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Biological Assessment of Coral Reefs in Southern Puerto Rico: A Technical Approach for Coral Reef Protection Under the U.S. Clean Water Act

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Abstract

States and other jurisdictions may protect coral reefs using biological water quality standards outlined by the United States Clean Water Act (CWA). Such protection will require long-term, regional monitoring of the resource using biological indicators and a probability-based sampling design. A 60-station survey targeting nearshore linear coral reef was conducted across southern Puerto Rico in December 2011 to document the status of reef inhabitants using a probabilistic, regional sampling design. The quantity, type and condition of stony corals, fish, gorgonians and sponges were documented from each station, providing a robust representation of linear reef status and composition across the region. Fish represented 106 unique taxa and stony corals 32 unique taxa. Benthic organisms (stony corals, sponges and gorgonians) averaged nearly 12 colonies per square meter, more than half of which were gorgonians. Assessment results can be used as a baseline to compare with future regional surveys to quantify change in reef condition over time (trend). Both temporal and spatial changes can be expected after large-scale disturbances like hurricanes Maria and Irma in 2017. The indicators and probabilistic sampling design support the long-term regional monitoring envisioned by the Environmental Protection Agency to implement CWA protections in Puerto Rico and elsewhere.

Keywords

coral reef biological status assessments; Clean Water Act; biological criteria; biocriteria; probability-based regional sampling

Introduction

Coral reefs worldwide are threatened by global stressors such as thermal stress and ocean acidification (Hoegh-Guldberg et al. 2007; Richardson and Poloczanska 2008; Spalding and Brown 2015; Heron, Maynard and van Hooidek 2016; Hughes et al. 2017) and local stressors such as overfishing, physical damage and terrestrial runoff containing pollutants, sewage and sediment (Edmunds 2002; Gardner et al. 2003; Knowlton and Jackson 2008; Mora 2008; Sandin et al. 2008). Also at risk, as coral reefs deteriorate, are the ecosystem goods and services they provide (Orlando and Yee 2016). Healthy coral reef ecosystems deliver social and economic benefits to humans, contributing to fisheries, tourism, shoreline protection, and pharmaceutical and biochemical products (Pendleton 2008; Principe et al. 2012). Consequently, there is increasing urgency for improved regulatory protection under the U.S. Clean Water Act (CWA; 33 U.S.C. § 1251 et seq. 1972). The CWA requires that U.S. States and Territories maintain and restore the chemical, physical and biological integrity of the Nation's aquatic resources to protect human health, fish, wildlife and recreation in and on the water (CWA §101 and §502). This protection extends to coral reefs within the 3-mile U.S. territorial zone and can be applied to address a wide range of stressors from both coastal waters and the upstream watershed (Fore et al. 2008; Fore et al. 2009; Bradley et al. 2010).

Biological criteria (biocriteria) incorporated in state water quality standards is one option under the CWA that can be used to protect and restore coral reefs (Adler 1995; USEPA 2002; Fore et al. 2008; Keller and Cavallaro 2008; Fore et al. 2009; Bradley et al. 2010; USEPA 2012). Biological water quality standards can be an important addition to physical and chemical criteria. They have the same authority under the CWA and can be used in conjunction with physical and chemical standards. Moreover, biocriteria provide a mechanism to link regulatory actions to the condition of the biota, not simply the physical and chemical status of the water. An important advantage to biological endpoints and thresholds is that they integrate the cumulative effects of multiple stressors over time (Jameson et al. 1998; Jameson et al. 2001; Davies and Jackson 2006; Fore et al. 2008; Fore et al. 2009; USEPA 2012). Physical and chemical measurements are generally easier to make but represent single stressors at a single point in time. Eventual implementation of coral reef biocriteria will not only establish regulatory goals, but the data and thresholds generated for a biocriteria program will support existing management and conservation programs such as Marine Protected Areas, protection of endangered and threatened species, and adaptations to climate change (Fore et al. 2009).

Setting biological water quality standards requires 1) testing and validation to identify biological indicators that are sensitive to human disturbance, 2) characterizing reference conditions based on those indicators and establishing thresholds (criteria) for regulatory

enforcement and 3) initiating a long-term regional monitoring program for CWA §305b reporting. For coral reefs, several of these requirements are being met. Some stony coral indicators, for example, have already been shown to be sensitive to human disturbance, including taxa richness, colony surface area, variability of colony surface area and colony live surface area (Fisher et al. 2008; Smith et al. 2008; Oliver, Lehrter, and Fisher 2011). Additionally, expert panels are currently working to establish reference and threshold values for stony coral and fish indicators (Bradley, Santavy, and Gerritsen 2014). Still to be developed, and the focus of this study, are monitoring designs to generate an effective and tractable regional monitoring program to detect the biological effects of anthropogenic stressors (Fore, Fisher, and Davis 2006; Fisher et al. 2014).

There was concern in the 1980's that there were no means to evaluate the status of ecological resources or document progress towards legally mandated environmental goals (U.S. House of Representatives, 1984). In response, the U.S. Environmental Protection Agency (EPA) initiated the Environmental Monitoring and Assessment Program to estimate the status and trends of the nation's ecological resources on regional to national scales over years to decades with known confidence (Messer, Linthurst and Overton 1991). This required indicators that represented the resource and survey designs that would estimate the status of an ecosystem at a regional scale. Subsequently, long-term regional monitoring programs have been generated for a variety of ecosystems across the U.S. using a probabilistic survey design with spatially-balanced random site selection (Hughes, Paulsen, and Stoddard 2000). Random site selection allows assessment of large areas based on data collected from a representative sample of locations and provides an unbiased estimate of resource condition for the region (Stevens and Olsen 2004; Smith et al. 2011). The protocol and regional monitoring design developed by EPA were successfully applied for the first time to stony corals in the U.S. Virgin Islands (Fisher et al. 2014). The same approach was used in this study of Puerto Rico reefs with a design modification to ensure both large and small reefs were sampled. Additionally, this study included an expanded protocol to simultaneously assess stony coral, fish, sponge and gorgonian condition (Santavy et al. 2012; Oliver et al. 2014). A similar reef-assemblage approach has now been adopted by the interagency National Coral Reef Monitoring Program (NOAA 2014).

The biological characteristics measured in this study are intended to reflect potential effects of watershed stress and pollution. To this purpose, and as noted above, several of the stony coral measurements employed have been identified as responsive to human disturbance. Additionally, the sampling frame was purposely established in shallow nearshore waters where watershed inputs and potential stressors would be less diluted. Because of this focus, results from this study do not represent all reefs of southern Puerto Rico, only those that occur within the geographic and habitat constraints of the sampling frame, i.e., nearshore linear reef. Data from this study provide for the first time a regional condition assessment of the linear reef assemblage, the results of which can be used as a baseline for comparisons with future reef assessments in a long-term monitoring program that will support development of biocriteria and other management options.

Methods and Materials

Nearshore linear reef along the southern coastline of Puerto Rico (PR) was surveyed during Nov 27-Dec 13, 2011 from Yabucoa in the east to Cabo Rojo at the southwest corner of the island (Fig. 1). Reef assessments incorporated several biological attributes, including presence, type and condition of fish, stony corals, sponges, gorgonians and *palythoa*, and topographic complexity (rugosity).

Probabilistic survey design

The target population was defined as *linear coral reefs* that occur in the *coral reef and hardbottom* substrate category of benthic habitat maps for southern Puerto Rico (Kendall et al. 2001). Based on the expected survey period (two weeks) and sampling design (see below), it was pre-determined that 60 stations in the region would be sampled. The sampling frame (area containing the population to be sampled) was developed in ArcGIS v 9.2 from coral reef maps generated by Kendall (2001). Reef perimeters were delineated as areal polygons, and if the centroid of any reef polygon was within 2-12 m depth and within 1.5 km of shore (including shores of emergent cays within the targeted substrate), the reef was included in the sampling frame (Fig. 1). This nearshore delineation was purposely established to capture any potential signal from land-based human activity before dilution in deeper, offshore waters. A preliminary probabilistic survey design designated a high number of stations located on large reefs, but to the exclusion of stations on small reefs. Because large and small reefs may have different habitat characteristics, a second survey design was developed and implemented that took reef size (area of the reef polygon) into consideration. To ensure a more balanced sampling, stations were distributed across eight strata based on reef size (e.g., 5,000-50,000 m², see Table 1). The number of samples taken from each stratum was determined by the proportion of the total target area cumulatively occupied by reefs in that stratum. To acquire a spatially-balanced random sample, stations were selected using a Generalized Random Tessellation Stratified (GRTS) approach (Stevens and Olsen 2004), ensuring that the appropriate number of stations were identified for each stratum. Because there were a larger number of small than large reefs, probability assessments incorporated inclusion probabilities (weighting factors) for each stratum. With these constraints, the resulting sampling frame was 16.2 km². The resulting design placed at least one sampling location at 54.4% of the linear reefs in the target population, and the combined area of reefs with at least one sampling location comprised 5.7% of the sampling frame (Fig 1).

Site assessment and transect areas

Underwater diving operations were conducted using dive boats launched from EPA's Ocean Survey Vessel *BOLD*. At each predetermined survey location, a weighted surface buoy was dropped within 5 m of geographic coordinates (latitude and longitude) using Geographic Positioning System instruments aboard each dive boat. On several occasions the coordinates placed the boat on a reef crest or too near shore for safety so, by predetermined convention, the station location was moved directly south on the reef to a safer location and the new coordinates recorded. Data were recorded for all 60 stations.

Sampling methods followed the EPA survey protocol (Santavy et al. 2012). At least four divers were used to assess each station. Starting at the buoy weight, the first pair of divers laid out a 25-m tape in the direction of the best available stony coral habitat (visual estimate of the highest abundance and size of stony corals). While swimming, the fish surveyor recorded the species and size of all fish found within 2 m on either side of the tape (25 m X 4 m = 100 m² fish transect area). A second pair of divers entered the water 15 minutes later, one diver recording the species, colony size, colony percent live tissue, and any disease or bleaching on all stony corals found within 1 m of the right-hand side of the tape (25 m² stony coral transect area); and the other diver recording the morphology and size of all gorgonians and sponges found in five 1-m² quadrats along the left side of the tape at the 0, 5, 10, 15 and 20-m marks (a total 5 m² sponge and gorgonian transect area at each station). The percent area covered by the zoanthid *Palythoa caribaeorum* was also recorded in each of the sponge/gorgonian quadrats. The first pair of divers, once completing the fish survey, performed rugosity measures using the 6-m chain method at five locations (0, 5, 10, 15, and 20 m marks) along the transect tape.

Fish measurements and indicators

Methods for fish assessment followed the 100 m² transect swimming assessment used by NOAA's Coral Reef Conservation Program (Menza et al. 2006; Caldow et al. 2009) and adopted by EPA (Santavy et al. 2012). The fish assessment diver swam slowly while unreeling a 25-m measuring tape and documenting every fish seen in a transect 2 m to each side of the tape and to the surface. The 100 m² transect was completed in about 15 min at each station. The diver recorded species and size (5-cm increments) for every visible fish within the transect area.

Fish indicators from these measurements included taxa richness (TR: # of different species encountered in 100 m²), frequency of occurrence for each taxon (TFR: percent of stations where a particular species was observed), density (Den: # fish in 1 m²), relative abundance (RA: percent of fish observed for each species relative to the total number of fish observed in the survey), biomass (B: estimated weight of a fish or a population of fish) and relative biomass (RB: percent contribution of each species to the total biomass of all species observed in the survey). Biomass for each fish was calculated as $B = \alpha L^\beta$, where L is fish length (cm) and α and β coefficients are species-specific length-weight relationships reported in Fishbase (Froese and Pauly 2007). Biomass for each species was calculated by summing B for all individuals of that species. Comparisons were also made among trophic guilds, including herbivores, piscivores, invertivores, detritivores and zooplanktivores (Caldow et al. 2009).

Stony coral measurements and indicators

Each stony coral colony with any dimension ± 10 cm and occurring within the transect area was documented by species (Fisher 2007, Santavy et al. 2012). Small colonies (<10 cm) were not included because the surveys were not intended to assess recruitment. This constraint reduced dive time at each survey station; it does not prevent inclusion of small colonies in future surveys, but the data should be expunged for comparison with the results reported here. Target species were the same as those listed in Fisher et al. (2014) and

included the hydrocoral *Millepora complanata*, but not *M. alcicornis*, which is often encrusting. Two dimensions of each colony were measured; height was recorded as the greatest distance of any part of the colony from the substrate and diameter as the greatest distance of the colony parallel to the substrate. The amount of living tissue (%LT) on the entire colony was estimated visually and documented in 10% increments (Fisher 2007). This estimate, %LT, is the inverse of 'partial mortality' measured in many studies (e.g., Smith et al. 2008, NOAA 2014). Colonies were also examined for polyp bleaching (loss of zooxanthellae), disease and infestation by the boring sponge *Cliona* spp. Colonies that were completely devoid of tissue (denuded skeletons) were included in the assessment if they could be reasonably identified as recently dead stony corals using remnant calices as indicators (Lang 2003).

Intermediate and final indicator values were calculated from the three *in situ* stony coral observations (taxon, colony height and diameter, and percent live tissue) as described in Fisher et al. (2014). These included taxa richness (TR: number of species in the 25 m² transect), density (Den: # stony corals in 1 m²), colony surface area (CSA; m², including both living and denuded portions of the colony) and live colony surface area (LCSA: m², including only living portions of the colony). Colony LCSA was calculated by multiplying CSA and the decimal %LT recorded by divers. Total surface area (TSA) and live surface area (LSA) represent the sum of CSA and LCSA, respectively, in a transect or for the survey. Total coral cover (TC: m² coral per m² substrate) and live cover (LC: m² live coral per m² substrate) were calculated by dividing the total CSA and LCSA from all colonies in a transect by the area of the transect (25 m²).

All surface areas (total and live) and coral cover indicators are based on three-dimensional (3D) estimates from colony size and morphology, and are not comparable to similar indicators measured in two-dimensions (planar). Estimates of 3D surface area were calculated using the equation $SA = M\pi r^2$ where r=average radius and M is dependent on colony morphology (Alcala and Vogt 1997; Courtney et al. 2007; Fisher et al. 2014). Morphological types and relative values included flat (M=1), hemisphere (M=2), domes, plates and lobes (M=3), and branched (M=4) colonies.

Additional stony coral calculations were intended to highlight population characteristics of individual species, and included frequency of occurrence (TFR: percent of stations where a particular taxon was observed), relative abundance (RA: percent contribution of each species to the total abundance), relative surface area (RSA: percent contribution of each species to the combined surface area of all stony corals), and relative live surface area (RLSA: percent contribution of each species to the total living surface area of all stony corals).

Sponge and gorgonian measurements and indicators

Sponges and gorgonian octocorals were documented simultaneously by the same observer, who identified them in morphological categories (morphotype) rather than taxonomic categories (Santavy et al. 2012). Morphological categories were assigned to estimate surface area (habitat) provided by each sponge and gorgonian colony. Typical taxa for each morphological category were described in Santavy et al. (2012). Indicators for both included morphological richness (MR: number of different morphotypes encountered in five 1-m²

transect areas), frequency of occurrence (MFr: percent of stations where a particular morphotype was observed), density (Den: number of sponges or gorgonians in 1 m²), relative abundance (RA: percent contribution of each morphotype to the total number of sponges or gorgonians observed), colony surface area (CSA: calculated from regressions provided in Santavy et al. (2013), relative surface area (RSA: percent contribution of surface area by different morphotypes to the surface area of all gorgonians or sponges observed), and total cover (surface area of sponges or gorgonians per m² substrate). Total coral cover was calculated by summing CSA for all colonies in the transect and dividing by the size of the transect area (5 m²).

Sessile benthic invertebrates

Density and percent cover were calculated for all sessile benthic invertebrates (stony corals, sponges and gorgonians combined) that were documented in the survey.

***Palythoa* cover**

Percent cover of *Palythoa caribaeorum* was estimated using the same five 1-m² grids as the sponge and gorgonian assessment. An estimate was made for each grid and averaged for a station value.

Topographic complexity

Topographic complexity was reflected by the rugosity index (Risk 1972; McCormick 1994; Rogers et al. 1994; Lang 2003; Santavy et al. 2012), which is the ratio of the length of a chain (6m) over the distance covered by the chain when draped over a segment of the transect (all rugosity values are ± 1). Chains were placed under gorgonians and sponge projections, so the results reflect topography generated by the substrate and stony corals. Rugosity was measured at five locations along the transect tape (0, 5, 10, 15, and 20 m marks) and averaged for the station.

Results

Assessments of stony corals, fish, sponges, gorgonian octocorals, *Palythoa* and topographic complexity (rugosity) were completed at 60 randomly-selected locations along the southern coast of Puerto Rico. Attributes are reported as a percent of the sampling frame, i.e., the area containing the target population, which is a recommendation for CWA reporting. Uncertainty estimates (standard errors, SE) were calculated considering stratification by reef size and weighting by inclusion probabilities. Descriptive statistics for fish, stony coral, gorgonian and sponge indicators are also presented.

Survey design

This design was reasonably successful in distributing stations across reef categories (Table 1). At least one station was located on every reef in the three highest reef-size categories. A decreasing percentage of polygons were sampled as reef sizes decreased because there were so many additional reefs in these categories. Because regional assessments are reported as the percent of area sampled in the region exhibiting a particular value for a given

characteristic, weighting factors were assigned for each category based on the area of the region represented by that size category.

Fish condition indicators

Visual surveys at 60 random stations across southern Puerto Rico documented 9,075 fish with an average density of 1.5 fish m⁻² substrate and an average biomass of 0.067 kg fish⁻¹, or 0.102 kg fish m⁻² substrate (Table 2, Fig. 2). There were 106 unique taxa observed across all stations and taxa richness averaged 16.4 unique species at a station. A rarefaction curve showed that unique species observations increased dramatically over the first eight stations and maintained a constant increase through nearly all 60 stations (Fig. 2A).

Species that were broadly distributed (TFr > 50% of the stations) included bicolor damselfish, blue tang, bluehead, doctorfish, dusky damselfish, ocean surgeonfish, redband parrotfish, stoplight parrotfish, striped parrotfish, yellowtail damselfish and yellowtail snapper (Table 3). The most abundant fish species observed in the survey were bluehead (RA = 24.7%), followed by dusky damselfish (RA = 9.5%) and striped parrotfish (RA = 7.5%). Southern sennet contributed the highest biomass (RB = 10.8%), followed by doctorfish (RB = 9.8%), stoplight parrotfish (RB = 8.2%), striped parrotfish (RB = 7.8%) and blue runner (RB = 6.5%). Despite the high abundance of bluehead, they contributed only 1.1% to fish biomass. Density distribution across guilds (according to Caldwell et al. 2009) demonstrated a relatively high density of herbivores and invertivores but biomass was highest for the herbivores (Fig. 3).

Stony coral condition indicators

Documented in the survey were 3,480 stony coral colonies of 32 unique species (33 species documented counting the hydrozoan (*Millepora complanata*). Taxa richness averaged 7.1 species at a station and density averaged 2.3 colonies m⁻² (Table 4, Fig. 4). The total (3D) colony surface area contributed by all species from all 60 stations was 765.8 m². Surface area for individual colonies (CSA) averaged 0.24 m² across all stations and species. Total coral cover (TC) averaged 0.5 m² coral m⁻² substrate and live coral cover (LC) averaged 0.29 m² live tissue m⁻² substrate (Table 4, Fig 4).

Widely distributed species (TFr > 50% of the stations) included *Montastraea cavernosa*, *Orbicella faveolata*, *Porites astreoides*, *Psuedodiploria strigosa* and *Siderastrea siderea* (Table 5). *Porites astreoides* were most often encountered in the survey (RA = 42.2%), followed by *S. siderea* (RA = 18.5%) and *P. strigosa* (RA = 10.8%). Rarely encountered (RA < 0.1) were *Agaricia lamarcki*, *Dendrogyra cylindrus*, *Isophyllia rigida*, *Madracis decactis*, *Mycetophyllia aliciae*, *M. ferox*, *M. lamarckiana*, *M. danaana*, *Porites branneri*, and *P. furcata* (Table 5).

The largest colony surface areas (CSA) recorded were for *Dendrogyra cylindrus* (average CSA = 9.93 m², the largest colony at 27.2 m²) and *Acropora palmata* (average CSA = 4.9 m², the largest colony at 23.8 m²). Two *Orbicella annularis* colonies were also large (28.4 and 22.6 m²), but all other colonies for all other species were <15 m². Many of the more abundant species, such as *Porites astreoides* (average CSA = 0.04 m²), *Siderastrea siderea*

(average CSA = 0.09 m²), *P. strigosa* (average CSA = 0.12m²) and *Montastraea cavernosa* (average CSA = 0.19 m²) exhibited colony sizes that were substantially smaller.

Colony live tissue (436.8 m²) was 57% of the total surface area provided by stony corals (765.9 m²) documented in the survey. Despite its low abundance (RA = 1.2%), *Acropora palmata* provided the most surface area (RSA = 27.9%) and the most live surface area (RLSA = 20.2%) of any species (Table 5, Fig. 5) followed by *Orbicella annularis* and *O. faveolata*. *Orbicella annularis* contributed more CSA than *O. faveolata*, but *O. faveolata* contributed more LCSA because of its higher percent live tissue (Fig. 5). Species with the highest average percent live tissue (LCSA x 100) included *Millepora complanata* (88.8%), *P. astreoides* (86.7%), *Stephanocoenia intersepta* (81.8%) and *P. clivosa* (83.6%); species with the lowest average percent living tissue included *P. porites* (53.4%), *A. palmata* (41.4%), *D. cylindrus* (44.7%), and *O. annularis* (46.2%). *Acropora cervicornis* exhibited an average percent live tissue of 61%.

Bleaching was recorded for 88/3480 (2.5%) of the stony corals reported, including *A. cervicornis* (3/46), *P. strigosa* (13/375), *P. astreoides* (20/1468) and *S. siderea* (39/642). At least some bleaching (1-3 bleached colonies) was observed at 52% of the survey locations; and the most at any station was 15 bleached colonies. Diseases were encountered on 31/3480 (0.9%) of stony corals, including *A. cervicornis* (2/46), *P. strigosa* (7/375), *O. annularis* (9/92) and *S. siderea* (10/642). Disease was found at 23% of the survey locations; 17% of the stations had 1 or 2 colonies with evidence of disease and the most at any station was 9 colonies exhibiting signs of disease. Boring sponges, *Cliona* spp., were recorded on 49/3480 (1.4%) of stony corals, including *P. strigosa* (4/375), *O. annularis* (11/92), *O. faveolata* (1/172), *P. astreoides* (11/1468) and *S. siderea* (16/642). Clonid sponges occurred at 25% of survey locations; 18% of the stations had 1-3 colonies infested with *Cliona* and the most at any station was 13 infested colonies.

Sponge condition indicators

A total 937 sponges were documented at the 60 survey stations (5 m² transect area). Over half the area sampled exhibited sponge densities at ≤ 3 m² (Fig. 6A). The average sponge density was 3.1 m⁻² (SE = 0.38) and two stations had > 10 sponges m⁻². Sponge colony surface area (CSA) estimates averaged 0.07 m² (SE = 0.01) and averages for a station ranged from 0 to 0.18 m². Sponge 3D cover averaged 0.26 m² sponge m⁻² substrate and ranged from 0 to 1.8 m²/m². Approximately 2/3 of the area sampled exhibited sponge cover ≤ 0.3 m²/m² (Fig 6B). Rods were the most abundant morphotype (RA = 39.8%) followed by the mound morphotype (RA = 33.9%). These two morphotypes also contributed the greatest surface area (Table 6).

Gorgonian condition indicators

Surveyors recorded 1820 gorgonian octocorals at the 60 survey stations, reflecting an average density of 6.1 m⁻² (SE = 0.62). Some stations had over 15 colonies m⁻² and over half the area sampled had gorgonian densities greater than 5 colonies m⁻² (Fig. 7A). Colony surface area (CSA) estimates for gorgonians averaged 0.32 m² (SE = 0.04), with averages for a station ranging from 0 to 1.15 m². The average gorgonian cover was 2.32 m² gorgonian

m⁻² substrate and averages for a station ranged from 0 to 10.6 m²/m² (Fig 7B). The most abundant morphological type was branched sea rods (RA = 26.5%) followed by branched sea whips (RA = 22%); each of the other morphological types contributed <15% of the gorgonians observed (Table 7). The greatest surface area was provided by sea plumes (49% relative surface area) even though they constituted only 13% of the gorgonian population (Table 5). Branched sea rods, though most plentiful, contributed only 10% of the gorgonian surface area.

Density and surface area of sessile benthic organisms

The average density of all stony corals, sponges and gorgonians documented in the survey was 2.3, 3.1 and 6.1 colonies m⁻², respectively, reflecting an average 11.5 sessile benthic organisms m⁻² substrate and ranging from 0.48 to 27.9 organisms m⁻² (Fig. 8A). The average colony surface area was 0.51, 0.27 and 2.32 m² surface area per m² substrate for stony corals, sponges and gorgonians, respectively, which combined for an average oversubstrate (above-ground) habitat provision of 3.09 m² per m² substrate. The average benthic cover for a station ranged from 0.01 to 11 m² per m² substrate (Fig. 8B).

Palythoa cover and Rugosity Index

Percent cover of *Palythoa caribaeorum* at each station ranged from 0-50% with approximately 3/4 of the area sampled exhibiting cover of < 5 % (Fig. 9). Rugosity was not measured at one of the 60 stations. Station rugosity indices ranged from 1.0 to 2.0 and averaged 1.26; more than 3/4 of the area sampled had rugosity < 1.4 (Fig. 10).

Discussion

A survey of nearshore linear coral reefs was performed along the southern coast of Puerto Rico to demonstrate the indicators, protocol and probabilistic survey design that can be used by U.S. jurisdictions to develop and implement long-term monitoring programs in support of coral reef biocriteria. Resource managers are seeking ways, like biocriteria, to aid in protection and restoration of this critical ecosystem. Appropriate technical methods to evaluate reef condition, such as those presented here, are imperative for development of defensible condition thresholds to be established under aegis of the Clean Water Act. This regional condition assessment provided data for setting management goals and established a baseline dataset for comparison with future surveys. The data may be particularly useful as a pre-hurricane baseline for Puerto Rico after large-scale disturbances by hurricanes Maria and Irma in 2017. For future comparisons, raw and computed data from this survey are being made available on EPA's Environmental Dataset Gateway (EDG 2018). The survey also provides the first record of regional reef condition (nearshore linear reefs in coral and hardbottom substrate) that includes simultaneous assessment of four major biological assemblages—fish, stony corals, sponges and gorgonians. The reef-assemblage approach provides a comprehensive representation of the regional condition of linear reefs and allows further exploration of ecological relationships, ecosystem goods and services (e.g., Yee et al. 2014; Yee, Oliver and Ditmar 2014), benthic substrate cover and habitat provision by sessile benthic organisms. Also, because sizes of individuals were estimated, the data provide an opportunity to analyze population demographics for all four reef populations.

The principal purpose for the survey was to support development of biological water quality standards under the regulatory and reporting framework of the CWA. A first step to institute biological standards is to develop effective biological indicators. Several of the stony coral indicators used in this study have been shown to be sensitive to human disturbance (Fisher et al. 2008; Smith et al. 2008; Oliver, Lehrter, and Fisher 2011; Oliver et al. 2014). However, the indicators for fish, sponges and gorgonians have not yet been tested for responsiveness to human disturbance. An additional step required for CWA reporting includes characterization of reference condition and thresholds (criteria) for management actions. To this end, EPA has convened panels of coral reef experts tasked with defining categories of biological condition (Bradley, Santavy, and Gerritsen 2014). Results from this survey, along with photos and videos of the transect areas, are being used by the panel to characterize reef conditions in categories ranging from unaltered to highly degraded. Ultimately, these categories and the attributes that define them can be used to establish enforceable biological criteria for U.S. jurisdictions in the Caribbean.

The final step is to demonstrate an effective monitoring protocol and survey design. A stony coral survey in U.S. Virgin Islands demonstrated the utility of a regional probabilistic survey design (Fisher et al. 2014). This study expands on that design by incorporating additional protocols for fish, sponges and gorgonians, and by ensuring representativeness using a sampling design stratified by reef size. Additionally, weighting factors assigned through inclusion probabilities allowed calculation of uncertainty in attribute values. The survey approach used here can be improved upon in at least two respects. First, when confronted with reef crests or other hazardous diving conditions, the most acceptable solution for a probabilistic design is to sample additional computer-selected stations (random ‘over-stations’). However, because the region was so large, moving back and forth to over-stations was deemed logistically unacceptable and a decision was made to allow survey crews to move directly south to safer locations. To avoid bias, a predetermined travel distance should also be established. Second, this survey assigned the fish assessor the role of selecting the direction for running the transect tape based on the ‘best available habitat’, as had been prescribed for previous surveys (e.g., Fisher et al. 2014). A probabilistic survey should predetermine the direction of the transect (e.g., north, parallel to shore) and establish additional conventions for oversampling. Addressing these logistical issues will strengthen the representativeness of future regional condition estimates.

Indicators measured in this study are also useful for documenting and valuing the ecosystem goods and services provided by coral reefs (MEA 2005). Resource conservation and protection are reinforced when stakeholders recognize the value of reefs and the real cost of their degradation (Orlando and Yee 2016). Ecosystem goods and services provided by coral reefs include shoreline storm protection, habitat provision for commercial and recreational fish species, tourism and recreation, and natural products discovery (CI 2008; Pendelton 2008; Principe et al. 2012). Many of the measurements in this survey can be used as indicators of ecosystem services provision. For example, stony coral and gorgonian colony size and density can inform the value of coral reefs for shoreline storm protection; and colony surface area and benthic cover can inform habitat provision (Principe et al., 2012; Yee, Dittmar, and Oliver 2014; Orlando and Yee 2016). Density and taxa richness of sessile benthic organisms, especially sponges, can inform the potential for natural products

discovery (Principe and Fisher 2018). Number, density, biomass and taxa richness of fish and benthic organisms are potential indicators for fisheries, tourism and recreation. A variety of available production functions can be applied to estimate the ecosystem services provided by reefs (Yee, Dittmar, and Oliver 2014). Using data from these and similar studies, EPA and the NOAA Sanctuaries Program initiated a collaborative project to value tourism related to coral reefs in Puerto Rico (NOAA 2018) following the pattern of similar studies (Leeworthy 1996; Leeworthy and Wiley 1997; Bishop et al. 2011).

The three colony-based measurements (taxon, size and percent live tissue) for stony corals are currently performed in all EPA reef surveys and in surveys conducted by The Nature Conservancy's Florida Reef Resilience Program (FRRP 2013). Similar measurements are now being used in the National Coral Reef Monitoring Program (NOAA 2014). Colony size measurements not only provide data for demographic analysis but allow the estimation of three-dimensional surface area from previously described morphological conversion factors (e.g., Courtney et al. 2007; Fisher et al. 2014). One outcome of these measurements is the ability to compare total and live surface area. In Figure 5 two large, reef-building species, *A. palmata* and *O. annularis*, are shown to have the lowest percentage of live tissue (<50%). Many smaller and more populous species, such as *P. astreoides* and *S. siderea*, have a higher percentage of live tissue ($\pm 75\%$). Live surface area and colony size have long been recognized as important ecological attributes of stony corals (Dahl 1973; Luckhurst and Luckhurst 1978; Bak and Meesters 1998; Fisher 2007), as has coral reef relief and topographic complexity (Risk 1972; Luckhurst and Luckhurst 1978; Zawada, Piniak and Hearn 2010; Graham and Nash 2013). Here, the approach was extended to sponges and gorgonians, converting measures of colony height and radius to estimate three-dimensional colony surface area using regression factors developed from colony morphology (Santavy et al. 2013). Conversion factors used here to estimate stony coral, sponge and gorgonian colony surface area are obviously not exact; but neither are they arbitrary and can be improved over time.

A unique outcome of the study is simultaneous documentation of three foundational groups in the sessile benthic assemblage, stony corals, sponges and gorgonians. Combined, the three populations averaged 11.7 colonies per m² substrate, more than half of which were gorgonians. Likewise, gorgonians contributed the most surface area to over-substrate habitat. Relating habitat availability to presence of fish, however, is challenging because of varying fishing pressure and the ability of fish, especially smaller fish, to escape detection at stations with dense gorgonian presence.

The probabilistic survey design covering a large region limits comparisons with previous Puerto Rico assessments, which have commonly targeted smaller geographic scales. Comparisons for stony corals are further limited by the colony-based measurements used here versus the more conventional percent cover. Nonetheless, the survey supports the findings of previous assessments, including surveys in the area by Morelock et al. (2001), Garcia-Sais et al. (2009) and Pittman et al. (2010). Similarities include the dominant fish species (such as striped parrotfish and redband parrotfish) and the lack of large fish species. The latter is reflected in relatively low biomass estimated for most of the region. Also, the same dominant stony coral species were found (such as *Orbicella* and *Porites*), even though

O. annularis reported in Pittman et al. (2010) were fewer in this study compared to *O. faveolata* and *M. cavernosa*. Stony coral bleaching (2.4%) and disease (0.8%) prevalence were relatively low compared to other reports, although there was evidence of bleaching at 52% and disease at 23% of the stations. Perhaps an emerging concern for stony coral colonization is the presence of *Palythoa caribaeorum* across ~3/4 of the area sampled, with as much as 50% cover at some stations.

There is an urgency for improved protection for coral reefs in the Caribbean Sea. The CWA establishes a regulatory and scientific framework to support a variety of protective actions, including biological criteria, which can address a range of stressors from both the coastal zone and the watershed. Data generated by this and similar surveys (Fisher et al. 2014) and biological thresholds under development to support CWA programs (Bradley, Santavy, and Gerritsen 2014) can be used to augment existing management and restoration programs such as Marine Protected Areas, protection of endangered and threatened species, and climate change adaptation strategies (Fore et al. 2009).

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Figure 1. Location and Distribution of Sampling Stations. Location of randomly selected coral survey locations (red circles) were distributed across the target substrate along the southern PR coastline. Coral reef and colonized hardbottom substrate (grey shading) and linear reefs (green shading) are shown, but the area sampled was limited to linear reefs within 1.5 km of shore (including cays in the target substrate) and between 2-12 m depth. Data were collected from all 60 stations.

Figure 2.

Fish Indicators. Indicator values for fish at 60 stations (100 m² transect areas) across southern Puerto Rico. (A) Rarefaction curve showing the number of unique fish species found with each additional station surveyed. (B-D) Distribution of values expressed as a percentage of the area sampled ($\pm$ SE) for taxa richness, fish density and fish biomass.

Figure 3. Density (A) and biomass (B) per square meter substrate for fish guilds documented at 60 stations across southern Puerto Rico ($\pm$ SE). Species groupings into guilds followed the categorization of Caldow et al. (2009).

Figure 4.

Stony Coral Indicators. Indicator values for stony corals at 60 stations (25 m² transect areas) across southern Puerto Rico. (A) Rarefaction curve showing the number of additional stony coral species found with each additional station surveyed. (B-F) Distribution of values across stations expressed as a percentage of the area sampled ($\pm$ SE) for taxa richness, colony density, average colony surface area in a transect (m²), total coral cover (m² surface area m⁻² substrate), and live coral cover (m² live tissue surface area m⁻² substrate). Surface

area and cover calculations were based on 3D estimates of colony size. Note that abscissa ranges in D-F are not regular.

Figure 5.

Comparison of total surface area (TSA = CSA) and live surface area (LSA = LCSA) provided by each of 33 species documented at all 60 stations. Species include *Montastraea cavernosa* (MCAV), *Pseudodiploria strigosa* (PSTR), *Porites astreoides* (PAST), *Siderastrea siderea* (SSID), *Orbicella faveolata* (OFAV), *O. annularis* (OANN) and *Acropora palmata* (APAL); additional data points for many species with minor contributions to CSA and LCSA are overlapping and not distinctly visible. The solid line denotes 50% and the dotted line denotes 75% live tissue to total tissue surface area (LSA/CSA x 100).

Figure 6.

Sponge indicators. Distribution of indicator values ($\pm$ SE) for sponges at 60 stations (5 m^2 transect areas) along the southern coast of PR shown as a percent of the area sampled. (A) Density of sponge colonies (number per m^2 substrate). (B) Sponge cover (surface area per m^2 substrate, based on estimates of 3D colony surface area).

Figure 7.

Gorgonian Indicators. Distribution of indicator values ($\pm$ SE) for gorgonians at 60 stations (5 m² transect areas) along the southern coast of PR shown as a percent of the area sampled.

(A) Density of gorgonian colonies (number per m² substrate). (B) Gorgonian cover (surface area per m² substrate) based on 3D estimates of colony surface area.

Figure 8.

Distribution ($\pm$ SE) of sessile benthic organisms (stony corals, sponges and gorgonians) across 60 stations sampled along the southern coast of PR shown as a percent of the area sampled. (A) Combined density of sessile organisms (colonies per m² substrate). (B) Benthic cover (m² surface area per m² substrate) based on 3D estimates of colony surface area.

Figure 9.
Distribution ($\pm$ SE) of *Palythoa* (% cover) for 60 stations along the southern coast of PR shown as a percent of the area sampled.

Figure 10.

Distribution ($\pm$ SE) of rugosity index values for 59 stations along the southern coast of PR shown as a percent of the area sampled. One station of sixty in the survey design was not measured for rugosity.

Table 1.

Probabilistic Survey Statistics

Size Ranges of Reef (m ²)	No. reef polygons	Cumulative Area (m ²) of polygons	No. stations sampled	No. reef polygons sampled	% reef polygons sampled	Weighting
5,000-50,000	72	1,634,231	17	16	22.2	0.0817
50,000-100,000	21	1,582,659	10	8	38.1	0.1759
100,000-200,000	27	3,923,616	11	10	37.0	0.3924
200,000-300,000	12	3,022,041	8	6	50	0.4317
300,000-400,000	5	1,738,933	5	4	80	0.3478
400,000-500,000	1	447,449	2	1	100	0.2237
500,000-1,000,000	2	1,117,214	4	4	100	0.2793
>1,000,000	1	2,752,401	3	3	100	0.9175

Table 2.

Fish measurement means and standard errors (SE)

Fish Variable	Mean $\pm$ SE	Median	Range	Units
Density	1.5 $\pm$ 0.12	1.28	0.2-4.1	fish m ⁻² substrate
Biomass	0.102 $\pm$ 0.015	0.06	0.002 – 0.72	kg fish m ⁻² substrate
Taxa Richness	16.4 $\pm$ 0.62	16.5	5-26	taxa station ⁻¹

Table 3.

Fish indicators^a

Species	TFr	Tot #	RA	Tot BioM	RB	Species	TFr	Tot #	RA	Tot BioM	RB	Species	TFr	Tot #	RA	Tot BioM	RB
Banded butterflyfish	18.3	26	0.3	1.2	0.2	Gray snapper	1.7	3	<0.1	1.7	0.3	Reef croaker	10.0	21	0.2	1.2	0.2
Bar jack	28.3	401	4.3	4.0	0.7	Graysby	5.0	3	<0.1	0.3	0.1	Rock hind	1.7	1	<0.1	0.3	0.1
Barred hamlet	5.0	6	0.1	0.1	<0.1	Great barracuda	3.3	2	<0.1	13.1	2.2	Saddled blenny	6.7	5	0.1	<0.1	<0.1
Beaugregory	33.3	71	0.8	0.6	0.1	Greater soapfish	3.3	2	<0.1	0.2	<0.1	Saddled goby	1.7	4	<0.1	<0.1	<0.1
Bicolor damselfish	68.3	249	2.7	1.5	0.2	Grun sp	3.3	39	0.4	<0.1	<0.1	Sailors choice	3.3	2	<0.1	0.5	0.1
Black durgon	1.7	9	0.1	6.8	1.1	Hamlet sp	1.7	1	<0.1	<0.1	<0.1	Sand diver	3.3	2	<0.1	0.5	0.1
Black margate	1.7	5	0.1	1.8	0.3	Harlequin bass	11.7	8	0.1	0.1	<0.1	Sand tilefish	1.7	1	<0.1	0.2	<0.1
Blackbar soldierfish	16.7	18	0.2	3.8	0.6	Hoghat	1.7	1	<0.1	<0.1	<0.1	Saucereye pogy	3.3	2	<0.1	0.3	0.1
Blackear wrasse	25.0	35	0.4	0.8	0.1	Hogfish	3.3	2	<0.1	0.1	<0.1	Schoolmaster	31.7	54	0.6	12.5	2.1
Blue chromis	1.7	3	<0.1	0.1	<0.1	Indigo hamlet	1.7	1	<0.1	<0.1	<0.1	Sergeant major	28.3	93	1.0	5.8	0.9
Blue runner	3.3	102	1.1	39.5	6.5	Inshore lizardfish	1.7	1	<0.1	0.2	<0.1	Sharpnose puffer	20.0	15	0.2	0.1	<0.1
Blue tang	61.7	250	2.8	15.2	2.5	Lane snapper	10.0	41	0.5	3.7	0.6	Slippery dick	46.7	124	1.4	3.6	0.6
Bluehead wrasse	81.7	2,280	25.1	8.1	1.3	Lantern bass	3.3	2	<0.1	<0.1	<0.1	Smallmouth grunt	5.0	41	0.5	2.1	0.3
Bluestriped grunt	3.3	2	<0.1	0.9	0.1	Lionfish sp	1.7	6	0.1	0.3	<0.1	Southern sennet	1.7	35	0.4	65.8	10.8
Bridled goby	6.7	10	0.1	<0.1	<0.1	Longfin damselfish	31.7	155	1.7	3.0	0.5	Spanish grunt	6.7	4	<0.1	0.6	0.1
Brown chromis	8.3	53	0.6	1.8	0.3	Longspine squirrelfish	11.7	8	0.1	1.6	0.3	Spanish hogfish	15.0	18	0.2	3.0	0.5
Butter hamlet	3.3	2	<0.1	<0.1	<0.1	Mahogany snapper	10.0	13	0.1	1.7	0.3	Spotfin butterflyfish	1.7	2	<0.1	0.1	<0.1
Caesar grunt	18.3	121	1.3	12.4	2.0	Moray eel sp	3.3	2	<0.1	<0.1	<0.1	Spotted goatfish	16.7	28	0.3	5.0	0.8
Cero	1.7	1	<0.1	0.3	<0.1	Mutton snapper	1.7	1	<0.1	0.6	0.1	Spotted moray	3.3	2	<0.1	0.2	<0.1
Chub ^b	3.3	6	0.1	9.8	1.6	Neon goby	1.7	2	<0.1	<0.1	<0.1	Squirrelfish	25.0	29	0.3	5.8	0.9
Cleaning goby	5.0	3	<0.1	<0.1	<0.1	Ocean surgeonfish	60.0	305	3.4	18.6	3.0	Stoplight parrotfish	60.0	198	2.2	50.2	8.2
Clown wrasse	41.7	166	1.8	1.6	0.3	Orange spotted filefish	1.7	2	<0.1	0.2	<0.1	Striped parrotfish	78.3	688	7.6	47.7	7.8
Cocoa damselfish	10.0	17	0.2	0.1	<0.1	Planehead filefish	1.7	1	<0.1	0.1	<0.1	Tan hamlet	1.7	1	<0.1	<0.1	<0.1
Coney	3.3	3	<0.1	0.2	<0.1	Porcupinefish	1.7	1	<0.1	1.5	0.2	Threespot damselfish	18.3	222	2.4	4.4	0.7

Species	TFR	Tot #	RA	Tot BioM	RB	Species	TFR	Tot #	RA	Tot BioM	RB	Species	TFR	Tot #	RA	Tot BioM	RB
Creole wrasse	1.7	4	<0.1	0.7	0.1	Porgy sp	5.0	4	<0.1	1.0	0.2	Trumpetfish	8.3	7	0.1	1.6	0.3
Crested goby	1.7	8	0.1	<0.1	<0.1	Porkfish	20.0	21	0.2	2.7	0.5	White grunt	6.7	21	0.2	4.6	0.8
Doctorfish	53.3	487	5.4	59.8	9.8	Princess parrotfish	8.3	19	0.2	1.3	0.2	Yellow goatfish	11.7	92	1.0	11.9	2.0
Dog snapper	1.7	1	<0.1	4.7	0.8	Puddingwife	16.7	20	0.2	0.6	0.1	Yellowcheek wrasse	1.7	2	<0.1	0.2	<0.1
Dusky damselfish	66.7	874	9.6	11.3	1.9	Queen angelfish	1.7	1	<0.1	0.5	0.1	Yellowfin mojarra	1.7	1	<0.1	<0.1	<0.1
Dusky squirrelfish	1.7	1	<0.1	0.1	<0.1	Queen triggerfish	6.7	8	0.1	4.4	0.7	Yellowhead wrasse	18.3	39	0.4	1.7	0.3
Four-eye butterflyfish	41.7	117	1.3	4.0	0.7	Red hind	11.7	11	0.1	3.3	0.5	Yellowtail damselfish	53.3	155	1.7	19.8	3.2
French angelfish	11.7	10	0.1	9.6	1.6	Redband parrotfish	83.3	320	3.5	34.1	5.6	Yellowtail hamlet	8.3	12	0.1	0.2	<0.1
French grunt	45.0	481	5.3	29.1	4.8	Redlip blenny	25.0	50	0.6	0.3	0.1	Yellowtail parrotfish	35.0	76	0.8	10.9	1.8
Glasseye snapper	1.7	1	<0.1	0.2	<0.1	Redspotted hawkfish	1.7	5	0.1	<0.1	<0.1	Yellowtail snapper	56.7	183	2.0	21.3	3.5
Glassy sweeper	1.7	5	0.1	0.2	<0.1	Redtail parrotfish	1.7	1	<0.1	0.2	<0.1						
Gray angelfish	1.7	3	<0.1	1.6	0.3	Reef butterflyfish	1.7	2	<0.1	0.3	0.1						

^aIndicators include frequency of occurrence for each species (TFR, % of stations), the total number for each species observed in the survey (Tot #), the relative abundance of each species as compared to total fish abundance (RA, % of total), the total fish biomass contributed by each species in the survey (Tot BioM; Kg) and the relative biomass of each species as compared to total fish biomass (RB, % of total). A zero (0) signifies a value <0.1

^bChub includes both Bermuda and yellow chub species

Table 4.

Stony coral measurement means and standard errors (SE)

Stony Coral Variable	Mean $\pm$ SE	Median	Range	Units
Taxa Richness (TR)	7.1 $\pm$ 0.34	7	1 - 16	taxa 25 m ⁻² substrate
Density (Den)	2.3 $\pm$ 0.26	1.7	0.16 – 10.7	colonies m ⁻² substrate
Colony Surface Area (CSA) ^a	0.24 $\pm$ 0.05	0.12	0.03 – 2.31	m ²
3D Total Coral Cover (TC) ^a	0.5 $\pm$ 0.09	0.21	0.01 – 3.88	m ² coral m ⁻² substrate
3D Live Coral Cover (LC) ^a	0.29 $\pm$ 0.05	0.15	0.05 – 1.83	m ² live coral m ⁻² substrate

^aColony surface area and cover values (CSA, TC and LC) were calculated using 3D surface areas

Table 5.

Stony coral indicators^a

Species	TFr	# Col	RA	TSA	RSA	LSA	RLSA
<i>Acropora cervicornis</i>	11.7	46	1.32	15.74	2.06	9.60	2.20
<i>Acropora palmata</i>	16.7	43	1.24	214.26	27.98	88.11	20.17
<i>Agaricia agaricites</i>	25.0	28	0.80	0.49	<0.1	0.44	0.10
<i>Agaricia fragilis</i>	6.7	38	1.09	0.61	<0.1	0.48	0.11
<i>Agaricia humilis</i>	21.7	59	1.70	0.57	<0.1	0.53	0.12
<i>Agaricia lamarcki</i>	1.7	1	<0.1	<0.1	<0.1	<0.1	<0.1
<i>Colpophyllia natans</i>	21.7	32	0.922	9.26	1.21	4.43	1.01
<i>Dendrogyra cylindrus</i>	5.0	3	<0.1	29.79	3.89	13.31	3.05
<i>Dichocoenia stokesi</i>	10.0	7	0.20	0.24	<0.1	0.18	<0.1
<i>Diploria labyrinthiformis</i>	6.7	5	0.14	0.32	<0.1	0.24	<0.1
<i>Isophyllastrea rigida</i>	1.7	1	<0.1	0.02	<0.1	0.02	<0.1
<i>Isophyllia sinuosa</i>	15.0	19	0.555	1.21	0.16	0.97	0.22
<i>Madracis decactis</i>	3.3	2	<0.1	0.24	<0.1	0.18	<0.1
<i>Meandrina meandrites</i>	6.7	13	0.37	0.39	<0.1	0.38	<0.1
<i>Millepora complanata</i>	20.0	54	1.55	21.1	2.76	18.74	4.29
<i>Montastraea cavernosa</i>	58.3	182	5.23	35.12	4.59	26.66	6.10
<i>Mycetophyllia aliciae</i>	5.0	3	<0.1	<0.1	<0.1	<0.1	<0.1
<i>Mycetophyllia ferox</i>	1.7	1	<0.1	<0.1	<0.1	<0.1	<0.1
<i>Mycetophyllia lamarckiana</i>	3.3	3	<0.1	<0.1	<0.1	<0.1	<0.1
<i>Mycetophyllia daniana</i>	1.7	1	<0.1	<0.1	<0.1	<0.1	<0.1
<i>Orbicella annularis</i>	20.0	92	2.64	168.46	22.00	77.84	17.82
<i>Orbicella faveolata</i>	53.3	172	4.94	86.31	11.27	56.27	12.88
<i>Orbicella franksi</i>	5.0	4	0.11	1.18	0.16	0.53	0.12
<i>Porites astreoides</i>	91.7	1,468	42.20	57.28	7.48	49.67	11.37
<i>Porites branneri</i>	1.7	1	<0.1	<0.1	<0.1	<0.1	<0.1
<i>Porites divaricata</i>	5.0	6	0.17	0.49	<0.1	0.42	0.10
<i>Porites furcata</i>	1.7	1	<0.1	<0.1	<0.1	<0.1	<0.1
<i>Porites porites</i>	30	65	1.87	7.87	1.03	4.20	0.96
<i>Psuedodiploria clivosa</i>	45.0	65	1.87	6.70	0.88	5.60	1.28
<i>Psuedodiploria strigosa</i>	83.3	375	10.82	46.78	6.11	34.40	7.88
<i>Siderastrea siderea</i>	95.0	642	18.51	58.56	7.65	41.91	9.60
<i>Solenastrea bournoni</i>	3.3	6	0.17	0.77	0.1	0.65	0.15
<i>Stephanocoenia intersepta</i>	31.7	36	1.03	0.93	0.12	0.76	0.17
<i>Unknown species</i>	10.0	6	0.17	0.85	0.1	0	0

^aIndicators include frequency of occurrence for different taxa (TFr, % of stations), number of colonies (# Col), relative abundance (RA, % of total), total surface area (TSA), relative surface area (RSA, % of total), live surface area (LSA) and relative live surface area (RLSA, % of total) for the 33 different coral species documented during the survey.

Table 6.Sponge indicators^a

Sponge Morphology	MFr	RA	Avg CSA	RSA
Barrel	6.7	0.85	0.36	3.59
Branched Ropey	58.3	18.8	0.03	7.35
Bushy	1.7	0.11	0.08	0.1
Globe	18.3	1.4	0.07	1.08
Mound	76.7	33.9	0.04	15.99
Rod	63.3	39.8	0.12	57.85
Tube	28.3	4.2	0.27	13.34
Vase	6.7	0.96	0.06	0.72

^a Indicators include frequency of occurrence for each sponge morphology (MFr, % of stations), relative abundance (RA, % of total sponges), average 3D colony surface area (Avg CSA, m²), and relative surface area contribution to habitat (RSA, % of total sponge surface area)

Table 7.Gorgonian indicators^a

Gorgonian Morphology	MFr	RA	Avg CSA	RSA
Sea Fan (complex)	18.3	1.2	0.81	2.46
Sea Fan (planar)	83.3	14.6	0.30	11.3
Sea Plume	56.7	12.8	1.46	48.7
Sea Rod (branched)	80.0	26.5	0.15	10.2
Sea Rod (bushy)	51.7	6.4	0.39	6.7
Sea Rod (planar)	41.7	5.1	0.09	1.2
Sea Rod (unbranched)	46.7	4.5	0.16	1.9
Sea Whip (branched)	71.7	22.4	0.05	2.7
Sea Whip (bushy)	46.7	6.5	0.87	15.0

^aIndicators include frequency of occurrence for each gorgonian morphology (MFr, % of stations), relative abundance (RA, % of total gorgonians), average 3D colony surface area (Avg CSA, m²) and relative surface area contribution (RSA, % of total gorgonian surface area).