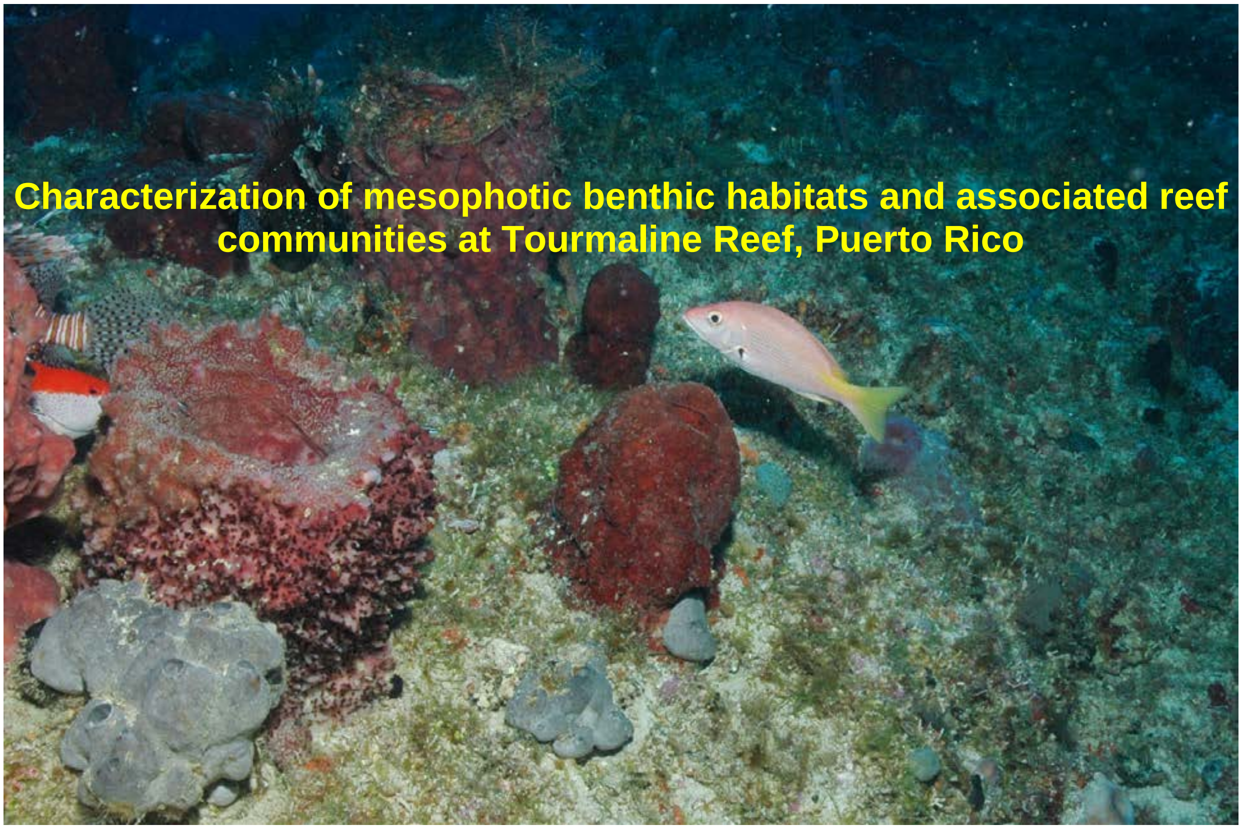
**FINAL REPORT**

# Characterization of mesophotic benthic habitats and associated reef communities at Tourmaline Reef, Puerto Rico



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## I. Executive Summary

This research provides mapping and a physical description of the mesophotic benthic habitats of Tourmaline Reef, along with a quantitative and qualitative characterization of the sessile-benthic, fish, and shellfish (queen conch, spiny lobster) populations associated with each of the main benthic habitats present within a 30 – 50 m depth range. Density estimates of large commercially important fish and shellfish populations were produced to contribute fishery independent data for assessment of fishery stocks within mesophotic habitats/sites of the Puertorrican EEZ. This project forms part of an on-going research initiative directed towards the characterization of essential fish habitats (EFH) and associated reef communities from Puerto Rico and the U. S. Virgin Islands sponsored by NMFS thru the Caribbean Fishery Management Council (CFMC). This research complements ongoing programs of coral reef community characterizations and monitoring sponsored by NOAA thru the Department of Natural and Environmental Resources of Puerto Rico (DNER) and the U. S. V. I., Division of Coastal Zone Management.

Five main benthic habitat types were recognized within the 30 – 50 m depth range. These included a mostly unconsolidated and abiotic 1) sandy substrate; 2) scattered patch reefs surrounded by sand; 3) colonized pavement; 4) algal rhodolith reef deposits; and 5) a slope wall rocky habitat. Sand was the main substrate type in terms of areal cover with approx. 6.7 km$^2$, or 48.1 % of the total study area, yet mostly uncolonized (abiotic), with the sporadic occurrence of interspersed gorgonians and occasional sightings of milk and/or queen conch. Rhodolith reef deposits were the most prominent benthic habitat present along the western section of the mesophotic outer shelf, and represented the dominant biotic habitat in terms of areal cover with 5.19 km$^2$, or 37.5 % of the total study area within the 30 – 50 m depth range. Live coral reef habitats within the mesophotic 30 – 50 m depth range were very scarce at Tourmaline Reef and only associated with a small yellow-pencil (*Madracis auretenra*) biotope growing as a patch within the rhodolith reef. The virtual absence of live coral from mesophotic benthic habitats at Tourmaline appears to be related both to the high areal cover by sand and by its potential abrasive effect on adjacent hard ground attachment substrates.

The community structure of sessile-benthic biota evidenced a pattern of higher affinities within habitat types than within depths. Distinct patterns of community structure dissimilarities were detected between habitat types. Sessile-benthic community structure at the wall differed significantly from all other benthic habitat types. Also, statistically significant differences in the taxonomic composition and rank order of sessile-benthic substrate categories were observed between the rhodolith and colonized pavement habitats. Higher percent cover by sponges, and octocorals, and lower percent of substrate cover by abiotic categories were consistently measured from the slope wall habitat, as compared to other benthic habitat types. Also, the density of scleractinian coral colonies (mostly orange cup coral, *Tubastraea coccinea*) at the slope wall was higher than at any other habitat type surveyed. Colonized pavement and scattered patch reef habitats did not differ significantly in terms of community structure from each other. Both habitats exhibited high abiotic and benthic algae cover, low cyanobacteria cover and high species richness of sponges. Despite what appeared to be adequate hard bottom conditions for attachment and good light penetration, live scleractinian coral cover was very low on both of these habitats probably due to the intense abrasion associated with sand flux.

A total of 78 fish and three shellfish species were observed within mesophotic habitats during diver surveys at Tourmaline Reef. The taxonomic composition of reef fishes and their rank order abundance conferred higher affinities within habitat types than within depths, a pattern that is consistent with the sessile-benthic community characterization for this site. Fish community structure at the slope wall (W) differed significantly from all other benthic habitats. Statistically significant differences in the taxonomic composition and rank order abundance of fishes were observed between the rhodolith and scattered patch reef habitats. The fish assemblage at the slope wall differed from all other benthic habitats mostly due to the prominent abundance of blackfin snapper (*Lutjanus buccanella*) relative to other habitats surveyed. Other fish species were observed only, or in higher abundance at the wall relative to other benthic habitats. These include the blue and sunshine chromis (*Chromis cyanea, C. insolata*), fairy basslet (*Gramma loreto*), blackjack and blue runner (*Caranx lugubris, C. crysos*), French angelfish (*Holacanthus ciliaris*), and large adult dog and cubera snappers (*Lutjanus jocu, L. cyanopterus*). The

slope wall appears to function as a recruitment habitat for blue and sunshine chromis, and also as a reproductive and foraging site for large demersal and pelagic reef fishes. Differences between fish assemblages at the colonized pavement and scattered patch reef habitats were mostly related to the higher relative abundance of bicolor damselfish at the colonized pavement, and an overall higher number of species at the former. Fish assemblages at the scattered patch reef habitat were unique in that the most abundant species within transects surveyed was the squirrelfish (*Holocentrus rufus*). In addition to the squirrelfish, the scattered patch reef habitat exhibited higher relative abundance of yellowtail snapper (*Ocyurus chrysurus*), reef butterfly fish (*Chaetodon sedentarius*), long jaw squirrelfish (*H. adcensionis*), orangeback basslet (*Serranus annularis*), doctorfish (*Acanthurus chirurgus*) and redspotted hawkfish (*Amblycirrhitus pinos*) than the colonized pavement habitat and the rhodolith reef habitat. The rhodolith reef exhibited the typical fish community structure that has been previously reported for this type of mesophotic benthic system. Numerically dominant species of the fish assemblage include the bicolor damselfish (*Stegastes partitus*), cherubfish (*Centropyge argi*), chalk-bass (*Serranus tortugarum*), yellow-head and blue-head wrasses (*Halichoeres garnoti, Thalassoma bifasciatum*), and the greenblotch parrotfish (*Sparisoma atomarium*).

A total of 318 queen conch individuals were observed within belt-transects during fishery independent surveys at Tourmaline Reef.  Queen conch were present in all four benthic habitats surveyed, but were more abundant at the rhodolith reef (7.4 Ind/1000 $m^2$) and colonized pavement habitats (7.0 Ind/1000 $m^2$) within a depth range of 30 – 40 m. The mean density of queen conch from all mesophotic habitats surveyed at Tourmaline Reef was similar to that found at neighbor mesophotic habitats of Abrir la Sierra. The maximum size (length) however, as well as the proportion of larger individuals within the population appeared to be higher at Abrir la Sierra. Spiny lobsters were observed from mesophotic habitats at Tourmaline Reef, with higher densities at the colonized pavement and lowest (none) at the rhodolith reef habitat. The size distribution indicates that both juvenile and adult spiny lobsters are utilizing mesophotic habitats from Tourmaline Reef.

Mutton, blackfin, dog and cubera snappers, red hinds, lionfish, hogfish and queen triggerfishes were the most abundant of the large demersal commercially important fishes present within the mesophotic habitats of Tourmaline Reef. Mean density of queen conch, hogfish, mutton, dog and cubera snappers were much higher at Tourmaline and Abrir La Sierra than at oceanic mesophotic systems previously studied. It is here suggested that such higher abundance is related to the stronger physical connectivity of mesophotic habitats at Tourmaline and Abrir la Sierra with recruitment habitats of the shallow neritic shelf as compared to oceanic sites (Desecheo and Bajo de Sico) that are separated from the insular shelf by oceanic depths.

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## II. Introduction

Tourmaline Reef, located due west of Bahía Bramadero, Cabo Rojo was designated as a Natural Reserve in 1996 in recognition of its ecological value as the most important coral reef system of the west coast of Puerto Rico. It is seasonally closed to fishing during the spawning aggregation of the red hind, *Epinephelus guttatus* between January and March. Tourmaline is also an important fishery ground for spiny lobster, *Panulirus argus*, queen conch, *Strombus gigas* and other reef fishes. Because of its extension beyond the nine-mile local jurisdictional limit, Tourmaline reef is managed both by the Department of Natural and Environmental Resources (PRDNER) and the Caribbean Fishery Management Council (CFMC). The DNER included Tourmaline in its National Coral Reef Monitoring Program, and monitoring surveys of its coral reef community are available from 2000 until present (Garcia-Sais et al., 2012a). Its seasonal fishing closure was a CFMC initiative and is enforced by the Federal government since 1996.

As part of the NMFS-CFMC research program toward the mapping and biological characterization of mesophotic reef systems in the U.S. Caribbean EEZ, sites at Isla Desecheo, Bajo de Sico and Abrir La Sierra in Mona Passage, and El Seco off southeast Vieques have been surveyed from Puerto Rico (Garcia-Sais et al., 2005, 2007, 2010a, 2011). The Marine Conservation District of St. Thomas, and Lang Bank, located off the eastern tip of St. Croix have also been recently studied In the USVI (Nemeth et al., 2008, Smith et al. 2010, Garcia-Sais et al, 2013). These mesophotic systems have shown to be of exceptional ecological and socioeconomic value due to their live coral and/or fishery resources. For example, mesophotic coral reefs at El Seco, the MCD and Lang Bank are the most extensive continuous live coral reef systems of Puerto Rico, St. Thomas and St. Croix, respectively. As such, these systems represent an invaluable source of coral reef fish and invertebrate larvae to adjacent coral reef systems and adjacent coastal recruitment habitats, with potentially relevant influences on the biodiversity, productivity and fisheries across the entire Caribbean island region and beyond. All the aforementioned mesophotic sites studied as part of the NMFS-CFMC initiative are also the residential habitats and spawning aggregation sites for large, commercially important groupers and snappers, and perhaps other species still to be reported. They also represent important foraging areas for endangered sea turtles and highly valuable (commercial/recreational fisheries) migratory fish species (Garcia-Sais et al, 2007), and constitute residential and reproductive habitats for a healthy population of queen conch at Abrir la Sierra (Garcia-Sais et al, 2010a, 2012b).

The present study of Tourmaline Reef provides essentially a continuation of the benthic habitat mapping and quantitative/qualitative biological characterization of the mesophotic (30 – 50 m) habitats associated with the outer shelf and upper insular slope of the west coast between Cabo Rojo and Mayaguez, since Tourmaline Reef connects at the northern boundary of Abrir la Sierra, a reef system previously studied by Garcia-Sais et al. (2010a). In addition to the baseline quantitative biological characterization of benthic habitats based on photo-transects, and visual fish/shellfish surveys within belt-transects, an effort towards the production of density estimates of large commercially important fish and shellfish resources has been included as part of this study at Tourmaline Reef. This data will contribute to a recent assessment of fishery stocks within mesophotic sites of the Puertorrican EEZ (e.g. Isla Desecheo, Abrir la Sierra and Bajo de Sico) recently completed by Garcia-Sais (2012b).

## III. Research Background

Characterizations of reef habitats and associated sessile-benthic and fish communities at depths between 30 – 100 m (mesophotic) are rare in the Caribbean, and until recently, mostly available from submersible surveys. Colin (1974; 1976) described the taxonomic composition of reef fishes at depths between 90 – 305 m off the coasts of Jamaica, Belize and the Bahamas as a mixed assemblage of shallow reef (< 30 m) and true “deep-reef” species seldom present shallower than 50 m. Colin (1974) argued that the vertical distribution of some reef fish species was more related to local environmental conditions (habitat features) than depth, and noted ontogenetic trends in the vertical distribution of “deep-reef” species, where juvenile stages were typically observed at shallower depths than adults. In Puerto Rico, the Seward Johnson- Sea Link submersible survey (Nelson and Appeldoorn, 1985) provided a qualitative characterization of benthic habitats and associated fishes of the insular slope, encompassing depths between 100 – 1,250 m. Despite observations of a “rich and highly complex” reef fish community associated with the upper insular slope (30 – 100 m), these habitats were left virtually undescribed by the Seward Johnson - Sea Link survey.

Quantitative assessments of reef substrate cover by sessile-benthic communities from mesophotic reef habitats in the Caribbean include the autonomous underwater vehicle (AUV) surveys of the La Parguera shelf-edge (Singh et al., 2004) and the Marine Conservation District (MCD) coral reef system located south of St. Thomas, USVI (Armstrong et al., 2006). Menza et al. (2007) reported on coral taxonomic composition, percent substrate cover, and recent degradation of a mesophotic coral reef system (MSR-1) dominated by *Montastraea annularis* (complex) on the outer shelf south of St. John, USVI using video and still camera images dropped from the NOAA R/V Nancy Foster. The aforementioned studies identified mayor differences of sessile-benthic community structure associated with the various mesophotic habitat types and depth gradients, but lack inferences about their reef fish communities. Beets and Friedlander (1997) and Nemeth (2005) conducted quantitative surveys of the red hind (*Epinephelus guttatus*) population within the MCD, a known spawning aggregation site for this species. These studies provided a baseline and an assessment of the effectiveness of the closed fishing regulation for the recovery of the red hind population within the MCD, but did not include information on fish - habitat associations for other species. A more general description of the fish community at the MCD from AGRRA surveys is available from Nemeth et al. (2008).

The CFMC through the Coral Reef Conservation Grant Program is working toward the mapping and characterization of mesophotic reef systems in the U.S. Caribbean EEZ. The Magnuson-Stevens Act calls for the description and specifically the benthic habitat mapping of essential fish habitats (EFH). Research recently completed on Isla Desecheo (García-Sais et al., 2005), Bajo de Sico (García-Sais et al., 2007), Abrir La Sierra (García-Sais et al., 2010a), El Seco (Garcia-Sais et al. 2011) and the St. Thomas, USVI MCD Reef (Nemeth et al. 2010) have contributed to the location and mapping of mesophotic reefs within the region.

Statistically significant differences of sessile-benthic and fish community structure were noted between euphotic and mesophotic habitats at Isla Desecheo (Garcia-Sais, 2010b). The percent of live coral cover and the relative composition of coral species, sponges and benthic algae exhibited marked variations with depth and/or benthic habitat (Garcia-Sais et al. 2005, Garcia-Sais, 2010b). Similar findings were reported for Bajo de Sico and Abrir La Sierra (Garcia-Sais et al., 2007, 2010a), where important shifts of sessile-benthic and fish community structure appear to be associated not only with depth, but also with habitat type, slope and rugosity. All of these mesophotic reefs share the presence of large demersal fishes in abundances never previously reported for shallow reefs in Puerto Rico. In general, fish assemblages exhibit marked differences of relative abundance associated with habitat type and/or depths, high taxonomic connectivity between habitats across depth gradients, and presence of what appears to be a small group of indicator fish species of mesophotic reefs (Garcia-Sais et al., 2007; Garcia-Sais, 2010b).

A relevant conclusion from this research is that mesophotic reefs function as the residential and foraging habitats for a broad range of commercially exploited reef fishes, particularly large groupers and snappers, sea turtles and queen conch. Some of these populations appear to migrate from their mesophotic residential habitats to their spawning aggregation sites in shallower sections of the shelf-edge, whereas others aggregate within mesophotic habitats (Garcia-Sais et al. 2011). Also, the particularly high abundance of post-settlement juveniles of Coneys (*Cephalopholis fulva*), Blue Chromis (*Chromis cyanea*) and Fairy Basslet (*Gramma loreto*) reported for Isla Desecheo, Bajo de Sico and Abrir La Sierra suggest that these mesophotic reefs may function as prime recruitment sites for these and other reef fish populations. The present characterization of the mesophotic habitats at Tourmaline Reef contributes to our present understanding of the life cycles and reef habitat utilization by fish and shellfish populations. The information on these mesophotic communities supplement an extensive data base that has been obtained from shallow reef zones down to the shelf-edge as part of the National Coral Reef Monitoring Program for Puerto Rico and the U. S. Virgin Island.

## IV. Study Objectives:

1) Provide a baseline quantitative and qualitative characterization of the sessile-benthic, motile-megabenthic invertebrate and demersal fish communities associated with the principal mesophotic reef habitats within a depth range of 30 – 50 m at Tourmaline Reef.
2) Construct a georeferenced map of the mesophotic benthic habitats of Tourmaline Reef based on direct diver and drop camera observations within a depth range of 30 - 50 m.
3) Analyze fish-habitat relationships to evaluate the function of mesophotic habitats in the life cycle of commercially important reef fish populations
4) Provide a fisheries-independent assessment of the density and size frequency distributions of commercially important fish and shellfish populations associated with mesophotic (30 – 50 m) reef habitats at Tourmaline Reef
5) Produce a digital photographic and video album of deep reef communities from Tourmaline Reef

## V. Methods

### A. Benthic Habitat Map

Production of the benthic habitat map of Tourmaline Reef was based on a series of field observations and substrate classifications by rebreather divers. Initial recognition of the main topographic features within the 30 – 50 m depth range were based on the bathymetry footprint produced by NOAA Biogeography Team aboard the R/V Nancy Foster (http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/data.html) (Figure 1). The mesophotic area of Tourmaline Reef has essentially a boomerang shape and includes sections of the outer shelf, the shelf-edge, and the upper insular slope in most sections. In order to provide full geographical coverage of the study area and depths, a series of 10 equidistant transversal profiles of the outer shelf, including the shelf-edge and the upper insular slope were pre-established. At each transversal profile, three depths (sampling stations) were occupied for full biological characterizations at 30, 40 and 50 m for a total of 32 stations (11 stations ea. were surveyed at 30 and 40 m). At each of these georeferenced stations substrate classifications were produced in support of the benthic habitat map. In addition, 63 drift dives were made as part of an effort to produce fishery independent data on commercially important fish and shellfish populations. On each of these dives georeferenced benthic habitat information was produced to supplement the construction of the benthic habitat map. Finally, a series of 62 georeferenced drop video camera (Go-Pro) surveys were performed at strategic seafloor locations to complete the information package on the benthic habitat map based on a total of 157 field verified data points (Figure 2). Exact station geographic positions, depths, habitat, and survey work data is presented in Appendix 1.The final benthic habitat map was prepared in ESRI Arc-Map software.

### B. Sessile-benthic community characterizations

Sessile-benthic communities were quantitatively described from a total of 32 -10 m long transects located along 10 transversal sections of the outer shelf. Along each section, stations at 30, 40 and 50 m benthic communities were sampled by one 10 m long transect set close to the bottom with a metric fiberglass measuring tape (reference line). A total of 10 non-overlapping digital images (still photos) from each transect were taken and analyzed using the Coral Point Count software v.4.1. A template of 25 random points was overlaid on each image and the substrate categories under each point identified. The cumulative number of points over each substrate category in the ten images analyzed per transect was divided by the total number of points overlaid per transect (e.g. 25 points per image x 10 images = 250 points per transect) and reported as the percent substrate cover for each substrate category on each transect. The reef substrate area encompassed in still images ranged between 0.8 and 1.0 $m^2$.

Sessile-benthic reef categories included in the photographic image analysis included the following:

1) Scleractinian corals – percent cover and density of colonies per transect reported by species. Both hermatypic (e.g. *Montastraea cavernosa*) and ahermatypic (e.g. *Tubastraea coccinea*) taxa included.

2) Octocorals - (soft corals) percent cover and density of colonies per transect reported by species; or lowest identifiable taxon; includes vertically projected colonies, such as *Iciligorgia schrammi* and encrusting colonies, such as *Erythropodium caribaeorum*)

3) Antipatharians – (black corals), percent cover and density of colonies per transect reported to the lowest identifiable taxon;

4) Hydrocorals – (fire and lace corals), percent cover and density of colonies per transect reported by species; or lowest identifiable taxon; includes vertically projected colonies, such as *Stylaster roseus,* and encrusting colonies, such as *Millepora spp*.

5) Sponges – percent cover reported by species, or lowest possible taxon

6) Algal Turf – percent cover reported by assemblage, consisting of mixed populations of short articulate coralline red, and brown macroalgae, intermixed with other small epibenthic biota forming a mat or carpet over hard substrate.

7) Calcareous Algae – reported as species (*Halimeda sp*.) total calcareous algae, or lowest possible taxon

8) Fleshy Algae – vertically projected, mostly brown, red and green macroalgae reported as total fleshy algae, or lowest possible taxon (e.g. *Lobophora variegata*)

9) Cyanobacteria – blue green algal mats

10) Abiotic Substrates – includes unconsolidated sediment, bare rock, deep holes and gaps.

Common names and coral taxonomy followed Veron (2000) and Humann and Deloach (2003).

### C. Characterization of fish and shellfish communities

Belt-transects 10 m long x 3 m wide were centered along the reference line of transects used for sessile-benthic reef characterizations for estimation of densities of demersal (non-cryptic), mostly territorial reef fish and shellfish (lobsters and conch) populations. Thus, a total of 32 transects were surveyed in characterization of fish and shellfish species associated with mesophotic benthic habitats at Tourmaline Reef. In order to provide supplemental information on the taxonomic composition and density of the large demersal and transitory pelagic fish and shellfish species that were part of the benthic habitats studied each transect was extended approximately 100 m x 6 m by swimming at a normal pace for 10 minutes in the direction of the prevailing current to identify and count only the large commercially important fish and shellfish species. The total area covered by each transect was estimated from the distance given by the point of entry and the end point signaled by divers sinking three times a marker buoy multiplied by six (6) meters as the width measurement of the visual cone. The end position was georeferenced at the surface with the GPS on-board. These transect extensions were also used to supplement fishery independent surveys of fish and shellfish species from each mesophotic habitat. A detailed description of the survey protocol for territorial fish enumerations within belt-transects is presented in García-Sais et al. (2005).

Fishery independent surveys of the commercially important fish and shellfish populations that include large, elusive fishes and shellfish populations (spiny lobsters and queen conch) were visually surveyed by a series of down current drift dives executed by a pair of rebreather divers producing belt-transects of approximately 200 m long by 6 m wide (1,200 $m^2$) each. A total of 63-drift belt-transects were performed at depths between 30 – 50 m. The point of origin was predetermined from the multi-beam bathymetry map. Survey start points were entered in boat GPS and a marker buoy with a lead at the bottom was deployed upon arrival. Divers went down by the marker and carried the lead weight during the drift dive to allow tracking by the boat GPS. The marker float was pulled three times by the divers to signal the end of the transect swath. The start and finish positions were annotated and each distance covered calculated by GIS. Target species included Nassau, black, yellowfin, and red hind groupers, dog, mutton and cubera snappers, sharks, large pelagic species, spiny lobsters, and queen conch. Common names of reef fishes were taken from Humann and Deloach (2006).

### D. Data Analysis

Patterns of sessile-benthic and ichthyofaunal similarities between and benthic habitats and depths were examined using a non-metric multidimensional scaling (NMDS) procedure on the data of percent substrate cover by benthic categories and fish abundance from replicate transects at each depth. Double standardization of the data was performed to smooth effects of numerically dominant species with highly aggregated spatial distributions. Data ordination was based on Bray-Curtis distances. ANOSIM and SIMPER routines in the PRIMER (Anderson, 2001) statistical package were used to analyze similarities of benthic and fish community structure between benthic habitats and depths, and to identify relevant species contributions to similarity/dissimilarity percentages within and between habitats. Statistically significant differences of sessile-benthic and fish community structure were tested using PERMANOVA (Anderson, 2008; Peck, 2010).

Preliminary analyses of the sessile-benthic data (% substrate cover ranks by category) showed that the main patterns of benthic community structure varied independently from depths within the 30 – 50 m range, but were associated with differences in habitat types. Variations of fish community structure were also more associated with habitat type than depth. Thus, sessile-benthic and fish data were organized in tables to characterize distinct benthic habitat types, instead of depths. Also, most habitat types, except the slope wall, were distributed within depth ranges that were broader than 10 meters, which were the depth interval criteria for preliminary station designation (e.g. 30, 40 and 50 m).

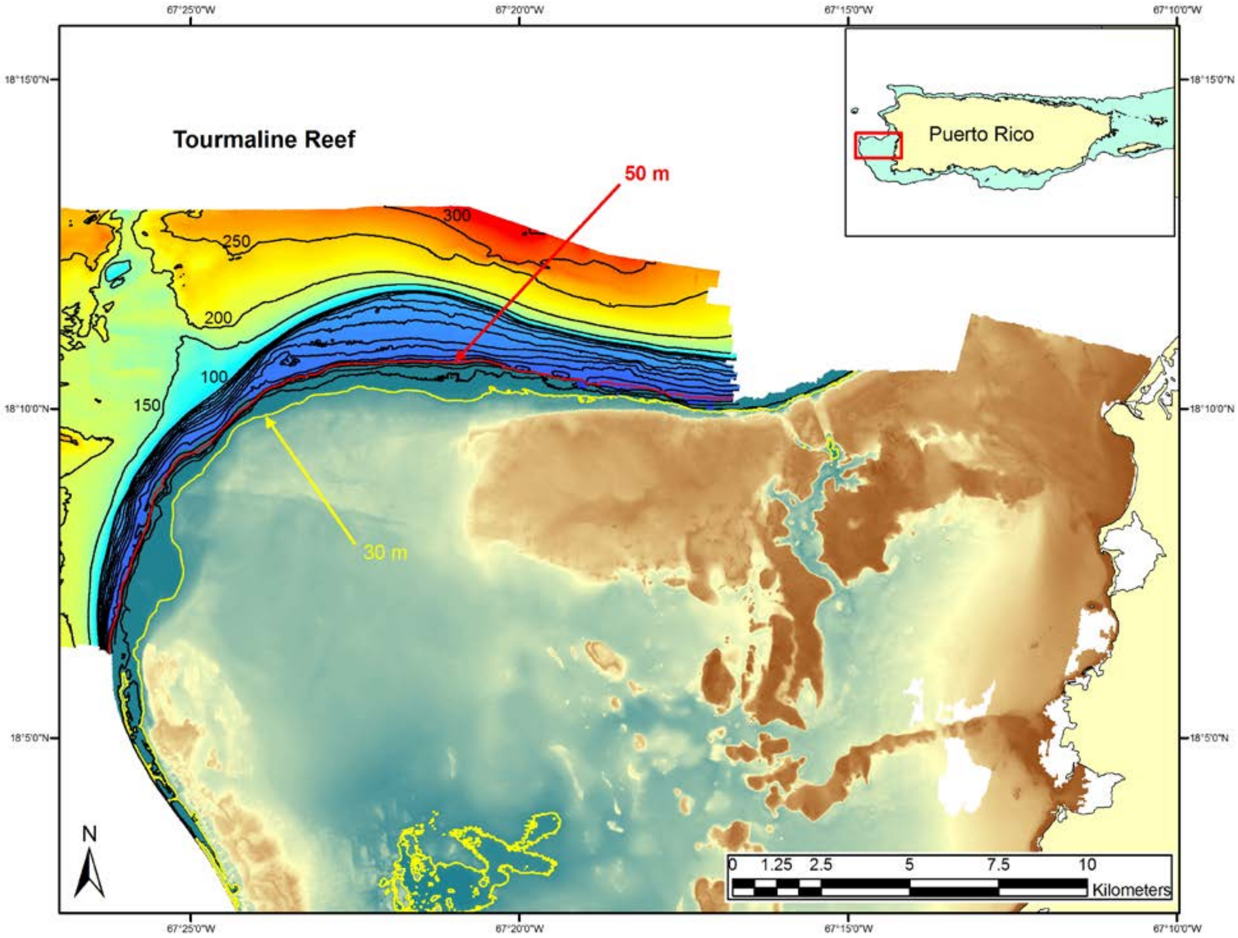


**Figure 1**. Location of Tourmaline Reef in the west coast of Puerto Rico with the multi-beam bathymetry prepared by NOAA (2008) (http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/data.html)

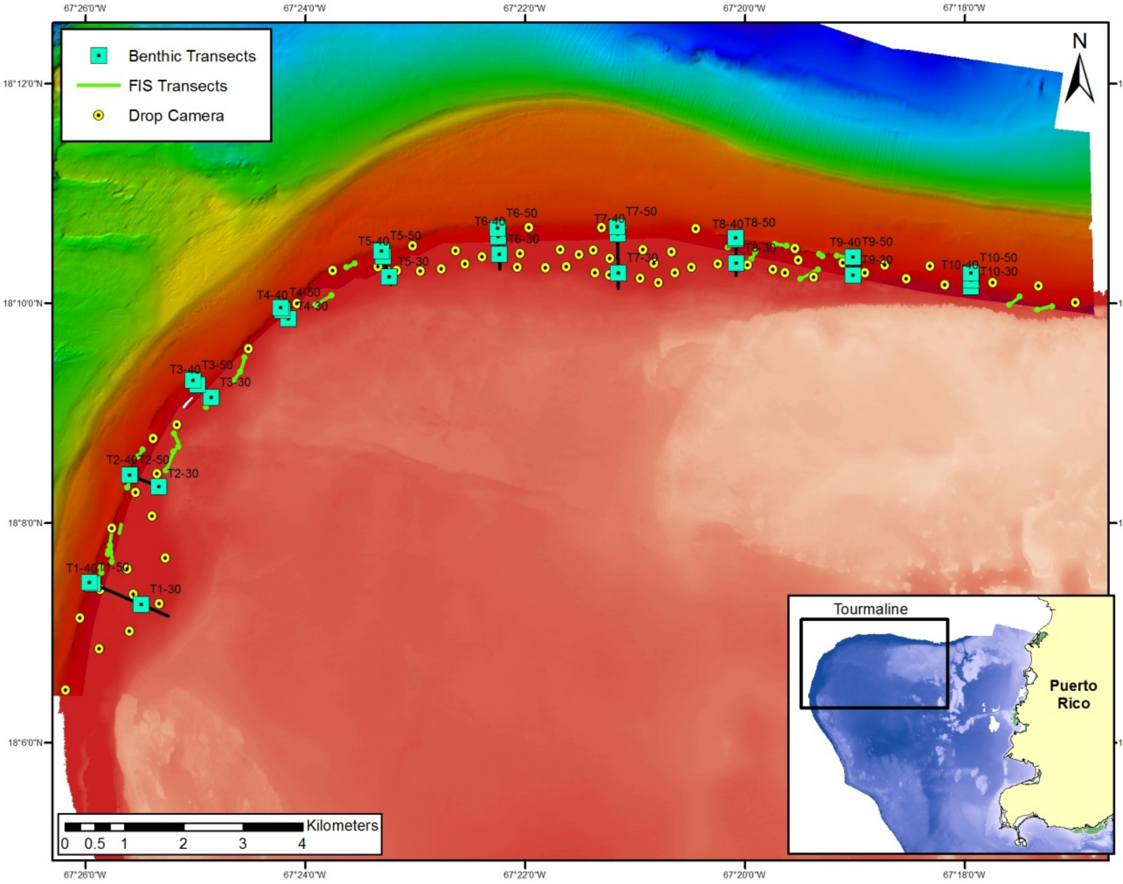


**Figure 2**. Location of sampling stations for biological community characterizations and production of a benthic habitat map within the 30 – 50 m mesophotic region of Tourmaline Reef, Mayaguez, 2012-13.

## VI. Results

### A. Benthic Habitat Map

Five main benthic habitat types were recognized within the 30 – 50 m mesophotic realm of Tourmaline Reef. These included a mostly unconsolidated and abiotic 1) sandy substrate; 2) scattered patch reefs surrounded by sand; 3) colonized pavement; 4) algal rhodolith reef deposits; and 5) a slope wall rocky habitat. The spatial distribution of these benthic habitats is shown in Figure 3. The estimated areal cover of the main benthic habitats within the mesophotic section of Tourmaline Reef is included in Table 1. Throughout most of the northern section of the study area a wide fringe of sandy substrate that extends offshore from the outer neritic shelf towards the shelf edge was found. Sand was the main substrate type in terms of areal cover within the entire 30 – 50 m range with approx. 6.7 km$^2$, or 48.1 % of the total study area (Table 1).

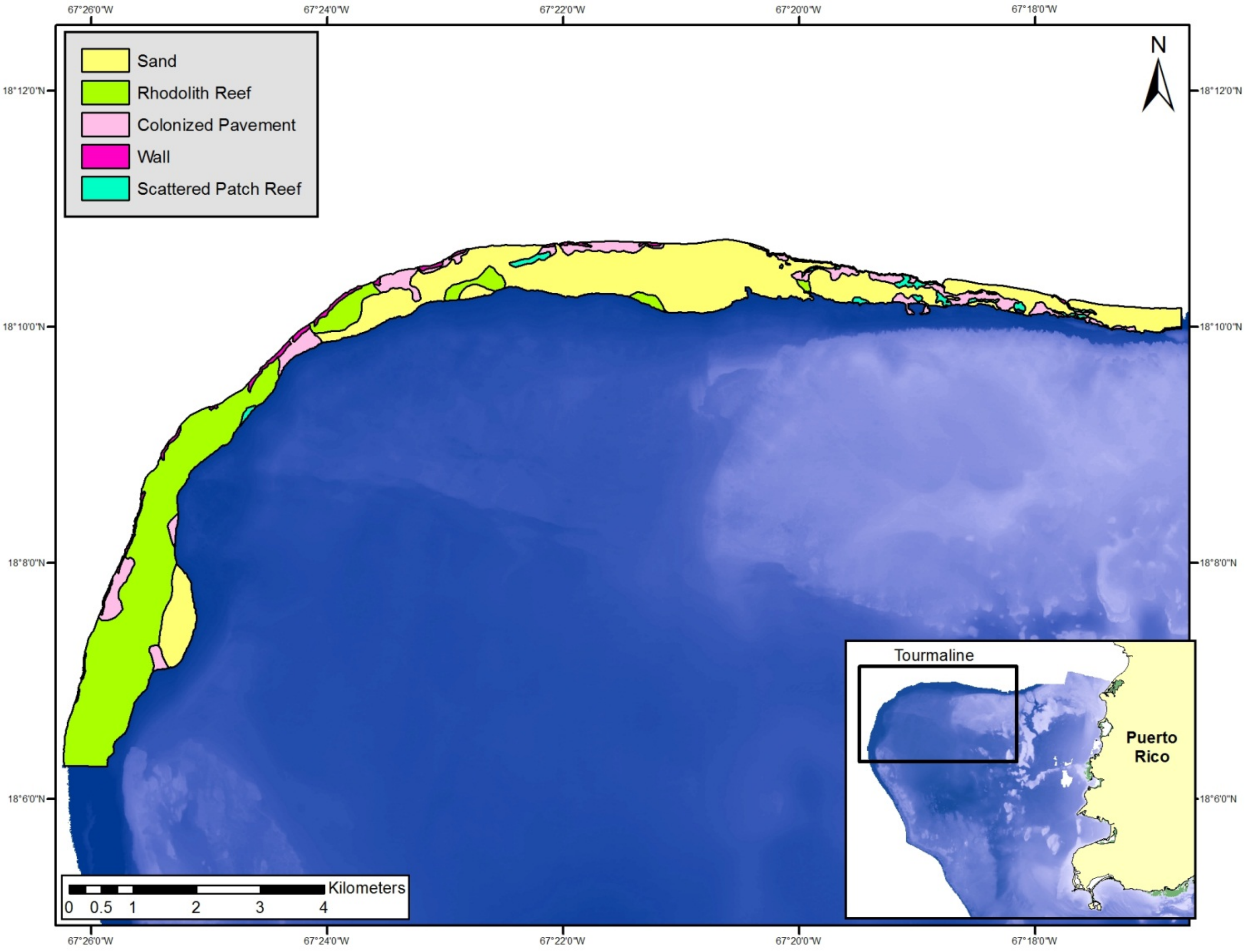


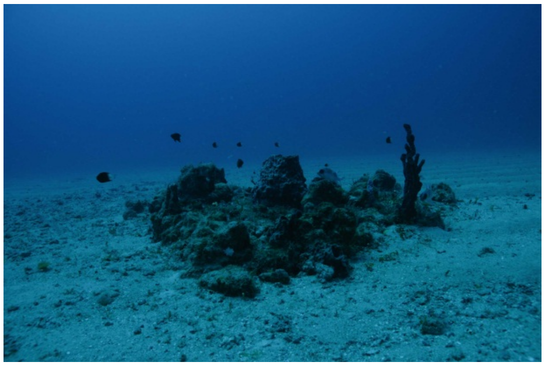
**Figure 3**. Benthic habitat map of the mesophotic region within the 30 – 50 m depth range at Tourmaline Reef, Mayaguez, 2012-13

**Table 1.** Areal distribution of the main mesophotic benthic habitat categories from Tourmaline Reef.

| Benthic Habitat | m2 | km2 | Hectares | % |
|---|---|---|---|---|
| Sand | 6657598 | 6.66 | 665.76 | 48.1 |
| Rhodolith Reef | 5192335 | 5.19 | 519.23 | 37.5 |
| Colonized Pavement | 1407867 | 1.41 | 140.78 | 10.2 |
| Wall | 314937 | 0.31 | 31.49 | 2.3 |
| Scattered Patch Reef | 265463 | 0.27 | 26.55 | 1.9 |
| **Totals** | **13,838,201** | **13.84** | **1,383.81** | **100** |

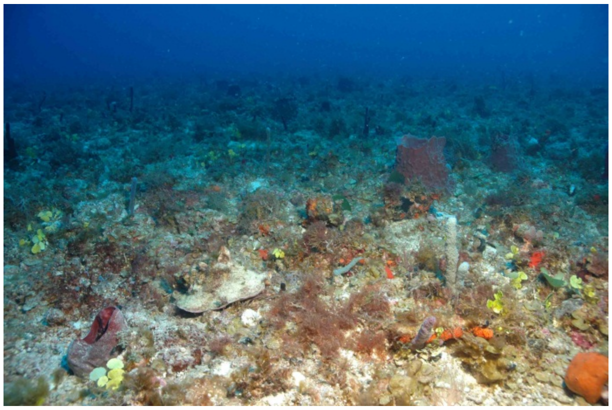
This habitat proved to be mostly abiotic with the sporadic occurrence of highly interspersed gorgonians and occasional sightings of milk and/or queen conch. The sandy habitat appears to be inappropriate for queen conch, as it appears to be too loose (unconsolidated) for conch to move effectively over it. Also, its evidently dynamic state appears to constrain limits growth of the benthic algae that may serve as food for queen conch. The marked formation of ripples denotes that this sediment is in dynamic state and thus, has a high potential for abrasion, which may also limit as well the growth of corals and the formation of coral reefs within this geographic area.

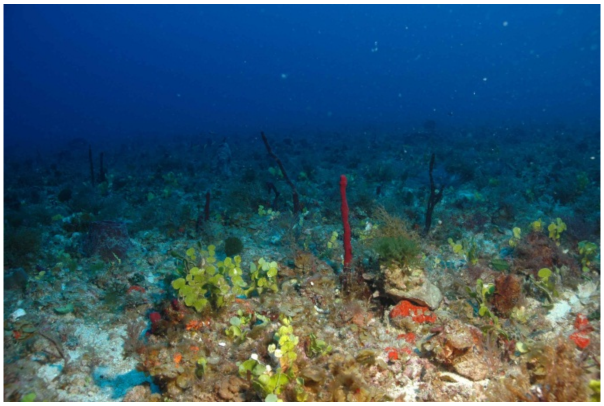
Small, scattered patch reefs of variable dimensions, but not exceeding 20 m in diameter were observed mostly within the northeast section of the sandy habitat at depths of 30 – 40 m, covering an estimated 0.27 km$^2$, or 1.9 % of the total study area (Table 1). These patch reefs appear to be small hard bottom outcrops that rise above the sand deposit. The virtual absence of live coral from these patch reefs and dominance of erect sponges suggest that these features may be sporadically covered by sand in what appears to be a zone of highly dynamic inshore-offshore sand transport.  Evidently, the mesophotic zone at Tourmaline is an interface, or transition zone between the extensive sand deposit of the relatively wide insular shelf and the insular slope.

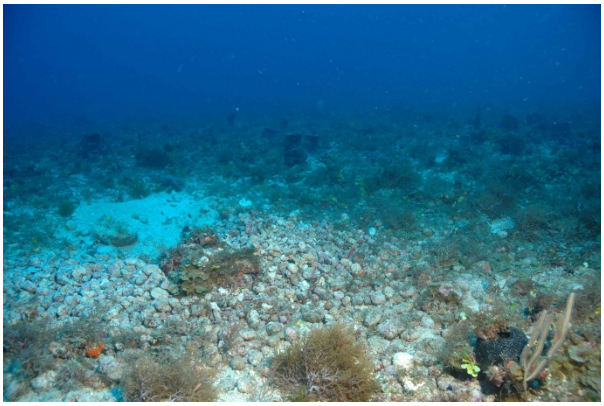


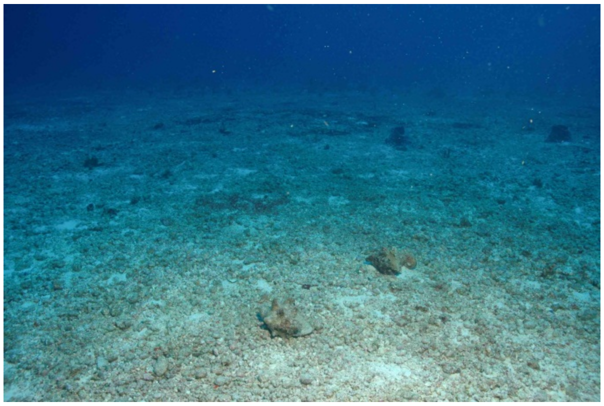
Reaching towards the shelf edge, particularly along the northern section and at the elbow of the study area, but mostly throughout the shelf-edge a low relief hard ground platform largely colonized by turf algae and other encrusting biota was found and categorized as the colonized pavement habitat (Figure 3). Total areal cover of colonized pavement within the 30 – 50 m depth range at Tourmaline Reef was 1.41 km$^2$, or 10.1 % of the total area surveyed (Table 1). This substrate appears be the underlying hard bottom of the Tourmaline Reef insular platform that remains uncovered by sand and has been colonized by benthic algae and other encrusting biota, particularly sponges. The colonized pavement habitat was not uniform across any considerable distance and varied markedly in terms of its colonizing biota from place to place. Sand pockets were found interspersed within the pavement and algal nodules, or rhodoliths were commonly present in sandy/rubble pockets. Scleractinian corals were present in very low density and growing mostly as encrusting colonies of small size that did not contribute in any significant way to the topographic relief and its associated structural/biological complexity within the colonized pavement habitat.

Rhodolith reef deposits were the most prominent benthic habitat present along the western section of the mesophotic outer shelf (Figure 3), and represented the dominant biotic habitat in terms of areal cover with 5.19 km$^2$, or 37.5 % of the total study area within the 30 – 50 m depth range (Table 1). The rhodolith reef at Tourmaline Reef is actually the northern extension of a rhodolith habitat corridor that prevails throughout the deep outer shelf basin at Abrir la Sierra and that was described as the main habitat for a reproductively active population of adult queen conch (Garcia-Sais et al., 2010a). The structural features of the rhodolith reef habitat at Tourmaline Reef resemble those previously described for Abrir la Sierra, perhaps with a more prominent prevalence of sand /rubble pockets intermixed within the rhodolith deposit. Rhodoliths appear to be in dynamic motion since they did not present any colonization by corals or large sponges. The main colonizing agent was the encrusting fan alga, *Lobophora variegata*. Erect barrel sponges, *Xestospongia muta* were the most important contributor to topographic relief at the rhodolith reef.

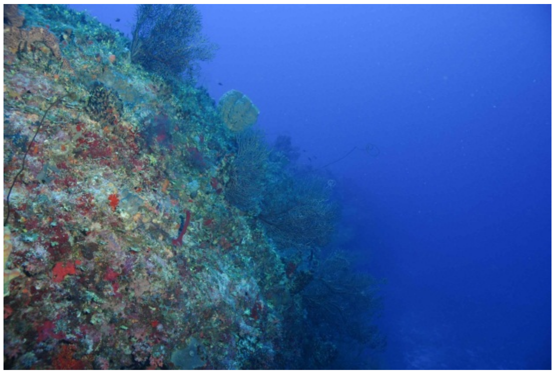


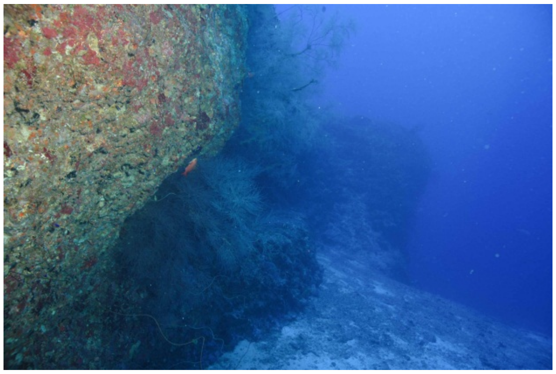


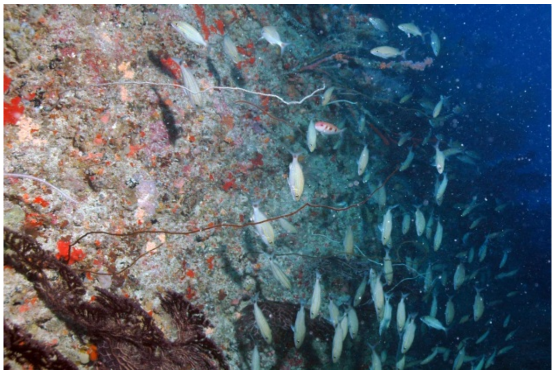




Right at the mid-section of the study area there is an elbow with an almost 90 degree eastward projection from its due south wing. Around this corner, the shelf-edge exhibits an abrupt, vertically projected wall that steps down from a gradually sloping shelf at 40 m to a platform at 60 m (Figure 3). Despite its low areal cover of 0.31 km$^2$, or 2.3 % of the study area (Table1), this wall feature of the insular slope is very important as a habitat for large demersal fishes and appears to represent the upper habitat range of deep sea snappers, such as the blackfin snapper (*Lutjanus buccanella*).







Coral reef habitats within the 30 – 50 m depth range were very scarce at Tourmaline Reef. There is an extensive coral reef system associated with the shelf-edge that has developed as a rather diffuse spur and groove formation from depths of 10 m to a maximum depth of 28 m. The shelf-edge at Tourmaline exhibits a series of steps with hard ground terraces where coral reefs have developed (Garcia-Sais et al., 2012a). There are sections where live scleractinian corals associated with the reef system extend their distribution down to 30 m, but at this point they occur mostly as isolated colonies. Within the rhodolith reef a small biotope of yellow-pencil coral, *Madracis auretenra* was found at a depth of 32 m. This is a coral reef system that served as protective habitat for juvenile coral reef fishes but due to its limited geographic extension was not included in the benthic habitat map.

### B. Sessile-benthic community characterization

The community structure of sessile-benthic biota at transects surveyed within 30 – 50 m evidenced a pattern of higher affinities within habitat types than between depths. All habitat types presented depth overlaps of at least 10 m within the 30 – 50 m range, yet differences of community structure between depths were not statistically significant (PERMANOVA, $p > 0.05$). Distinct patterns of community structure dissimilarities, based on the rank ordination of their percent substrate cover within transects were detected between habitat types. Sessile-benthic community structure at the wall (W) differed significantly from all other benthic habitat types (PERMANOVA, $p < 0.05$; see Appendix 2). Also, statistically significant differences in the taxonomic composition and rank order of sessile-benthic substrate categories were observed between the rhodolith (RR) and colonized pavement (CP) habitats (PERMANOVA, $p < 0.05$). The nMDS plot in Figure 4 shows that the most pronounced community structure differences, as evidenced by the distance between transect data points were between the wall and rhodolith habitats (average dissimilarity = 49.1 %). The main substrate categories contributing dissimilarities between habitat types in pair-way comparisons are summarized in Table 2. Higher percent cover by sponges and octocorals, and lower percent of substrate cover by abiotic categories were consistently measured from the slope wall habitat, as compared to other benthic habitat types. Also, the density of scleractinian coral colonies at the slope wall was higher than at any other habitat type surveyed (Figure 5).

The taxonomic composition and mean percent cover of substrate categories at the slope wall habitat are presented in Table 3. The dominant substrate category in terms of percent cover was turf algae with an average of 48.3%. Calcareous macroalgae, particularly *Halimeda* spp. and fleshy brown macroalgae, including *Dictyota* sp. and *Lobophora variegata* were also present within transects. Sponges were represented by a total of 33 species within the 5 transects surveyed with an average substrate cover of 16%. This was almost twice as high as at any other benthic habitat. *Agelas conifera*, *Plakortis halichondriodes*, *Spirastrella coccinea* and an unidentified encrusting sponge were the main sponge taxa contributing substrate cover at the wall (Table 3).

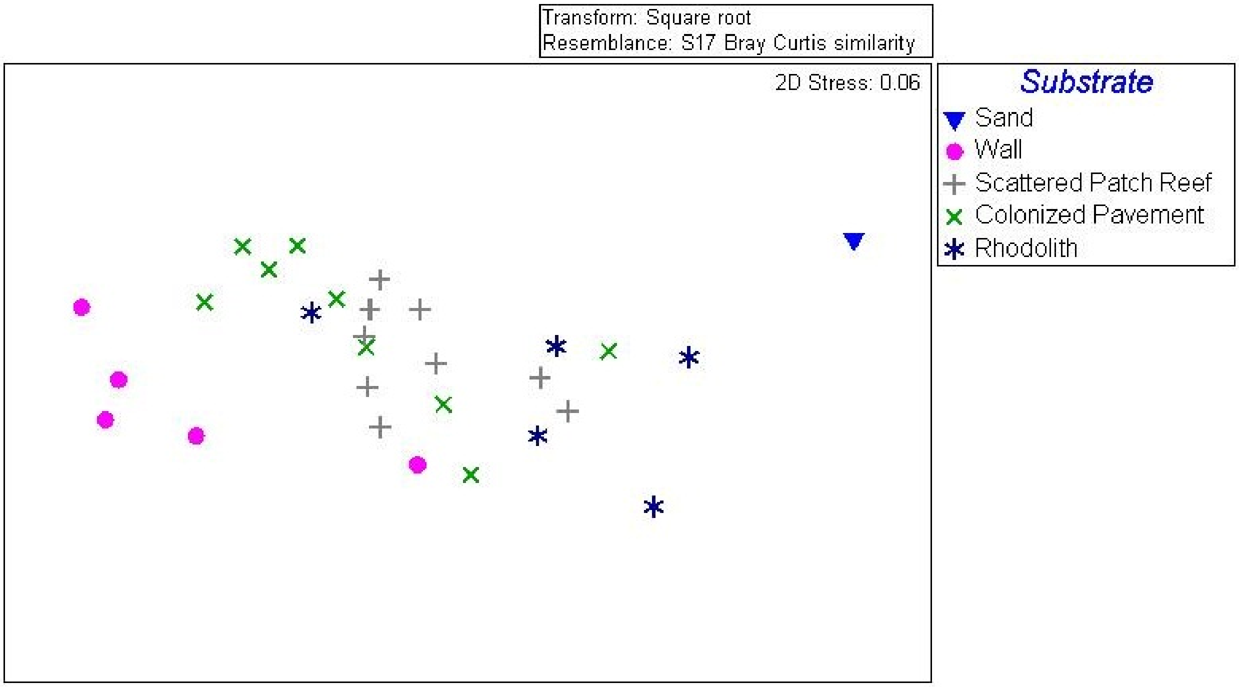


**Figure 4**. Nonmetric multidimensional (nMDS) plot shows the similarity of sessile-benthic organisms between the five substrate types (sand, rhodolith, wall, scattered patch reef, and colonized pavement).

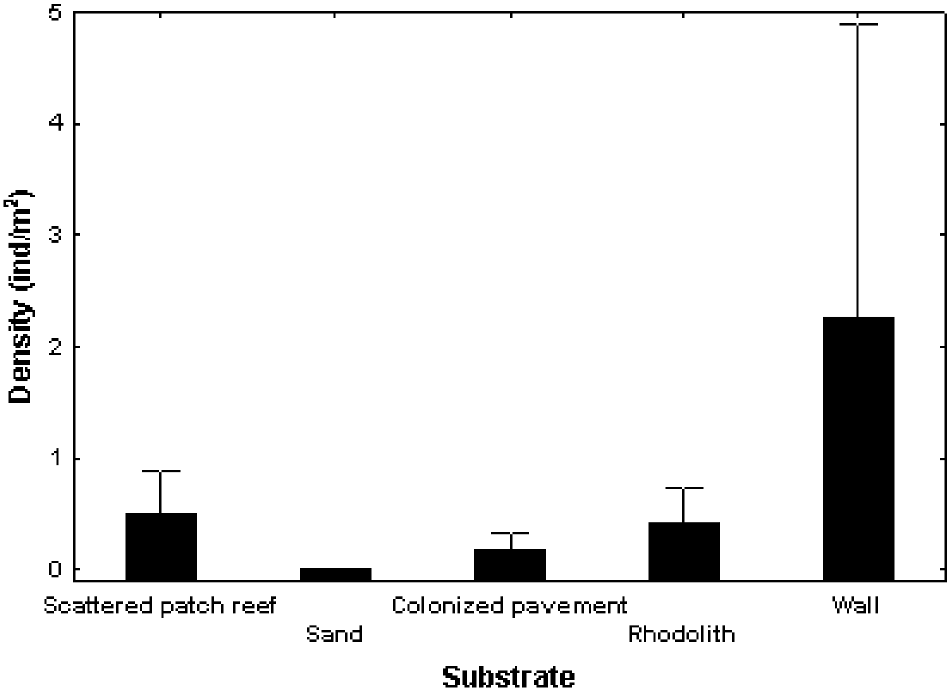


**Figure 5**. Mean density of scleractinian coral colonies (# colonies/$m^2$) from the different benthic habitats at Tourmaline Reef. Bars are standard deviations from replicate transects.

**Table 2**. Results from the SIMPER test identifying the main substrate categories contributing to dissimilarity in pairwise comparisons between benthic habitat types at Tourmaline Reef, Mayaguez 2012-13. All pairwise comparisons presented were statistically different (PERMANOVA; $p < 0.05$).

**Colonized pavement (CP) vs Rhodolith (RO)**

Average dissimilarity = 32.25

| | CP | RO | | | |
|---|---|---|---|---|---|
| | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% |
| Algae | 7.64 | 4.96 | 10.06 | 1.56 | 31.19 |
| Abiotic | 4.77 | 7.41 | 9.93 | 1.54 | 30.79 |
| Cyanobacteria | 0.85 | 2.23 | 6.08 | 1.17 | 18.86 |
| Sponges | 2.65 | 1.92 | 3.23 | 1.55 | 10.01 |

**Scattered patch reef (SPR) vs Wall (W)**

Average dissimilarity = 34.40

| | SPR | W | | | |
|---|---|---|---|---|---|
| | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% |
| Abiotic | 5.95 | 1.54 | 14.4 | 2.22 | 41.85 |
| Sponges | 2.43 | 4.55 | 6.49 | 2 | 18.85 |
| Algae | 7.25 | 7.95 | 3.95 | 1.17 | 11.49 |
| Octocoral | 0.08 | 1.27 | 3.78 | 0.79 | 11 |
| Cyanobacteria | 1.38 | 0.16 | 3.73 | 1.58 | 10.85 |

**Colonized pavement (CO) vs Wall (W)**

Average dissimilarity = 31.38

| | CO | W | | | |
|---|---|---|---|---|---|
| | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% |
| Abiotic | 4.77 | 1.54 | 12.35 | 1.8 | 39.34 |
| Sponges | 2.65 | 4.55 | 5.87 | 2.23 | 18.71 |
| Algae | 7.64 | 7.95 | 4.97 | 1.13 | 15.82 |
| Octocoral | 0.83 | 1.27 | 3.78 | 0.97 | 12.04 |
| Cyanobacteria | 0.85 | 0.16 | 2.54 | 0.72 | 8.1 |

**Rhodolith (RO) vs Wall (W)**

Average dissimilarity = 49.21

| | RO | W | | | |
|---|---|---|---|---|---|
| | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% |
| Abiotic | 7.41 | 1.54 | 18.69 | 2.13 | 37.98 |
| Algae | 4.96 | 7.95 | 10.1 | 1.65 | 20.53 |
| Sponges | 1.92 | 4.55 | 8.12 | 2.39 | 16.5 |
| Cyanobacteria | 2.23 | 0.16 | 6.42 | 1.14 | 13.05 |
| Octocoral | 0 | 1.27 | 3.91 | 0.78 | 7.94 |

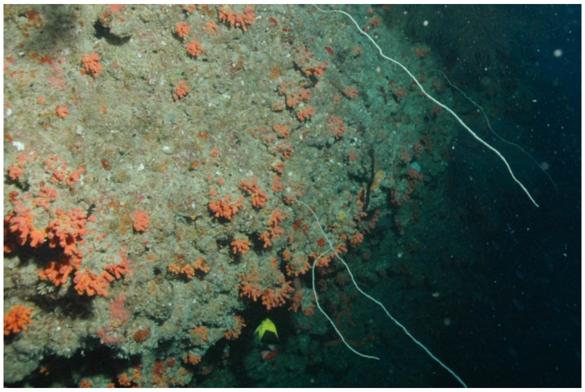
**Table 3**. Taxonomic composition and percent substrate cover of sessile-benthic categories within photo-transects at the slope wall habitat, Tourmaline Reef, 2012-13.

| | **Wall-Transects** | | | | | |
|---|---|---|---|---|---|---|
| **Substrate Categories** | **T1-50m** | **T2-50m** | **T3-50m** | **T8-50m** | **T9-50m** | **Mean** |
| Abiotic | 42.6 | | 1.3 | | | **8.8** |
| Benthic algae | | | | | | |
| Algal turf | 7.2 | 1.7 | 9.4 | 68.0 | 73.6 | **32.0** |
| Calcareous algae | 15.4 | 2.4 | 8.7 | | | **5.3** |
| *Halimeda* spp. | 2.5 | 6.3 | 4.7 | | | **2.7** |
| Fleshy algae | | | | | | |
| *Dictyota* spp. | 4.9 | 1.3 | 6.6 | | | **2.6** |
| *Lobophora variegata* | 5.4 | 7.3 | 4.3 | | | **3.4** |
| Mixed macroalgae | | 1.9 | 9.4 | 0.7 | | **2.4** |
| Total Benthic algae | 35.3 | 20.9 | 43.1 | 68.7 | 73.6 | **48.3** |
| Cyanobacteria | | | 0.7 | | | **0.1** |
| Sponges | | | | | | |
| *Agelas conifera* | 1.4 | | 7.3 | | | **1.7** |
| *Agelas dispar* | | | | | 0.7 | **0.1** |
| *Aiolochroia crassa* | | | | 0.7 | | **0.1** |
| *Aka coralliphaga* | | | | 0.7 | | **0.1** |
| *Aka xamaycaensis* | | | | | 0.7 | **0.1** |
| *Amphimedon compressa* | 0.8 | | 0.7 | | | **0.3** |
| *Aplysina cauliformis* | | | | 0.7 | | **0.1** |
| *Aplysina fistularis* | 1.7 | | | 0.7 | | **0.5** |
| *Callyspongia plicifera* | | | | | 0.7 | **0.1** |
| *Callyspongia tenerrima* | | | | 0.7 | | **0.1** |
| *Clathria* spp. | | 0.7 | | | 2.0 | **0.5** |
| *Clathria virgultosa* | | | | 1.3 | | **0.3** |
| *Ircinia felix* | | | | 0.7 | 0.7 | **0.3** |
| *Ircinia* spp. brown | | | 0.7 | | | **0.1** |
| *Monanchora arbuscula* | | | 0.7 | | | **0.1** |
| *Myrmekioderma gyroderma* | | 0.7 | 0.7 | | | **0.3** |
| *Myrmekioderma rea* | 0.8 | | | | | **0.2** |
| *Niphates digitalis* | | | 0.7 | | | **0.1** |
| *Niphates erecta* | 0.8 | | | | | **0.2** |
| *Oceanapia bartschi* | | 2.8 | 0.7 | | | **0.7** |
| *Petrosia weinbergi* | | | 4.5 | | | **0.9** |
| *Plakortis angulospiculatus* | 0.8 | | 1.3 | | 0.7 | **0.6** |
| *Plakortis halichondriodes* | 3.1 | 1.5 | 0.7 | 0.7 | | **1.2** |
| *Plaktoris* spp. | | 0.7 | | | | **0.1** |
| *Prosuberites laughlini* | 0.8 | | | 1.3 | 1.3 | **0.7** |
| *Spirastrella coccinea* | 2.4 | 2.6 | | 0.7 | 0.7 | **1.3** |
| *Spirastrella hartmani* | | 0.7 | | | | **0.1** |
| unknown black sponge | | 0.7 | | | | **0.1** |
| unknown encrusting | 0.8 | 4.3 | | 2.0 | 11.3 | **3.7** |

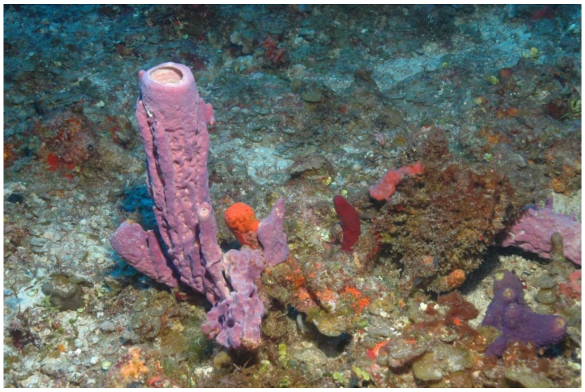
**Table 3. Continued**

| | | | | | | |
|---|---|---|---|---|---|---|
| unknown lobate | | 0.8 | | | | **0.2** |
| unknown sponge | | 0.7 | | 1.3 | 1.4 | **0.7** |
| *Verongula rigida* | | | | 0.7 | | **0.1** |
| Total Sponges | 13.4 | 16.2 | 17.9 | 12.0 | 2.7 | **16.0** |
| Scleractinian corals | | | | | | |
| *Montastraea cavernosa* | | | 2.0 | | | **0.4** |
| *Tubastraea coccinea* | | | | | 0.7 | **0.1** |
| Total Corals | | | 2.0 | | 0.7 | **0.5** |
| Invertebrates | | | | | | |
| Tunicate | | | | 0.7 | | **0.1** |
| Total Invertebrates | | | | 0.7 | | **0.1** |
| Octocorals | | | | | | |
| *Iciligorgia schrammi* | | 19.1 | | | 1.4 | **4.1** |
| *Pseudopterogorgia* spp. | | | | 0.7 | | **0.1** |
| Total Octocorals | | 19.1 | | 0.7 | 1.4 | **4.2** |

Octocorals, particularly the deep water fan, *Iciligorgia schrammi* were present at the wall with a mean cover of 4.2 %. Scleractinian corals only contributed a mean 0.5 % substrate cover at the slope wall habitat, but this was higher than at any other benthic habitat surveyed (Figure 5). Great star coral, *Montastraea cavernosa* and orange cup coral, *Tubastraea coccinea* were the only scleractinian species present within transects.



The rhodolith reef habitat was characterized by very high percent of abiotic cover associated with sand (mean = 57.8%). Evidently, the rhodolith deposit is very much subjected to constant sand abrasion and as a result, displayed relatively low colonization by biological components. The encrusting fan alga, *Lobophora variegata* was the dominant biological category in terms of substrate cover with a mean of 12.3 %. The total cover by benthic algae, with contributions from calcareous (*Halimeda spp.*), fleshy brown (*Dictyota spp*.), turf, and other mixed macroalgae was 27.2 %.  Sponges, represented by 17 species were the main invertebrate taxa in terms of substrate cover with a mean of 4.5 % within photo-transects surveyed. Scleractinian corals were only represented by one colony of great star coral, *Montastraea cavernosa* within transects, yielding an average cover of 0.1 % (Table 4).



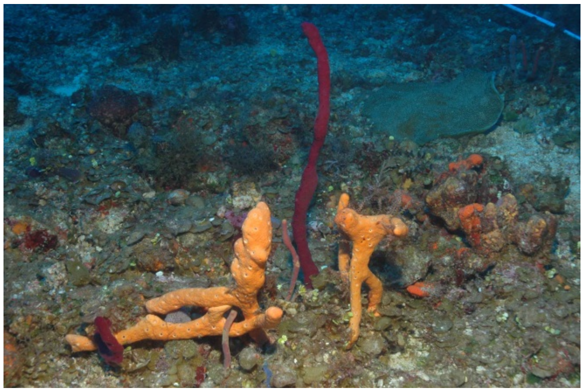


**Table 4**. Taxonomic composition and percent substrate cover of sessile-benthic categories within photo-transects at the rhodolith reef habitat, Tourmaline Reef, Mayaguez 2012-13.

| | **Rhodolith Reef Transects** | | | | | |
|---|---|---|---|---|---|---|
| **Substrate Categories** | **T1-40m** | **T2-40m** | **T4-40m** | **T4-50m** | **T5-50m** | **Mean** |
| Abiotic | 18.0 | 56.7 | 68.0 | 58.0 | 88.5 | **57.8** |
| Benthic algae | | | | | | |
| Algal turf | | | 15.4 | 2.0 | | **3.5** |
| Calcareous algae | 0.5 | 0.5 | | 0.5 | | **0.3** |
| *Halimeda* spp. | 2.0 | 1.0 | 0.6 | 5.5 | | **1.8** |
| Fleshy algae | | | | | | |
| *Dictyota* spp. | 7.5 | | 8.6 | 1.0 | 0.5 | **3.5** |
| *Lobophora variegata* | 56.5 | 2.2 | 0.6 | 2.0 | | **12.3** |
| Mixed macroalgae | 8.0 | 6.5 | 3.4 | 4.0 | 7.0 | **5.8** |
| Total Benthic Algae | 74.5 | 10.2 | 28.6 | 15.0 | 7.5 | **27.2** |
| Cyanobacteria | | 31.7 | 1.1 | 7.5 | 3.0 | **8.7** |
| Sponges | | | | | | |
| *Agelas clathrodes* | 2.0 | 0.5 | | | | **0.5** |
| *Agelas conifera* | 0.5 | | | | | **0.1** |
| *Aplysina cauliformis* | 1.0 | | | | | **0.2** |
| *Cinachyrella kuekenthali* | | | 0.6 | | | **0.1** |
| *Desmapsamma anchorata* | | | | | 0.5 | **0.1** |
| *Ircinia felix* | | | | 0.5 | | **0.1** |
| *Ircinia* spp. *white* | 0.5 | | | | | **0.1** |
| *Myrmekioderma gyroderma* | 0.5 | | | | | **0.1** |
| *Petrosia pellasarca* | 0.5 | | | | | **0.1** |
| *Plakortis angulospiculatus* | 0.5 | | | | | **0.1** |
| *Scopalina ruetzleri* | | | | 0.5 | | **0.1** |
| *Spirastrella coccinea* | 1.0 | | | | 0.5 | **0.3** |
| *unknown black sponge* | | | | 7.0 | | **1.4** |
| unknown encrusting | 0.5 | 0.5 | 1.1 | 2.0 | | **0.8** |
| unknown sponge | | | | 5.0 | | **1.0** |
| *Verongula reiswigi* | | 0.5 | | | | **0.1** |
| *Xestospongia muta* | | | 0.6 | | | **0.1** |
| Total Sponges | 7.0 | 1.5 | 2.3 | 1.5 | 1.0 | **4.5** |
| Scleractinian corals | | | | | | |
| *Montastraea cavernosa* | 0.5 | | | | | **0.1** |
| Total Corals | 0.5 | | | | | **0.1** |

Colonized pavement and scattered patch reef habitats did not differ significantly in terms of community structure from each other (PERMANOVA; $p > 0.05$; Appendix 2). The composition of substrate categories within photo-transects surveyed at both benthic habitats are presented in Tables 5 and 6. Both habitats exhibited a mean abiotic cover within the 26 – 37% range, mean benthic algal cover within the 45 – 55 % range, cyanobacteria cover within the 2 – 3% range, and sponge cover within the 6 – 8 % range. In terms of species richness, sponges were the main taxa with more than 30 species represented within transects at both habitat types. The high similarity of sessile-benthic community structure between both habitat types stems from the fact that although the colonized pavement habitat is a more continuous environment, the attachment surface for sessile-benthic biota is essentially similar. Also, both share a similar flat seafloor slope and strong influence of abrasive conditions upon benthic components. Despite what appear to be adequate hard bottom conditions for attachment and good light penetration, live scleractinian coral cover was very low on both of these habitats probably due to the intense abrasion associated with sand transport (Tables 5 - 6).

**Table 5**. Taxonomic composition and percent substrate cover of sessile-benthic categories within photo-transects at the colonized pavement habitat, Tourmaline Reef, 2012-13.

| | **Colonized Pavement-Transects** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Substrate Categories** | **T5-40m** | **T6-50m** | **T7-30m** | **T8-30m** | **T8-40m** | **T9-30m** | **T9-40m** | **T10-30m** | **T10-40m** | **Mean** |
| Abiotic | 79.0 | 36.0 | 46.9 | 32.0 | 18.7 | 7.6 | 1.0 | 12.5 | 3.0 | **26.3** |
| Benthic algae | | | | | | | | | | |
| Algal turf | | 7.0 | 24.0 | 49.5 | 57.2 | 7.3 | 73.0 | 84.5 | 84.5 | **43.0** |
| Calcareous algae | | | 0.5 | | | | | | | **0.1** |
| *Halimeda* spp. | 3.0 | 2.5 | 2.0 | | | | 1.0 | | | **0.9** |
| Fleshy algae | | | | | | | | | | |
| *Dictyota* spp. | 6.0 | 1.5 | 0.5 | 2.0 | 1.5 | 0.5 | | | | **1.3** |
| *Lobophora variegata* | | 1.0 | 0.5 | | | | | | | **0.2** |
| Mixed macroalgae | 3.5 | 23.5 | 12.5 | 8.0 | 15.5 | 12.2 | 9.5 | | | **9.4** |
| Total Benthic algae | 12.5 | 35.5 | 40.0 | 59.5 | 74.2 | 20.0 | 83.5 | 84.5 | 84.5 | **54.9** |
| Cyanobacteria | 1.0 | 18.0 | 1.5 | | 1.5 | | | | | **2.4** |
| Sponges | | | | | | | | | | |
| *Aiolochroia crassa* | 0.5 | 0.5 | | | | 1.0 | | 0.5 | | **0.3** |
| *Aiolochroia crassa yellow* | | | 0.5 | | | | | 0.5 | | **0.1** |
| *Aplysina archeri* | | | | 1.0 | | | | | | **0.1** |
| *Aplysina cauliformis* | | | | | 1.4 | | | | | **0.2** |
| *Aplysina fistularis* | 0.5 | | | | | | | 0.5 | | **0.1** |
| *Aplysina insularis* | | | 0.5 | | | | | | | **0.1** |
| *Callyspongia armigera* | | | 0.5 | | | | | | | **0.1** |

**Table 5. Continued**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Callyspongia fallax* | | | 0.5 | | | | | 0.5 | | **0.1** |
| *Cinachyrella kuekenthali* | | | | 1.0 | | | | | | **0.1** |
| *Clathria schoenus* | | 0.5 | | | 0.5 | | 0.5 | | 1.5 | **0.3** |
| *Cribrochalina vasculum* | | | 1.6 | | | | | | | **0.2** |
| *Desmapsamma anchorata* | | | | | 0.5 | | | | 0.5 | **0.1** |
| *Iotrochota brotulata* | | | 0.5 | | | | | | | **0.1** |
| *Ircinia felix* | | | | 0.5 | | | | | | **0.1** |
| *Ircinia strobilina* | | 0.5 | 0.5 | | | | | | | **0.1** |
| *Myrmekioderma gyroderma* | 1.0 | | | | | | | | | **0.1** |
| *Niphates alba* | 0.5 | | | | | | | | | **0.1** |
| *Niphates erecta* | | 0.5 | | 2.0 | | | | | 0.5 | **0.3** |
| *Oceanapia bartschi* | 0.5 | | 0.5 | | | | | | | **0.1** |
| *Petrosia weinbergi* | | | | 1.0 | | | | | | **0.1** |
| *Plakortis angulospiculatus* | | | 0.5 | | | | | | | **0.1** |
| *Plakortis halichondriodes* | | | | | | 1.4 | | | | **0.2** |
| *Plaktoris* spp. | | | | | 0.5 | | | | | **0.1** |
| *Prosuberites laughlini* | 0.5 | | | | | | | | | **0.1** |
| *Smenospongia conulosa* | 1.5 | | | | | | | | | **0.2** |
| *Spheciospongia vesparium* | | | 0.5 | 0.5 | | | | | | **0.1** |
| *Spirastrella coccinea* | 0.5 | | 1.0 | | 0.5 | 0.5 | | | | **0.3** |
| unknown massive | | | | | | 0.5 | | | | **0.1** |
| unknown encrusting | 0.5 | 1.0 | 1.5 | 1.0 | 1.0 | | | 0.5 | 1.5 | **0.8** |
| unknown lobate | | 0.5 | 0.5 | 0.5 | | | | | | **0.2** |
| unknown sponge | | | | 0.5 | | 1.2 | 0.5 | | | **0.2** |
| *Verongula rigida* | 1.0 | | | | 0.5 | | 0.5 | | | **0.2** |
| *Xestospongia muta* | 0.5 | 7.0 | 2.5 | | | 1.0 | 4.5 | | 6.0 | **2.4** |
| Total Sponges | 7.5 | 1.5 | 11.6 | 8.0 | 4.9 | 5.6 | 5.5 | 2.5 | 11.0 | **7.5** |
| Octocorals | | | | | | | | | | |
| *Eunicea* spp. | | | 0.5 | | 1.0 | 1.5 | | | 1.0 | **0.4** |
| *Iciligorgia schrammi* | | | | | | | 1.0 | | | **0.1** |
| *Muricea* spp. | | | | | | 1.5 | | | | **0.2** |
| *Plexaurella* spp. | | | | | | | | 0.5 | | **0.1** |
| *Pseudoplexaura* spp. | | | | 0.5 | | 1.5 | | | 0.5 | **0.3** |
| Total Octocorals | | | 0.5 | 0.5 | 1.0 | 4.5 | 1.0 | 0.5 | 1.5 | **1.1** |

**Table 6**. Taxonomic composition and percent substrate cover of sessile-benthic categories within photo-transects at the scattered patch reef habitat, Tourmaline Reef, 2012-13.

| | **Scattered Patch Reef-Transect** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Substrate Categories** | **T1-30m** | **T2-30m** | **T3-30m** | **T3-40m** | **T4-30m** | **T5-30m** | **T6-40m** | **T7-40m** | **T7-50m** | **Mean** |
| Abiotic | 39.8 | 23.0 | 29.5 | 25.0 | 28.0 | 31.5 | 27.4 | 61.9 | 65.0 | **36.8** |
| Benthic algae | | | | | | | | | | |
| Algal turf | | 1.0 | | | | 2.0 | 0.5 | 19.6 | 11.0 | **3.8** |
| Calcareous algae | | | | 1.2 | | | | | | **0.1** |
| *Halimeda* spp. | 4.2 | 1.5 | 4.0 | 1.4 | 3.5 | 1.5 | 7.6 | 1.0 | 3.0 | **3.1** |
| Fleshy algae | | | | | | | | | | |
| *Dictyota* spp. | 9.5 | 24.0 | 11.5 | 16.3 | 3.5 | 32.0 | 3.5 | 0.5 | 2.0 | **11.4** |
| *Lobophora variegata* | 1.6 | 1.5 | 22.5 | 17.5 | 9.0 | 9.0 | 2.5 | | | **7.1** |
| Mixed macroalgae | 27.7 | 25.5 | 26.0 | 23.3 | 26.5 | 9.5 | 37.2 | 1.2 | 7.5 | **20.5** |
| *Sargassum hystrix* | | | 1.0 | | | | | | | **0.1** |
| Total Benthic algae | 43.1 | 53.5 | 65.0 | 59.6 | 42.5 | 54.0 | 51.3 | 22.3 | 23.5 | **46.1** |
| Cyanobacteria | 2.0 | 1.0 | 3.0 | 0.6 | | 0.5 | 4.4 | 4.0 | 7.5 | **2.6** |
| Sponges | | | | | | | | | | |
| *Agelas clathrodes* | | 0.5 | | | | | | | | **0.1** |
| *Agelas conifera* | | | | 0.6 | | | 0.5 | | | **0.1** |
| *Agelas dispar* | | | | | | | 0.5 | | | **0.1** |
| *Amphimedon compressa* | | 0.5 | | | 0.5 | | | | | **0.1** |
| *Aplysina cauliformis* | 0.5 | | | | | 1.0 | | | 1.0 | **0.3** |
| *Cinachyrella kuekenthali* | | | | | | | | | 1.0 | **0.1** |
| *Cliona delitrix* | | | | | | | 0.5 | | | **0.1** |
| *Cribrochalina vasculum* | 0.5 | | | 0.6 | | 1.5 | | | | **0.3** |
| *Desmapsamma anchorata* | | | | | | | | | 0.5 | **0.1** |
| *Erylus formosus* | | | | | | 1.0 | | | 0.5 | **0.2** |
| *Halisarca caerulea* | 0.5 | | | | | | | | | **0.1** |
| *Ircinia campana* | | | | | | | 0.5 | | | **0.1** |
| *Ircinia felix* | 0.5 | | | | | | | | | **0.1** |
| *Ircinia strobilina* | | | | | 0.5 | | 0.5 | | | **0.1** |
| *Ircinia* spp. brown | | 0.5 | | 0.6 | | | | | | **0.1** |
| *Myrmekioderma gyroderma* | | | 0.5 | | | | | | | **0.1** |
| *Neopetrosia proxima* | 0.5 | | | | 0.5 | | | | | **0.1** |
| *Neopetrosia* spp. | | | | 2.4 | | | | | | **0.3** |
| *Niphates erecta* | 1.0 | | | | | | | 0.5 | | **0.2** |
| *Oceanapia bartschi* | | | | | | | 0.5 | | | **0.1** |
| *Plakortis angulospiculatus* | 0.5 | | | | | | | | | **0.1** |
| *Prosuberites laughlini* | | | | | | | | 0.5 | | **0.1** |
| *Scopalina ruetzleri* | | 0.5 | | | | | | | | **0.1** |
| *Spheciospongia vesparium* | | 0.5 | | | | | | | | **0.1** |
| *Spirastrella coccinea* | 1.2 | | | | | | | | 0.5 | **0.2** |
| unknown encrusting | 0.5 | 0.5 | | | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | **0.6** |
| unknown lobate | | | 1.0 | | 0.5 | | 0.5 | | | **0.2** |
| unknown rope | | | | 2.4 | | 0.5 | | | | **0.3** |

**Table 6. Continued**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| unknown sponge | | | | 0.6 | | | | | | **0.1** |
| *Verongula reiswigi* | | | | | | | 0.5 | | | **0.1** |
| *Verongula rigida* | | | | 0.6 | | 0.5 | | 0.5 | | **0.2** |
| *Xestospongia muta* | | 1.5 | 0.5 | 0.6 | | 7.5 | 11.1 | 1.0 | | **2.5** |
| Total Sponges | 5.7 | 4.5 | 2.0 | 8.2 | 2.5 | 13.5 | 17.2 | 3.0 | 4.0 | **6.7** |
| Scleractinian corals | | | | | | | | | | |
| *Agaricia agaricites* | 0.1 | | | | | | | | | **0.0** |
| *Montastraea cavernosa* | | | | | | | 0.5 | | | **0.1** |
| Total Corals | 0.1 | | | | | | 0.5 | | | **0.1** |
| Invertebrates | | | | | | | | | | |
| *Tridedemnum solidum* | 0.5 | | | | | | | | | **0.1** |
| Total Invertebrates | 0.5 | | | | | | | | | **0.1** |
| Octocorals | | | | | | | | | | |
| *Muricea* spp. | | | | | | 0.5 | | | | **0.1** |
| Total Octocorals | | | | | | 0.5 | | | | **0.1** |
| Unknown organism | 0.5 | | | | | | | | | **0.1** |

### C. Fish and shellfish community characterization

A total of 78 fish and three shellfish species were observed within mesophotic habitats during diver surveys at Tourmaline Reef. The taxonomic composition of reef fishes and their rank order abundance within belt transects surveyed at depths between 30 – 50 m exhibited higher affinities within habitat types than between depths, a pattern that is consistent with the sessile-benthic community characterization for this site. All benthic habitat types had depth overlaps of at least 10 m within the 30 – 50 m range, yet differences of community structure between depths were not statistically significant (PERMANOVA, $p > 0.05$). Distinct patterns of fish community structure dissimilarities were detected between benthic habitat types (PERMANOVA; $p < 0.05$, see Appendix 3). Fish community structure at the slope wall (W) differed significantly from all other benthic habitat types. Also, statistically significant differences in the taxonomic composition and rank order of fishes were observed between the rhodolith (RR) and scattered patch reef habitats (SPR). The nMDS plot in Figure 6 shows that the most pronounced fish community structure differences, as evidenced by the distance between transect data points were between the slope wall and rhodolith habitats (average dissimilarity = 96.1 %). The main fish taxa contributing dissimilarities between habitat types are summarized in Table 7. The complete SIMPER analysis of fish species contributing to similarities within benthic habitat types and to dissimilarities between benthic habitats in pairwise comparisons is included as Appendix 4.

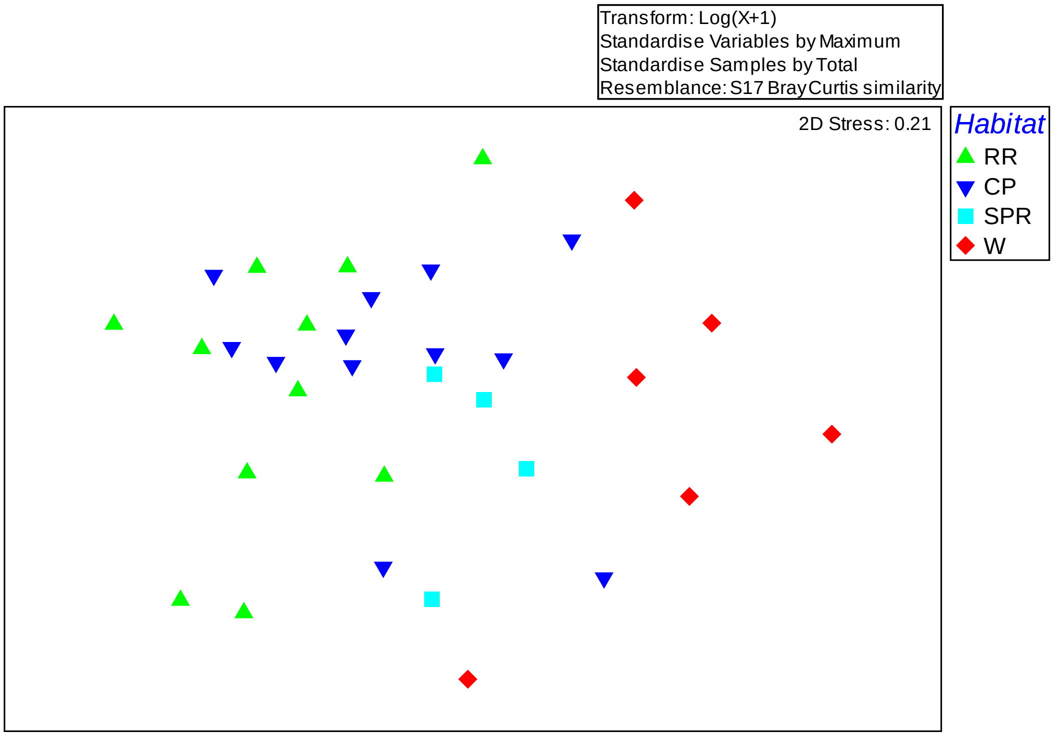


**Figure 6**. Nonmetric multidimensional (nMDS) plot showing the similarity fish taxonomic composition and rank order of abundance between habitat types (rhodolith-RR, Wall-W, Scattered Patch Reef-SPR, and Colonized Pavement-CP.

**Table 7**. Results from SIMPER identifying the main fish taxonomic categories contributing to dissimilarity in pairwise comparisons between mesophotic benthic habitat types at Tourmaline Reef, Mayaguez 2012-13. Pairwise comparisons shown were statistically different (PERMANOVA; $p < 0.05$).

***Groups RR & W***

Average dissimilarity = 96.14

PERMANOVA test; p = 0.002

| Species | Group RR Av.Abund | Group W Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Stegastes partitus | 24.12 | 0.00 | 12.06 | 0.90 | 12.54 | 12.54 |
| Lutjanus bucannella | 0.00 | 7.86 | 3.93 | 0.86 | 4.09 | 16.63 |
| Balistes vetula | 6.04 | 3.06 | 3.82 | 0.66 | 3.98 | 20.61 |
| Caranx lugubris | 3.23 | 5.09 | 3.70 | 0.61 | 3.85 | 24.46 |
| Serranus tigrinus | 6.17 | 0.00 | 3.09 | 0.61 | 3.21 | 27.67 |
| Gramma loreto | 0.00 | 5.64 | 2.82 | 1.20 | 2.93 | 30.60 |
| Elagatis bipinnulata | 2.41 | 3.71 | 2.72 | 0.71 | 2.83 | 33.43 |
| Epinephelus fulva | 0.92 | 4.96 | 2.69 | 0.65 | 2.80 | 36.23 |
| Lachnolaimus maximus | 0.00 | 5.37 | 2.69 | 0.44 | 2.79 | 39.02 |
| Epinephelus guttatus | 3.72 | 1.86 | 2.28 | 0.79 | 2.37 | 41.39 |

**Table 7. Continued**

***Groups CP & W***

Average dissimilarity = 93.70

PERMANOVA test; p = 0.001

| | Group CP | Group W | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| Stegastes partitus | 17.03 | 0.00 | 8.52 | 0.92 | 9.09 | 9.09 |
| Lutjanus buccanella | 1.39 | 7.86 | 4.00 | 0.93 | 4.27 | 13.36 |
| Epinephelus fulva | 4.94 | 4.96 | 3.98 | 0.72 | 4.25 | 17.61 |
| Thalassoma bifasciatum | 7.92 | 0.00 | 3.96 | 0.64 | 4.23 | 21.83 |
| Lutjanus analis | 7.73 | 0.00 | 3.87 | 0.73 | 4.13 | 25.96 |
| Epinephelus guttatus | 7.13 | 1.86 | 3.56 | 0.91 | 3.80 | 29.76 |
| Halichoeres garnoti | 7.14 | 1.90 | 3.22 | 1.14 | 3.44 | 33.20 |
| Balistes vetula | 3.98 | 3.06 | 3.02 | 0.63 | 3.22 | 36.42 |

***Groups SPR & W***

Average dissimilarity = 91.52

PERMANOVA test; p = 0.05

| | Group SPR | Group W | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| Ocyurus chrysurus | 9.11 | 4.04 | 5.21 | 0.90 | 5.69 | 5.69 |
| Chaetodon sedentarius | 7.05 | 2.17 | 4.07 | 0.70 | 4.44 | 10.13 |
| Lachnolaimus maximus | 3.86 | 5.37 | 3.97 | 0.69 | 4.34 | 14.47 |
| Lutjanus buccanella | 0.20 | 7.86 | 3.89 | 0.85 | 4.25 | 18.72 |
| Acanthurus bahianus | 6.96 | 0.00 | 3.48 | 0.57 | 3.80 | 22.52 |
| Holocentrus adcensionis | 6.96 | 0.00 | 3.48 | 0.57 | 3.80 | 26.32 |
| Epinephelus fulva | 4.40 | 4.96 | 3.27 | 1.04 | 3.58 | 29.90 |
| Lachnolaimus maximus | 6.22 | 1.50 | 3.11 | 0.99 | 3.40 | 33.30 |
| Lutjanus jocu | 0.00 | 2.20 | 1.10 | 0.45 | 1.20 | 90.19 |

***Groups RR & SPR***

Average dissimilarity = 88.18

PERMANOVA test; p = 0.012

| | Group RR | Group SPR | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| Stegastes partitus | 24.12 | 5.44 | 9.84 | 0.75 | 11.1 | 11.16 |
| Ocyurus chrysurus | 0.00 | 9.11 | 4.56 | 0.79 | 5.17 | 16.33 |
| Acanthurus bahianus | 1.70 | 6.96 | 3.91 | 0.65 | 4.43 | 20.76 |
| Chaetodon sedentarius | 0.00 | 7.05 | 3.53 | 0.57 | 4.00 | 24.75 |
| Balistes vetula | 6.04 | 2.67 | 3.52 | 0.65 | 3.99 | 28.74 |
| Holocentrus adcensionis | 0.00 | 6.96 | 3.48 | 0.57 | 3.95 | 32.69 |
| Holocentrus rufus | 0.00 | 6.40 | 3.20 | 2.53 | 3.63 | 36.32 |
| Lachnolaimus maximus | 0.00 | 6.22 | 3.11 | 0.94 | 3.52 | 39.84 |

A list of 33 fish species observed within the 10 x 3m and 100 x 6m belt-transects surveyed from the slope wall habitat and their estimated densities at depths between 45 – 50 m are shown in Table 8. The fish assemblage at the slope wall differed from all other benthic habitats mostly due to the prominent abundance of blackfin snapper (*Lutjanus buccanella*) relative to other habitats surveyed (Table 7). This is an insular slope dwelling snapper of high commercial value, which appears to extend its upper distribution range towards the interface of the outer shelf-edge at depths of 45 – 50 m. This fish was typically observed close to the bottom in schools of up to 40 individuals. They are fast, active swimmers and appeared to be attracted to divers, perhaps due to an opportunistic feeding behavior potentially related to mechanical disturbances of the bottom occasionally caused by divers setting transects. Other fish species were observed only, or in higher abundance at the wall relative to other benthic habitats, these include the blue and sunshine chromis (*Chromis cyanea, C. insolata*), fairy basslet (*Gramma loreto*), blackjack and blue runner (*Caranx lugubris, C. crysos*), French angelfish (*Holacanthus ciliaris*), and large adult dog and cubera snappers (*Lutjanus jocu, L. cyanopterus*). Most of the aforementioned species displayed aggregated distributions which introduced substantial bias (error) to the between station comparisons rendering them statistically insignificant and/or reducing/minimizing their relative contribution to the between station dissimilarities. Still, their concentrated occurrences within certain sections of the slope wall seem to reflect preference for this habitat.

The slope wall appears to function as a recruitment habitat for blue and sunshine chromis, as the vast majority of individuals observed from these taxa were observed in dense schools of post-settlement and early juvenile stages using branching sponges, black corals, and deepwater fans as protective habitat. Conversely, the wall habitat appears to serve also as a reproductive and foraging site for large demersal and pelagic predators. One large reproductive aggregation of approximately 250+ dog snappers (*L. jocu*) was observed at the wall engaged in what seem to be reproductive behavior as the fish were closely packed in a circular formation swirling in concentric circles. Also, a group of approx. 30 large adult cubera snappers (*L. cyanopterus*) were observed aggregated at the wall, not engaged in any particular behavior, but moving as a school. It is unclear whether this may be of any reproductive or predatory significance, but a similar behavior has been previously reported for cubera snappers at El Seco, a mesophotic reef system in southeast Vieques (Garcia-Sais et al. 2010 b). Fairy basslets (*G. loreto*) use the small crevices present throughout the wall as their residential habitat. Likewise, the slope wall appears to be the residential habitat of French angelfishes (*H. ciliaris*), creole fish (*Paranthias furcifer*), coneys and graysbe (*Epinephelus fulva, E. cruentatus*). The slope wall fish assemblage also differed from fish assemblages at the rhodolith and colonized pavement habitats due to absence of bicolor damselfish (*Stegastes partitus*) and bluehead wrasse (*Thalassoma bifasciatum*), which were numerically dominant at these low relief, horizontally oriented habitats. Large motile megabenthic invertebrates were not observed from the slope wall.

A total of 33 fish and two shellfish species were observed within belt-transects at the colonized pavement habitat in Tourmaline Reef at depths between 30 – 40 m (Table 9). The fish/shellfish assemblage at the colonized pavement habitat differed significantly from the slope wall (PERMANOVA; p= 0.001) and scattered patch reef (PERMANOVA; p= 0.012) habitats, but was not different from the assemblage at the rhodolith reef (PERMANOVA; p = 0.225). Bicolor damselfish was the numerically dominant species within transects, representing 40.4 % of the total individuals and contributing 34% to the within habitat similarity in belt-transects surveyed. Other three species, including the yellow-head and bluehead wrasses, and the sunshine chromis were also part of the numerically dominant assemblage, representing an additional 30.1 % of the total individuals (Table 9). Differences between fish assemblages at the colonized pavement and scattered patch reef habitats were mostly related to the higher relative abundance of bicolor damselfish at the colonized pavement, and an overall higher number of species at the former. Also, higher relative abundance of Harlequin bass (*Serranus tigrinus*), trunkfish (*Lactophrys trigonus*) and striped parrotfish (*Scarus iserti*) was observed at the colonized pavement, relative to the scattered patch reef. Among fish species of commercial value, the red hind (*Epinephelus guttatus*) and the cubera snapper (*Lutjanus cyanopterus*) were observed in six and four out of the 12 transects surveyed, respectively. Yellowfin snapper (*Lutjanus buccanella*) was observed in two of the transects close to the shelf-edge, indicative that such insular slope species occasionally rise to the shelf in search of food. Queen conch (*Strombus gigas*) and spiny lobster (*Panulirus argus*) were both present within belt-transects at the colonized pavement habitat. Queen conch were observed at 5 of the 12 belt transects surveyed with a mean density of 3.9 Individuals/1000 m$^2$ (Table 9).

Fish assemblages at the scattered patch reef habitat were unique in that the most abundant species within transects surveyed was the squirrelfish (*Holocentrus rufus*). It was present in all four transects surveyed with an average density of 0.56 Ind/m$^2$ (Table 10). In addition to the squirrelfish, the scattered patch reef habitat exhibited higher relative abundance of yellowtail snapper (*Ocyurus chrysurus*), reef butterfly fish (*Chaetodon sedentarius*), long jaw squirrelfish (*H. adcensionis*), orangeback basslet (*Serranus annularis*), doctorfish (*Acanthurus chirurgus*)

**Table 8**. Taxonomic composition and density of fish species within belt-transects surveyed at the slope wall habitat in Tourmaline Reef, Mayaguez, 2012-13.

| | **Belt-transects** | | | | | | |
|---:|---:|---:|---:|---:|---:|---:|---:|
| ***Species*** | **T-8-50** | **T-8-50** | **T-9-50** | **445** | **T-2-50** | **T-3-50** | **Mean Density (Ind/m$^2$)** |
| *Chromis insolata* | 0.0000 | 0.0000 | 0.0000 | 30.0000 | 0.0000 | 6.2000 | 6.0333 |
| *Chromis cyanea* | 0.0000 | 0.0000 | 0.0000 | 10.0000 | 0.0000 | 0.9000 | 1.8167 |
| *Gramma loreto* | 0.0000 | 0.1000 | 0.2000 | 0.8000 | 0.8000 | 0.0000 | 0.3167 |
| *Coryphopterus personatus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.6000 | 0.2667 |
| *Pterois sp* | 0.0000 | 0.0000 | 0.0000 | 1.4000 | 0.0000 | 0.0000 | 0.2333 |
| *Epinephelus fulva* | 0.0000 | 0.0000 | 0.4000 | 0.0000 | 0.2000 | 0.0000 | 0.1000 |
| *Halichoeres garnoti* | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.1000 | 0.3000 | 0.1000 |
| *Lutjanus jocu* | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.4333 | 0.0725 |
| *Scarus iserti* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.4000 | 0.0000 | 0.0667 |
| *Epinephelus cruentatus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.2000 | 0.0500 |
| *Bodianus rufus* | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0333 |
| *Holacanthus ciliaris* | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0333 |
| *Paranthias furcifer* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.1000 | 0.0333 |
| *Pseudupeneus maculatus* | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0333 |
| *Lutjanus buccanella* | 0.0017 | 0.0417 | 0.0667 | 0.0017 | 0.0000 | 0.0283 | 0.0233 |
| *Canthigaster rostrata* | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0167 |
| *Chaetodon aculeatus* | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0167 |
| *Chaetodon sedentarius* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0167 |
| *Holocentrus rufus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0167 |
| *Pomacanthus arcuatus* | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0167 |
| *Pomacanthus paru* | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0167 |
| *Caranx crysos* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0833 | 0.0142 |
| *Lutjanus cyanopterus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0500 | 0.0000 | 0.0083 |
| *Balistes vetula* | 0.0033 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0008 |
| *Caranx lugubris* | 0.0033 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0008 |
| *Elagatis bipinnulata* | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0017 | 0.0000 | 0.0006 |
| *Epinephelus guttatus* | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0017 | 0.0000 | 0.0006 |
| *Ocyurus chrysurus* | 0.0033 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0006 |
| *Sparisoma guacamaia* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0033 | 0.0000 | 0.0006 |
| *Caranx lugubris* | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0003 |
| *Ginglymostoma cirratum* | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0003 |
| *Lachnolaimus maximus* | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| *Dasyatis americana* | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |

**Table 9**. Taxonomic composition and density of fish species observed within belt-transects surveyed at the Colonized Pavement habitat in Tourmaline Reef, Mayaguez, 2012-13.

| *Species* | CP HG-40-1 | CP HG-30-1 | CP HG-30-2 | CP HG-40-2 | CP HG-30-3 | CP HG-30-4 | CP HG-40-3 | CP HG-40-4 | CP HG-40-5 | CP HG-50-1 | CP HG-30-5 | CP HG-30-6 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Stegastes partitus* | 1.0000 | 0.2000 | 0.0000 | 0.0000 | 0.3000 | 0.5000 | 0.2000 | 0.2000 | 0.5000 | 0.3000 | 1.9000 | 1.7000 | 0.5667 |
| *Halichoeres garnoti* | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.3000 | 0.2000 | 0.1000 | 0.2000 | 0.1000 | 0.3000 | 0.4000 | 0.2000 | 0.1667 |
| *Thalassoma bifasciatum* | 0.0000 | 0.3000 | 0.0000 | 0.1000 | 0.7000 | 0.2000 | 0.3000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.1417 |
| *Chromis insolata* | 0.0000 | 0.0000 | 0.0000 | 1.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 |
| *Holocentrus rufus* | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.1000 | 0.1000 | 0.1000 | 0.2000 | 0.2000 | 0.0000 | 0.0750 |
| *Epinephelus fulva* | 0.0000 | 0.1000 | 0.2000 | 0.4000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0667 |
| *Scarus iserti* | 0.0000 | 0.3000 | 0.4000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0583 |
| *Canthigaster rostrata* | 0.0000 | 0.3000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0500 |
| *Centropyge argi* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0333 |
| *Serranus tortugarum* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0250 |
| *Serranus tigrinus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0167 |
| *Sparisoma atomarium* | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0167 |
| *Acanthurus bahianus* | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0083 |
| *Bodianus rufus* | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0083 |
| *Chaetodon aculeatus* | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0083 |
| *Chaetodon capistratus* | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0083 |
| *Halichoeres cyanocephalus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0083 |
| *Pseudupeneus maculatus* | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0083 |
| *Serranus annularis* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0083 |
| *Pterois sp* | 0.0238 | 0.0037 | 0.0030 | 0.0000 | 0.0088 | 0.0000 | 0.0000 | 0.0009 | 0.0033 | 0.0100 | 0.0000 | 0.0000 | 0.0045 |
| *Lutjanus buccanella* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0027 | 0.0000 | 0.0400 | 0.0000 | 0.0000 | 0.0036 |
| *Lutjanus analis* | 0.0026 | 0.0000 | 0.0030 | 0.0000 | 0.0000 | 0.0013 | 0.0000 | 0.0018 | 0.0033 | 0.0033 | 0.0000 | 0.0000 | 0.0013 |
| *Epinephelus guttatus* | 0.0000 | 0.0018 | 0.0015 | 0.0000 | 0.0022 | 0.0013 | 0.0000 | 0.0000 | 0.0017 | 0.0017 | 0.0000 | 0.0000 | 0.0008 |
| *Lutjanus cyanopterus* | 0.0026 | 0.0018 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0007 |

**Table 9.Continued**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Balistes vetula* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0036 | 0.0000 | 0.0017 | 0.0000 | 0.0017 | 0.0006 |
| *Lachnolaimus maximus* | 0.0000 | 0.0018 | 0.0015 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0004 |
| *Ocyurus chrysurus* | 0.0000 | 0.0018 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| *Lactophrys trigonus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0017 | 0.0003 |
| *Caranx crysos* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0022 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0002 |
| *Scomberomorus cavalla* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| *Seriola rivoliana* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| *Sphyraena barracuda* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| *Aeobatis marinari* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| Totals | 1.0291 | 1.4110 | 1.3089 | 2.0000 | 1.3132 | 1.1026 | 1.0067 | 0.5089 | 1.2150 | 1.4583 | 2.7000 | 1.9033 | 1.4131 |
| Invertebrates | | | | | | | | | | | | | |
| *Strombus gigas* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0197 | 0.0103 | 0.0083 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0067 | 0.0039 |
| *Panulirus argus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0001 |

**Table 10**. Taxonomic composition and density of fish species within belt-transects surveyed at the Scattered Patch Reef habitat in Tourmaline Reef, Mayaguez, 2012-13

| | **Belt-Transects** | | | | |
|---|---|---|---|---|---|
| ***Fish Species*** | **SPR 366 T-8-30** | **SPR 600 T-7-30** | **SPR 600 T-6-40** | **SPR 600 T-7-50** | **Mean Density (Ind/m$^2$)** |
| *Holocentrus rufus* | 0.3000 | 0.2000 | 1.6000 | 0.2000 | 0.5750 |
| *Stegastes partitus* | 0.3000 | 0.2000 | 1.0000 | 0.3000 | 0.4500 |
| *Chromis cyanea* | 0.0000 | 0.0000 | 1.4000 | 0.0000 | 0.3500 |
| *Halichoeres garnoti* | 0.0000 | 0.0000 | 1.3000 | 0.0000 | 0.3250 |
| *Chromis insolata* | 0.0000 | 0.0000 | 1.2000 | 0.0000 | 0.3000 |
| *Thalassoma bifasciatum* | 0.0000 | 0.0000 | 0.7000 | 0.0000 | 0.1750 |
| *Epinephelus fulva* | 0.0000 | 0.1000 | 0.2000 | 0.1000 | 0.1000 |
| *Canthigaster rostrata* | 0.0000 | 0.2000 | 0.1000 | 0.0000 | 0.0750 |
| *Amblycirrhitus pinos* | 0.0000 | 0.0000 | 0.3000 | 0.0000 | 0.0750 |
| *Halichoeres cyanocephalus* | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0500 |
| *Serranus annularis* | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0500 |
| *Acanthurus bahianus* | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0250 |
| *Acanthurus chirurgus* | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0250 |
| *Chaetodon sedentarius* | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0250 |
| *Holacanthus tricolor* | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0250 |
| *Holocentrus adcensionis* | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0250 |
| *Pomacanthus paru* | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0250 |
| *Lutjanus analis* | 0.0000 | 0.0000 | 0.0033 | 0.0067 | 0.0025 |
| *Pterois sp* | 0.0027 | 0.0017 | 0.0033 | 0.0000 | 0.0019 |
| *Ocyurus chrysurus* | 0.0055 | 0.0017 | 0.0000 | 0.0000 | 0.0018 |
| *Lachnolaimus maximus* | 0.0000 | 0.0017 | 0.0000 | 0.0050 | 0.0017 |
| *Caranx crysos* | 0.0055 | 0.0000 | 0.0000 | 0.0000 | 0.0014 |
| *Balistes vetula* | 0.0000 | 0.0017 | 0.0017 | 0.0017 | 0.0013 |
| *Epinephelus guttatus* | 0.0000 | 0.0000 | 0.0033 | 0.0017 | 0.0013 |
| *Lutjanus buccanella* | 0.0000 | 0.0000 | 0.0000 | 0.0033 | 0.0008 |
| *Seriola rivoliana* | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0004 |
| **Totals** | **0.8137** | **0.9067** | **8.2117** | **0.8200** | **2.6880** |
| Shellfishes | | | | | |
| *Strombus gigas* | 0.0055 | 0.0000 | 0.0000 | 0.0000 | 0.0014 |
| *Panulirus argus* | 0.0000 | 0.0000 | 0.0017 | 0.0017 | 0.0008 |

and redspotted hawkfish (*Amblycirrhitus pinos*) than the colonized pavement habitat and the rhodolith reef habitat. It is possible that the high prevalence of small invertebrate opportunistic feeders, such as squirrelfishes and small yellowtail snappers were related to food availability, as invertebrates may become exposed during mechanical disturbances of the sandy bottom. Fish community structure at the scattered patch reef was in general, consistent with those found in low relief and horizontally oriented mesophotic habitats and markedly differed from the slope wall assemblage due to the lack of typical slope, high relief mesophotic species, such as fairy basslets, creole fish, French angelfishes and Yellowfin snappers. Spiny lobsters were observed in two and queen conch were observed in one out of the four transects surveyed, respectively.

The rhodolith habitat at Tourmaline Reef exhibited the typical fish community structure that has been previously reported for this type of mesophotic benthic system (Garcia-Sais et al. 2005, 2007, 2009, 2010). Numerically dominant species of the fish assemblage include the bicolor damselfish (*Stegastes partitus*), cherubfish (*Centropyge argi*), chalk-bass (*Serranus tortugarum*), yellow-head and blue-head wrasses (*Halichoeres garnoti, Thalassoma bifasciatum*), and the greenblotch parrotfish (*Sparisoma atomarium*) (Table 11).  Other fish species present in lower abundance that (in addition to the aforementioned species) markedly contributed to the within habitat similarity in terms of the rank order abundance of fish species included mutton snapper (*Lutjanus analis*), harlequin bass (*Serranus tigrinus*), and queen triggerfish (*Balistes vetula*).

Differences of fish assemblages between the rhodolith and slope wall habitat were previously discussed and appear to be very strongly associated both with the magnitude of topographic relief and the slope. The rhodolith reef habitat is characterized by an almost flat, low relief topography, and consequently mostly small territorial fishes, such as bicolor damselfish, cherubfish and greenblotch parrotfish can fit within the small protective microhabitats created by the rhodolith rocks. Fishes that feed largely from mechanical disturbances of the bottom or from demersal invertebrates and/or fishes, such as wrasses, triggerfishes, red hinds and mutton snappers are common at the rhodolith reef, but are rare at the slope wall habitat. Conversely, the zooplanktivorous food web assemblage comprised by chromis spp., creole fish, fairy basslet, yellowtail snapper and others is more typical of high relief and vertically oriented habitats. An important component of the rhodolith reef habitat that was virtually absent from the slope wall habitat is the queen conch (*Strombus gigas*). Consistent with previous findings of an adult population of queen conch inhabiting the mesophotic rhodolith reef habitat of Abrir Sierra (Garcia-Sais et al. 2010) a similar population was observed at the adjacent Tourmaline Reef.

The high relative abundance of bicolor damselfish, queen triggerfish, harlequin bass, bluehead and yellowhead wrasse, mutton snapper and red hind was shared between the rhodolith reef and colonized pavement habitats. It must be noted that the colonized pavement habitat at Tourmaline reef occurred in some sections as a transition from the rhodolith reef and rhodoliths were in many cases found intermixed within the pavement. Thus, differences of fish assemblages between both habitats were not statistically significant (PERMANOVA; $p = 0.225$). Difference of fish assemblages between the rhodolith reef and the scattered patch ref habitat were largely associated with the much higher relative abundance of bicolor damselfish and the absence of squirrelfishes and yellowtail snappers at the rhodolith reef (Table 2).

**Table 11**. Taxonomic composition and density of fish species within belt-transects surveyed at the rhodolith reef habitat in Tourmaline Reef, Mayaguez, 2012-13.

| | RR 358 | RR 354 | RR 355 | RR T-3-30 | RR T-1-40 | RR T-2-40 | RR T-3-40 | RR T-4-40 | RR T-5-50 | RR T-4-50 | RR T-1-50 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Fish Species*** | | | | | | | | | | | | |
| *Centropyge argi* | 0.0000 | 0.2000 | 0.7000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 33.7000 | 0.0000 | 3.1545 |
| *Stegastes partitus* | 0.8000 | 1.8000 | 1.0000 | 1.2000 | 1.6000 | 0.8000 | 0.6000 | 1.2000 | 0.3000 | 0.3000 | 0.0000 | 0.8727 |
| *Serranus tortugarum* | 0.0000 | 0.0000 | 0.4000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.9000 | 2.3000 | 0.0000 | 0.3273 |
| *Halichoeres garnoti* | 0.2000 | 0.9000 | 0.6000 | 0.1000 | 0.1000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.1909 |
| *Sparisoma atomarium* | 0.0000 | 0.4000 | 0.2000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0636 |
| *Thalassoma bifasciatum* | 0.3000 | 0.0000 | 0.3000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0545 |
| *Serranus tigrinus* | 0.0000 | 0.2000 | 0.1000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0455 |
| *Opistognathus aurifrons* | 0.0000 | 0.1000 | 0.3000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0364 |
| *Serranus baldwini* | 0.0000 | 0.0000 | 0.4000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0364 |
| *Chromis cyanea* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3000 | 0.0000 | 0.0000 | 0.0000 | 0.0273 |
| *Pomacanthus paru* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3000 | 0.0273 |
| *Bodianus rufus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0182 |
| *Caranx ruber* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0182 |
| *Coryphopterus glaucophraenum* | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0182 |
| *Epinephelus fulva* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0182 |
| *Holacanthus tricolor* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0182 |
| *Malacanthus plumieri* | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0182 |
| *Serranus annularis* | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0182 |
| *Caranx crysos* | | | | | | | | | | | 0.0100 | 0.0100 |
| *Acanthurus bahianus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0091 |
| *Canthigaster rostrata* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0091 |
| *Caranx lugubris* | | | | | | | | | 0.0050 | | | 0.0050 |
| *Negaprion brevirostris* | | | | | 0.0033 | | | | | | | 0.0033 |
| *Lutjanus cyanopterus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0200 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0018 |

**Table 11. Continued**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Acanthostracion quadricomis* | | | 0.0017 | | | | | | | | | 0.0017 |
| *Balistes vetula* | 0.0000 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0067 | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0083 | 0.0017 |
| *Lactophrys trigonus* | 0.0017 | | | | | | | | | | | 0.0017 |
| *Elagatis bipinnulata* | | | | | | | | | | 0.0017 | | 0.0017 |
| *Seriola dumerili* | | | | | | | | | 0.0017 | | | 0.0017 |
| *Sphyraena barracuda* | | | | | | | | | | | 0.0017 | 0.0017 |
| *Pterois sp* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0167 | 0.0015 |
| *Lutjanus analis* | 0.0017 | 0.0017 | 0.0000 | 0.0000 | 0.0033 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0009 |
| *Epinephelus guttatus* | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0033 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0006 |
| *Lutjanus jocu* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0002 |
| *Totals* | 1.4033 | 3.6033 | 4.3033 | 1.5000 | 1.9100 | 0.8283 | 0.6000 | 2.5017 | 1.3067 | 36.4017 | 0.5417 | 5.0152 |
| *Strombus gigas* | 0.0000 | 0.0017 | 0.0000 | 0.0000 | 0.0200 | 0.0000 | 0.0017 | 0.0017 | 0.0083 | 0.0083 | 0.0000 | 0.0038 |
| *Panulirus argus* | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0033 | 0.0003 |

## D. Fishery Independent Survey of Commercially Important Fish and Shellfish Species

### 1. Queen Conch (*Strombus gigas*)

A total of 318 queen conch individuals were observed within belt-transects during fishery independent surveys at Tourmaline Reef. Queen conch were present in all four benthic habitats surveyed, but were more abundant at the rhodolith reef (7.43 Ind/1000 $m^2$ and colonized pavement habitats (7.04 Ind/1000 $m^2$) within a depth range of 30 – 40 m (Figure 7). The combined abundance of queen conch at the rhodolith and colonized pavement habitats represented 67.3 % of the total individuals. The population present within mesophotic habitats at Tourmaline Reef was largely comprised of adult individuals within a size (length) range of 20 – 27 cm (Figure 8). More than 90% of the total individuals observed from all mesophotic benthic habitats were at least 22 cm in total length. There was no clear ontogenetic trend of habitat selectivity by queen conch, as individuals within the 20 - 26 cm length range were present from all habitats except at the wall (Figure 9). Queen conch were only sighted in one transect as a patch of large (25 cm) individuals concentrated near the upper edge of the wall at the interface with the colonized pavement.

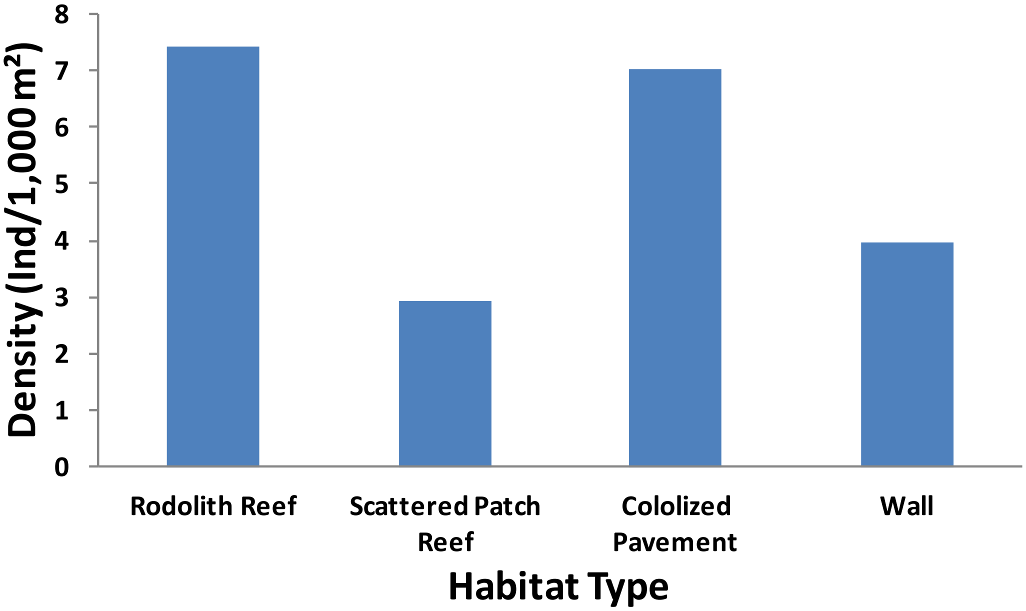


**Figure 7**. Queen Conch (*Strombus gigas*). Mean densities (Ind/1000 $m^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13.

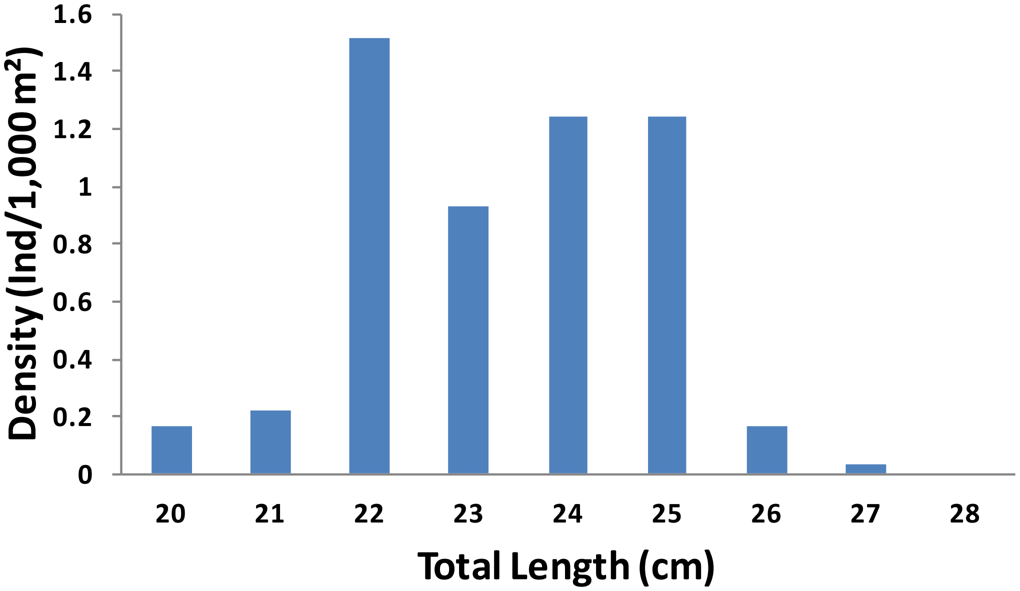


**Figure 8.** Queen Conch (*Strombus gigas*). Combined length (cm) frequency distribution from all mesophotic habitats at Tourmaline Reef, 2012-13

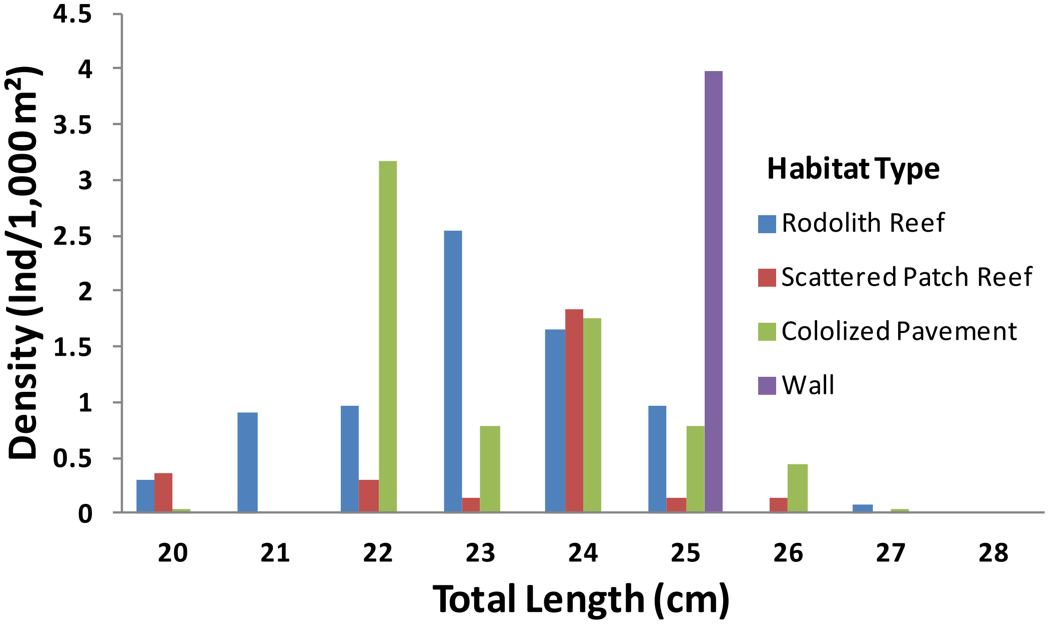


**Figure 9**. Queen Conch (*Strombus gigas*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

The mean density of queen conch from all mesophotic habitats surveyed at Tourmaline Reef was similar to that found at neighbor mesophotic habitats of Abrir la Sierra (Figure 9). The maximum size (length) however, as well as proportion of larger individuals within the population appeared to be higher at Abrir la Sierra (Figure 10). The maximum length reported for queen conch in this study, 27.0 cm is slightly below the maximum reported for the species at 30.4 cm (Table 12).

Queen conch growth is deterministic, with maximum length attained at sexual maturity, corresponding to the formation of the flared lip of the shell (McCarthy, 2008). Although lip thickness measurements were not made in this study, all conch individuals were observed to have flared lips at lengths of 20 cm or larger, which is indicative that the queen conch population from mesophotic habitats at Tourmaline Reef was mostly comprised by an adult and reproductively active population.  Lip thickness (LT) increases with age and has been used to estimate adult conch growth since maturation (Appeldoorn, 1988).  Queen conch shell lengths from mesophotic habitats and sites previously surveyed, including ALS (Garcia-Sais et al, 2010a, Garcia-Sais et al, 2012), Bajo de Sico (BDS) (Garcia-Sais et al, 2007, Garcia-Sais et al, 2012) and Isla Desecheo (Des) (Garcia-Sais et al 2005, Garcia-Sais et al 2012) consistently found large adult specimens, with the bulk of individuals in the 24 – 27 cm TL range. It is also evident that queen conch populations at mesophotic habitats from Tourmaline Reef and ALS were much more abundant than those from BDS and Des (Figure 11). This may be strongly influenced by the direct, within shelf habitat connectivity at Tourmaline Reef and ALS, since deep oceanic barriers separate both BDS and Des from the insular shelf of Puerto Rico (PR), where seagrass nurseries for queen conch are plentiful (Garcia-Sais et al, 2012).

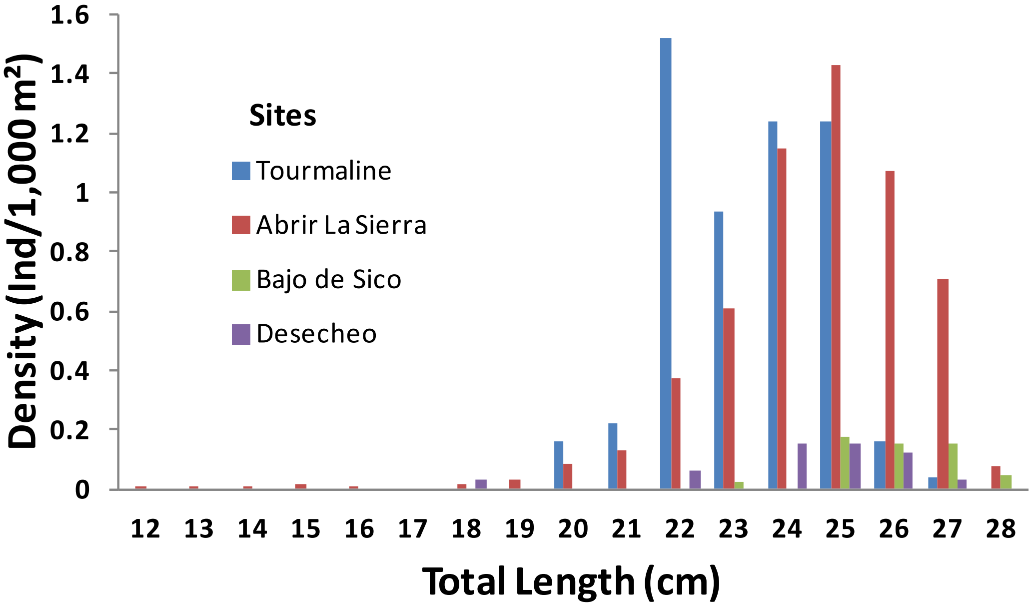


**Figure 10**. Queen Conch (*Strombus gigas*). Variations of length (cm) frequency distributions at mesophotic reef systems surveyed in Puerto Rico.

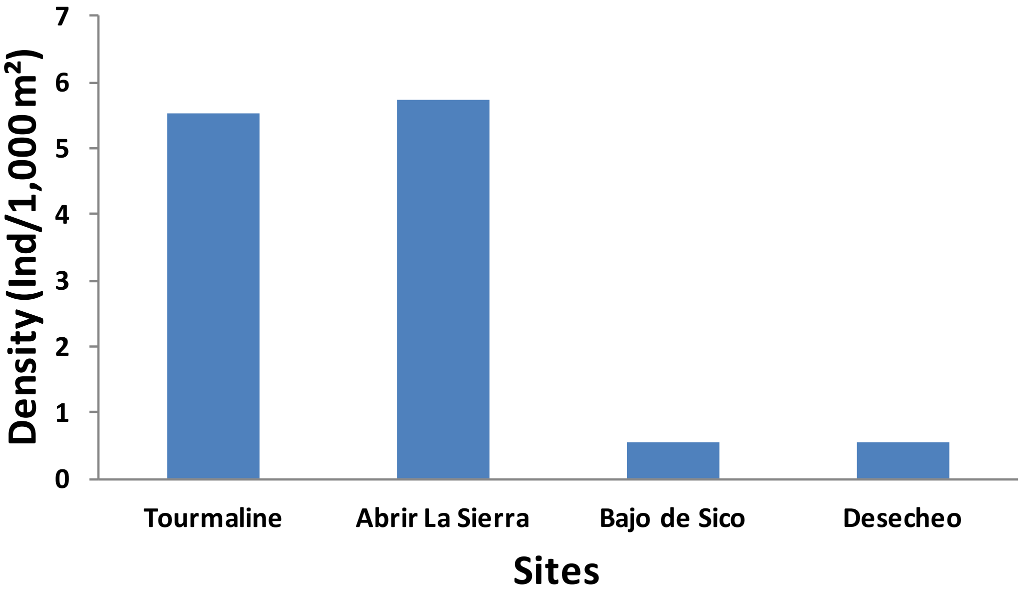


**Figure 11**. Queen Conch (*Strombus gigas*). Mean densities from mesophotic reef systems surveyed in Puerto Rico, 2005-13.






### 2. Spiny Lobster (*Panulirus argus*)

A total of 24 spiny lobster individuals were observed from mesophotic habitats at Tourmaline Reef, with the higher densities observed from the colonized pavement and lowest (none) at the rhodolith reef (Figure 12). Cephalothorax length (CFT) ranged from 5 – 14 cm, with a strong mode at 11.0 cm (Figure 13). The size distribution suggests that both juvenile and adult spiny lobsters are utilizing mesophotic habitats from Tourmaline Reef. Compared to other mesophotic reef sites previously studied, the size distribution of spiny lobsters at Tourmaline Reef seems to be skewed toward smaller specimens (Figure 14). This may be related to the lack of substrate relief and scarcity of appropriate microhabitats for large lobsters and perhaps closer and stronger connectivity with juvenile recruitment habitats in the insular shelf. Conversely, spiny lobster density within mesophotic habitats were higher at Tourmaline Reef relative to other sites previously surveyed (Figure 15). Spiny lobsters at Tourmaline Reef showed a strong preference for the colonized pavement habitat, within a depth range of 30 – 45 m. It was noted that this habitat has many small crevices and ledges that seem to function as protective habitat for small lobsters. Despite the small size of spiny lobsters relative to other mesophotic sites surveyed, it was noted that several females with a CFT length of 8 cm and larger were gravid and thus reproductively active.  The minimum CFT size at first reproduction for spiny lobsters in the Caribbean has been reported as 5.4 cm.

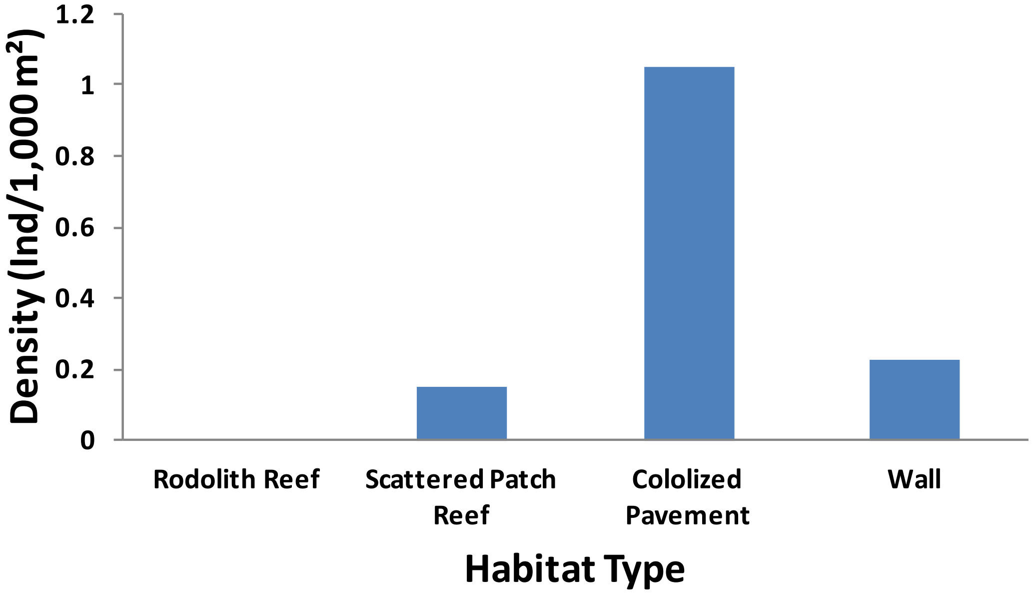


**Figure 12**. Spiny lobster (*Panulirus argus*). Mean densities (Ind/1000 m$^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13.

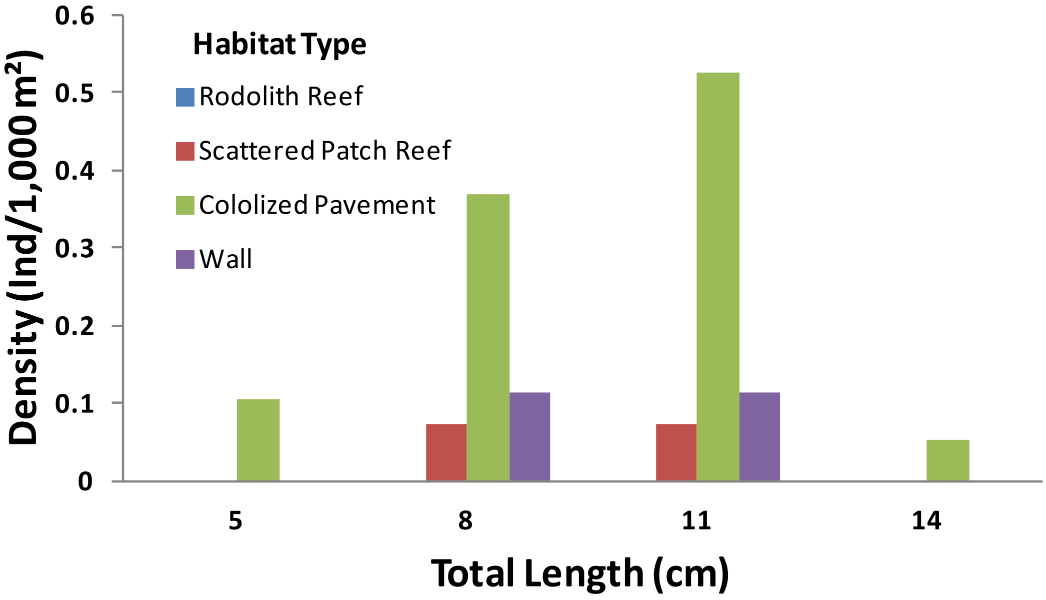


**Figure 13.** Spiny lobster (*Panulirus argus*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

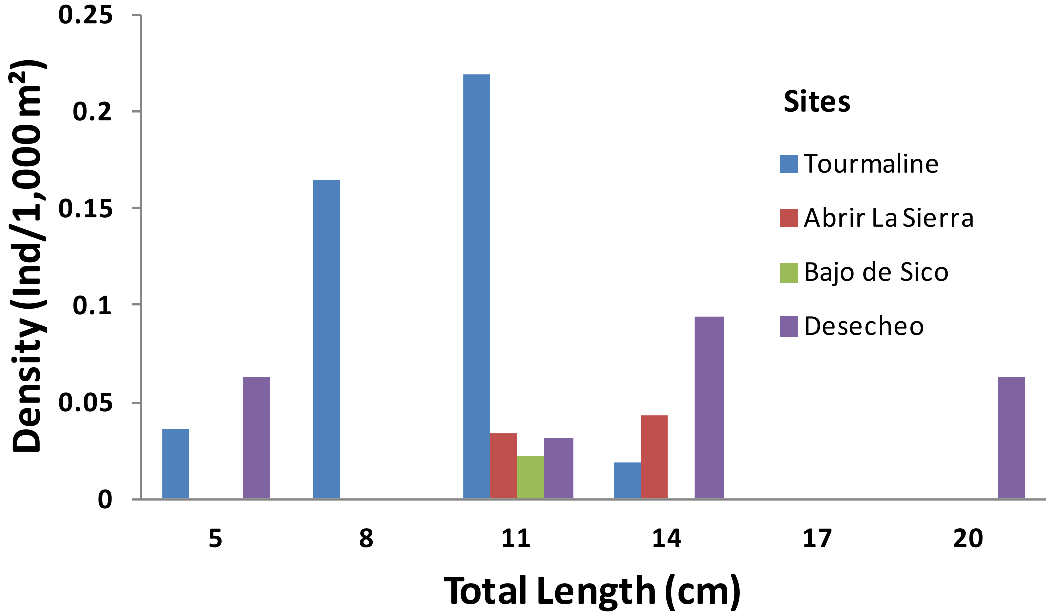


**Figure 14**. Spiny lobster (*Panulirus argus*). Variations of length (cm) frequency distributions at mesophotic reef systems surveyed in Puerto Rico.

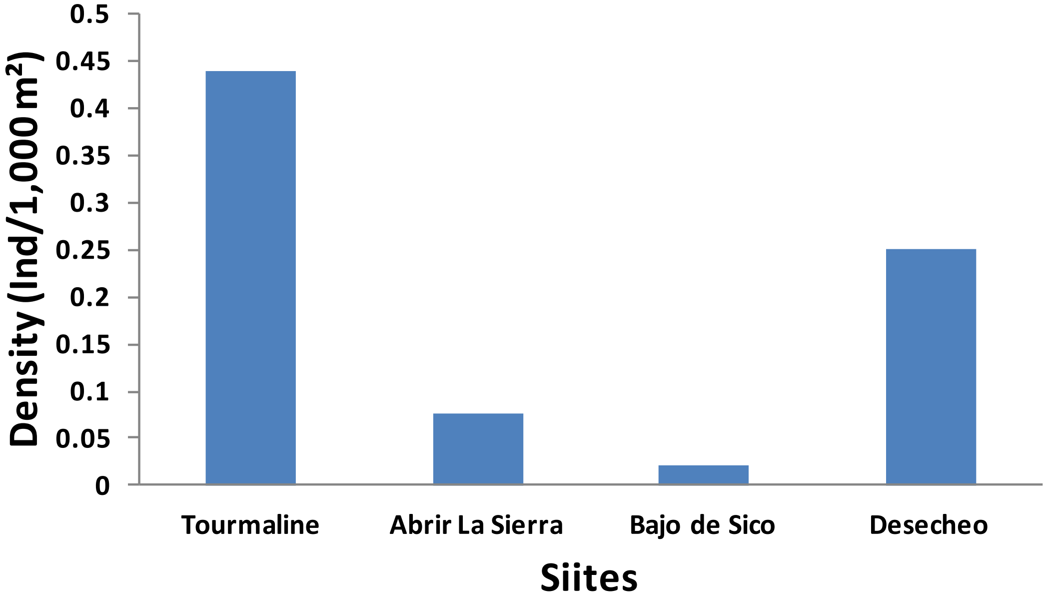


**Figure 15**. Spiny lobster (*Panulirus argus*). Mean densities from mesophotic reef systems surveyed in Puerto Rico, 2005-13.

### 3. Mutton Snapper (*Lutjanus analis*)

A total of 101 individual mutton snappers were observed from all mesophotic habitats at Tourmaline Reef within a depth range of 30 – 50 m. Peak density (2.5 Ind/1000 $m^2$) was observed from the colonized pavement habitat, but all other habitats exhibited densities above 1.0 Ind/1000 $m^2$ (Figure 16). The size distribution of mutton snappers ranged between 20 – 60 cm, indicative that mesophotic habitats from Tourmaline Reef are relevant for both juvenile and adult individuals in the population. No ontogenetic trends in the benthic habitat distribution of mutton snappers were observed from Tourmaline Reef since both juvenile and adult specimens were observed virtually from all benthic habitats (Figure 17). Modal length was at 50 cm (TL). The reported length at first reproduction for mutton snapper is 41.0 cm (Table 12). These data show that approximately 60 % of the total individuals observed at Tourmaline Reef were juveniles, although if we consider that 40 cm long individuals are at a marginal size for being reproductively active, then the proportion of juvenile to adults may be closer to 50%. The maximum length of mutton snapper visually estimated during our surveys at 60 cm is well below the maximum length reported of 94.0 cm, but closer to the maximum length reported for the Caribbean Antilles at 74.0 cm (Table 12).

In a recent fishery independent survey of commercially important fish and shellfish species from mesophotic reefs in Puerto Rico (Garcia-Sais 2012), mutton snappers were not observed either at Bajo De Sico (BDS) or Isla Desecheo (Des). There are previous reports of mutton snappers both from Des and BDS (Garcia-Sais et al. 2005, 2007), but their occurrence at these oceanic sites was rare. More mutton snappers were observed in this study at Tourmaline Reef than at all other mesophotic sites previously surveyed (Figure 18). The wide plasticity of size distributions (Figure 19) and habitat types in which mutton snappers occurred at Tourmaline Reef and ALS suggests that their virtual absence from Des and BDS is not habitat related, but perhaps more related to larval dispersal dynamics and/or to the lack of connectivity with their neritic recruitment and nursery habitats, which are present at Tourmaline Reef and ALS and not so at oceanic sites (see Garcia-Sais et al 2012).

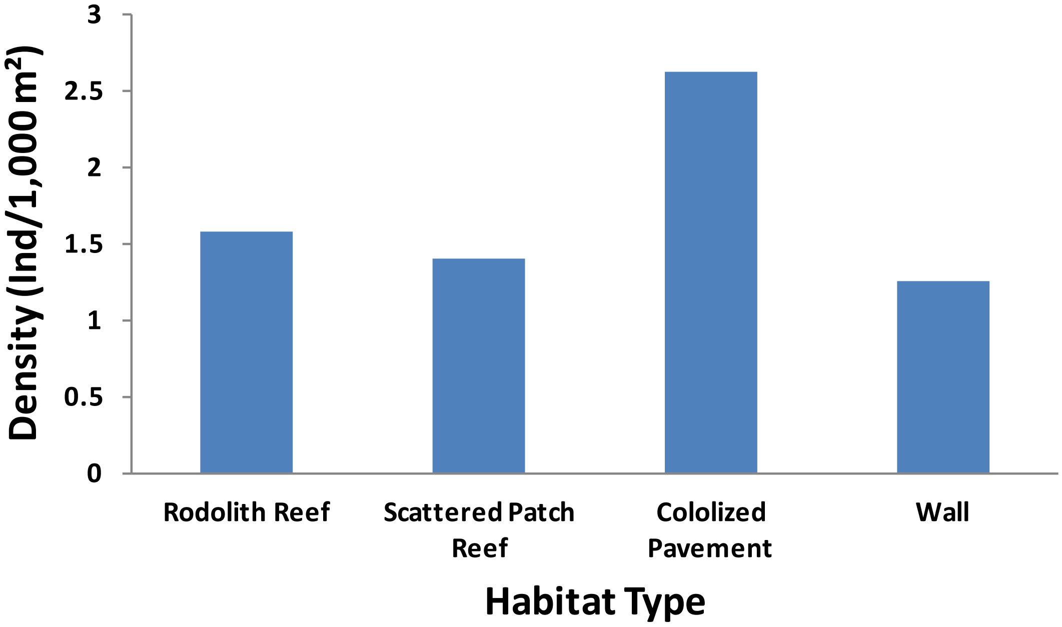


**Figure 16**. Mutton snapper (*Lutjanus analis*). Mean densities (Ind/1000 $m^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13.

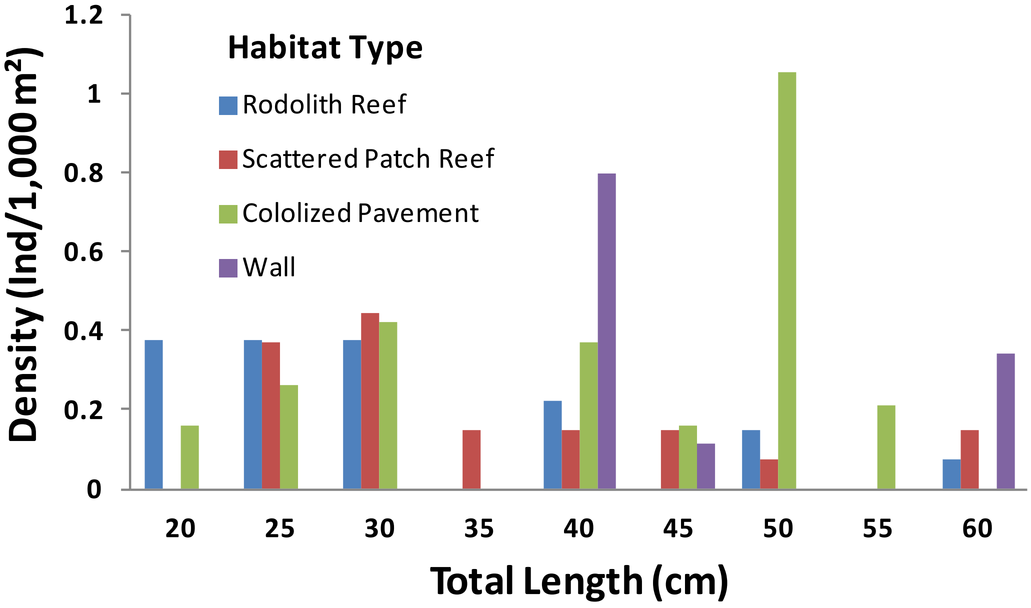


**Figure 17.** Mutton snapper (*Lutjanus analis*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

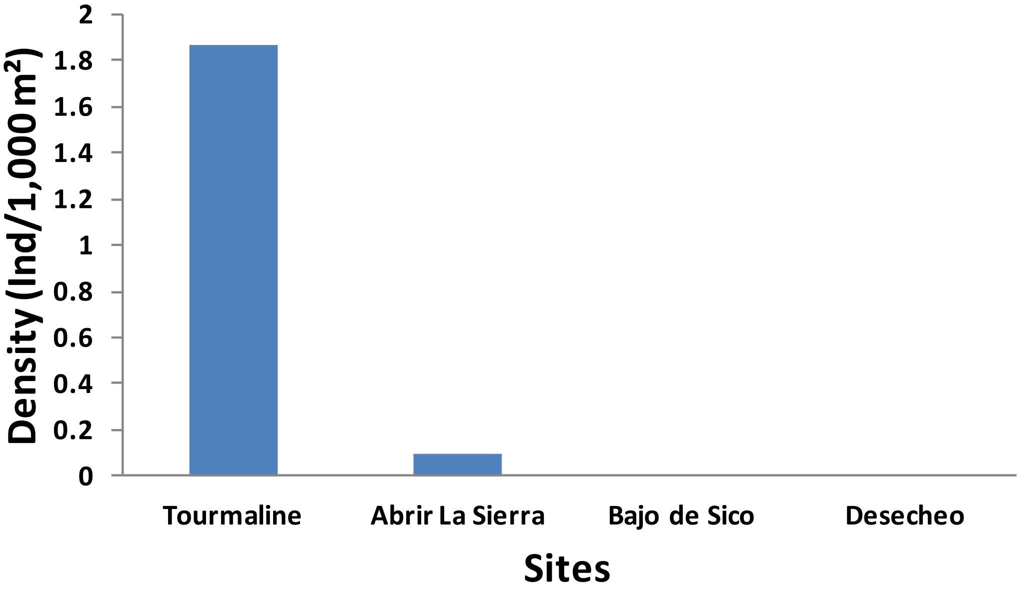


**Figure 18**. Mutton snapper (*Lutjanus analis*). Mean densities from mesophotic reef systems surveyed in Puerto Rico, 2005-13.

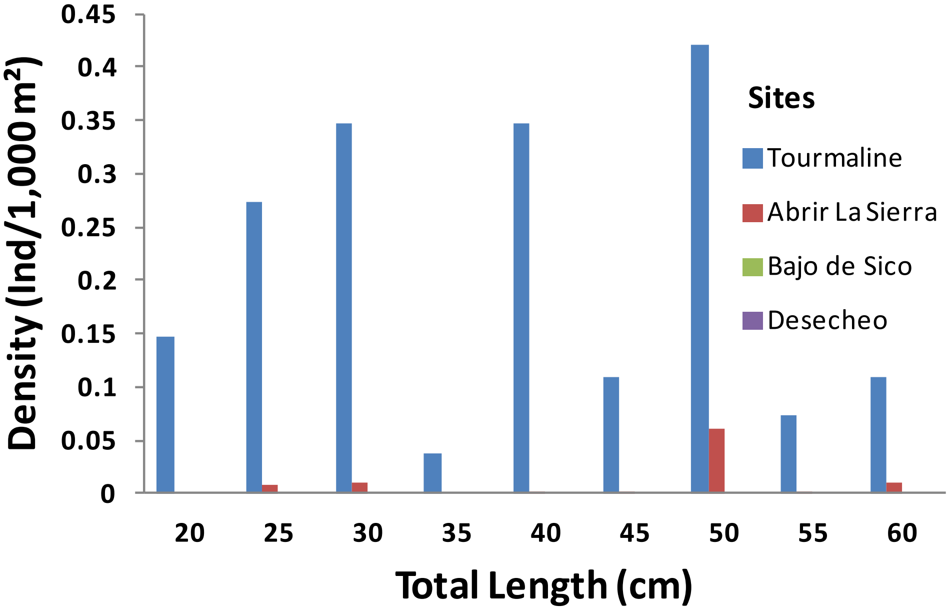


**Figure 19**. Mutton snapper (*Lutjanus analis*). Variations of length (cm) frequency distributions at mesophotic reef systems surveyed in Puerto Rico.

### 4. Red Hind (*Epinephelus guttatus*)

A total of 101 red hind individuals were observed from mesophotic habitats at Tourmaline Reef within the 30 – 50 m depth range. Red hinds were present in all benthic habitats surveyed, but higher density was observed at the colonized pavement, where 73 out of the 101 total individuals or 72.3 % were sighted (Figure 20). Individual lengths ranged between 10 – 35 cm TL, but 84 % of the total individuals fell within 20 – 30 cm TL range. The strongest length mode was estimated at 20 cm with a smaller mode at 30 cm (Figure 21). Applying the reported length at first reproduction of 25 cm (Table 12) to the size distribution of red hind, a balanced population of juveniles and adults was present from mesophotic habitats of Tourmaline Reef during our survey. Yet, most of the juveniles observed were close to the adulthood threshold reported (Table 12). Whereas a clear ontogenetic trend for benthic habitats was not evident from this study (Figure 22), it is interesting to note that one individual of only 10 cm was observed at the rhodolith reef, suggesting that this habitat may have recruitment potential for red hinds.  Conversely, only individuals of 25 cm or larger were observed at the wall. More red hind juveniles were observed from Tourmaline Reef than at any other mesophotic reef site studied so far (Figure 23). This may be related to strong connectivity between mesophotic and coastal recruitment habitats. Mean abundance of red hinds at Tourmaline Reef fell within the range of other mesophotic reef systems studied in Puerto Rico (Figure 24). The maximum length of red hind from this study at 35 cm was well below the maximum length reported of 76.0 cm, but fell closer to the maximum length reported for the Caribbean Antilles at 54.5 cm (Table 8).

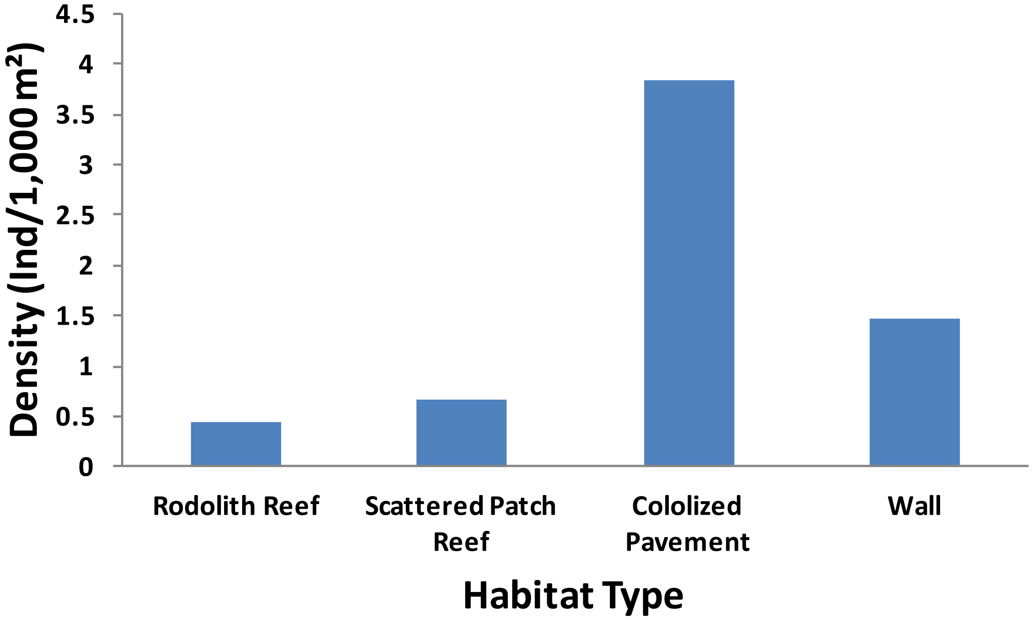


**Figure 20**. Red hind (*Epinephelus guttatus*). Mean densities (Ind/1000 $m^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13.

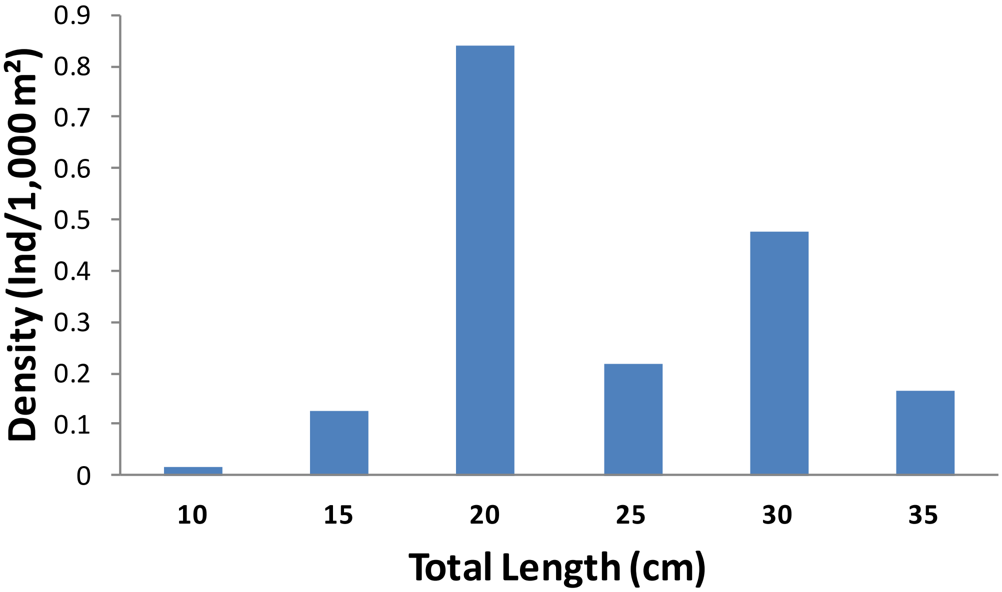


**Figure 21.** Red hind (*Epinephelus guttatus*). Combined length (cm) frequency distribution from all mesophotic habitats at Tourmaline Reef, 2012-13

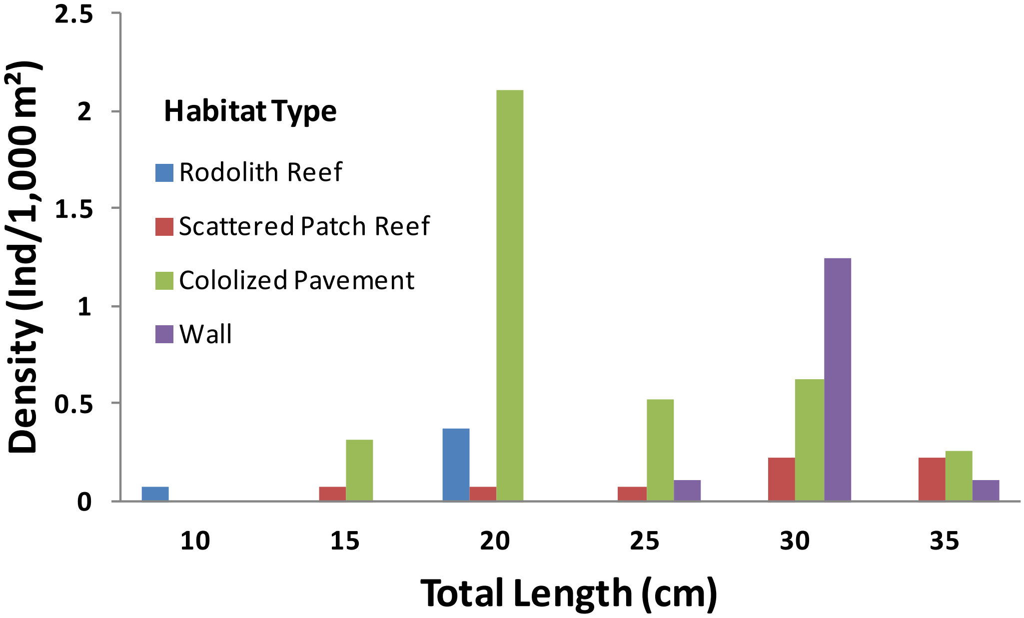


**Figure 22.** Red hind (*Epinephelus guttatus*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

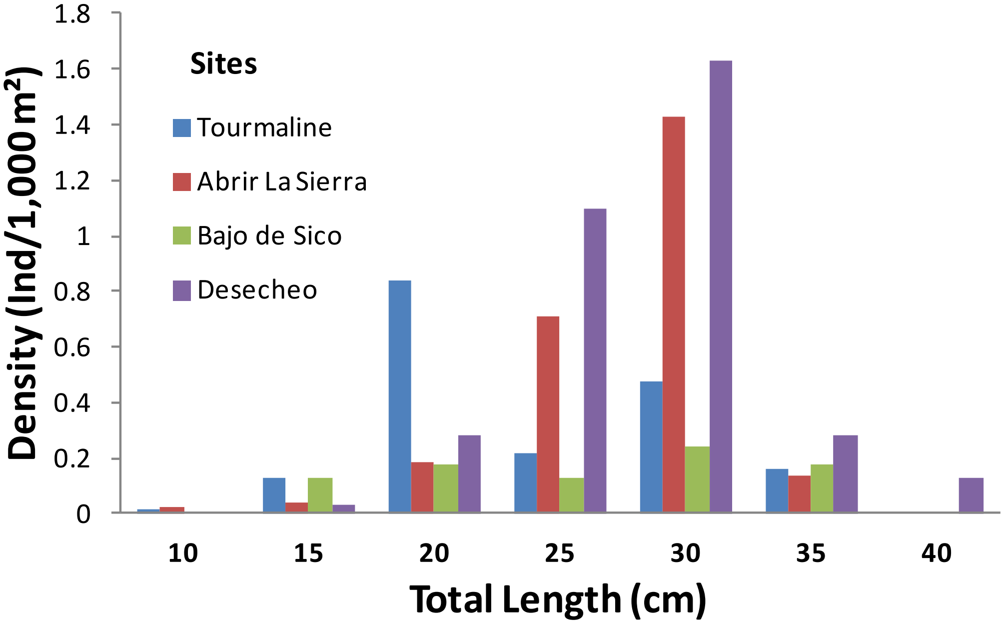


**Figure 23**. Red hind (*Epinephelus guttatus*). Variations of length (cm) frequency distributions at mesophotic reef systems surveyed in Puerto Rico.

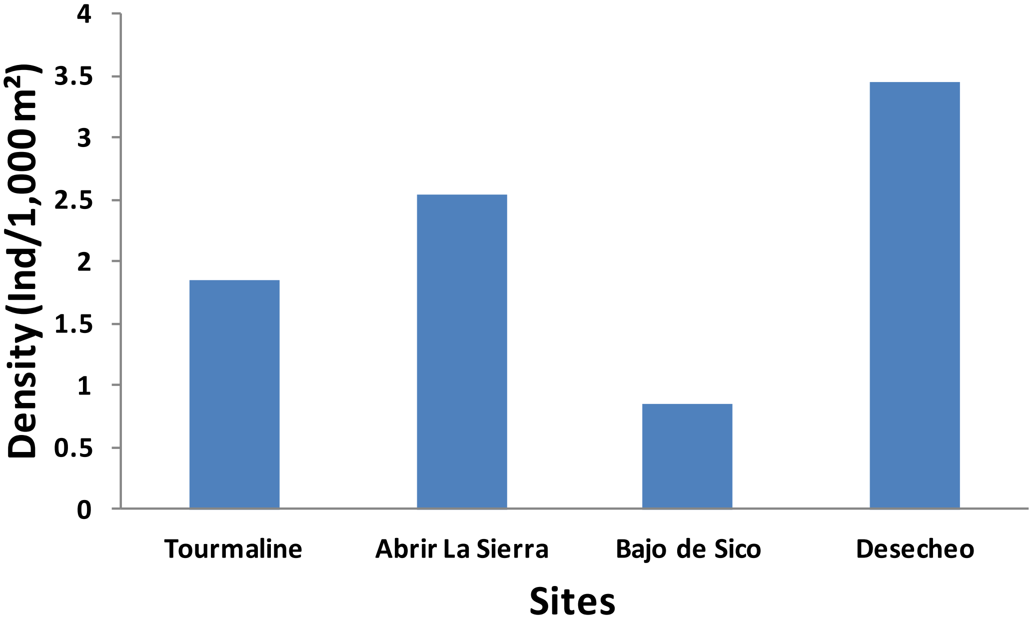


**Figure 24**. Red hind (*Epinephelus guttatus*). Mean densities from mesophotic reef systems surveyed in Puerto Rico, 2005-13.

### 5. Queen Triggerfish (*Balistes vetula*)

Queen triggerfish were observed from all mesophotic habitats and depths surveyed at Tourmaline Reef with higher density at the colonized pavement (Figure 25). A total of 57 individuals were sighted within transects. The population presented a size range of 15 to 50 cm (FL), with a strong mode at 30 cm (FL) and a smaller mode at 35 cm (Figure 26). The size distribution was strongly skewed towards the larger individuals, suggesting that mesophotic habitats at Tourmaline serve mostly for an adult population. Clear ontogenetic patterns of size distributions at preferred habitats were not evidenced, yet the smaller individuals were observed at the rhodolith reef (Figure 27). Age at first reproduction of queen triggerfish has been reported as 23 cm (Table 12). Thus, 96.5 % of the entire population observed from mesophotic habitats at Tourmaline Reef was comprised of adult individuals. This is consistent with findings from other mesophotic sites surveyed (Garcia-Sais, 2012). Maximum length reported for queen triggerfish is 60 cm, with a maximum reported for the Caribbean Antilles at 54.6 cm. Thus, our maximum length estimate of 50 cm is close to the maximum length reported for the species. Compared to other mesophotic sites surveyed, Tourmaline exhibited the broader size distribution range (Figure 28) , as well as the highest density of total individuals (Figure 29). Again, this may be associated with the strong connectivity between mesophotic and recruitment /residential habitats of the insular shelf. Still, a previous study has shown that effective mechanisms favoring the transport of queen triggerfish to oceanic (off the insular shelf) sites is in place (Garcia-Sais et al. 2012).

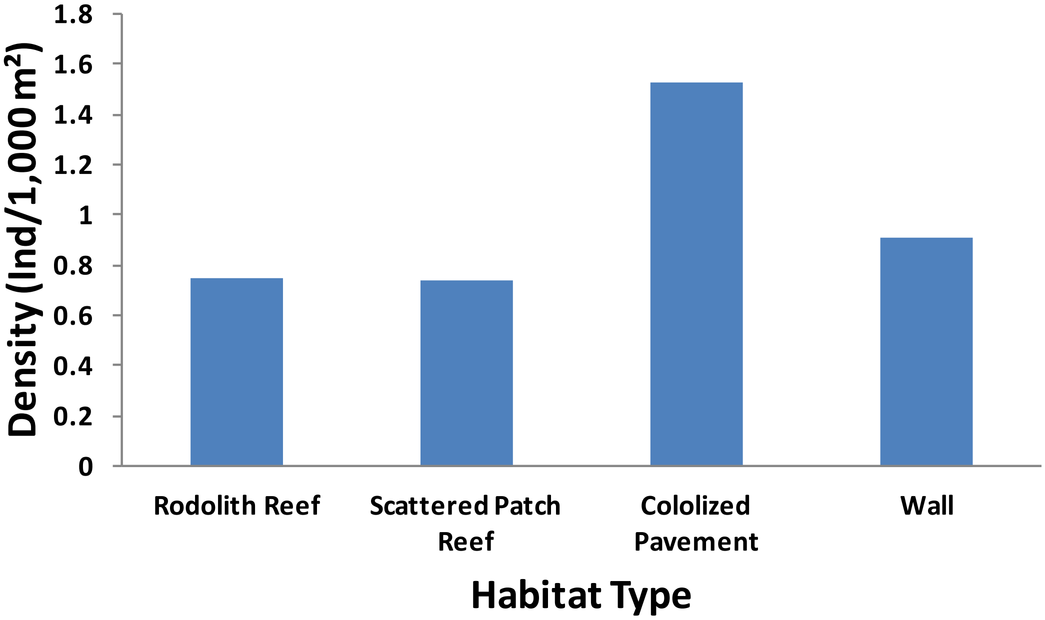


**Figure 25**. Queen Triggerfish (*Balistes vetula*). Mean densities (Ind/1000 m$^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13

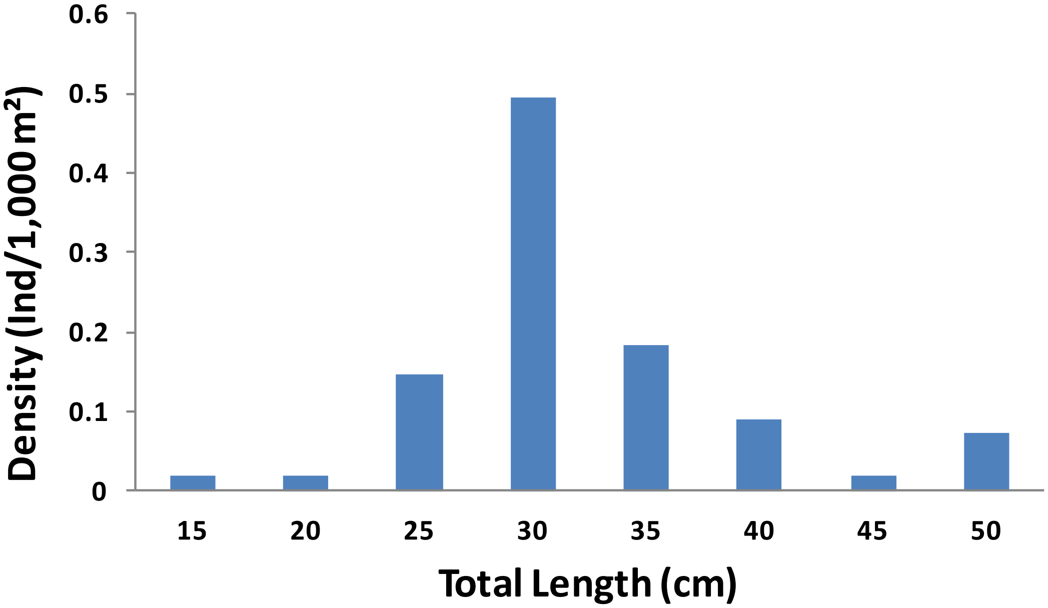


**Figure 26.** Queen Triggerfish (*Balistes vetula*). Combined length (cm) frequency distribution from all mesophotic habitats at Tourmaline Reef, 2012-13

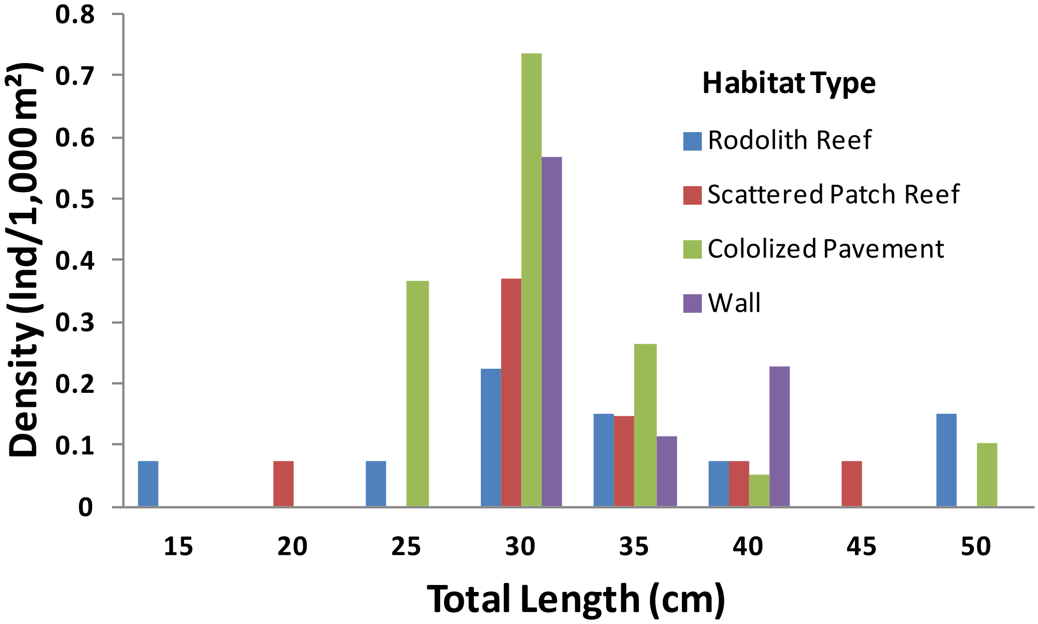


**Figure 27.** Queen Triggerfish (*Balistes vetula*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

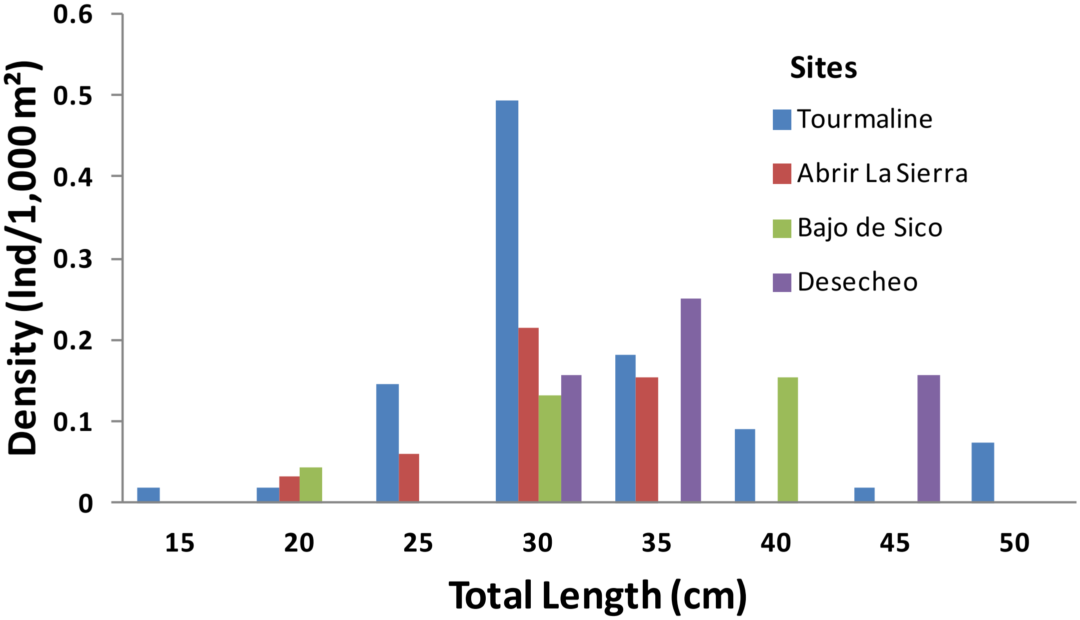


**Figure 28**. Queen Triggerfish (*Balistes vetula*). Variations of length (cm) frequency distributions at mesophotic reef systems surveyed in Puerto Rico.

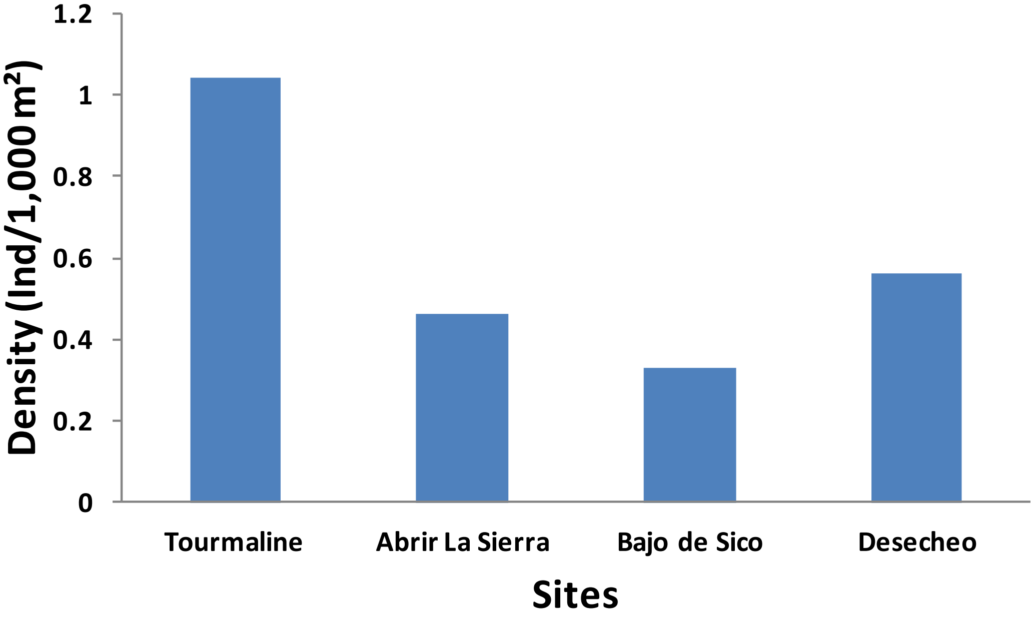


**Figure 29**. Queen Triggerfish (*Balistes vetula*). Mean densities from mesophotic reef systems surveyed in Puerto Rico, 2005-13.

### 6. Cubera Snapper (*Lutjanus cyanopterus*)

A total of 69 cubera snappers were observed from mesophotic habitats of Tourmaline Reef within a depth range of 30 – 50 m. Several cubera snappers were observed at the rhodolith reef (12) and colonized pavement habitats (8), but 71.0 % of the total individuals (49/69) were sighted at the slope wall within the 45 – 50 m depth range (Figure 30). Cubera snappers were mostly concentrated within a relatively small section of the wall, where they formed an impressive school of very large individuals. Including all habitats surveyed, cubera snappers were observed within a size range of 30 – 130 cm (TL) with a strong mode at 100 cm (Figure 31). Data on length at first reproduction (Lm) for cubera snappers is not currently available, but since it is a larger and perhaps, longer lived species than its congener *L. jocu* which has a Lm = 32.0 (Table 12), it must be assumed that it's Lm is larger than 32 cm. The size distribution of cubera snappers is indicative that mostly adult individuals prevailed at mesophotic habitats of Tourmaline Reef, but there was a small component of juvenile individuals mostly observed from the colonized pavement habitat (Figure 32). The maximum length of cubera snappers estimated from this study at 130 cm approaches the maximum size reported for the species (e.g. 160 cm, Table 12), and now represents the maximum (visually estimated) size reported for the Caribbean Antilles, previously reported as 109.0 cm; see Table 12).

Compared to other mesophotic sites surveyed in Puerto Rico (Garcia-Sais et al 2012), cubera snappers from Tourmaline Reef presented the broadest size range of individuals (Figure 33), as well as the highest densities (Figure 34). Cubera snappers represent one of the top demersal predators of shelf-edge habitats, where they are transient between outer neritic and upper insular slope domains. They seem to have wide foraging areas within a broad depth range. Their higher abundance from Tourmaline Reef and its neighbor mesophotic system at Abrir la Sierra relative to mesophotic habitats in oceanic sites may be related to a stronger connectivity with recruitment and/or nursery habitats of the insular shelf and/or to larval dispersal dynamics (Garcia-Sais et al. 2012).

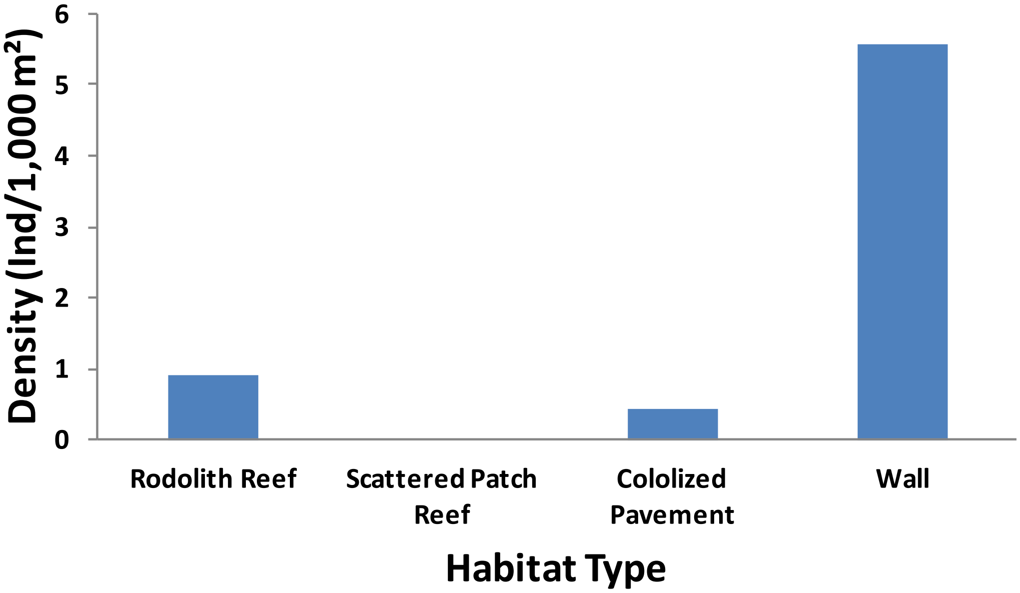


**Figure 30**. Cubera Snapper (*Lutjanus cyanopterus*). Mean densities (Ind/1000 $m^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13

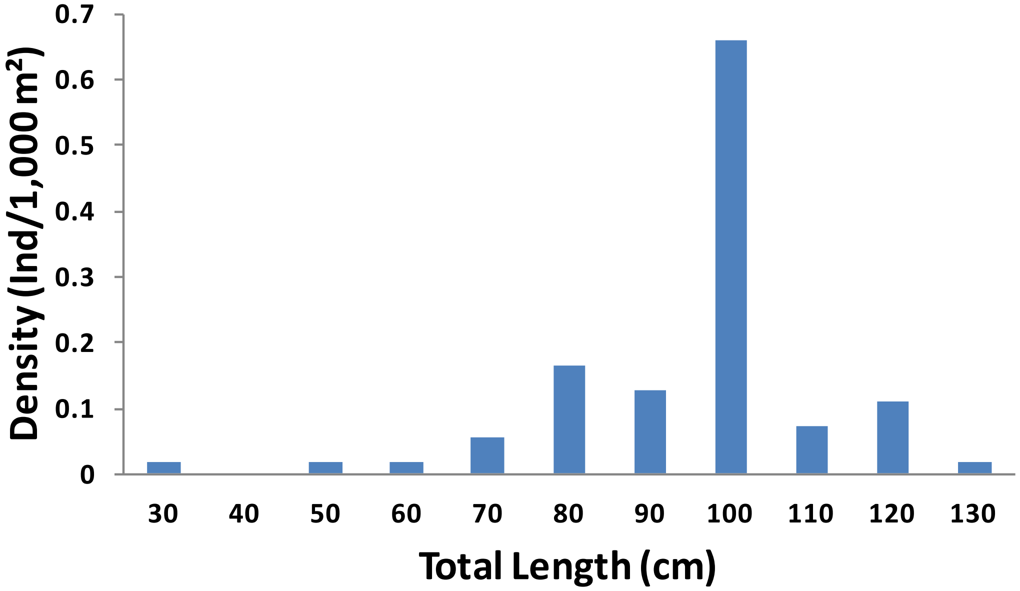


**Figure 31.** Cubera Snapper (*Lutjanus cyanopterus*). Combined length (cm) frequency distribution from all mesophotic habitats at Tourmaline Reef, 2012-13

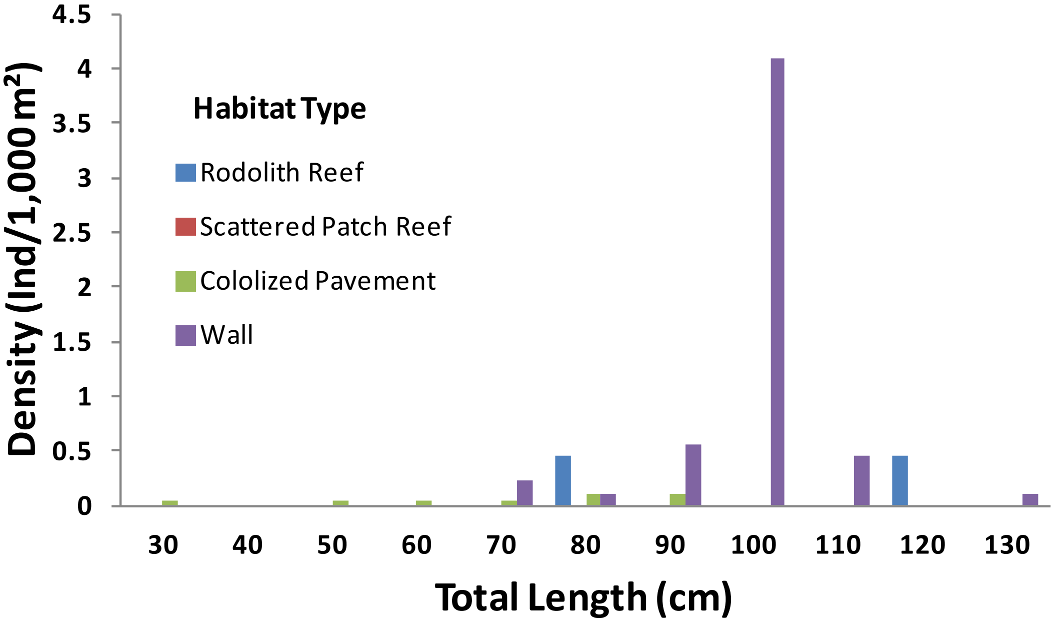


**Figure 32.** Cubera Snapper (*Lutjanus cyanopterus*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

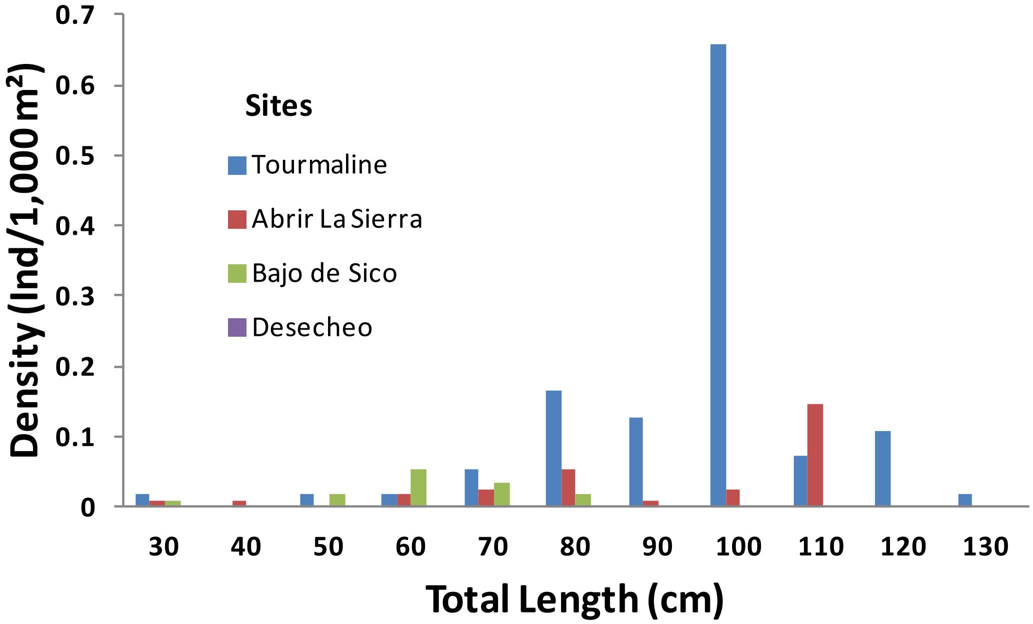


**Figure 33.** Cubera Snapper (*Lutjanus cyanopterus*). Variations of length (cm) frequency distributions at mesophotic reef systems surveyed in Puerto Rico.

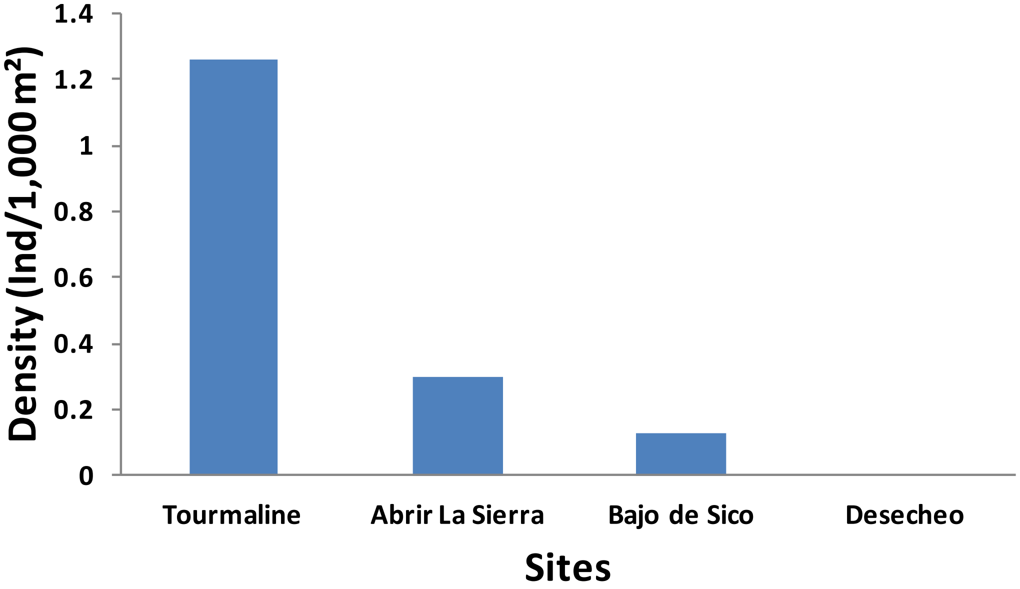


**Figure 34**. Cubera Snapper (*Lutjanus cyanopterus*). Mean densities from mesophotic reef systems surveyed in Puerto Rico, 2005-13.

### 7. Blackfin Snapper (*Lutjanus buccanella*)

Schools of blackfin snappers were observed mostly from the wall, with some penetration at the deeper section of the colonized pavement habitat near the shelf-edge, at the interface with the slope wall (Figure 35). A total of 113 individuals were sighted within a 15 – 30 cm (TL) size range, with a strong mode at 25 cm (Figure 36). Blackfin snappers were typically present either as a dense round schooling formation of 15 – 40 individuals at the slope wall, or as smaller scattered groups of 5 – 10 individuals swimming fast over the colonized pavement near the shelf-edge towards divers. Size (TL) at first reproduction has been reported as 31.0 cm (range 21 – 35 cm) (Table 12). Thus, most of the individuals observed from mesophotic habitats of Tourmaline Reef are either young adults or late juveniles. Still, the size range of blackfin snappers observed from Tourmaline Reef is well below the maximum size for the species reported as 75 cm TL (Table 12). Nevertheless, it is evident that the upper insular slope habitat is within the normal foraging range of juvenile and/or young adult blackfin snappers at Tourmaline Reef and perhaps other similar mesophotic habitats off the insular slope. Also, there is the potential for penetration of larger individuals at night at the upper insular slope.

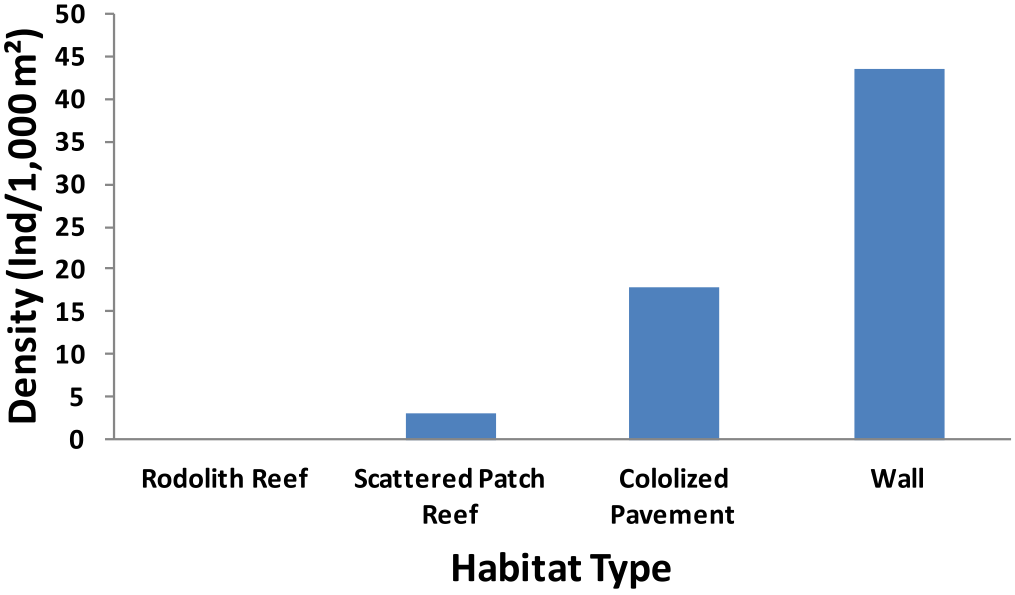


**Figure 35**. Blackfin Snapper (*Lutjanus buccanella*). Mean densities (Ind/1000 m$^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13

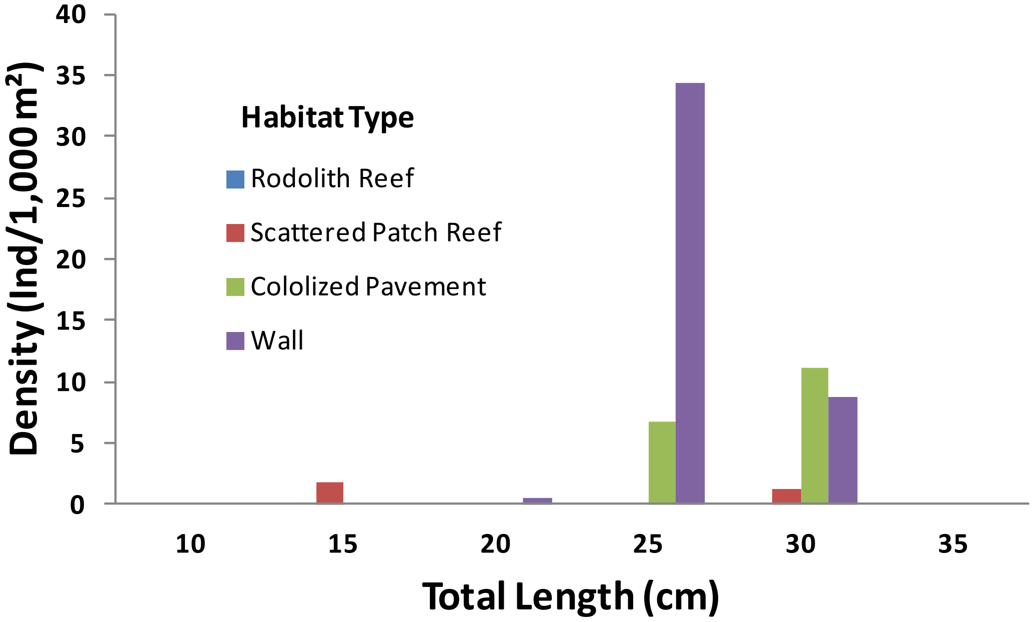


**Figure 36.** Blackfin Snapper (*Lutjanus buccanella*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

### 8. Dog Snapper (*Lutjanus jocu*)

Sightings of dog snapper in mesophotic habitats of Tourmaline Reef included 24 individuals distributed into two schools of 9 and 15 individuals at the colonized pavement and 287 individuals from the slope wall (Figure 37). The high fish density recorded at the slope wall was largely associated with what appeared to be an unexpected reproductive aggregation consisting of 261 individuals. These were all large adult fishes of similar size visually estimated as of approximately 60 cm (Figure 38). The aggregation swirled in concentric circles while moving forward over a small terrace of the slope wall at a depth of 45 m. Release of gametes was not observed. According to the data base prepared by Froese and Pauly (2005; Table 12), dog snappers reach a maximum size of 128 cm, are common at 60 cm, and reproduce when they reach a length of 32.0 cm (TL). All dog snapper individuals surveyed from mesophotic habitats of Tourmaline Reef were above 32 cm, which implies that particularly the slope wall habitat may function as a place for reproductive aggregations. Such aggregations may have other implications, predatory perhaps, in this system.

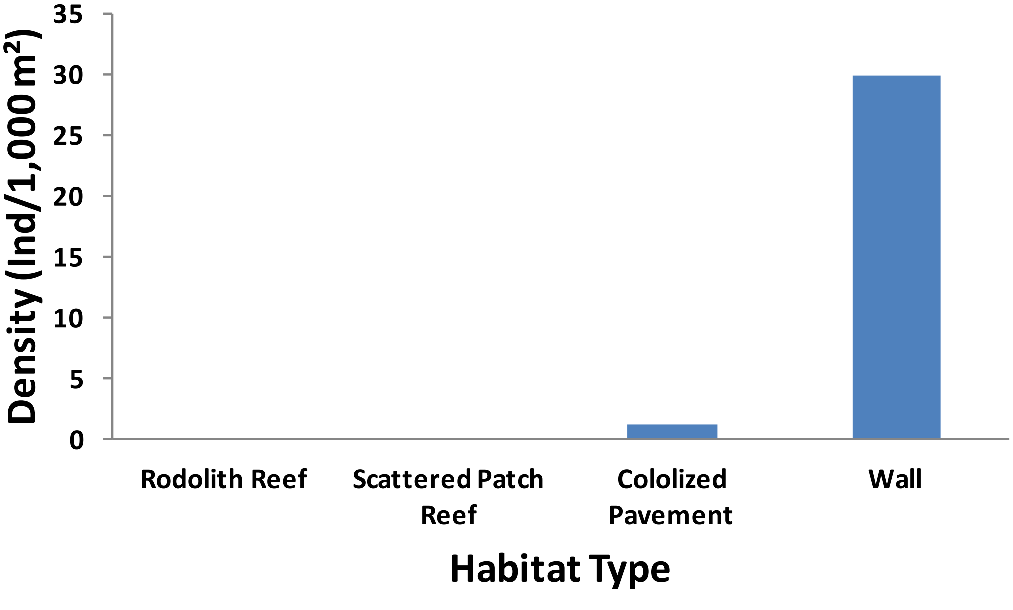


**Figure 37**. Dog Snapper (*Lutjanus jocu*). Mean densities (Ind/1000 m$^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13

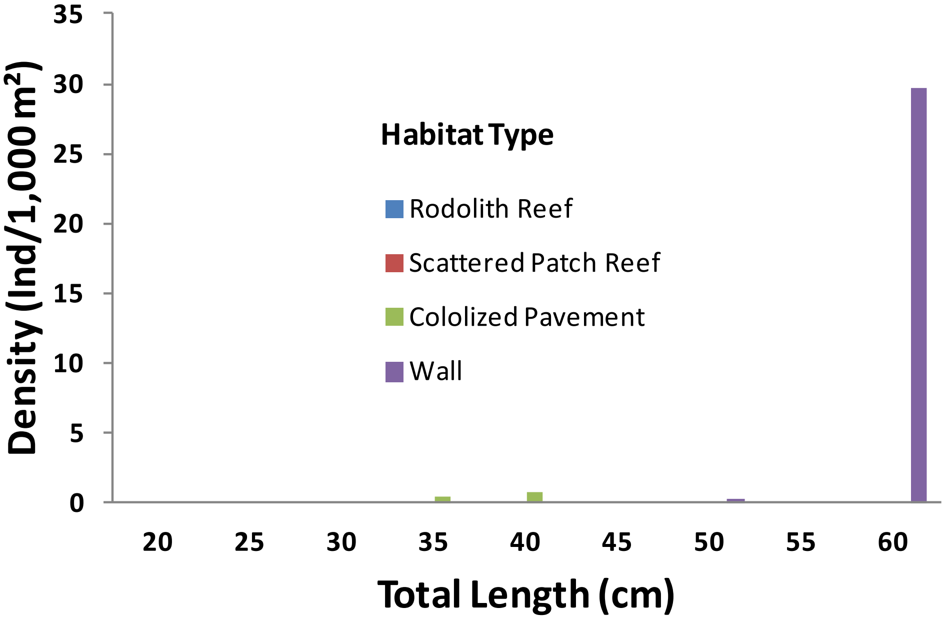


**Figure 38.** Dog Snapper (*Lutjanus jocu*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

### 9. Hogfish (*Lachnolaimus maximus*)

A total of 38 hogfishes were sighted from mesophotic habitats at Tourmaline Reef. The higher density was observed at the colonized pavement (24 individuals), but they were also present on scattered patch reefs (9) and at the slope wall (5) (Figure 39). Hogfishes ranged in length from a minimum (FL) of 25 cm to a maximum (FL) of 70 cm, with a clearly bimodal distribution at 25 cm and 50 cm (Figure 40). Length at first reproduction (Lm) for hogfish is not available, but given that hogfishes grow to a maximum reported size of 91 cm it is improbable that such 25 cm individuals have reached maturity. In which case mesophotic habitats of Tourmaline Reef may be serving as residential and foraging areas for both juvenile and adult hogfishes. The maximum size of hogfish from this study (70 cm) is similar to the maximum reported for the Caribbean Antilles (Table 12).

Trends of ontogenetic habitat selectivity by hogfishes were not evident at Tourmaline Reef since broad size distributions were recorded from all three benthic habitats where present (Figure 41). Compared to other mesophotic sites surveyed by Garcia-Sais et al (2012), the size distribution range of hogfish at Tourmaline Reef was similar to that of the neighbor system Abrir la Sierra, but densities and particularly at the early juvenile size class were much higher (Figure 42). The presence of hogfishes in relatively high density provides further evidence to the theory advanced by Garcia-Sais et al (2012) in that the lack of physical connectivity with coastal recruitment habitats may be limiting hogfish populations in oceanic habitats. Hogfishes were reported from all benthic habitats, seasons and depths at ALS (Garcia-Sais et al 2012). The present findings at Tourmaline Reef provide further support of the broad habitat plasticity exhibited by hogfish on mesophotic sites that are physically connected to the insular shelf (Figure 43). Therefore, it is improbable that their absence from mesophotic habitats at oceanic sites surveyed be habitat related. These data suggests that the physical connectivity to recruitment and/or nursery habitats within the insular shelf, which applies both for Tourmaline Reef and ALS, is a critically important aspect of their life strategy. Larval dispersal is not likely to be a factor limiting recruitment to nearby oceanic sites within Mona Passage because larval Labridae are known to have oceanic distributions (Ramirez and Garcia 2003).

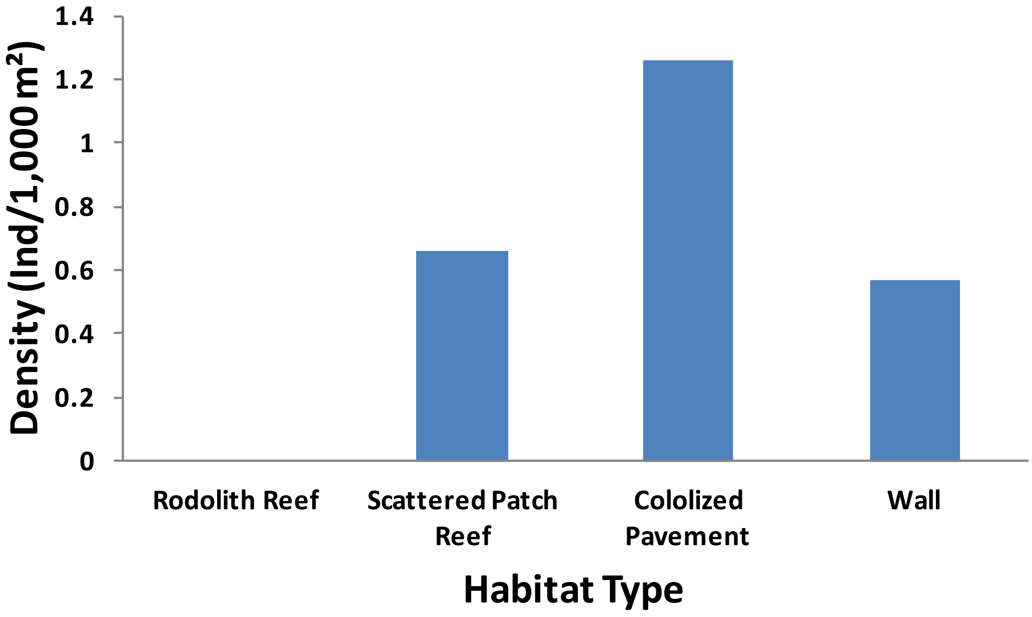


**Figure 39**. Hogfish (*Lachnolaimus maximus*). Mean densities (Ind/1000 m$^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13

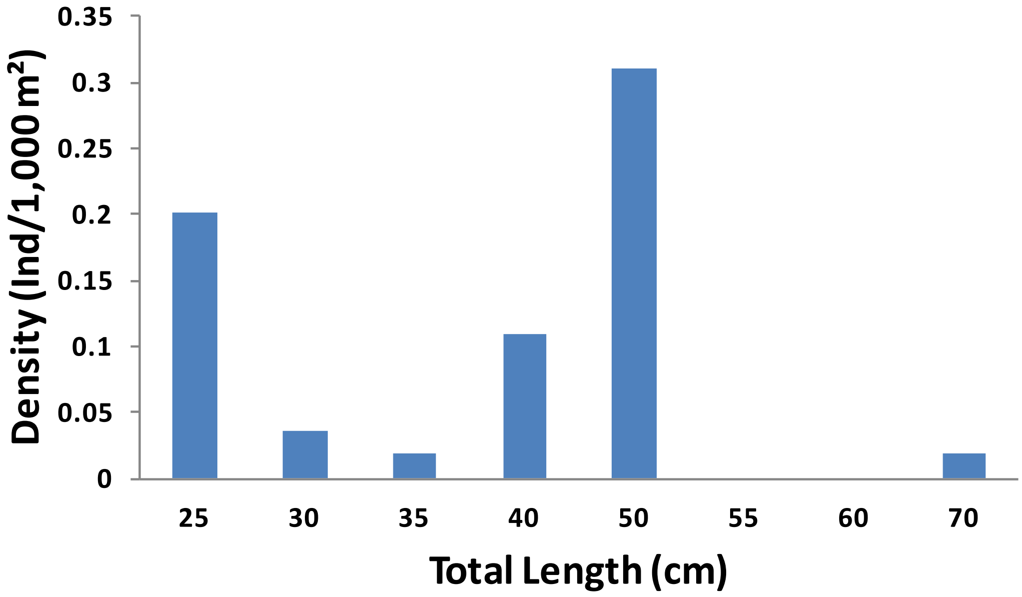


**Figure 40.** Hogfish (*Lachnolaimus maximus*). Combined length (cm) frequency distribution from all mesophotic habitats at Tourmaline Reef, 2012-13

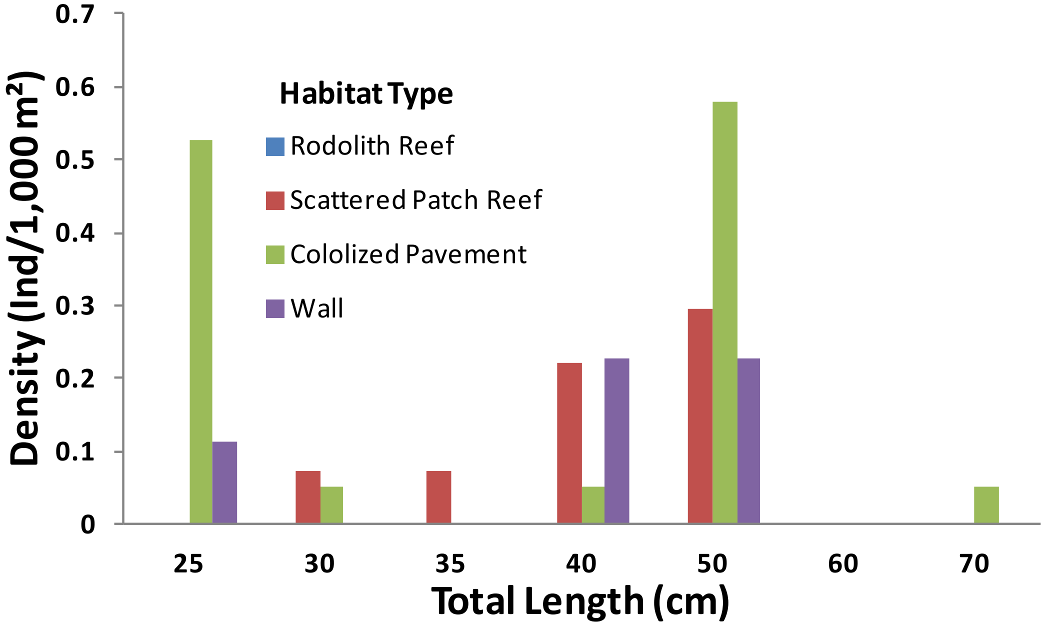


**Figure 41.** Hogfish (*Lachnolaimus maximus*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

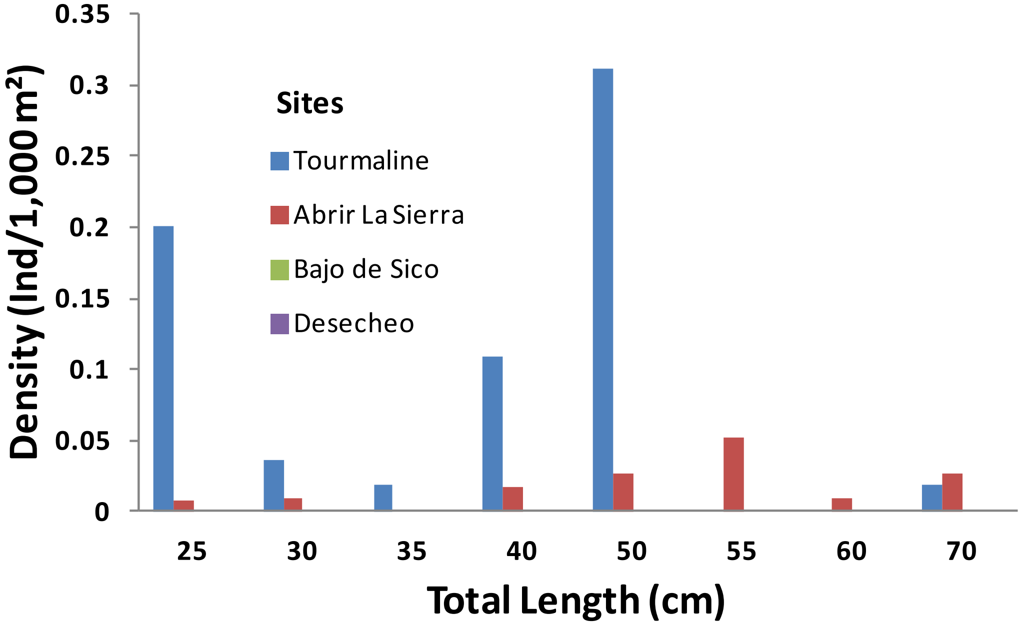


**Figure 42.** Hogfish (*Lachnolaimus maximus*). Variations of length (cm) frequency distributions at mesophotic reef systems surveyed in Puerto Rico.

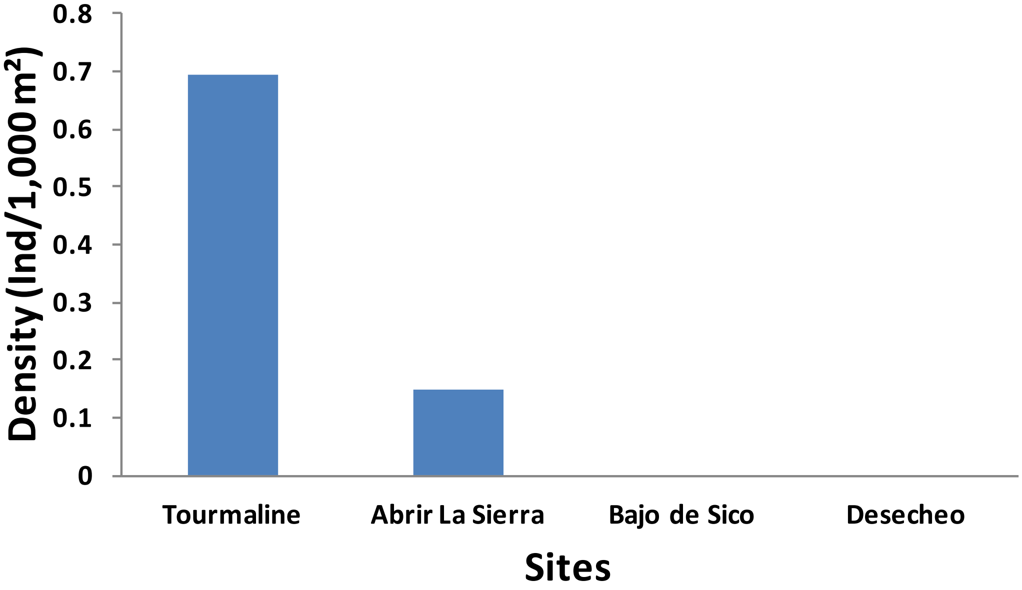
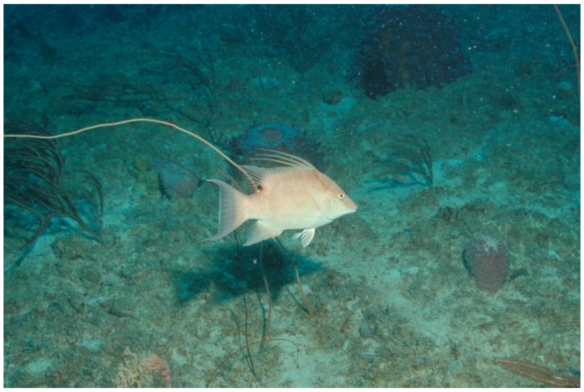


**Figure 43**. Hogfish (*Lachnolaimus maximus*). Mean densities from mesophotic reef systems surveyed in Puerto Rico, 2005-13.



### 10. Lionfish (*Pterois sp.*)

Lionfishes were observed from all mesophotic habitats and depths surveyed at Tourmaline Reef with perhaps lower density at the colonized pavement (Figure 44). A total of 71 individuals were sighted within transects. The population presented a size range of 10 to 30 cm (TL), with a strong mode at 25 cm. The size distribution was skewed towards the larger individuals, suggesting that mesophotic habitats at Tourmaline serve mostly for an adult population. Clear ontogenetic patterns of size distributions at preferred habitats were not evidenced as broad size distributions were observed from all major benthic habitats (Figure 45). Age at first reproduction of lionfish has been reported as 23 cm (Table 12). Thus, 83.1 % of the entire population observed from mesophotic habitats at Tourmaline Reef was comprised of adult individuals. This is consistent with findings from other mesophotic sites surveyed (Garcia-Sais, 2012). Maximum length reported for lionfish is 38.0 cm. Thus, our maximum length estimate of 30.0 cm is close to the maximum length reported for the species. Compared to other mesophotic sites surveyed, lionfish at Tourmaline Reef exhibited a similar size distribution range (Figure 46), and fell within the range of density estimates for the species from all mesophotic habitats (Figure 47).

The broad size distribution range suggests that lionfishes have adapted to lifetime residence at mesophotic habitats within Tourmaline Reef and elsewhere among mesophotic habitats within the Puerto Rico EEZ (Garcia-Sais, 2012). Their relatively high abundance within mesophotic habitats at oceanic sites, such as at BDS and Desecheo implies that effective larval dispersal mechanisms, as well as appropriate early juvenile recruitment adaptations to mesophotic habitats are operational for this species. Also, the relatively high amount of large individuals (e.g. 25 - 30 cm) is indicative that lionfishes are reaching their full development at mesophotic habitats and perhaps experiencing low fishing mortality.

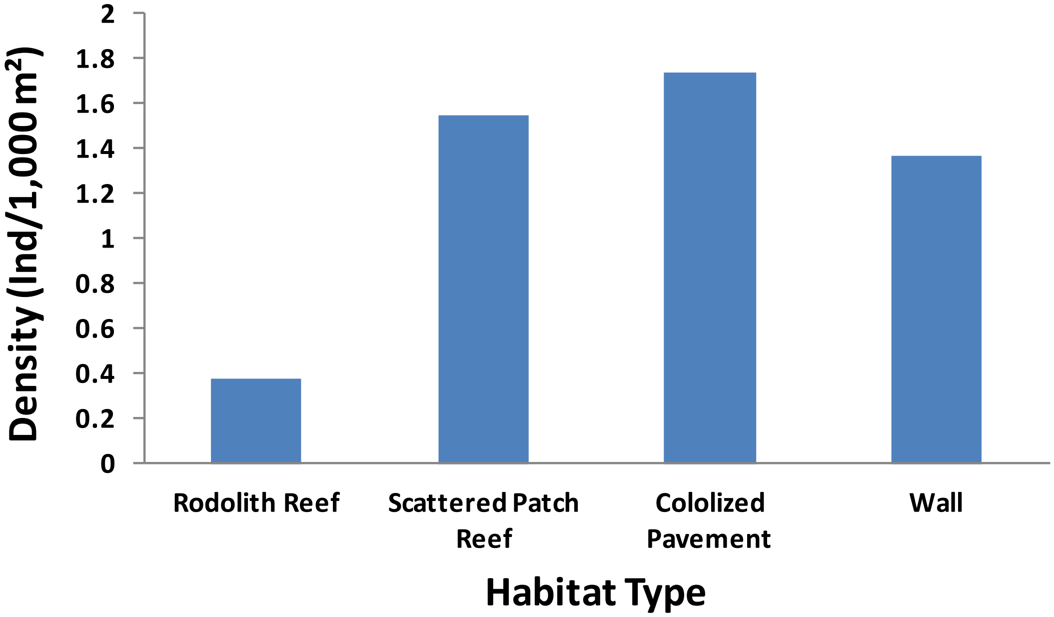


**Figure 44**. Lionfish (*Pterois sp.*). Mean densities (Ind/1000 m$^2$) at mesophotic benthic habitats (30 – 50 m depth) from Tourmaline Reef, 2012-13

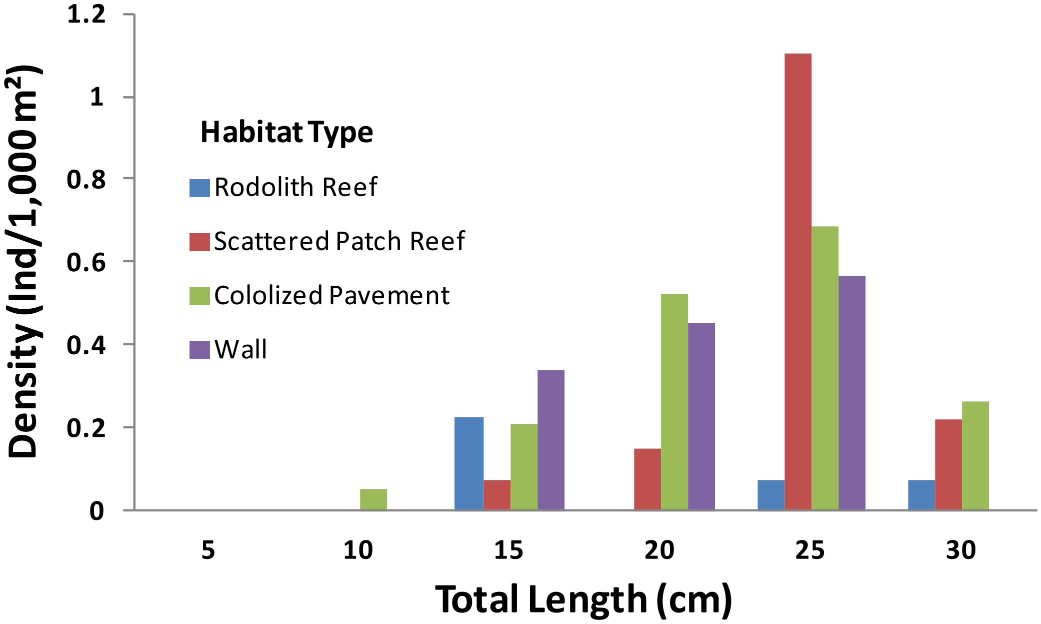


**Figure 45**. Lionfish (*Pterois sp.*). Length (cm) frequency distributions at the benthic habitats surveyed from Tourmaline Reef. 2012-13

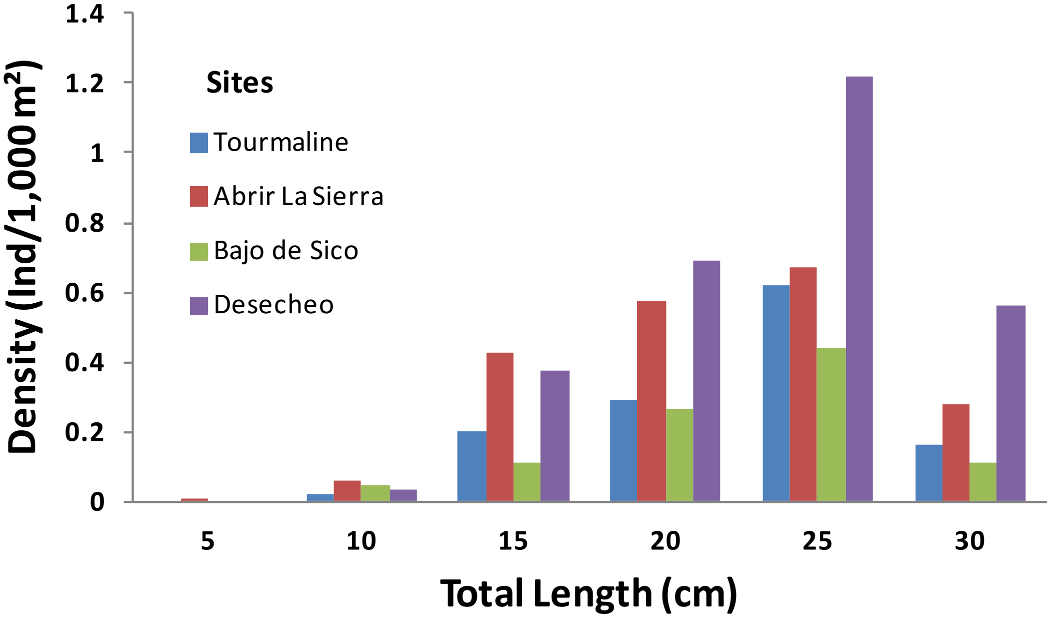


**Figure 46.** Lionfish (*Pterois sp.*). Variations of length (cm) frequency distributions at mesophotic reef systems surveyed in Puerto Rico

.

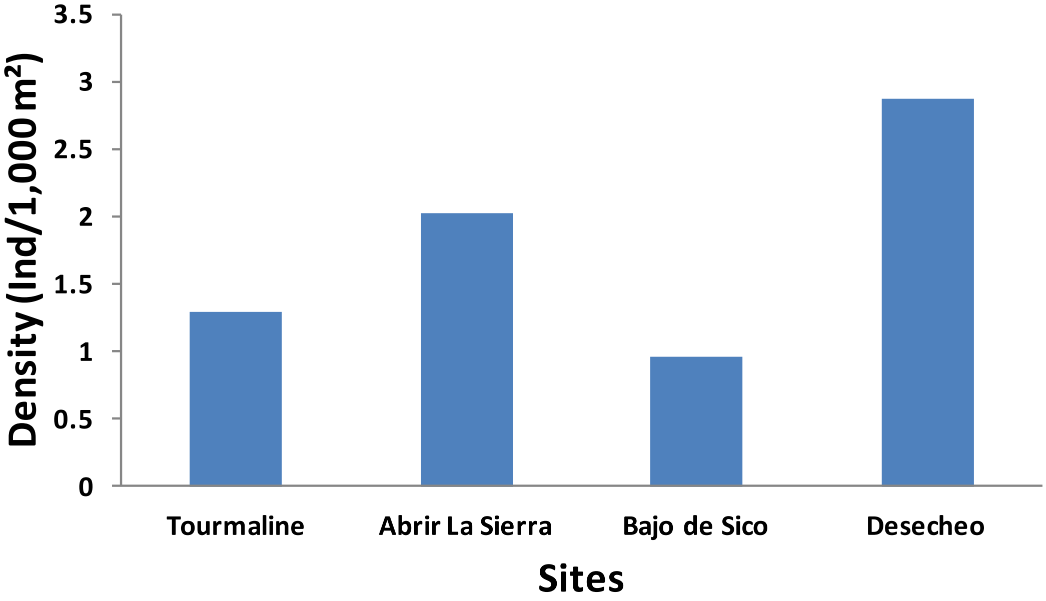


**Figure 47.** Lionfish (*Pterois sp.*). Mean densities from mesophotic reef systems surveyed in Puerto Rico, 2005-13






## VII. Conclusions

1. The mesophotic system of Tourmaline Reef within the 30 – 50 depth range covers an areal extension of approximately 13.8 $km^2$. It is a narrow, elbow-shaped fringe associated with the shelf-edge, and represents the interface between the shallow neritic shelf and the insular slope off Mayaguez Bay.
2. The most relevant physical feature of the seafloor within the 30 – 50 m depth range was the lack of underwater topographic features that contribute reef structural complexity.
3. Of the five main benthic habitat types present (e.g. sandy substrate; scattered patch reefs; colonized pavement; algal rhodolith reef; and slope wall), none exhibited substantial topographic relief nor relict structural features that could be attributed to coral growth.
4. Sand plains, evidently in dynamic state and mostly uncolonized by sessile-benthic biota represented the main substrate (habitat) type in terms of areal cover with approx. 6.7 $km^2$, or 48.1 % of the total study area. Thus, almost half of the study area consists of a largely abiotic habitat.
5. The sessile-benthic community structure evidenced a pattern of higher affinities within habitat types than within depths. Differences associated with higher density of sponges, gorgonians and corals at the insular slope wall, relative to other benthic habitats appears to be determined by higher availability of attachment substrates devoid of sand and/or abrasive forces that prevail at the colonized pavement and scattered patch reef habitats
6. The scarcity of scleractinian corals and absence of coral reef formations within the 30 – 50 m depth range appears to be related to the high substrate cover by sand and its abrasive effect on exposed, horizontally oriented hard ground surfaces.
7. The rhodolith habitat is here considered as a reef system because the biogenic construction and deposition of crustose algal nodules have produced an horizontally extensive physical structure that provides topographic relief and microhabitats for a specialized reef community, thereby influencing sedimentation patterns and (increasing) benthic and pelagic biodiversity relative to adjacent benthic habitats.
8. Consistent with the sessile-benthic community characterization, the taxonomic composition of reef fishes and their rank order abundance in belt-transects surveyed conferred higher affinities within habitat types than within depths.
9. Differences of fish community structure between the slope wall and other benthic habitats appears to be strongly related with the higher prominence of fish species associated with zooplankton based food webs, presence of large demersal predators that form reproductive and/or foraging aggregations, and deepwater (slope) species that use the wall at the upper insular slope as part of their foraging habitat range.
10. Fish assemblages at the rhodolith reef and the colonized pavement and scattered patch reef habitats appear to be largely comprised by small, invertebrate and small fish feeders that inhabit the available microhabitats created by crevices, gaps and rhodolith that prevail over an otherwise flat and topographically featureless seafloor.
11. The rhodolith reef habitat at Tourmaline is a continuation of the rhodolith habitat that has been described for the adjacent mesophotic reef system, Abrir la Sierra and was observed to function as a prime habitat for an adult population of queen conch.
12. Spiny lobsters were observed from mesophotic habitats at Tourmaline Reef, with higher densities at the colonized pavement and lowest (none) at the rhodolith reef. The size distribution showed that both juvenile and adult spiny lobsters are utilizing mesophotic habitats from Tourmaline Reef.

13. Mutton, blackfin, dog and cubera snappers, red hinds, lionfish, hogfish and queen triggerfishes were the most abundant of the large demersal commercially important fishes present within mesophotic habitats of Tourmaline Reef.
14. The slope wall habitat at the elbow of Tourmaline Reef was observed to function as a spawning aggregation site for dog snapper, *Lutjanus jocu*, and as an aggregation site for cubera snappers, *L. cyanopterus*.
15. Mean density of queen conch, hogfish, mutton, dog and cubera snappers were much higher at Tourmaline and Abrir La Sierra than at oceanic mesophotic systems previously studied. It is here suggested that such higher abundance is related to the stronger physical connectivity of mesophotic habitats at Tourmaline and Abrir la Sierra with recruitment habitats of the shallow neritic shelf as compared to oceanic sites (Desecheo and Bajo de Sico) that are separated from the insular shelf by oceanic depths.

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# IX. Appendices

**Appendix 1.** Field logbook with georeferenced information of sampling stations, benthic habitat types, depths and survey dates. Tourmaline Reef, Mayaguez 2012-13.

| Dive | Date | Station | Latitude | Longitude | Habitat | Depth (m) | Distance (m) |
|---|---|---|---|---|---|---|---|
| 1 | 1/27/2012 | Tour-1 | 18.17377 | -67.31770 | Col pavement | 40.9 | |
| 2 | 1/27/2012 | Tour-3 | 18.16978 | -67.31810 | Col Pavement | 33.0 | |
| 3 | 1/27/2012 | Tour-5 | 18.15396 | -67.41572 | Rhodolith Reef | 36.4 | |
| 5 | 2/2/2012 | Tour-6 | 18.14081 | -67.42637 | Rhodolith | 36.4 | |
| 6 | 2/3/2012 | 354 | 18.15640 | -67.41068 | Rhodolith | 36.4 | |
| 7 | 2/3/2012 | 355 | 18.16146 | -67.40669 | Rhodolith | 30.9 | |
| 8 | 2/3/2012 | 356 | 18.16605 | -67.39561 | Sand | 31.8 | |
| 8 | | 357 | 18.14265 | -67.42258 | Sand | 31.8 | |
| 11 | 3/22/2012 | Tour-11 | 18.17560 | -67.33488 | Patch Reef | 36.4 | 113 |
| 11 | | Tour-11-End | 18.17523 | -67.33588 | Patch Reef | 36.4 | |
| 14 | 3/23/2012 | Tour-15 | 18.17282 | -67.39245 | HG into Rhodolith | 38.2 | 153 |
| 14 | | 371 | 18.17220 | -67.39374 | HG into Rhodolith | 38.2 | |
| 15 | 3/23/2012 | Tour-16 | 18.16793 | -67.39596 | Rhodolith Reef | 33.3 | 301 |
| 15 | | 372 | 18.16654 | -67.39841 | Rhodolith Reef | 33.3 | |
| 16 | 3/23/2012 | Tour-17 | 18.15634 | -67.40984 | Patch Reef | 33.3 | 182 |
| 16 | | 374 | 18.15503 | -67.41088 | Patch Reef | 33.3 | |
| 17 | 3/24/2012 | Tour-19 | 18.17429 | -67.34091 | Patch Reef | 34.8 | 4166 |
| 17 | | 384 | 18.16920 | -67.30190 | Patch Reef | 34.8 | |
| 18 | 3/24/2012 | Tour-20 | 18.17188 | -67.32222 | HG/Patch | 33.3 | 321 |
| 18 | | 383 | 18.17046 | -67.32487 | HG/Patch | 33.3 | |
| 20 | 3/24/2012 | Tour-22 | 18.16780 | -67.29161 | Coral Reef | 27.3 | 223 |
| 20 | | 385 | 18.16649 | -67.29321 | Coral Reef | 27.3 | |
| 21 | 4/2/2012 | T-9-40 | 18.17362 | -67.31697 | HG | 37.9 | 270 |
| 21 | | 388 | 18.17392 | -67.31937 | HG | 37.9 | |
| 22 | 4/2/2012 | T-10-40 | 18.17023 | -67.29907 | HG | 36.4 | 63 |
| 22 | | 389 | 18.17009 | -67.29964 | HG | 36.4 | |
| 23 | 4/2/2012 | T-10-30 | 18.16916 | -67.29904 | HG | 33.3 | 91 |
| 23 | | 392 | 18.16924 | -67.29819 | HG | 33.3 | |
| 24 | 4/2/2012 | T-9-30 | 18.17098 | -67.31697 | HG | 30.3 | 112 |
| 24 | | 393 | 18.17078 | -67.31593 | HG | 30.3 | |
| 25 | 4/13/2012 | T-7-40 | 18.17719 | -67.35267 | Sand | 40.9 | 187 |
| 25 | | 396 | 18.17838 | -67.35142 | Sand | 40.9 | |
| 26 | 4/13/2012 | T-8-40 | 18.17637 | -67.33475 | Sand/Col pav | 37.9 | 61 |
| 26 | | 397 | 18.17631 | -67.33532 | Sand/Col pav | 37.9 | |
| 30 | 4/19/2012 | T-3-30 | 18.15238 | -67.41431 | RR | 31.8 | 171 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 30 | | 405 | 18.15101 | -67.41506 | RR | 31.8 | |
| 31 | 4/19/2012 | T-4-30 | 18.16437 | -67.40261 | HG | 31.8 | 76 |
| 31 | | 408 | 18.16408 | -67.40325 | HG | 31.8 | |
| 32 | 4/19/2012 | T-5-30 | 18.17066 | -67.38734 | HG | 31.8 | 129 |
| 32 | | 411 | 18.17182 | -67.38741 | HG | 31.8 | |
| 34 | 4/20/2012 | T-1-40 | 18.12415 | -67.43227 | RR | 39.4 | 50 |
| 34 | | 417 | 18.12371 | -67.43237 | RR | 39.4 | |
| 35 | 4/20/2012 | T-2-40 | 18.14058 | -67.42659 | RR | 39.4 | 0 |
| 35 | | T-2-40 | 18.14058 | -67.42659 | RR | 39.4 | |
| 36 | 4/20/2012 | T-2-30 | 18.13886 | -67.42222 | Col pavement | 33.3 | 0 |
| 36 | | T-2-30 | 18.13886 | -67.42222 | Col pavement | 33.3 | |
| 37 | 4/20/2012 | T-1-30 | 18.12099 | -67.42492 | Col pavement | 33.3 | 0 |
| 37 | | t-1-30 | 18.12099 | -67.42492 | Col pavement | 33.3 | |
| 47 | 5/17/2012 | T-8-50 | 18.17665 | -67.33475 | Wall | 48.5 | 0 |
| 47 | | T-8-50 | 18.17665 | -67.33475 | Wall | 48.5 | |
| 58 | 9/13/2012 | 685 | 18.12584 | -67.43095 | Reef | 37.9 | 95 |
| 58 | | 686 | 18.12670 | -67.43100 | | 37.9 | |
| 59 | 9/13/2012 | wp0687 | 18.12917 | -67.42983 | reef | 37.9 | 97 |
| 59 | | wp0689 | 18.13001 | -67.42957 | | 37.9 | |
| 60 | 9/13/2012 | wp690 | 18.13169 | -67.42830 | HG | 33.6 | 183 |
| 60 | | wp691 | 18.13330 | -67.42789 | HG | 33.6 | |
| 61 | 9/13/2012 | wp692 | 18.14134 | -67.42112 | Rhodolith | 33.3 | 343 |
| 61 | | wp693 | 18.14425 | -67.42001 | Rhodolith | 33.3 | |
| 62 | 9/14/2012 | wp695 | 18.14343 | -67.42540 | Rhodolith | 40.9 | 145 |
| 62 | | wp696 | 18.14453 | -67.42465 | | 40.9 | |
| 63 | 9/14/2012 | wp693 | 18.14425 | -67.42001 | Patch/Rhodol | 30.3 | 120 |
| 63 | | wp697 | 18.14500 | -67.41919 | | 30.3 | |
| 64 | 9/14/2012 | wp697 | 18.14500 | -67.41919 | HG/RR | 30.3 | 232 |
| 64 | | wp698 | 18.14699 | -67.41988 | | 30.3 | |
| 65 | 9/14/2012 | Tour-17 | 18.15634 | -67.40989 | Rhodolith | 31.8 | 249 |
| 65 | | wp699 | 18.15851 | -67.40921 | | 31.8 | |
| 66 | 9/20/2012 | Fit-29 | 18.17570 | -67.3288 | Wall | 43.9 | 196 |
| 66 | | wp702 | 18.17545 | -67.32697 | | 43.9 | |
| 67 | 9/20/2012 | Fit-30 | 18.17389 | -67.32157 | Wall | 40.9 | 60 |
| 67 | | wp704 | 18.17420 | -67.32203 | | 40.9 | |
| 68 | 9/20/2012 | Fis-28 | 18.17451 | -67.33174 | Col pavement | 35.5 | 131 |
| 68 | | wp706 | 18.17347 | -67.33234 | | 35.5 | |
| 69 | 9/20/2012 | Fis-31 | 18.16630 | -67.28671 | Reef | 31.8 | 246 |
| 69 | | wp708 | 18.16576 | -67.28897 | | 31.8 | |
| 71 | 9/21/2012 | T2-40 | 18.14058 | -67.42659 | Wall | 43.9 | 204 |
| 71 | | wp709 | 18.13877 | -67.42695 | | 43.9 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 72 | 9/21/2012 | wp689 | 18.13001 | -67.42957 | HG | 37.9 | 278 |
| 72 | | wp710 | 18.12751 | -67.42931 | | 37.9 | |
| 73 | 9/21/2012 | DC-30 | 18.13260 | -67.42932 | HG | 37.9 | 436 |
| 73 | | wp712 | 18.12870 | -67.42993 | | 37.9 | |

**Appendix 2.** Results from permutational multivariate analysis of variance (PERMANOVA) tests comparing the composition of sessile-benthic substrate categories between depths and habitat types.

| Source | df | SS | MS | Pseudo-F | P |
|---|---|---|---|---|---|
| Depth | 2 | 290.47 | 145.24 | 0.19652 | 0.88 |
| Habitat | 4 | 13129 | 3282.3 | 11.533 | 0.001 |

Pair-wise PERMANOVA test comparing the composition of sessile-benthic substrate categories between habitat types. SPR=Scattered patch reef, S=Sand, CP= Colonized pavement, R=Rhodolith, and W=Wall.

| Habitat | t value | P |
|---|---|---|
| SPR, S | 6.323 | 0.019 |
| SPR, CP | 1.5275 | 0.114 |
| SPR, R | 1.7125 | 0.084 |
| SPR, W | 3.6463 | 0.003 |
| S, CP | 4.7384 | 0.02 |
| S, R | 2.6783 | 0.038 |
| S, W | 6.1899 | 0.042 |
| CP, R | 2.3234 | 0.038 |
| CP, W | 2.2006 | 0.021 |
| R, W | 3.6285 | 0.021 |

**Appendix 3.** Results from permutational multivariate analysis of variance (PERMANOVA) tests comparing the rank order densities of fish species in belt-transects surveyed between habitat types.

PERMANOVA
Permutational MANOVA

*PERMANOVA table of results*

| Source | df | SS | MS | Pseudo-F | P(perm) | Unique perms |
|---|---|---|---|---|---|---|
| Ha | 3 | 19380 | 6460 | 1.8326 | 0.001 | 999 |
| Res | 29 | 1.0223E5 | 3525.1 | | | |
| Total | 32 | 1.2161E5 | | | | |

*Estimates of components of variation*

| Source | Estimate | Sq.root |
|---|---|---|
| S(Ha) | 376.36 | 19.4 |
| V(Res) | 3525.1 | 59.373 |

*PAIR-WISE TESTS*

Term 'Ha'

| Groups | t | P(perm) | Unique perms |
|---|---|---|---|
| RR, CP | 1.0963 | 0.225 | 999 |
| RR, SPR | 1.3442 | 0.012 | 698 |
| RR, W | 1.6503 | 0.002 | 961 |
| CP, SPR | 1.0048 | 0.445 | 758 |
| CP, W | 1.614 | 0.001 | 956 |
| SPR, W | 1.2278 | 0.05 | 209 |

*Denominators*

| Groups | Denominator | Den.df |
|---|---|---|
| RR, CP | 1*Res | 21 |
| RR, SPR | 1*Res | 13 |
| RR, W | 1*Res | 15 |
| CP, SPR | 1*Res | 14 |
| CP, W | 1*Res | 16 |
| SPR, W | 1*Res | 8 |

*Average Similarity between/within groups*

| | RR | CP | SPR | W |
|---|---|---|---|---|
| RR | 17.207 | | | |
| CP | 18.081 | 19.744 | | |
| SPR | 11.821 | 19.25 | 18.294 | |
| W | 3.863 | 6.2971 | 8.4812 | 9.0023 |

**Appendix 4.** Fish species contributions to similarity percentages within habitats and dissimilarity percentages between habitats based on the rank ordination of densities within belt-transects surveyed at Tourmaline Reef, Mayaguez 2012-13

SIMPER

Similarity Percentages - species contributions

*Group RR*

Average similarity: 17.21

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| Stegastes partitus | 24.12 | 10.70 | 1.25 | 62.20 | 62.20 |
| Halichoeres garnoti | 3.91 | 1.26 | 0.54 | 7.32 | 69.51 |
| Lutjanus analis | 3.75 | 1.14 | 0.44 | 6.61 | 76.13 |
| Serranus tigrinus | 6.17 | 1.07 | 0.30 | 6.20 | 82.32 |
| Balistes vetula | 6.04 | 0.64 | 0.22 | 3.71 | 86.03 |
| Epinephelus guttatus | 3.72 | 0.56 | 0.24 | 3.24 | 89.27 |
| Sparisoma atomarium | 3.99 | 0.54 | 0.21 | 3.16 | 92.43 |

*Group CP*

Average similarity: 19.74

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| Stegastes partitus | 17.03 | 6.70 | 0.75 | 33.95 | 33.95 |
| Halichoeres garnoti | 7.14 | 3.29 | 0.81 | 16.64 | 50.59 |
| Epinephelus guttatus | 7.13 | 2.26 | 0.51 | 11.45 | 62.05 |
| Lutjanus analis | 7.73 | 2.11 | 0.49 | 10.68 | 72.73 |
| Thalassoma bifasciatum | 7.92 | 1.87 | 0.47 | 9.48 | 82.20 |
| Holocentrus rufus | 2.77 | 0.87 | 0.46 | 4.43 | 86.63 |
| Epinephelus fulva | 4.94 | 0.60 | 0.31 | 3.06 | 89.69 |
| Canthigaster rostrata | 4.17 | 0.56 | 0.21 | 2.82 | 92.51 |

*Group SPR*

Average similarity: 18.29

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| Stegastes partitus | 5.44 | 4.56 | 4.66 | 24.92 | 24.92 |
| Holocentrus rufus | 6.40 | 4.54 | 2.35 | 24.83 | 49.75 |
| Epinephelus fulva | 4.40 | 2.33 | 0.91 | 12.73 | 62.48 |
| Lachnolaimus maximus | 6.22 | 1.57 | 0.41 | 8.58 | 71.06 |
| Ocyurus chrysurus | 9.11 | 1.44 | 0.41 | 7.85 | 78.91 |
| Epinephelus guttatus | 4.34 | 1.29 | 0.41 | 7.04 | 85.95 |
| Balistes vetula | 2.67 | 1.16 | 0.87 | 6.35 | 92.30 |

*Group W*

Average similarity: 9.00

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| Gramma loreto | 5.64 | 2.51 | 0.72 | 27.86 | 27.86 |
| Lutjanus bucannella | 7.86 | 2.16 | 0.48 | 24.01 | 51.86 |
| Paranthia fucifer | 4.19 | 0.81 | 0.26 | 8.99 | 60.86 |
| Elaggatis bipinnulata | 3.71 | 0.67 | 0.26 | 7.49 | 68.34 |
| Chromis insolata | 2.93 | 0.50 | 0.26 | 5.54 | 73.88 |
| Halichoeres garnoti | 1.90 | 0.46 | 0.41 | 5.09 | 78.97 |
| Epinephelus fulva | 4.96 | 0.44 | 0.26 | 4.87 | 83.84 |
| Epinephelus cruentatus | 3.23 | 0.42 | 0.26 | 4.70 | 88.54 |
| Epinephelus guttatus | 1.86 | 0.34 | 0.26 | 3.75 | 92.29 |

*Groups RR & CP*
Average dissimilarity = 81.92

| Species | Group RR<br>Av.Abund | Group CP<br>Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Stegastes partitus | 24.12 | 17.03 | 11.45 | 0.95 | 13.98 | 13.98 |
| Balistes vetula | 6.04 | 3.98 | 4.26 | 0.65 | 5.20 | 19.18 |
| Serranus tigrinus | 6.17 | 3.30 | 4.22 | 0.67 | 5.15 | 24.33 |
| Thalassoma bifasciatum | 2.01 | 7.92 | 4.21 | 0.71 | 5.14 | 29.47 |
| Lutjanus analis | 3.75 | 7.73 | 4.04 | 0.89 | 4.93 | 34.39 |
| Epinephelus guttatus | 3.72 | 7.13 | 3.97 | 0.96 | 4.85 | 39.24 |
| Halichoeres garnoti | 3.91 | 7.14 | 3.29 | 1.21 | 4.02 | 43.26 |
| Epinephelus fulva | 0.92 | 4.94 | 2.70 | 0.52 | 3.29 | 46.55 |
| Lactophrys trigonus | 0.00 | 5.36 | 2.68 | 0.42 | 3.27 | 49.82 |
| Sparisoma atomarim | 3.99 | 1.40 | 2.36 | 0.67 | 2.88 | 52.70 |
| Serranus tortugarum | 4.46 | 0.48 | 2.34 | 0.54 | 2.85 | 55.56 |
| Acanthurus bahianus | 1.70 | 3.21 | 2.31 | 0.42 | 2.82 | 58.38 |
| Canthigaster rostrata | 0.68 | 4.17 | 2.26 | 0.60 | 2.75 | 61.13 |
| Serranus annularis | 2.82 | 0.95 | 1.71 | 0.55 | 2.09 | 63.22 |
| Sphiraena barracuda | 1.86 | 1.76 | 1.65 | 0.43 | 2.02 | 65.24 |
| Caranx lugubris | 3.23 | 0.00 | 1.62 | 0.32 | 1.97 | 67.21 |
| Seriola dumerili | 3.23 | 0.00 | 1.62 | 0.32 | 1.97 | 69.19 |
| Buffalo cowfish | 2.99 | 0.00 | 1.50 | 0.32 | 1.83 | 71.01 |
| Malacanthus plumieri | 2.95 | 0.00 | 1.47 | 0.45 | 1.80 | 72.81 |
| Centropige argi | 2.76 | 0.22 | 1.42 | 0.38 | 1.73 | 74.54 |
| Holocentrus rufus | 0.00 | 2.77 | 1.38 | 0.83 | 1.69 | 76.23 |
| Scarus iserti | 0.00 | 2.76 | 1.38 | 0.44 | 1.69 | 77.92 |
| Scomberomorus cavalla | 0.00 | 2.49 | 1.24 | 0.30 | 1.52 | 79.44 |
| Seriola rivoliana | 0.00 | 2.49 | 1.24 | 0.30 | 1.52 | 80.96 |
| Elaggatis bipinnulata | 2.41 | 0.00 | 1.21 | 0.32 | 1.47 | 82.43 |
| Bodianus rufus | 1.86 | 0.64 | 1.19 | 0.40 | 1.45 | 83.88 |
| Lutjanus cyanopterus | 1.84 | 0.62 | 1.17 | 0.42 | 1.43 | 85.31 |
| Reef shark | 1.86 | 0.00 | 0.93 | 0.32 | 1.14 | 86.45 |
| Pomacanthus paru | 1.86 | 0.00 | 0.93 | 0.32 | 1.13 | 87.58 |
| Spotted Eagle Ray | 0.00 | 1.76 | 0.88 | 0.30 | 1.07 | 88.65 |
| Opistognathus aurifrons | 1.75 | 0.00 | 0.88 | 0.45 | 1.07 | 89.72 |
| Caranx ruber | 1.70 | 0.00 | 0.85 | 0.32 | 1.04 | 90.77 |

*Groups RR & SPR*
Average dissimilarity = 88.18

| Species | Group RR<br>Av.Abund | Group SPR<br>Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Stegastes partitus | 24.12 | 5.44 | 9.84 | 0.75 | 11.16 | 11.16 |
| Ocyurus chrysurus | 0.00 | 9.11 | 4.56 | 0.79 | 5.17 | 16.33 |
| Acanthurus bahianus | 1.70 | 6.96 | 3.91 | 0.65 | 4.43 | 20.76 |
| Chaetodon sedentarius | 0.00 | 7.05 | 3.53 | 0.57 | 4.00 | 24.75 |
| Balistes vetula | 6.04 | 2.67 | 3.52 | 0.65 | 3.99 | 28.74 |
| Holocentrus adcensionis | 0.00 | 6.96 | 3.48 | 0.57 | 3.95 | 32.69 |
| Holocentrus rufus | 0.00 | 6.40 | 3.20 | 2.53 | 3.63 | 36.32 |
| Lachnolaimus maximus | 0.00 | 6.22 | 3.11 | 0.94 | 3.52 | 39.84 |
| Serranus tigrinus | 6.17 | 0.00 | 3.09 | 0.60 | 3.50 | 43.34 |
| Canthigaster rostrata | 0.68 | 5.77 | 2.98 | 0.75 | 3.38 | 46.72 |
| Lutjanus analis | 3.75 | 5.07 | 2.92 | 1.09 | 3.31 | 50.03 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Epinephelus guttatus | 3.72 | 4.34 | 2.85 | 1.02 | 3.23 | 53.26 |
| Serranus annularis | 2.82 | 3.86 | 2.68 | 0.72 | 3.04 | 56.30 |
| Halichoeres garnoti | 3.91 | 2.41 | 2.32 | 1.01 | 2.63 | 58.93 |
| Epinephelus fulva | 0.92 | 4.40 | 2.26 | 1.54 | 2.56 | 61.49 |
| Serranus tortugarum | 4.46 | 0.00 | 2.23 | 0.50 | 2.53 | 64.02 |
| Sparisoma atomarium | 3.99 | 0.00 | 2.00 | 0.55 | 2.26 | 66.28 |
| Pomacanthus paru | 1.86 | 2.56 | 1.98 | 0.63 | 2.24 | 68.52 |
| Lachnolaimus maximus | 0.00 | 3.86 | 1.93 | 0.57 | 2.19 | 70.71 |
| Seriola rivoliana | 0.00 | 3.86 | 1.93 | 0.57 | 2.19 | 72.90 |
| Thalassoma bifasciatum | 2.01 | 2.41 | 1.86 | 0.71 | 2.11 | 75.01 |
| Caranx lugubris | 3.23 | 0.00 | 1.62 | 0.31 | 1.83 | 76.84 |
| Seriola dumerili | 3.23 | 0.00 | 1.62 | 0.31 | 1.83 | 78.68 |
| Buffalo cowfish | 2.99 | 0.00 | 1.50 | 0.31 | 1.70 | 80.37 |
| Malacanthus plumieri | 2.95 | 0.00 | 1.47 | 0.45 | 1.67 | 82.04 |
| Centropige argi | 2.76 | 0.00 | 1.38 | 0.36 | 1.56 | 83.61 |
| Holocanthus tricololr | 1.70 | 1.26 | 1.37 | 0.52 | 1.55 | 85.16 |
| Elaggatis bipinnulata | 2.41 | 0.00 | 1.21 | 0.31 | 1.37 | 86.52 |
| Acanthurus chirurgus | 0.00 | 2.41 | 1.20 | 0.57 | 1.37 | 87.89 |
| Amblycirrhitus pinos | 0.00 | 2.41 | 1.20 | 0.57 | 1.37 | 89.26 |
| Halichoeres cyanocephalus | 0.00 | 2.41 | 1.20 | 0.57 | 1.37 | 90.62 |

*Groups CP & SPR*
Average dissimilarity = 80.75

| Species | Group CP Av.Abund Cum.% | Group SPR Av.Abund | Av.Diss | Diss/SD | Contrib% | |
|---|---|---|---|---|---|---|
| Stegastes partitus | 17.03 | 5.44 | 6.93 | 0.82 | 8.59 | 8.59 |
| Ocyurus chrysurus | 1.42 | 9.11 | 4.57 | 0.84 | 5.66 | 14.24 |
| Acanthurus bahianus | 3.21 | 6.96 | 4.50 | 0.64 | 5.58 | 19.82 |
| Lutjanus analis | 7.73 | 5.07 | 4.41 | 0.98 | 5.46 | 25.28 |
| Thalassoma bifasciatum | 7.92 | 2.41 | 4.14 | 0.72 | 5.12 | 30.40 |
| Canthigaster rostrata | 4.17 | 5.77 | 3.79 | 0.90 | 4.70 | 35.10 |
| Epinephelus guttatus | 7.13 | 4.34 | 3.65 | 1.02 | 4.52 | 39.62 |
| Chaetodon sedentarius | 0.00 | 7.05 | 3.53 | 0.57 | 4.37 | 43.99 |
| Holocentrus adcensionis | 0.00 | 6.96 | 3.48 | 0.57 | 4.31 | 48.30 |
| Halichoeres garnoti | 7.14 | 2.41 | 3.42 | 1.18 | 4.24 | 52.54 |
| Epinephelus fulva | 4.94 | 4.40 | 3.27 | 0.74 | 4.05 | 56.59 |
| Lachnolaimus maximus | 1.67 | 6.22 | 3.11 | 1.05 | 3.85 | 60.44 |
| Seriola rivoliana | 2.49 | 3.86 | 2.85 | 0.62 | 3.53 | 63.97 |
| Balistes vetula | 3.98 | 2.67 | 2.69 | 0.63 | 3.33 | 67.30 |
| Lactophrys trigonus | 5.36 | 0.00 | 2.68 | 0.42 | 3.32 | 70.61 |
| Holocentrus rufus | 2.77 | 6.40 | 2.35 | 1.62 | 2.91 | 73.52 |
| Serranus annularis | 0.95 | 3.86 | 2.17 | 0.64 | 2.69 | 76.21 |
| Lachnolaimus maximus | 0.00 | 3.86 | 1.93 | 0.57 | 2.39 | 78.60 |
| Serranus tigrinus | 3.30 | 0.00 | 1.65 | 0.30 | 2.04 | 80.64 |
| Halichoeres cyanocephalus | 0.92 | 2.41 | 1.46 | 0.64 | 1.81 | 82.46 |
| Scarus iserti | 2.76 | 0.00 | 1.38 | 0.44 | 1.71 | 84.17 |
| Pomacanthus paru | 0.00 | 2.56 | 1.28 | 0.57 | 1.59 | 85.75 |
| Scomberomorus cavalla | 2.49 | 0.00 | 1.24 | 0.30 | 1.54 | 87.29 |
| Acanthurus chirurgus | 0.00 | 2.41 | 1.20 | 0.57 | 1.49 | 88.78 |
| Amblycirrhitus pinos | 0.00 | 2.41 | 1.20 | 0.57 | 1.49 | 90.28 |

*Groups RR & W*
Average dissimilarity = 96.14

| Species | Group RR Av.Abund | Group W Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Stegastes partitus | 24.12 | 0.00 | 12.06 | 0.90 | 12.54 | 12.54 |
| Lutjanus bucannella | 0.00 | 7.86 | 3.93 | 0.86 | 4.09 | 16.63 |
| Balistes vetula | 6.04 | 3.06 | 3.82 | 0.66 | 3.98 | 20.61 |
| Caranx lugubris | 3.23 | 5.09 | 3.70 | 0.61 | 3.85 | 24.46 |
| Serranus tigrinus | 6.17 | 0.00 | 3.09 | 0.61 | 3.21 | 27.67 |
| Gramma loreto | 0.00 | 5.64 | 2.82 | 1.20 | 2.93 | 30.60 |
| Elaggatis bipinnulata | 2.41 | 3.71 | 2.72 | 0.71 | 2.83 | 33.43 |
| Epinephelus fulva | 0.92 | 4.96 | 2.69 | 0.65 | 2.80 | 36.23 |
| Lachnolaimus maximus | 0.00 | 5.37 | 2.69 | 0.44 | 2.79 | 39.02 |
| Epinephelus guttatus | 3.72 | 1.86 | 2.28 | 0.79 | 2.37 | 41.39 |
| Chaetodon acuelatus | 0.00 | 4.49 | 2.25 | 0.44 | 2.34 | 43.73 |
| Pseudopeneus maculatus | 0.00 | 4.49 | 2.25 | 0.44 | 2.34 | 46.07 |
| Serranus tortugarum | 4.46 | 0.00 | 2.23 | 0.50 | 2.32 | 48.38 |
| Paranthias furcifer | 0.00 | 4.19 | 2.10 | 0.70 | 2.18 | 50.56 |
| Ocyurus chrysurus | 0.00 | 4.04 | 2.02 | 0.44 | 2.10 | 52.66 |
| Sparisoma atomarium | 3.99 | 0.00 | 2.00 | 0.55 | 2.08 | 54.74 |
| Halichoeres garnoti | 3.91 | 1.90 | 1.97 | 0.98 | 2.05 | 56.79 |
| Holacanthus ciliaris | 0.00 | 3.87 | 1.93 | 0.44 | 2.01 | 58.80 |
| Southern Stingray | 0.00 | 3.87 | 1.93 | 0.44 | 2.01 | 60.81 |
| Lutjanus analis | 3.75 | 0.00 | 1.87 | 0.82 | 1.95 | 62.76 |
| Lutjanus cyanopterus | 1.84 | 2.02 | 1.75 | 0.53 | 1.82 | 64.58 |
| Bodianus rufus | 1.86 | 1.69 | 1.62 | 0.52 | 1.68 | 66.26 |
| Seriola dumerili | 3.23 | 0.00 | 1.62 | 0.31 | 1.68 | 67.94 |
| Epinephelus cruentatus | 0.00 | 3.23 | 1.61 | 0.65 | 1.68 | 69.62 |
| Pomacanthus paru | 1.86 | 1.63 | 1.60 | 0.52 | 1.66 | 71.28 |
| Buffalo cowfish | 2.99 | 0.00 | 1.50 | 0.31 | 1.56 | 72.84 |
| Malacanthus plumieri | 2.95 | 0.00 | 1.47 | 0.45 | 1.53 | 74.37 |
| Chromis insolata | 0.00 | 2.93 | 1.47 | 0.69 | 1.52 | 75.89 |
| Serranus annularis | 2.82 | 0.00 | 1.41 | 0.46 | 1.47 | 77.36 |
| Centropyge argi | 2.76 | 0.00 | 1.38 | 0.36 | 1.43 | 78.80 |
| Caranx crysos | 0.23 | 2.21 | 1.18 | 0.50 | 1.23 | 80.02 |
| Chromis cyanea | 0.19 | 2.27 | 1.16 | 0.64 | 1.21 | 81.23 |
| Lutjanus jocu | 0.01 | 2.20 | 1.10 | 0.45 | 1.14 | 82.38 |
| Chaetodon sedentarius | 0.00 | 2.17 | 1.08 | 0.44 | 1.13 | 83.50 |
| Coryphopterus personatus | 0.00 | 2.17 | 1.08 | 0.44 | 1.13 | 84.63 |
| Scarus iserti | 0.00 | 2.02 | 1.01 | 0.44 | 1.05 | 85.68 |
| Sparisoma guacamaia | 0.00 | 2.02 | 1.01 | 0.44 | 1.05 | 86.74 |
| Thalassoma bifasciatum | 2.01 | 0.00 | 1.01 | 0.42 | 1.05 | 87.78 |
| Reef shark | 1.86 | 0.00 | 0.93 | 0.31 | 0.97 | 88.75 |
| Sphyraena barracuda | 1.86 | 0.00 | 0.93 | 0.31 | 0.97 | 89.72 |
| Opistognathus aurifrons | 1.75 | 0.00 | 0.88 | 0.45 | 0.91 | 90.63 |

*Groups CP & W*
Average dissimilarity = 93.70

| Species | Group CP Av.Abund | Group W Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Stegastes partitus | 17.03 | 0.00 | 8.52 | 0.92 | 9.09 | 9.09 |
| Lutjanus buccanella | 1.39 | 7.86 | 4.00 | 0.93 | 4.27 | 13.36 |
| Epinephelus fulva | 4.94 | 4.96 | 3.98 | 0.72 | 4.25 | 17.61 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Thalassoma bifasciatum | 7.92 | 0.00 | 3.96 | 0.64 | 4.23 | 21.83 |
| Lutjanus analis | 7.73 | 0.00 | 3.87 | 0.73 | 4.13 | 25.96 |
| Epinephelus guttatus | 7.13 | 1.86 | 3.56 | 0.91 | 3.80 | 29.76 |
| Halichoeres garnoti | 7.14 | 1.90 | 3.22 | 1.14 | 3.44 | 33.20 |
| Balistes vetula | 3.98 | 3.06 | 3.02 | 0.63 | 3.22 | 36.42 |
| Gramma loreto | 0.00 | 5.64 | 2.82 | 1.20 | 3.01 | 39.43 |
| Lachnolaimus maximus | 0.00 | 5.37 | 2.69 | 0.44 | 2.87 | 42.29 |
| Lactophrys trigonus | 5.36 | 0.00 | 2.68 | 0.42 | 2.86 | 45.15 |
| Chaetodon aculeatus | 1.23 | 4.49 | 2.66 | 0.53 | 2.84 | 47.99 |
| Caranx lugubris | 0.00 | 5.09 | 2.54 | 0.52 | 2.71 | 50.70 |
| Ocyurus chrysurus | 1.42 | 4.04 | 2.49 | 0.58 | 2.66 | 53.36 |
| Pseudupeneus maculatus | 0.64 | 4.49 | 2.46 | 0.50 | 2.63 | 55.99 |
| Canthigaster rostrata | 4.17 | 0.61 | 2.24 | 0.60 | 2.39 | 58.37 |
| Paranthias furcifer | 0.00 | 4.19 | 2.10 | 0.70 | 2.24 | 60.61 |
| Scarus iserti | 2.76 | 2.02 | 2.06 | 0.62 | 2.20 | 62.81 |
| Holacanthus ciliaris | 0.00 | 3.87 | 1.93 | 0.44 | 2.06 | 64.87 |
| Southern Stingray | 0.00 | 3.87 | 1.93 | 0.44 | 2.06 | 66.93 |
| Elaggatis bipinnulata | 0.00 | 3.71 | 1.85 | 0.70 | 1.98 | 68.91 |
| Serranus tigrinus | 3.30 | 0.00 | 1.65 | 0.30 | 1.76 | 70.67 |
| Chromis insolata | 0.87 | 2.93 | 1.63 | 0.78 | 1.74 | 72.41 |
| Epinephelus cruentatus | 0.00 | 3.23 | 1.61 | 0.65 | 1.72 | 74.13 |
| Acanthurus bahianus | 3.21 | 0.00 | 1.60 | 0.30 | 1.71 | 75.84 |
| Holocentrus rufus | 2.77 | 0.22 | 1.38 | 0.87 | 1.48 | 77.32 |
| Lachnolaimus maximus | 1.67 | 1.50 | 1.31 | 0.70 | 1.40 | 78.72 |
| Scomberomorus cavalla | 2.49 | 0.00 | 1.24 | 0.30 | 1.33 | 80.04 |
| Seriola rivoliana | 2.49 | 0.00 | 1.24 | 0.30 | 1.33 | 81.37 |
| Lutjanus cyanopterus | 0.62 | 2.02 | 1.22 | 0.57 | 1.30 | 82.67 |
| Caranx crysos | 0.10 | 2.21 | 1.13 | 0.47 | 1.21 | 83.88 |
| Chromis cyanea | 0.00 | 2.27 | 1.13 | 0.60 | 1.21 | 85.09 |
| Lutjanus jocu | 0.00 | 2.20 | 1.10 | 0.45 | 1.17 | 86.26 |
| Chaetodon sedentarius | 0.00 | 2.17 | 1.08 | 0.44 | 1.16 | 87.42 |
| Coryphopterus personatus | 0.00 | 2.17 | 1.08 | 0.44 | 1.16 | 88.58 |
| Bodianus rufus | 0.64 | 1.69 | 1.06 | 0.54 | 1.13 | 89.70 |
| Sparisoma guacamaia | 0.00 | 2.02 | 1.01 | 0.44 | 1.08 | 90.78 |

*Groups SPR & W*
Average dissimilarity = 91.52

| Species | Group SPR Av.Abund | Group W Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Ocyurus chrysurus | 9.11 | 4.04 | 5.21 | 0.90 | 5.69 | 5.69 |
| Chaetodon sedentarius | 7.05 | 2.17 | 4.07 | 0.70 | 4.44 | 10.13 |
| Lachnolaimus maximus | 3.86 | 5.37 | 3.97 | 0.69 | 4.34 | 14.47 |
| Lutjanus buccanella | 0.20 | 7.86 | 3.89 | 0.85 | 4.25 | 18.72 |
| Acanthurus bahianus | 6.96 | 0.00 | 3.48 | 0.57 | 3.80 | 22.52 |
| Holocentrus adcensionis | 6.96 | 0.00 | 3.48 | 0.57 | 3.80 | 26.32 |
| Epinephelus fulva | 4.40 | 4.96 | 3.27 | 1.04 | 3.58 | 29.90 |
| Lachnolaimus maximus | 6.22 | 1.50 | 3.11 | 0.99 | 3.40 | 33.30 |
| Holocentrus rufus | 6.40 | 0.22 | 3.09 | 2.38 | 3.38 | 36.68 |
| Canthigaster rostrata | 5.77 | 0.61 | 2.89 | 0.73 | 3.16 | 39.84 |
| Gramma loreto | 0.00 | 5.64 | 2.82 | 1.19 | 3.08 | 42.92 |
| Stegastes partitus | 5.44 | 0.00 | 2.72 | 4.44 | 2.97 | 45.89 |
| Caranx lugubris | 0.00 | 5.09 | 2.54 | 0.51 | 2.78 | 48.67 |
| Lutjanus analis | 5.07 | 0.00 | 2.53 | 0.79 | 2.77 | 51.44 |
| Chaetodon aculeatus | 0.00 | 4.49 | 2.25 | 0.44 | 2.45 | 53.89 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Pseudupeneus maculatus | 0.00 | 4.49 | 2.25 | 0.44 | 2.45 | 56.35 |
| Epinephelus guttatus | 4.34 | 1.86 | 2.17 | 1.15 | 2.37 | 58.72 |
| Balistes vetula | 2.67 | 3.06 | 2.14 | 0.94 | 2.33 | 61.05 |
| Paranthias furcifer | 0.00 | 4.19 | 2.10 | 0.69 | 2.29 | 63.34 |
| Southern Stingray | 0.00 | 3.87 | 1.93 | 0.44 | 2.11 | 65.46 |
| Holacanthus ciliaris | 0.00 | 3.87 | 1.93 | 0.44 | 2.11 | 67.57 |
| Seriola rivoliana | 3.86 | 0.00 | 1.93 | 0.57 | 2.11 | 69.68 |
| Serranus annularis | 3.86 | 0.00 | 1.93 | 0.57 | 2.11 | 71.79 |
| Elaggatis bipinnulata | 0.00 | 3.71 | 1.85 | 0.69 | 2.03 | 73.82 |
| Pomacanthus paru | 2.56 | 1.63 | 1.69 | 0.70 | 1.85 | 75.66 |
| Halichoeres garnoti | 2.41 | 1.90 | 1.68 | 0.96 | 1.83 | 77.49 |
| Epinephelus cruentatus | 0.00 | 3.23 | 1.61 | 0.64 | 1.76 | 79.26 |
| Chromis insolata | 0.55 | 2.93 | 1.56 | 0.80 | 1.70 | 80.96 |
| Chromis cyanea | 0.88 | 2.27 | 1.28 | 0.74 | 1.40 | 82.36 |
| Caranx crysos | 0.47 | 2.21 | 1.25 | 0.54 | 1.37 | 83.73 |
| Acanthurus chirurgus | 2.41 | 0.00 | 1.20 | 0.57 | 1.32 | 85.04 |
| Amblycirrhitus pinos | 2.41 | 0.00 | 1.20 | 0.57 | 1.32 | 86.36 |
| Thalassoma bifasciatum | 2.41 | 0.00 | 1.20 | 0.57 | 1.32 | 87.67 |
| Halichoeres cyanocephalus | 2.41 | 0.00 | 1.20 | 0.57 | 1.32 | 88.99 |
| Lutjanus jocu | 0.00 | 2.20 | 1.10 | 0.45 | 1.20 | 90.19 |