depth were accounted for, these densities were not higher than those for surrounding areas without corals (Parrish, 2006). Ross and Quattrini (2007) concluded that deep slope reefs function much like shallow corals reefs, hosting a unique, probably obligate, ichthyofauna, however other hardbottom habitats were not examined.

Even though our study demonstrated that *O. varicosa* serves a similar role for fishes as other hardbottom habitats, corals are still important and are major contributors to deep-sea habitat complexity and structure (Roberts et al., 2006). Significant numbers of gag and scamp aggregate on and use *O. varicosa* for spawning habitat and juvenile speckled hind use the coral for shelter suggesting a nursery value of the coral (Gilmore and Jones, 1992; Koenig et al., 2000; Koenig et al., 2005). Intact coral is not only valuable for fish, but invertebrates as well. As long as the coral is standing (live or dead), living space within the colony branches supports dense and diverse communities of associated invertebrates (Reed et al., 2002a, 2002b; Reed et al., 2007). However, once reduced to unconsolidated coral rubble, little living space is left except for infauna (George et al., 2007). A hypothetical trophic model of the *O. varicosa* ecosystem indicates significant loss of habitat, in particular intact

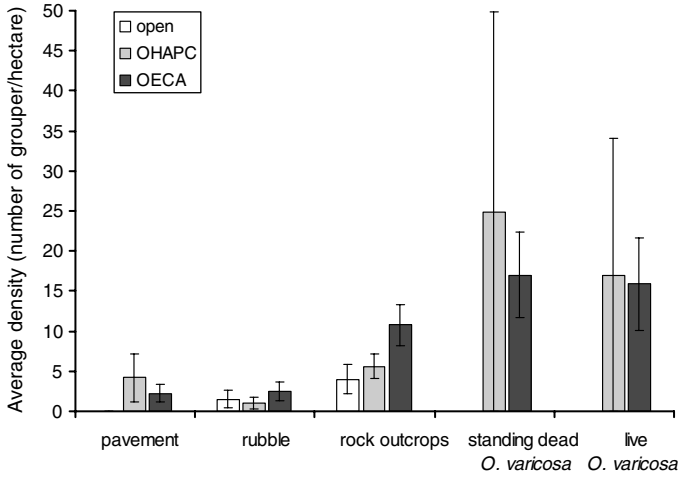

Figure 4

Average grouper densities (no./hectare) (±SE) for each management area by habitat type observed from remotely operated vehicle (ROV) transects conducted on the Oculina Bank during April/May 2003 and October 2005. Average grouper density for pavement in the open area was 0.0 fish/hectare, however, there were no live or standing dead *Oculina varicosa* transects for the open area.

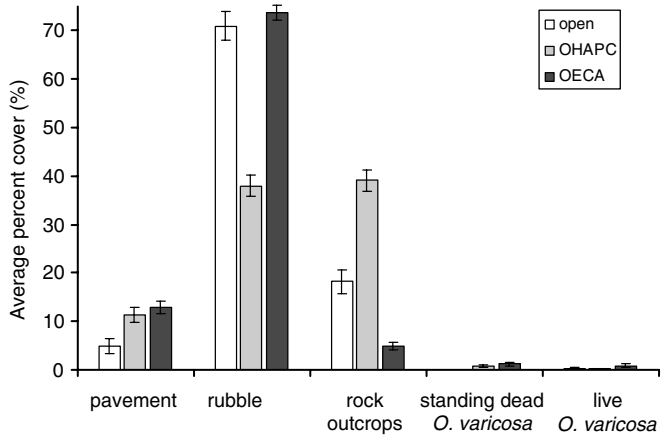

Figure 5

Average percent cover (±S.E.) of habitat types in each of the three management areas (open = any area outside the OHAPC open to fishing, OHAPC = areas where all bottom gear except hook and line are restricted, i.e., excluding the OECA, and OECA = inside the MPA where all bottom gear, including hook and line fishing, are restricted) from analysis of digital stills taken during remotely operated vehicle (ROV) transects on the Oculina Bank during April–May 2003 and October 2005.

live and dead standing coral, could bring dramatic shifts in the ecosystem (George et al., 2007). Conservation efforts, however, should focus on the intrinsic value of corals such as their slow growth, high sensitivity to disturbance, and questionable potential for recovery (Auster, 2005). A restoration project utilizing artificial reef structures is currently ongoing within the OECA. Between 1996 and 2001, a total of 125 large and 900 small restoration modules were deployed in a series of experiments to test their efficacy in the recovery of degraded coral and depleted fish populations (Koenig et al, 2005). The theory is that this will help *O. varicosa* restoration by providing stable settlement habitat, which may, in turn, provide suitable habitat for fish populations to recover. Early evidence (ROV dives from this study) found new coral recruits growing on the structures and groupers associated with them as well (Reed et al., 2005). While the scale of the artificial reefs is likely too small for fisheries replenishment, this experiment will provide insight to whether this tool is effective for coral restoration.

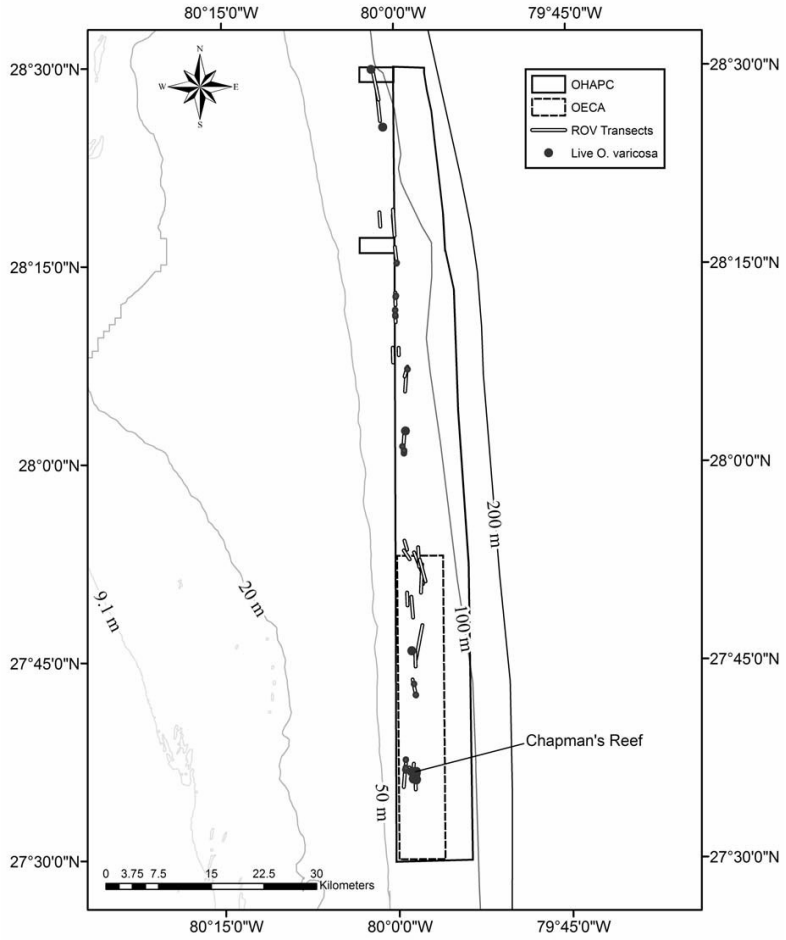

Figure 6

Locations of live *Oculina varicosa* (ivory tree coral) from video and digital stills collected during remotely operated vehicle (ROV) transects during April–May 2003 and October 2005.

Being the first study to compare fish assemblages among areas with different management levels on the Oculina Bank, the results are important to the South Atlantic Fishery Management Council as they evaluate the effectiveness of the OECA; this study and future surveys will help determine the fate of the closed area when it is reconsidered by the Coral and Habitat Advisory Panels in 2014. While MDS and ANOSIM analyses revealed no significant differences in the composition of fish assemblages among management areas, other positive effects of the closure were observed. Fish diversity was higher inside the OHAPC and OECA compared to the open area. Grouper densities were significantly higher in the OECA, particularly on rock outcrops, than in the OHAPC or open areas. Also, more coral was found in the OECA suggesting the restriction of fishing activity may have aided in conserving what little *O. varicosa* had not been destroyed by trawling. Habitat quantification analyses demonstrated there was significantly more live and standing dead *O. varicosa* in the OECA compared to the OHAPC and open. An important observation from the ROV transects was the presence of black sea bass (*Centropristis striata*) in 2005. Prior to that time, black sea bass had not been observed on the *O. varicosa* reefs since the 1980s when they dominated the area (Koenig et al., 2000). While black sea bass in the 1980s were large, mature individuals, most individuals in 2005 were small juveniles, ranging in length from 10 to 20 cm, suggesting initial stages of recovery for this species. Another significant discovery was the sighting of the first juvenile speckled hinds since the 1980s. All of these findings combined present initial evidence demonstrating effectiveness of the MPA for restoring reef fish and their habitat.

Sustained enforcement remains an ongoing problem for MPAs (Riedmiller and Carter, 2001; Rogers and Beets, 2001). Even relatively moderate levels of poaching can quickly deplete gains achieved by closure (Roberts and Polunin, 1991; Russ and Alcala, 1996). As of 2003, all trawling vessels working in the Oculina Bank area are required to have vessel monitoring systems, but this doesn't solve the problem of poaching by hook and line fishing. Between 2003 and 2007, illegal trawlers and fishers were observed within the MPA during our cruises, and several vessels have been cited and fined by the United States Coast Guard. ROV observations from this study indicate recent trawl nets, bottom long lines, and fishing lines inside the MPA long after these gears were banned from the area. Continued trawling and bottom fishing in the OHAPC likely will thwart management objectives.

In summary, unlike shallow-water ecosystems, understanding of the ecological and functional role of deep-water corals has only recently emerged. The current study is in agreement with most other recent literature, demonstrating that corals are functionally equivalent to other deep-sea structural habitats. Deep-sea corals, however, are clearly an important provider of structural habitat for fishes and are sensitive to fishing gear impacts and vulnerable to destruction due to their fragility and slow growth rates. Therefore, protection remains crucial. While an ecosystem approach to management has become widely accepted and MPAs have become a primary tool to manage deep-sea coral ecosystems, little evidence has been provided demonstrating MPA effectiveness. This study, however, revealed several positive effects of the closure including higher biodiversity, grouper densities, and percentage of intact coral suggesting initial effectiveness of the *Oculina* MPA.

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