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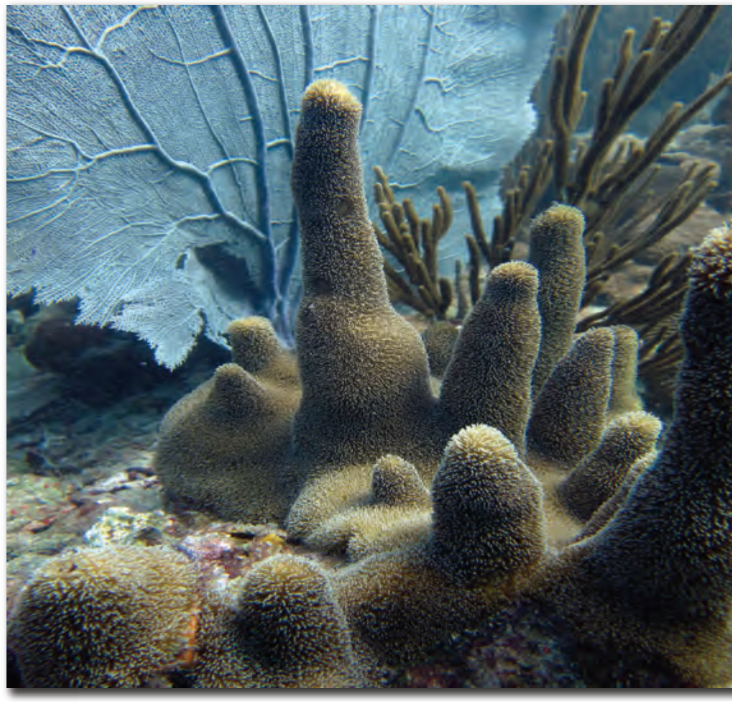
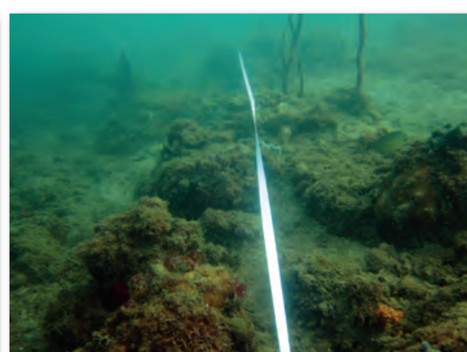
United States Environmental Protection Agency

# Workshop on Biological Integrity of Coral Reefs



Caribbean Coral Reef Institute
Isla Magueyes, La Parguera, Puerto Rico

August 21-22, 2012



**Office of Research and Development**
National Health and Environmental Effects Research Laboratory

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# Workshop on Biological Integrity of Coral Reefs
## August 21-22, 2012
## Caribbean Coral Reef Institute
## Isla Magueyes, La Parguera, Puerto Rico

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## Notice and Disclaimer

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Under authority of the Clean Water Act (CWA), EPA is committed to protecting the biological integrity of the Nation's waters, including marine coastal habitats such as mangroves, seagrasses and coral reefs that lie within the 3-mile territorial waters.

This report summarizes an EPA-sponsored workshop on coral reef biological integrity held at the Caribbean Coral Reef Institute in La Parguera, Puerto Rico, on August 21-22, 2012. The workshop brought together scientists with expertise in coral reef taxonomic groups (e.g., stony corals, fishes, sponges, gorgonians, algae, seagrasses and macroinvertebrates), specializing in community structure, organism condition, ecosystem function and ecosystem connectivity.

The experts evaluated photos and videos for 12 stations collected during EPA coral reef surveys (2010 and 2011) from Puerto Rico coral reefs exhibiting a wide range of conditions. The experts individually rated each station as to observed condition (good, fair or poor) and documented their rationale for the assignment. The group discussed the reef attributes that characterize biological integrity (or the natural condition) for Puerto Rico's coral reefs, which will serve as the baseline condition, since the CWA is grounded in the concept of natural, undisturbed conditions.

The long-term goal is to derive scientifically defensible thresholds for different levels of coral reef condition with a well-defined narrative for each level. Managers will be able to use the narratives to determine which level most appropriately describes the current condition of their coral reefs and which level is the desired condition. From this, managers can set easily communicated, quantitative goals for achieving those conditions. The conceptual model will serve as an interpretative framework to explicitly link science and monitoring information to management and decision-making.

This is a contribution to the EPA Office of Research and Development's Safe and Sustainable Waters Research Program, characterizing the effects of land use on estuarine and coastal resources.

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# Executive Summary

EPA's Office of Research and Development (ORD) and Office of Water (OW) hosted a workshop on coral reef biological integrity that brought together scientists with expertise in coral reef taxonomic groups (e.g., stony corals, fishes, sponges, gorgonians, algae, seagrasses and macroinvertebrates), specializing in community structure, organism condition, ecosystem function and ecosystem connectivity. The goals of this first workshop were to:

- Identify key qualitative and quantitative ecological characteristics (reef attributes) that determine the condition of linear coral reefs inhabiting shallow waters (<12 m) in southwestern Puerto Rico.
- Use those reef attributes to recommend categorical condition rankings for establishing a biological condition gradient.
- Ascertain through expert consensus those reef attributes that characterize biological integrity (a natural, fully-functioning system of organisms and communities) for coral reefs.
- Develop a conceptual, narrative model that describes how biological attributes of coral reefs change along a gradient of increasing anthropogenic (human-generated) stress.

The long-term goal is to derive scientifically defensible thresholds for different levels of coral reef condition that can be coupled with management objectives and used to evaluate alternative decision options.

The experts evaluated photos and videos for 12 stations collected in 2010 and 2011 during EPA coral reef surveys from Puerto Rico coral reefs exhibiting a wide range of conditions. The experts individually rated each station as to observed condition (good, fair or poor) and documented their rationale for the assignment. The group discussed the reef attributes that characterize biological integrity (or the natural condition) for Puerto Rico's coral reefs. These attributes will be further developed to characterize the baseline condition, an important concept for achieving Clean Water Act goals.

The attributes and thresholds will be organized into a conceptual, narrative model that describes how biological attributes of coral reefs change along a gradient of increasing anthropogenic stress. By providing the explicit characterization of how attributes of the biological system change as human disturbance increases, decision-makers will be able to use the narratives to determine which level most appropriately describes the current condition of their coral reefs and which level is the desired condition. From this, managers can set easily communicated, quantitative goals for achieving those conditions.

This is the first in a series of facilitated workshops and webinars with this group of coral reef experts.

# Chapter 1. Introduction

The approach described in this report will assist in developing a conceptual, narrative model that describes how biological attributes of coral reefs change along a gradient of increasing anthropogenic stress. The framework is expected to serve multiple purposes.

- It will assist decision-makers in understanding the current conditions of the Puerto Rico coral reefs relative to natural, undisturbed conditions, the critical attributes of the coral reefs and how each attribute changes in response to stress. Through this framework, decision-makers can set realistic goals for their coral reefs and establish monitoring (measurement) endpoints that are meaningful based upon the attributes identified by the scientific community.
- It will be used to support the development of an economic survey of Puerto Rico's coral reefs (another project being conducted in collaboration with the National Oceanic and Atmospheric Administration's Office of National Marine Sanctuaries).
- It will inform the Bayesian Belief Network (BBN) and Dynamic Systems Models being developed by the EPA modelers.
- It will contribute to the development of coral reef biological criteria for water quality standards under the Clean Water Act (CWA) for Puerto Rico.

To initiate the process, scientists with expertise in coral reef taxonomy, ecology, and management of stony corals, fishes, sponges, gorgonians, algae, seagrasses, and macroinvertebrates, specializing in community structure, organism condition, ecosystem function and ecosystem connectivity were brought together. These experts participated in the first workshop, held August 21-22, 2012, in La Parguera, Puerto Rico. (See Appendix B for a list of workshop participants.)

The goals of this first workshop were to:

- Identify key qualitative and quantitative ecological characteristics (reef attributes) that determine the condition of linear coral reefs inhabiting shallow waters (< 12 m) in southwestern Puerto Rico.
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- Ascertain through expert consensus those reef attributes that characterize biological integrity (a natural, fully-functioning system of organisms and communities) for coral reefs.
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The long-term goal is to derive scientifically defensible thresholds for different levels of coral reef condition that can be coupled with management objectives and used to evaluate alternative decision options.

## 1.1 Coral Reef Ecosystems

Coral reefs are the earth's most biologically diverse marine ecosystems (Sebens 1994; Odum 1997). Scleractinian (stony) corals, octocorals and sponges provide structural habitat that supports harvestable fish species and attracts tourists (Bradley et al. 2008). Stony corals also protect shorelines from erosion by physically blocking current and wave energy (Wilkinson 1996), and coral reefs provide food and income for 500 million people globally (TNC 2006).

Corals are generally found in clear, shallow tropical oceans, and their growth is limited by temperature, salinity, light intensity, water clarity, and other chemical and water quality characteristics (Wells 1957; Brown and Howard 1985; Hubbard 1997; Ogden 1997; Hoegh-Guldberg 1999). Coral reefs are sensitive to relatively small changes in the environment (Richmond 1993) and their lack of resilience to environmental change has led some to regard coral reefs as sentinels of oceanic environmental quality (Hatcher et al. 1987; Andrews and Pickard 1990; Barber et al. 2001).

Healthy stony corals appear to be critical for fish productivity, species richness and fish biomass, all of which have been reported to decrease with a decline in stony coral health (Warren-Rhodes et al. 2003). Additionally, there appears to be a strong positive correlation of habitat complexity to the biodiversity and ecosystem functions of a reef community (Alvarez-Filip et al. 2009), including fish species richness (Walker et al. 2009; Pittman et al. 2007a, b). The rich diversity of coral reefs is partly dependent on the provision of habitable surface area and partly on the variability of that surface area (Principe et al. 2012).

The adjacent habitats of seagrass meadows and mangrove forests are linked with coral reefs to form a complex dynamic mosaic that provides critical nurseries, foraging areas, and refugia for fish and invertebrates (Christensen et al. 2003; Mumby et al. 2004, 2008; Aguilar-Perera and Appeldoorn 2007; McField and Kramer 2007; Meynecke et al. 2008). Mangroves and seagrasses can also trap sediments, nutrients, and pollutants, which can improve the water quality on nearby reefs (Grimsditch and Salm 2006). Many juvenile fishes occupy shallow-water habitats such as mangroves and seagrasses, while the adult forms are found in adjacent coral reefs (Nagelkerken et al. 2000; Adams et al. 2006; Cerveny 2006; Dahlgren et al. 2006; Clark et al. 2009; Pittman et al. 2010).

## 1.2 Puerto Rico's Coral Reef Ecosystems

The US territory of Puerto Rico encompasses the main island of Puerto Rico, two inhabited islands (Culebra and Vieques) and three uninhabited islands (Mona, Monito and Desecheo). Puerto Rico has an estimated coastline of 930 km, a land area of 8,950 $km^2$ and fringing coral reefs with a total area of 3,370 $km^2$ off the east, south and west coasts (Wilkinson 2004; Burke and Maidens 2004).

The coral reef ecosystem in Puerto Rico is a complex mosaic of interrelated habitats, including mangrove forests, seagrass beds and coral reefs, as well as other coral communities (Garcia-Sais et al. 2008). Ballantine et al. (2008) listed 69 shallow-water (<40 m) scleractinian species, 260 fish species, 46 shallow-water alcyonarian species and 500 species of benthic marine algal flora, excluding cyanobacteria (Table 1-1).

**Table 1-1. Number of currently reported species in each of the major marine taxa for Puerto Rico** (adapted from Weil 2005).

| Taxon | # Species | Source |
|---|---|---|
| Algae (diatoms; red, green, blue-green and brown algae) | 492 | Ballantine and Aponte 1997a, b; Ballantine and Aponte 2002 |
| Mangroves | 5 | Cerame-Vivas 2001 |
| Seagrasses (*Marine Phanerogams*) | 7 | Vicente 1992 |
| Sponges (*Phylum Porifera*) | 61 | Wilson 1902; Weil 2005 |
| Corals, anemones, jellyfish (*Phylum Cnidaria*) | 171 | Vaughan 1902; Hargitt and Rogers 1902; Almy and Carrion-Torres 1963; Garcia et al. 2003; Weil 2005 |
| Unsegmented worms (*Phylum Nemertea*) | 8 | Coe 1902 |
| Bivalves, snails, octopus, mollusks, nudibranchs (*Phylum Mollusca*) | 1,176 | Dall and Simpson 1902; Grana 1993; Ortiz 1998; Garcia-Rios 2003 |
| Segmented worms, polychaetes (*Phylum Annelida*) | 129 | Treadwell 1902, 1939; Long 1975 |
| Ostracods, crabs, shrimp (*Phylum Arthropoda*) | 342 | Benedict 1902; Bigelow 1902; Moore 1902; Rathbun 1902; Menzies and Glynn 1968 |
| Starfish, sea urchins, brittle stars (*Phylum Echinodermata*) | 165 | Clark 1902, 1933 |
| Bryozoans (*Phylum Ectoprocta*) | 131 | Osburn 1940 |
| Fishes (Superclass Osteichthyes), sharks, rays (Class Chondrichthyes) | 677 | Dennis 2000; Dennis et al. 2004 |
| Reptiles (turtles, snakes) | 5 | Rivero 1978 |
| Mammals | 18 | Beller et al. 1999 |

While over 60 species of scleractinian corals inhabit the Western Caribbean, reefs in Puerto Rico were historically dominated by the reef-building coral taxa *Montastraea annularis* complex[1], *Agaricia agaricites*, *Montastraea cavernosa, Porites astreoides* and *Colpophyllia natans*. Additionally, *Acropora palmata* and *Acropora cervicornis* often formed dense, high-relief monospecific thickets; *A. palmata* in shallow exposed fore-reef habitats and *A. cervicornis* on fore-reefs and in shallow, protected back-reefs (Morelock et al. 2001).

Recent studies in Puerto Rico show that large corals of the genus *Montastraea* are critical for the biodiversity of fish and invertebrates and for maintaining the structure, function, and flow of reef ecosystem services (Beets and Friedlander 1998; Mumby et al. 2008). Mumby et al. (2008) found that one-fourth to one-third of benthic invertebrates and fish occurred in the *Montastraea*-dominated fore-reefs in the Caribbean. *A. palmata* and *A. cervicornis,* which have recently been listed as threatened species in the Caribbean, also significantly contribute to reef growth and development and provide essential fish habitat (NOAA 2012a; Principe et al. 2012).

[1] This report does not adopt the new classifications for the *Montastraea annularis* species complex (*Montastraea annularis*, *Montastraea faveolata* and *Montastraea franksi*) reclassified as the original genus *Orbicella* (Budd et al. 2012).

## 1.3 Timelines

### *1.3.1 Condition Timeline*

**1000**: Coral reefs would have been regarded as mostly pristine by current standards with healthy corals, large, well-structured fish and invertebrate communities, with probably only a depletion of some of the larger fauna (Wilkinson 2004).

**1800**: Large vertebrates such as the green turtle, hawksbill turtle, manatee and Caribbean monk seal were decimated in the central and northern Caribbean Sea (Jackson 1997).

**1880s**: Early taxonomic studies of reefs on Puerto Rico (e.g., mollusks [Gundlach 1883]; crustaceans [Gundlach 1887]; fishes [Poey 1881]; polyps, worms, fishes and crustaceans [Stahl 1883]; algae [Hauck 1888]; and coral [Vaughn 1902]).

**1900**: Most coral reefs were healthy and dominated by healthy branching corals, urchins, large schools of game fish, sharks and algal grazers. Waters were clear with low nutrient levels (Wilkinson 2004).

**1952:** The last confirmed sighting of the Caribbean monk seal was at Serranilla Bank between Jamaica and Nicaragua (Debrot 2000).

**Late 1950s and early 1960s**: Massive fishing pressure began in Puerto Rico (Appeldoorn personal communication). Herbivores and predators were reduced to very small fishes and sea urchins (Jackson 1997).

**1969**: An intensive and extensive coral bleaching event occurred on coral reefs of southwestern Puerto Rico. The bleaching was probably caused by 38.1 cm of rain during a hurricane that preceded the bleaching (Williams and Bunkley-Williams 1990).

**Late 1970s**: Extensive thickets of *Acropora palmata* were present in 40% of locations surveyed around Puerto Rico; 20% of these reefs had dense *A. palmata* patches and abundant colonies of *A. cervicornis* (Weil et al. 2003).

**Late 1970s and early 1980s**: A white-band disease (WBD) epizootic event caused extensive mass mortality of Acroporid corals throughout their range in the Caribbean with losses up to 95% (Gladfelter 1982; Weil et al. 2003, 2009; Weil and Rogers 2011).

**1981**: Minor but widespread bleaching caused by elevated sea surface temperatures (SST) occurred in southwestern and western Puerto Rico (Williams and Bunkley-Williams 1989, 1990).

**1983**: *Diadema antillarum* mass mortality, with 85-100% population declines (Bak et al. 1983; Lessios et al. 1984; Lessios 1988, 2005; Osborne 2000). The *Diadema antillarum* mortality was first observed in Puerto Rico in January 1984 in the coral reefs off La Parguera (Vicente and Goenega 1984b).

**Late 1980s**: Massive coral bleaching and mortality caused by elevated SST. Extensive partial coral colony mortalities and some total mortalities of coral reef organisms, including death of some 400-500 year-old coral colonies (Velazco-Dominguez et al. 2003; Burke and Maidens 2004). Massive coral bleaching events in Puerto Rico were first reported by Williams et al. 1987 and Goenega et al. 1989.

**1990**: Severe bleaching in the western north Atlantic caused by elevated SST and doldrum surface waters (from Bermuda, Texas, Florida, throughout the Caribbean, south to Brazil). High mortalities of fire corals, scleractinian corals, gorgonians, sponges and other coral reef organisms (Velazco-Dominguez et al. 2003).

**1994**: Cumulative impacts of disease, coastal development, coral bleaching and over-fishing have resulted in heavily damaged reefs. The more isolated reefs were in better condition because they were not affected by land-based stressors (Wilkinson 2004).

**1996**: Caribbean yellow-band disease (YBD) first observed in Puerto Rico with very low prevalence (Bruckner and Bruckner 1997, 2006; Weil et al. 2009). The disease was highly seasonal (summer-fall). YBD affects three species of the former *Montastraea annularis* species-complex *(M. faveolata, M. annularis and M. franksi),* the most important reef-building corals for this area (Bruckner and Bruckner 2006; Cróquer and Weil 2009; Harvell et al. 2009).

**1998**: Severe bleaching event in Puerto Rico caused by elevated SST (July–September); 99% of the colonies completely recovered after 9 months; 15% of the colonies bleached again in 1999 and recovered by January 2000 (Velazco-Dominguez et al. 2003).

**2000**: *Diadema* seem to be making a slow return in many localities in the Caribbean, including La Parguera, PR (Weil et al. 2005).

**2003**: YBD became chronic and colonies showed disease signs all year (Weil et al. 2009). Surveys of over 100 reefs along the coast and islands found that Acroporid populations continued to decline in some areas from persistent disease, storms and sedimentation coupled with the poor coastal environmental conditions (high turbidity, sub-optimal water quality, etc.) and algal overgrowth.

**2004**: Most inshore reefs show advanced stages of degradation. *Montastraea annularis* species-complex was the dominant stony coral, but it was virtually absent on reefs with low coral cover. The encrusting octocoral *Erythropodium caribaeorum* occurred at most stations, and zoanthids (particularly the encrusting *Palythoa* species) and sponges were the dominant sessile benthic invertebrates in shallow waters. Macroalgae and turf algae were dominant instead of corals on most intermediate-depth reefs (Garcia-Sais et al*.* 2008).

**2005**: A major bleaching event caused by elevated SST in the fall of 2005, followed in 2006 by mass cnidarian mortality, had a dramatic impact on Puerto Rican coral reefs. A total of 82 cnidarian species were impacted by the bleaching, including 52 scleractinians, 13 octocorals, four hydrocorals, four zoanthideans, four actiniarians, three corallimorpharians and two scyphozoans (Garcia-Sais et al. 2006, 2008). The most severe bleaching was observed among

*Montastraea annularis* species-complex (94%), *Helioseris cucullata* (94%), *Colpophyllia natans* (83%), *Siderastrea siderea* (65%), *Millepora* species (63%), *Mycetophyllia* species (2%), *Diploria* species[2] (54%), *Agaricia* species (48%) and *Montastraea cavernosa* (46%). Three genera appeared to be less susceptible to bleaching: *Eusmilia fastigiata* (22%), *Meandrina meandrites* (26%) and all *Porites* species (36%). *Millepora alcicornis* was completely bleached at all stations, and most colonies (>65%) had died by December 2005. In August 2006, most corals had regained normal coloration, with the exception of *Montastraea annularis* species colonies, which experienced extensive partial and full colony mortality throughout the region. Total coral cover declined throughout the region by 40-60%. Disease epizootics followed, including a white plague outbreak on the east and southern coasts, and Caribbean yellow-band disease (YBD) that primarily affected the *Montastraea annularis* species-complex that occurred right after the peak of the 2005 bleaching event (Garcia-Sais et al. 2008).

Intense bleaching of octocorals was first noted in late September to early October beginning with *Erythropodium caribaeorum*, followed by *Muricea*, *Briareum* and *Plexaurella* and later by *Pseudoplexeaura* and *Pterogorgia* species. Bleaching in scleractinian corals, hydrocorals and the zoanthid *Palythoa caribaeorum,* preceded bleaching of octocorals, suggesting octocorals may have higher tolerance to thermal stress compared to the other major cnidarian taxa. By late November 2005, the majority of the affected octocoral colonies had not died. The exceptions were the bleached colonies of *Muricea*, which had 90% mortality (Prada et al. 2009).

**2006**: NOAA's National Marine Fisheries Service (NMFS) listed *Acropora palmata* and *Acropora cervicornis* corals as threatened throughout their known range by authority of the Endangered Species Act (ESA). This designation became final in May 2006 (Federal Register 2006).

**2008:** The Caribbean monk seal was officially declared extinct after an exhaustive five-year search by NOAA NMFS.

**2014**: NOAA NMFS proposed seven Atlantic/Caribbean corals as endangered: *Acropora cervicornis*, *Acropora palmata*, *Dendrogyra cylindrus*, *Orbicella annularis*, *Orbicella faveolata*, *Orbicella franksi* and *Mycetophyllia ferox* and two species as threatened: *Agaricia lamarcki* and *Dichocoenia stokesii* (Brainard et al. 2011). In their final rule (August 27, 2014), NOAA listed *O. annularis*, *O. faveolata*, *O. franksi*, *D. cylindrus* and *M. ferox* as threatened species and determined that *D. stokesii* and *A. lamarcki* did not warrant listing. NOAA also determined that the listing of *Acropora cervicornis* and *Acropora palmata* as threatened in 2006 is still warranted.

[2] This report does not adopt the new classifications *Diploria strigosa* and *Diploria clivosa* as the genus *Pseudodiploria* (Budd et al. 2012).

### *1.3.2 Anthropogenic Activity Timeline*

**~2000-3000 B.C**.: The Ortoiroid people from the Orinoco region in South America settled in Puerto Rico. The Saladoid and Arawak Indians populated the island between 430 BC and 1000 AD. By 1000 AD the Taino culture was dominant (Rouse 1992). These early populations exploited coral reef resources, and there is strong archaeological evidence of major harvesting of fishes, molluscs, manatees and turtles (Wilkinson 2004).

**1493**: Christopher Columbus landed in Puerto Rico, beginning an intense period of colonization and resource extraction (mainly gold). The early explorers found the indigenous population cultivating, blending, rolling and smoking tobacco. Europeans had never seen tobacco. This discovery marked the start of an international passion for "New World" tobacco and its much sought after byproduct, the cigar.

**1496-1660**: Tobacco was the major crop. Half the shipping tonnage between Puerto Rico and Europe (mainly Spain) was comprised of tobacco.

**1508**: Juan Ponce de Leon founded a town (*Guaynía*, meaning "*a place with water*") on the shores of Guánica Bay. The narrow channel and calm waters of Guánica Bay made it a natural refuge for ships sailing the Caribbean Sea.

**Early 1500s**: Sugar was introduced (perhaps when Juan Ponce de Leon began colonizing the island), and many small landowners relied on its export as a source of income.

**1548**: Hundreds of sugar mills operated by waterpower. The industry was in the hands of small landowners whose enterprises succeeded or failed depending on the price of sugar in the market or the whims of the Spanish Crown.

**1736**: Coffee plants introduced to Puerto Rico, grown mostly for personal and domestic use.

**Mid-1800s**: French immigrants from the Mediterranean island of Corsica settled around Yauco and became well known as premium coffee exporters to Europe.

**1867**: (San Narciso), 1899 (San Ciricao), 1928 (San Felipe) and 1932 hurricanes virtually destroyed most coffee plantations and tobacco crops. Many farms never recovered.

**1873**: First "Centrales" or sugar factories with equipment operated by steam were established. Centrifuges were used to separate the sugar crystals from the molasses.

**1898**: Puerto Rico was ceded to US as a result of the Spanish American War. US markets opened to Puerto Rico products (tariff free). Sugar cane was the most important cash crop for the territory.

**1900**: The US enacted the Foraker Act, which removed the previous land ownership cap of 500 acres. Large monoculture farming began (primarily sugar).

**1901**: The South Porto Rico Sugar Company of New Jersey, USA, began construction of the Central Guánica sugar mill. The Central Guánica organized a company town around the sugar mill that included a hospital, school and housing facilities. This sugar mill was one of the largest in the

Caribbean and was one of the largest in the world until World War I (Ayala 1999; Wikipedia 2013).

**1900–1927**: Puerto Rico produced around 35 million pounds of tobacco a year. Tobacco represented 38% of the value of commercial crops in 1920 (sugar accounted for 25%). In 1910, 14% of farms reported the cultivation of coffee. 75% of the employed people in Puerto Rico were involved in the sugar industry controlled by US corporations (Miller and Lugo 2009).

**Early 1930s**: The Roosevelt Administration created the Puerto Rico Emergency Relief Administration, which became the Puerto Rican Reconstruction Administration in 1935. Rural resettlement communities and demonstration farms were established, and coffee and fruit production was reorganized.

**1934**: Jones-Costigan Act set a quota on the amount of sugar that could be exported to the US tariff free.

**1940s**: The Puerto Rico Water Resources Authority (PRWRA) initiated the Southwestern Puerto Rico Project (SWPRP). The SWPRP connected five watersheds and a retention pond through construction of dammed reservoirs and an underground aqueduct system that diverted water south into the Guánica Bay/Rio Loco watershed. This increased the watershed drainage area from approximately 57,000 to 97,000 acres.

**1941**: Land Reform Act was passed, limiting land ownership to 202 hectares (500 acres) or less. Many rural residents were now able to buy 10 hectare (25 acre) parcels, allowing them to grow crops for profit for both export and internal use. This broke up the land monopoly of the large sugar companies (Miller and Lugo 2009).

**Late 1940s**: The US Department of Agriculture (USDA) ended sugar subsidies for Puerto Rican farmers. Annual production of sugar dropped soon after. Massive numbers of Puerto Ricans migrated to the New York area.

**1948**: The Industrial Incentives Act (Operation Bootstrap) began to shift Puerto Rico from rural agriculture to more urbanized communities and industrial sources of income (shifts to manufacturing of pharmaceuticals, chemicals, machinery and electronics).

**1948**: The Guánica fertilizer plant opened, with storage silos and a shipping pier.

**1952**: Peak sugar production in Puerto Rico.

**1953**: Puerto Rico passed Act No. 65, authorizing the Lajas Valley Irrigation System.

**1954**: The Lajas Valley Irrigation (LVI) project, developed under the guidance of experts from the USDA led efforts to remove sugar plantations that had long characterized the region. This project also started small-scale agricultural farming and introduced cultivated fruits, mainly pineapple. The LVI project channelized 200,000 acres of land via 25 miles of a concrete-lined main canal, 60 miles of concrete-lined and unlined lateral canals and the corresponding drainage system. Two hydroelectric dams and two additional water reservoirs were built. Shade-grown coffee was transplanted into sun-exposed areas.

**1955**: Guánica Lagoon was drained to increase land available for agriculture.

**1970s**: Government subsidies and support for sun-grown coffee were implemented.

**1981**: Guánica sugar mill was closed.

**1980s**: Widespread conversion to sun-grown coffee reduced biodiversity (from loss of canopy habitat) and increased soil erosion from steep and now poorly vegetated, unprotected slopes. Soil washed from hillsides into streams and was trapped in the reservoirs, reducing their water storage capacity (Soler-López 2001) and increasing sediment deposition in Guánica Bay.

**1999**: Puerto Rico passed an agricultural reserve law in an attempt to reverse the trend of declining agriculture.

**2000**: The final two sugar factories closed (Coloso and Roig Centrales).

**2009**: The US Coral Reef Task Force (USCRTF) selected the Guánica Bay watershed as the location for its first multi-agency watershed initiative in an attempt to reduce watershed impacts on coral reefs in the coastal zone.

## 1.4 Southwestern Puerto Rico

Southwestern Puerto Rico is relatively rural, with low population density compared to northeastern Puerto Rico. There are, however, some population centers: Yauco (population 20,295), San Germán (population 12,055), Guánica (population 9,224) and Sabana Grande (population 8,961). The human presence has created a variety of environmental stresses in this region.

Agricultural growth in southwestern Puerto Rico has resulted in widespread land clearing and modification. Nearly 90% of the area was deforested by the end of the 19th century (Warne et al. 2005), and the largest natural freshwater body in Puerto Rico, the Guánica Lagoon, was drained in 1955 as part of an agricultural development project (Sturm et al. 2012). These modifications have led to increased watershed sediment and nutrient yield, thereby increasing sediment and nutrient discharge to the coastal shelf (Warne et al. 2005).

Municipal growth has increased impervious cover, generation of stormwater runoff and human sewage. Impervious cover increases the loading of nutrients, bacteria, sediments and contaminants such as polycyclic aromatic hydrocarbons (PAHs), heavy metals and other pollutants associated with automobiles. Stormwater accumulates debris, chemicals, dirt and other pollutants, which are untreated and then discharged into coastal rivers and bays. Sewage carries pathogens that can transmit disease to humans and other animals, contains organic matter that can cause odor and nuisance problems and nutrients that can cause eutrophication of receiving water bodies. Much of the rural population in southwestern Puerto Rico relies upon septic systems for their sewage treatment. Too often these are failing, inadequate or improperly maintained. There are also several wastewater treatment plants (WWTP) in the area, which only treat the sewage to eliminate pathogens and solids. Some of these WWTPs are being upgraded to advanced secondary treatment, which provides minimal nutrient reduction.

Communities in the coastal region of southwestern Puerto Rico rely partially on fishing and tourism for their livelihood. Fishing, if not conducted in a sustainable manner, can lead to overexploitation of marine living resources (both target species and the marine system as a whole). Boat anchors, traffic and groundings can adversely impact marine resources. For example, much of the seagrass in the shallow shelf area near La Parguera is vulnerable to damage from boat propellers. Lost fishing gear, such as hooks, lines, nets and lobster traps, can also be damaging to marine resources.

Finally, elevated SSTs are correlated with mass bleaching events (Goreau et al. 1992; Glynn 1988, 1991; Hoegh-Guldberg 1999; McClanahan et al. 2007; Meissner et al. 2012). Sea surface temperatures have been higher during the past three decades than at any other time since reliable observations began in 1880 (NOAA 2012b). Global warming is caused by human activities that emit heat-trapping carbon dioxide and result in increased SSTs. A summary table illustrating some of the major stressors and their sources is shown in Table 1-2.

**Table 1-2. Complex relationships between stressors exist in southwestern Puerto Rico.**

| Source of Stressor | Stressors |
|---|---|
| Agriculture | Increased sediment, nutrient, pesticide and herbicide loads to aquatic ecosystems |
| Urban development | Increased sewage (nutrients and pathogens), stormwater runoff (sediment, contaminants) |
| Fishing | Overexploitation of fish populations; by-catch; damage from fishing gear and boats |
| Increased global $CO_2$ emissions from power generation and transportation | Elevated sea surface temperature and acidification in the marine environment |

## 1.5 The Clean Water Act

The Clean Water Act (CWA) (33 U.S.C. § 1251 et seq. 1972) is the cornerstone for surface water quality protection in the United States. The CWA objective is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. The CWA authorizes EPA to determine "appropriate minimum levels" of protection and to provide oversight to states (states, territories and commonwealths), which are required to establish water quality standards that define the goals (designated uses) and pollution limits (water quality criteria) for all waters within their jurisdictions. States are also required to monitor conditions regularly and submit biannual reports summarizing water quality assessments. Waterbodies that do not meet the water quality criteria are reported as "impaired", triggering a series of management actions to determine the cause of impairment and to restore the condition of the waterbody and its resident biota.

Biological integrity is a long-term objective of the CWA, and water quality standards and criteria can be defined to protect valued aquatic resources, such as coral reef ecosystems. Biological assessments directly measure the condition of the aquatic resource to be protected and the cumulative response of the biological community to all sources of stress. Biological standards (biocriteria) set biological quality goals.

The President's Ocean Action Plan (US Commission on Ocean Policy 2004) required EPA to develop the tools and knowledge necessary to protect coral reefs from land-based pollution using coral reef biological criteria. A comprehensive guide (Bradley et al. 2010) describes the process for using the CWA and biological criteria to enhance coral reef protection efforts.

## 1.6 Why a Coral Reef Ecosystem Conceptual Model is Needed

Coral reef condition typically degrades as human disturbance increases. Human disturbances threatening coral reefs include polluted runoff from agriculture and land-use practices, over-fishing, ship groundings, coastal development, sewage discharge and climate change. Natural stressors such as tropical storms can also adversely impact coral reefs. Both natural and anthropogenic stressors can cause increases in coral bleaching and diseases. Reefs in the US Caribbean have declined from 50% total coral cover to less than 10% in just 25 years (Wilkinson 2004).

The biological communities of the coral reef reflect overall ecological integrity (i.e., chemical, physical and biological integrity), integrate effects of multiple stressors and provide a measure of aggregate impact (Barbour et al. 1999). Coastal resource managers and coral reef scientists routinely conduct biological assessments to evaluate the condition of coral reefs. This approach integrates the cumulative impacts of chemical, physical and biological stressors on aquatic life. However, while the stated intent of these biological assessments is to support decision-making, they more commonly document the decline of the coral reefs. A missing component in this approach is a scientifically derived process for identifying thresholds that can be coupled with management objectives and used to evaluate alternative decision options. A conceptual model can help to organize information and make sense of system components and their interactions.

## 1.7 The Framework: The Biological Condition Gradient (BCG)

Beginning in the late 1990s, EPA collaborated with aquatic scientists and managers across the United States to develop and implement the Biological Condition Gradient (BCG) for freshwater streams (Davies and Jackson 2006). The BCG is a conceptual model that describes how biological attributes of aquatic ecosystems (i.e., biological condition) might change along a gradient of increasing anthropogenic stress (e.g., physical, chemical and biological impacts). The BCG was designed to provide a means to map different indicators on a common scale of biological condition to facilitate comparisons between programs and across jurisdictional boundaries in context of the CWA.

Since then, many states have used the BCG to support water quality management, and several states have used the BCG to more precisely define freshwater stream designated aquatic life uses, identify impairment thresholds, monitor status and trends and track progress in restoration and protection (EPA 2011). Additionally, stream BCGs have been developed at the regional and local government scale throughout the US.

Since 2008 EPA has been collaborating with estuarine scientists and managers to adapt the stream BCG framework to more complex estuarine waterbodies (EPA in review). Estuarine BCG pilot work has focused on National Estuary Program (NEP) sites: Narragansett Bay (RI), Casco Bay (ME), Mobile

Bay (AL) and Tampa Bay (FL). NEPs play an important role as conveners of technical, management and public interests. Their ability to create connections among these constituencies makes them a valuable platform to work out the complexities of an estuarine BCG at different scales.

A BCG calibrated with field data can help states more precisely define biological expectations for their designated aquatic life uses, interpret current condition relative to CWA objectives and goals, track biological community responses to management actions and communicate environmental outcomes to the public. The model can serve as a template for organizing field data (biological, chemical, physical, landscape) at an eco-regional, basin, watershed or waterbody scale. It provides a framework for understanding current conditions relative to natural, undisturbed conditions.

In practice, the BCG is used to first identify the critical attributes of an aquatic community and then to describe how each attribute changes in response to stress. Coral reef managers can use the BCG to interpret biological condition along a standardized gradient, regardless of assessment method, and apply that information to different programs.

The BCG model provides a framework to help water quality managers do the following:

- Decide what environmental conditions are desired (goal-setting)—The BCG can provide a framework for organizing data and information and for setting achievable goals for waterbodies relative to natural conditions (e.g., condition comparable or close to undisturbed or minimally disturbed condition).
- Interpret the environmental conditions that exist (monitoring and assessment)—Practitioners can get a more accurate picture of current waterbody conditions.
- Plan for how to achieve the desired conditions and measure effectiveness of restoration—The BCG framework offers water program managers a way to help evaluate the effects of stressors on a waterbody, select management measures by which to alleviate those stresses and measure the effectiveness of management actions (EPA 2011: Case Example 3.16).
- Communicate with stakeholders—When biological and stress information is presented in this framework, it is easier for the public to understand the status of the aquatic resources relative to what high-quality places exist and what might have been lost.

### *1.7.1 How is the BCG Constructed?*

The BCG has been divided into six levels of biological conditions along the stressor-response curve, ranging from observable biological conditions found at no or very low levels of stress (level 1) to those found at high levels of stress (level 6) (Figure 1-1).

The BCG was developed to serve as a scientific framework to synthesize expert knowledge with empirical observations and develop testable hypotheses on the response of aquatic biota to increasing levels of stress.

It is intended to support more consistent interpretations of the response of aquatic biota to stressors and to clearly communicate this information to the public. It is being evaluated and piloted in several regions and states.

Davies and Jackson (2006) provides a description of how 10 attributes of aquatic ecosystems change in response to increasing levels of stressors along the gradient, from level 1 to 6. The attributes include several aspects of community structure, organism condition, ecosystem function, spatial and temporal extent and connectivity (Table 1-3).

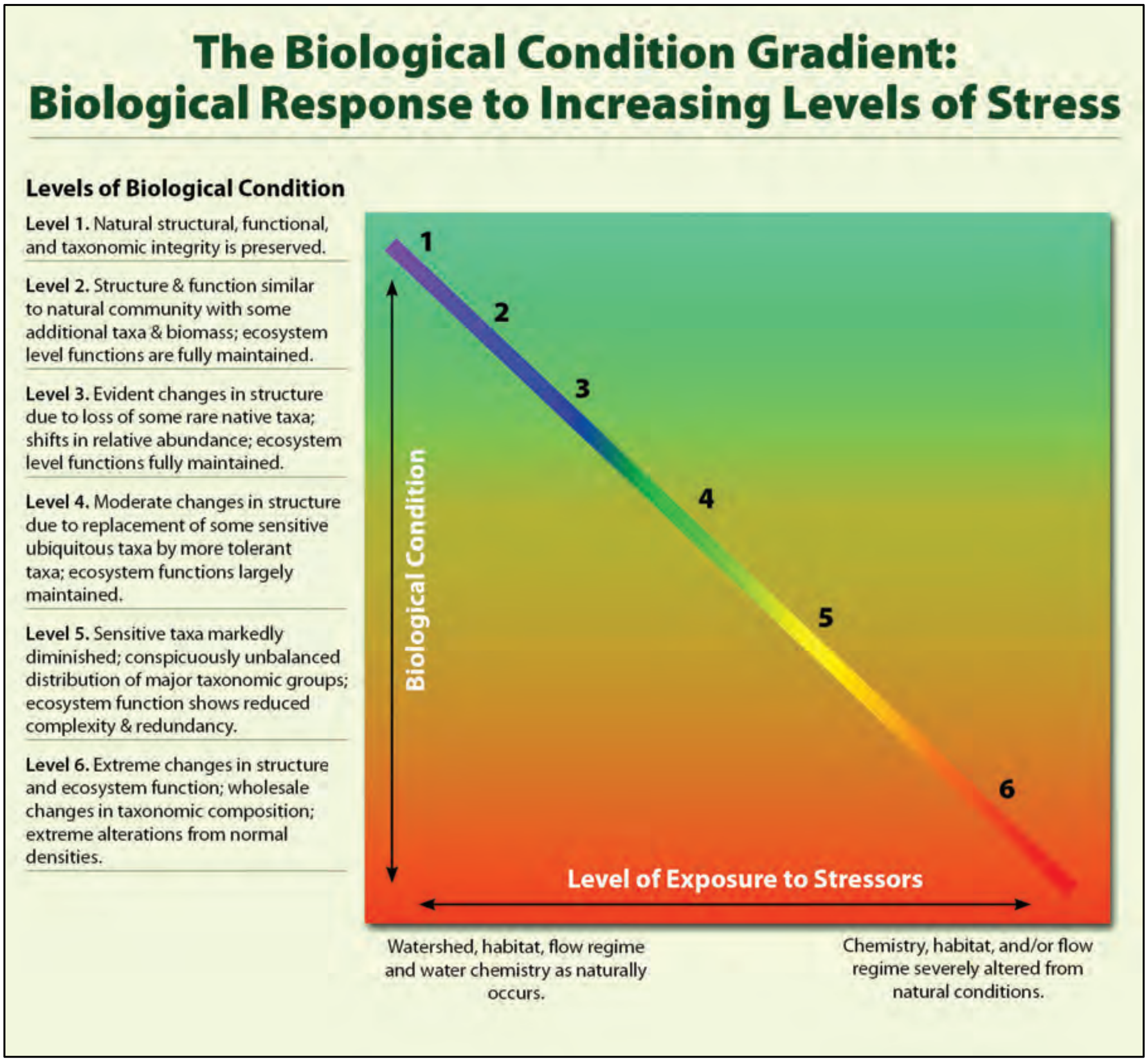


**Figure 1-1. The Biological Condition Gradient (BCG)** (modified from Davies and Jackson 2006).

**Table 1-3. Biological and other ecological attributes used to characterize the freshwater streams Biological Condition Gradient (BCG)** (Modified from Davies and Jackson 2006).

| Attribute | Description |
|---|---|
| **I.** Historically documented, sensitive, long-lived, or regionally endemic taxa | Taxa known to have been supported according to historical, museum or archeological records, or taxa with restricted distribution (occurring only in a locale as opposed to a region), often due to unique life history requirements (e.g., Sturgeon, American Eel, Pupfish, Unionid mussel species). |
| **II.** Highly sensitive (typically uncommon) taxa | Taxa that are highly sensitive to pollution or anthropogenic disturbance. Tend to occur in low numbers, and many taxa are specialists for habitats and food type. These are the first to disappear with disturbance or pollution (e.g., most stoneflies, Brook Trout [in the east], Brook Lamprey). |
| **III.** Intermediate sensitive and common taxa | Common taxa that are ubiquitous and abundant in relatively undisturbed conditions but are sensitive to anthropogenic disturbance/pollution. They have a broader range of tolerance than Attribute II taxa and can be found at reduced density and richness in moderately disturbed stations (e.g., many mayflies, many Darter fish species). |
| **IV.** Taxa of intermediate tolerance | Ubiquitous and common taxa that can be found under almost any conditions, from undisturbed to highly stressed stations. They are broadly tolerant but often decline under extreme conditions (e.g., filter-feeding caddisflies, many midges, many Minnow species). |
| **V.** Highly tolerant taxa | Taxa that typically are uncommon and of low abundance in undisturbed conditions but that increase in abundance in disturbed stations. Opportunistic species able to exploit resources in disturbed stations. These are the last survivors (e.g., tubificid worms, Black Bullhead). |
| **VI.** Non-native or intentionally introduced species | Any species not native to the ecosystem (e.g., Asiatic clam, zebra mussel, Carp, European Brown Trout). Additionally, there are many fish native to one part of North America that have been introduced elsewhere. |
| **VII.** Organism condition | Anomalies of the organisms; indicators of individual health (e.g., deformities, lesions, tumors). |
| **VIII.** Ecosystem function | Processes performed by ecosystems, including primary and secondary production; respiration; nutrient cycling; decomposition; their proportion/dominance; and what components of the system carry the dominant functions, for example, shift of lakes and estuaries to phytoplankton production and microbial decomposition under disturbance and eutrophication. |
| **IX.** Spatial and temporal extent of detrimental effects | The spatial and temporal extent of cumulative adverse effects of stressors; for example, groundwater pumping in Kansas resulting in change of fish composition from fluvial dependent to sunfish. |
| **X.** Ecosystem connectivity | Access or linkage (in space/time) to materials, locations and conditions required for maintenance of interacting populations of aquatic life; the opposite of fragmentation. For example, levees restrict connections between flowing water and floodplain nutrient sinks (disrupt function); dams impede fish migration, spawning. |

Each attribute provides some information about the biological condition of a waterbody. Combined into a conceptual model like the BCG, the attributes can offer a more complete understanding of current waterbody conditions and also provide a basis for comparison with naturally expected waterbody conditions. All states and tribes that have applied a BCG used the first five attributes that describe the composition and structure of the biotic community on the basis of the tolerance of species to stressors. Where available, states and tribes also included information on the presence or absence of native and non-native species for fish and amphibians, as well as observations of overall health and condition (e.g., size, weight, abnormalities, tumors and diseases).

The last three BCG attributes (ecosystem function, spatial and temporal extent of detrimental effects and ecosystem connectivity) can provide valuable information when evaluating the potential for a waterbody to be protected or restored. Several of EPA's NEPs, in conjunction with EPA ORD, are exploring application of those attributes at a whole-estuary scale (e.g., distribution and connectivity of critical aquatic habitats and associated biota).

Additionally, individual attributes might uniquely respond to a specific stressor or group of associated stressors (biological response signatures) (Yoder and Rankin 1995 a, b; Yoder and Deshon 2003). That information could contribute to the causal analysis of biological impairment, Stressor Identification (SI) and Causal Analysis/Diagnosis Decision Information System (CADDIS) (http://www.epa.gov/caddis/).

Currently, applications of the BCG that include development of a BCG-index (BCG-I) and incorporation of the BCG in a state's water quality management have been used only on freshwater streams. More recently, ongoing pilot efforts at several NEPs are extending the BCG concept to assessment and management of estuaries. Efforts to develop an estuarine conceptual model have focused on five attributes (structure, condition, function, connectivity and non-native species [Cicchetti 2010]) at scales ranging from the whole estuary to the single habitat, or biotope (e.g., seagrass beds, salt marshes and clam flats) (Table 1-4). This multi-scale approach is intended to improve restoration and management efforts. At larger scales, managers can prioritize and develop programs to restore the historic balance of critical habitats (biotopes) relative to an undisturbed historic benchmark, while also targeting restoration of all living habitats, to the maximum extent possible. The single habitat scale is assessed using biological assessments, which enjoy an established history within management approaches (Cicchetti and Greening 2011; EPA 2011).

Extending the BCG conceptual model to new waterbodies (coastal waters) and new assemblages (coral reef communities) is a multistep process. A successful process assembles a workgroup of experts on the habitats and assemblages and elicits from these experts: descriptions of the native aquatic assemblages under natural conditions, identifications of the predominant regional stressors and descriptions of degradation levels corresponding to the BCG. Descriptions should include the theoretical foundation and observed assemblage responses to stressors. In addition to expert opinion, the process makes use of empirical monitoring data. During a workshop, experts familiar with local conditions use the data to define the ecological attributes and set narrative statements. The experts determine narrative decision rules for assigning stations to a BCG level on the basis of the biological information collected at the stations. Further development of quantitative decision rules and a quantitative BCG is more involved and requires a greater time commitment from the expert panel to participate in iterative calibration steps and review of more extensive monitoring data.

**Table 1-4. Ecological attributes used to characterize the estuarine Biological Condition Gradient (BCG)** (EPA in review).

| Attributes | Potential Metrics and Description |
|---|---|
| **Structure and Compositional Complexity** | Community or habitat structure and complexity. May also recognize loss of habitats or species due to human activities.<br><br>Examples include macroinvertebrate or fish indices, phytoplankton or zooplankton community measures, epifaunal measures, biotope mosaics, presence/quality of sensitive or susceptible taxa or biotopes, wetland vegetative indices, etc. |
| **Condition** | Measures condition of the waterbody, habitat or species. Also includes measures of resiliency.<br><br>Examples include harmful algal blooms, disease outbreaks (locally or system-wide), measure of habitat or biotope health, such as seagrass condition or wetland condition, fish pathology or shellfish bed condition. |
| **Function** | Measures of energy flow, trophic linkages and material cycling. They may include proxy or snapshot metrics that correlate to functional measures.<br><br>Examples include photosynthesis/respiration ratios, benthic: pelagic production rates, chlorophyll *a* concentrations and macroalgal biomass. |
| **Connectivity** | Metrics of exchange or migrations of biota between adjacent waterbodies or habitats. Important measures within the area being studied may be strongly affected by factors adjacent to or larger than the immediate study area.<br><br>Proxies may need to be used as metrics. These may include linkages, fragmentation or hydrological measures. |
| **Non-native Taxa** | Metrics of non-native species. May include measures of the impact of invasive species and non-natives.<br><br>Examples include estimated numbers of species or individuals, biomass measures of natives and non-natives or replacement of native species. |

This report communicates the first results to apply the BCG conceptual model to the assessment of the condition of coral reefs. The first stage reported here is a proof-of-concept to introduce the conceptual model to coral reef experts and elicit a preliminary set of narrative decision rules for assigning coral reef stations to levels of the BCG. If the conceptual model passes muster among the experts, it will allow identification of the steps needed to develop and implement more comprehensive quantitative decision models.

# Chapter 2. Approach

The coral reef BCG will be developed through a series of facilitated expert workshops. In the workshops, the experts assess the condition of coral reef sites based on biological data collected at the sites (species composition, abundance, health) and assign each site to a condition category (level) of the BCG. The experts' reasoning for making assignments are developed into a set of decision rules, at first qualitative, but through iteration, increasingly quantitative. The expert-derived rules are translated to a quantitative decision algorithm, in this case using mathematical set theory (e.g., Droesen 1996). The decision algorithm allows independent assessments with results comparable to those of the expert panel. Furthermore, the decision rules are documented so that modifications can be made as information and needs change.

The participants for the initial workshop were invited based on their scientific knowledge of the coral reefs and reef organisms of Puerto Rico. As a first step, participants were asked to evaluate and rank coral reef condition from photos, videos and data collected during EPA's 2010 and 2011 coral reef assessment surveys in shallow waters (<12 m deep) of southwestern Puerto Rico. The biological assemblages considered were stony corals, fishes, sponges, gorgonians and benthic macroinvertebrates. Rugosity, a reef-scale indicator of reef complexity, was determined using a chain-transect method that compares the six-foot length of a chain draped along the top of corals and along the bottom of the reef to the length of a taut line across the same linear distance. Participants were asked to share videos and pictures of reefs from the present or past that they believed exhibited full biological integrity.

A unique aspect of this workshop was that participants were reacting to the visual imagery of the reefs and evaluating different levels of coral reef condition. Participants moved from a visual, simple approach to more complex data-driven analysis. The workshop was designed to encourage brainstorming, facilitate discussion and not get mired in EPA terminology or definitions at the beginning of the workshop. Participants examined the visual media, rated the condition of various coral reefs and provided rationale for their ratings. Descriptions of good and bad characteristics relative to ecological condition were captured by facilitated discussions. A preliminary list was generated describing attributes that would characterize a coral reef with high (minimally disturbed or reference) or good condition. A minimally disturbed condition provides a fixed point in time and can help us to avoid problems associated with shifting baselines (Pauly 1995; Stoddard et al. 2006). A firm concept of minimally disturbed anchors ecological condition as a reference and helps us deal with changes (e.g., climate change), which broadly affect conditions that occur after the anchored point. Further, a clear picture of minimally disturbed provides a basis for effective public communication of changes over time and can provide a reference point for certain indices of ecological condition.

The workshop was designed to last three days; however Day 3 was cancelled because of Tropical Storm Isaac. Certain planned activities from Day 3 were shifted into Day 2, and the remainder of workshop information was communicated during webinars.

## 2.1 Video and Photo Evaluations

On the first day, panelists were asked to view and rate the coral reef condition of 12 EPA stations on the south shore of Puerto Rico (Table 2-1).

**Table 2-1. Shallow inshore linear reefs used for BCG workshop stations that correspond to US EPA stations sampled along the southern coast of Puerto Rico.**

| Station | Year | EPA station | Latitude | Longitude | Depth (ft.) |
|---|---|---|---|---|---|
| 1 | 2010 | PR_2010_125 | 17.92486 | -66.20363 | 20 |
| 2 | 2011 | PR_2011_15 | 17.98198 | -66.77228 | 23 |
| 3 | 2011 | PR_2011_113 | 17.95942 | -67.03902 | 21 |
| 4 | 2011 | PR_2011_03 | 17.94420 | -66.91638 | 21 |
| 5 | 2011 | PR_2011_19 | 17.94180 | -66.88060 | 12 |
| 6 | 2010 | PR_2010_14 | 17.93875 | -67.10927 | 27 |
| 7 | 2010 | PR_2010_16 | 17.93922 | -67.06197 | 24 |
| 8 | 2010 | PR_2010_108 | 17.94085 | -67.07708 | 12 |
| 9 | 2010 | PR_2010_109 | 17.95373 | -67.05012 | 16 |
| 10 | 2011 | PR_2011_01 | 17.96380 | -67.04980 | 11 |
| 11 | 2011 | PR_2011_46 | 17.93418 | -67.10108 | 17 |
| 12 | 2011 | PR_2011_25 | 17.93670 | -66.88660 | 17 |

Stations were limited to shallow (<12 m), near-shore (less than 3 nautical miles from shore) linear reefs as designated by NOAA benthic maps (Kendall et al. 2001), see Figure 2-1.

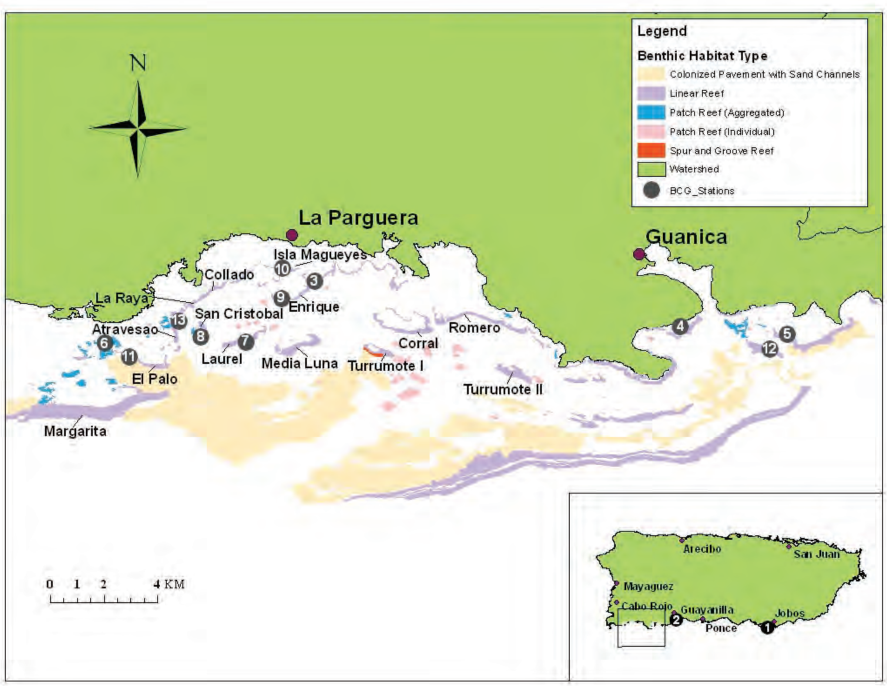


**Figure 2-1. Map with locations of the 12 EPA stations along the southern coast of Puerto Rico.**

Videos of eight stations were examined in the morning and four stations in the afternoon. Videos were displayed on four computers looping two stations per video in the morning and one station per video in the afternoon. Each station presented video footage from both panoramic and linear transect views, which began with 15 seconds showing the station number and the type of footage, to allow reviewers time to prepare for each video. A 60-second period between each station allowed panelists time to complete their evaluations before the next station video began. In addition to the video clips (ranging from 30 seconds to 3 minutes long), eight still photographs for each station (Appendix G) were provided in a notebook to supplement the videos and in particular, to capture aspects of the station not represented in the videos (e.g., fish).

The panelists were instructed to draw upon their overall personal experience and expertise to rate the reef condition for each station as either good, fair or poor based on what they viewed in videos and photos. Workshop binders organized by station included a photo diary of key representative photos, two ballots to rate the stations for each session (Appendices D and E) and note sheets (Appendix F) to document the traits or characteristics that panelists used to support their ratings. The panelists were asked to consider all aspects of the reef and specifically instructed to consider the characteristics of the condition of corals, sponges, gorgonians, fish, algae, reef rugosity and topographical heterogeneity. The facilitators suggested that panelists not compare ratings with each other, but panelists were free to discuss and view videos as a group. The panelists were not asked to rate any specific number of stations as good, fair or poor, but had free rein as they circulated around and viewed the video loops at their own pace. The facilitators were available if panelists had questions.

The panelists asked about shifting baseline conditions, and they were encouraged to draw upon their personal experience. Panelists also asked if each assemblage should be rated separately. Facilitators responded that it was all right to consider and document each assemblage, but they must finally select one single rating for each station. When all stations were evaluated, panelists recorded their individual ratings on the ballots and returned them to the facilitators. Note sheets were not collected—they were for each panelist to reference during subsequent discussions.

After ballots were collected from the panelists, the facilitators tabulated all the scores by ranking the stations in order from best condition to worst using a weighted ranking system (Table 2-2). Each good vote was given a value of 10 points, each fair vote 5 points and each poor vote 1 point. Table 2-3 shows the ranking given by each expert after visually evaluating videos and photographs for 12 EPA stations.

The panelists provided feedback on how to improve the process used to evaluate the stations. Many found it challenging to assess reef condition based on the video quality, which was raw footage from inexpensive video-enabled digital cameras. Still photos provided the best way to document fish populations, because many fishes were disturbed during the assessments that occurred before the video was taken. The fish surveyors were the first team to perform visual assessments, followed by

**Table 2-2. Coral reef condition evaluated by the experts.** Results were obtained from 20 coral reef experts after viewing videos and photos of 12 stations, with the highest score bolded. Overall rank is established by weighted ranking.

| Station No. | No. Good | % Good | No. Fair | % Fair | No. Poor | % Poor | Majority Rating | Weighted Score | Overall Rank |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 5 | 9 | 45 | 10 | **50** | Poor/Fair | 65 | 8 |
| 2 | 0 | 0 | 0 | 0 | 20 | **100** | Poor | 20 | 12 |
| 3 | 13 | **65** | 7 | 35 | 0 | 0 | Good | 165 | 1 |
| 4 | 0 | 0 | 2 | 10 | 18 | **90** | Poor | 28 | 11 |
| 5 | 0 | 0 | 10 | **50** | 10 | **50** | Fair/Poor | 60 | 9 |
| 6 | 0 | 0 | 6 | 30 | 14 | **70** | Poor | 44 | 10 |
| 7 | 4 | 20 | 16 | **80** | 0 | 0 | Fair | 120 | 4 |
| 8 | 0 | 0 | 15 | **75** | 5 | 25 | Fair | 80 | 6 |
| 9 | 1 | 5 | 12 | **60** | 7 | 35 | Fair | 77 | 7 |
| 10 | 5 | 25 | 14 | **70** | 1 | 5 | Fair | 121 | 3 |
| 11 | 2 | 10 | 17 | **85** | 1 | 5 | Fair | 106 | 5 |
| 12 | 6 | 30 | 12 | **60** | 2 | 10 | Fair | 122 | 2 |

**Table 2-3. Rankings given by experts after visually evaluating videos and photographs for 12 EPA stations.** Abbreviations: G rated good; F rated fair; P rated poor. Some ratings were intermediate between two classes.

| | Station Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Expert** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| **Appeldoorn** | P | P | G | P | F | P | F | F | F | F | F | F |
| **Ballantine** | F | P | G | F | F/P | P | F | F | G | G | G | G |
| **Bauzá** | F | P | G | P | F | P | G | F | F | F | F | F |
| **Canals** | F | P | F/G | P | P/F | P | F | F | P | F | F | F/G |
| **Cuevas** | F | P | G | P | F | P | F | F | P/F | F | F | F |
| **Diaz** | F/G | P | F/G | P | F/P | F/P | F/G | F/P | F/P | G | F/P | F |
| **Fisher** | P | P | G | P | P | P | G | F | F | G | F | G |
| **Hutchins** | P | P | F | P | P | P | F | P | P | F | F | F |
| **McField** | P/F | P- | F | P | F | P | F | P/F | P+ | F+ | F | P+ |
| **Miller** | F | P | G | P | P/F | P | F | P/F | F | G/F | F | G |
| **Pagan** | F/P | P- | G/F | P | P | F | F | F | P | F | F | F |
| **Ramos** | F | P | G | P | P | P | F | P | F | P | F | F |
| **Roberson** | P | P | F/P | P | P/F | F/P | F | P | F/P | F/P | P/F | F |
| **Ruiz** | F | P | G | P | F | F | G | F | F | G | G | F |
| **Sabat** | P | P | G | P | P/F | P/F | F | F | P | F/G | F | F |
| **Smith** | P | P | F | P | P/F | P/F | F | F | P | F | F | F |
| **Szmant** | P | P- | G | P | F | P | F | F | F/P | F | F/G | G |
| **Todd** | P | P | G | P | P | P | G | F | F | F | F | G |
| **Vicente** | P | P | F | P | F | F | F | F | F | F | F | F |
| **Yoshioka** | G/F | P | G | F | F/G | F | F/G | F | F/P | F/G | F | G/F |

the surveyors assessing other assemblages, including those photographing and video recording the reef. The photographers began potentially after many fishes had been scared away. The panelists also requested more details on the stations they were evaluating. Panelists felt they needed to know the location of the reef, what specific reef habitat they were viewing, the depth, the wave exposure and other features. They also wanted to know what stressors the station may have experienced. Recommendations for the future included upgrading video camera quality, standardizing the videography approach and providing more information to get a broader perspective of each station and its surrounding reef.

A facilitated discussion followed on the attributes that the panelists had identified to justify their ratings. The stations rated best and worst were considered first, with each panelist's comments captured on flip charts. Panelists were encouraged to edit posted pages of their comments if they felt their thoughts were not accurately captured. All participants were given the opportunity to submit comments on index cards if they wished to provide additional comments privately or anonymously. A summary of the characteristics considered by the panelists in rating the stations is provided in Section 2.2 for the best, worst and several fair stations.

## 2.2 Summary of Ratings

All of the photos given to the experts are found in Appendix G, ordered by station number.

### *2.2.1 Best Station, Ranked #1*

The experts rated the condition of Station 3 as the best of the 12. It was rated good by 65% of the experts and fair by 35%. No expert rated it as poor. The experts were asked what characteristics or attributes were present that caused them to rate it as the best station. Their responses follow:

- Abundance of *Montastraea annularis* species-complex was high, with low partial mortality of tissue and large colony sizes indicative of older, mature coral colonies.
- Reefs showed high structural complexity, surface heterogeneity and high rugosity or presence of three-dimensional structures, allowing better reef development than would a flat topography.
- Stony coral biodiversity was moderate and included *Colpophyllia natans*, *Siderastrea siderea* and *Porites astreoides,* as expected on near-shore linear reefs in southwestern Puerto Rico.
- The water column showed high clarity with no visible sediment; experts also noted a lack of siltation or films covering the substrate.
- Coralline algae were more abundant than brown algae, and *Dictyota* was rare or absent.
- Gorgonian coverage was high, with most sea fans intact and uninjured. *Diadema* was present. Stony coral colonies had no or few boring clionid sponges.
- Damselfish were seen and the presence of additional fish species contributed to a good rating.

The experts, who rated the station as fair, expressed concern about the uncertainty in identifying fish species because the visual media were not adequate to consider fish size distributions or trophic status. A few grazing fish species were seen, but not enough to alleviate concerns of low grazing potential. Another expert cited the presence of coral disease. Finally, sponge abundance and diversity were low, with an absence of arborescent, vase and barrel morphologies, which are dominant in high quality habitat.

- The experts were also asked what attributes were absent that caused them to not rate the station as excellent. Their responses follow:
- The station had lower than expected diversity of stony corals, fishes and sponges, with little evidence of any recruitment.
- Very few anemones and invertebrates were observed, again indicating low species diversity.
- One expert stated that sponges, because they are efficient filter feeders, might be one of the assemblages most sensitive to chemicals in the water column and could act as an indicator species.

### *2.2.2 Worst Station, Ranked #12*

All the experts agreed that Station 2 was in the worst condition, and rated it poor. This station was characterized by:

- High sedimentation and turbidity in the water column, which appeared as large patches of flocculent material creating low visibility, which the experts judged to represent low water quality.
- The reef colors were drab brown or green.
- Thick goopy sediment (probably of terrigenous origin) covered most of the bottom and organisms living on the bottom. Exposed hard substrate was absent, with no clear surfaces for attachment or recruitment.
- Algal cover was high, with lots of *Dictyota* and cyanobacteria as evidenced by a slimy appearance with a “skuzzy fuzzy” texture.
- Abundance of coralline algae was low.
- The absence of reef relief was coupled with low rugosity and no or very few small and live coral colonies.
- No fish or gorgonians were observed, although a few *Diadema* were noted.
- Sponge morphologies were ropy or encrusting, indicative of poor habitat and water quality.
- Heterotrophic sponges dominated, with a high abundance of filter feeders and no apparent autotrophic sponges. This is a characteristic typical of highly silted areas.

### *2.2.3 Stations Rated Fair*

***Station 8 ranked #6.*** This station was ranked as the most centric station among those with a fair rating. 75% of the experts rated it fair while 25% rated it poor. This station had the highest coverage of *Acropora palmata* in all stations viewed, although overall coral cover was low, with lots of coral rubble. *A. palmata* colonies varied greatly in size, condition and distribution and were present in about 25% of the transect area. Some very mature and large colonies were present in varying condition as evidenced by the amount of healthy coral tissue. Many of the *A. palmata* colonies lacked significant tissue and showed characteristics ranging from signs of tissue recovery, partial tissue mortality from white-band disease, lesions and white denuded tips, perhaps from fish predation. Some standing colonies were completely dead. The coral rubble on the bottom was composed of many broken and dead pieces of *A. palmata* skeletons, but finer sediments were absent. Several experts commented that the clean substrate and unconsolidated rubble showed significant and recent hurricane damage. Although some reef was dead, it showed signs of recovery and resiliency with the persistence of corals.

The clean substrate provided suitable areas available for settlement and recruitment of corals and other sessile invertebrates. Some coralline algae were present but overall algal diversity was low, with some fleshy algae. Much of the substrate appeared as though it had been highly grazed by *Diadema antillarum. Palythoa,* often considered an emerging opportunistic species, was prevalent throughout the transect colonizing dead coral skeletons. Several species of fish swam in large schools representing a decent diversity, including evidence of herbivores. The primary sources of rugosity were the *A. palmata* colonies; most other coral colonies showed relatively low relief. Few invertebrates other than those already mentioned were observed, with the exception of some small sea fans and low relief gorgonians.

***Station 5 ranked #9***. Half of the experts rated it fair and the other half rated it poor. This station shared many attributes with Station 8, but was judged to be in poorer condition because of higher sediment and turbidity, together with lower coral cover and diversity. The transect video showed substantial *A. palmata* coverage, but the colonies appeared to be in poorer condition than those seen in Station 8. One expert described the station as a “beat up Apal zone” (*A. palmata*) with large rubble between colonies. Thicker and larger algal turf patches and more sponges were present in comparison to Station 8. Parrotfish biting scars and scrapes were observed. However, it was noted that sedimentation, turbidity and water quality can vary with year, season and time of day, so the apparent condition could be extremely variable and dependent on when the video was taken.

***Station 10 ranked #3***. This station was rated as good by 25% of experts, fair by 70% of experts and poor by 5% of experts. Many of the features seen in the previous fair descriptions were also present here. A novel observation was the presence of the boring sea urchin *Echinometra,* which bioerodes coral skeletons; the herbivorous urchin *Diadema* is usually considered an indicator of better condition.

### *2.2.4 Station Rated Poor*

***Station 6 ranked #10***. This station was rated fair by 30% of experts and poor by 70% of experts. There was evidence of significant bioerosion on the reef surfaces, perhaps due to boring clionids and the encrusting sponge *Chondrilla nucula.* One expert asked if this was a hard bottom station (not a coral reef). Despite the poor condition of Station 6, all experts agreed that Station 2 was in the poorest condition.

## 2.3 Summary of Attributes

Attributes developed by the experts were assembled into a list. In a facilitated discussion, the experts reached consensus about which direction (increase or decrease) the attribute would go at a station with improving condition, and what types of measurements or sub-attributes would be important. This information is summarized in Table 2-4.

**Table 2-4. Summary of attributes and their relationships for assessing coral reef condition from station evaluations.**

| Attributes of good stations | | |
|---|---|---|
| **Direction with improving condition** | **Attribute** | **Sub-attribute/measurements** |
| increase | 3D structure | rugosity, cover |
| increase | stony coral abundance | *Montastraea annularis* complex, *Acropora palmata*, *Acropora cervicornis*, *Diploria strigosa,* large stony corals |
| increase | stony coral condition | % live tissue, absence of disease |
| increase | stony coral diversity | high number of stony coral species |
| increase | stony coral population structure | large colonies |
| increase | stony coral recruitment | |
| decrease | dominance of weedy, tolerant species | *Colpophyllia natans*, *Siderastrea siderea*, *Porites astreoides* |
| increase | coralline algae | |
| decrease | zoanthids | *Palythoa* species |
| decrease | exotic species | exotic fish, corals |
| decrease | filter feeders | heterotrophic sponges |
| increase | fish abundance | |
| increase | balance in fish population size and structure | |
| increase | fish biomass | |
| increase | balance in fish trophic structure | |
| increase | fish diversity | |
| decrease | fleshy algae | |
| increase | gorgonian abundance | |

| Table 2.4 (continued) | Attributes of good stations | |
|---|---|---|
| **Direction with improving condition** | **Attribute** | **Sub-attribute/measurements** |
| increase | gorgonian condition | % live tissue, absence of disease and predators (*Cyphoma gibbosum*) |
| increase | gorgonian diversity | |
| increase | other invertebrates | *Diadema antillarum*, conch, lobsters, crabs, anemones |
| increase | sponge abundance | autotrophic sponges |
| decrease | sponge abundance | heterotrophic sponges |
| increase | sponge diversity | |
| increase | substrate condition | clean, no fuzzy algae (cyanobacteria), open space recruitment |
| increase | water clarity | |
| decrease | corallivores/bioeroders | bioeroders, *Coralliophila* (large size), clionids |

## 2.4 Reference Condition for Biological Integrity

The panel agreed that all of the stations were impaired at some level. Many of the experts had been working in Puerto Rico for 30–40 years, while others had recently received their PhDs. The group had a rather lengthy discussion about the historical condition of Puerto Rico's coral reefs in an attempt to answer: What did the reefs look like before humans came along to stress them?

The term "reference condition" is used by BCG to define biological condition in the absence of human disturbance (Stoddard et al. 2006). The concept of reference condition arose from the objective of the Clean Water Act Section 101: "to restore and maintain the chemical, physical and biological integrity of the nation's waters". Biological integrity is defined as "the community of organisms having a species composition, diversity and functional organization comparable to those of natural habitats within a region" (Karr 1991).

Unfortunately, human activities have significantly affected coral reefs. Puerto Rico's coral reefs were severely degraded long before ecologists began to study them (Jackson 1997). According to Jackson et al. 2001, ecological extinction caused by overfishing preceded all other pervasive human disturbance to coastal ecosystems. Overfishing reduced species populations such as marine reptiles (green turtle, hawksbill turtle [1700s]), mammals (manatee and extinct Caribbean monk seal [1800s]), conch [1980s], fishes (Nassau and goliath groupers [1950s] and reef fishes [1970s]). By the time scientific studies began in the 1950s, herbivores and predators were reduced to very small fishes and sea urchins (Jackson 1997).

So, how can one estimate reference condition when no living human has ever seen a Puerto Rican reef in natural condition? One approach is the reference station approach, where scientists use reefs that are nearly unaffected by anthropogenic disturbance and the related stressors/exposures, or reefs whose present-day good condition is found in conjunction with the best available physical, chemical and biological habitat conditions, as surrogates for natural reefs. However, these approaches may fail to correctly identify the baseline population sizes, instead representing a shifted baseline as reference condition (Pauly 1995).

Another approach is to apply ecological theory and empirical models to extrapolate reference condition. A relatively recent method is the use of historical ecology, where scientists piece together an understanding of what coral reef ecosystems used to be. The challenge is to use these approaches to adjust our expectations of what a healthy coral reef baseline looks like and use that as reference condition.

### *2.4.1 Experts' Examples of Reference Condition for Biological Integrity*

Workshop panelists were urged to share examples of present or past reefs that they believed to exhibit full biological integrity. Dr. Szmant reported that she had participated in a discussion about shifting baselines with other experienced coral reef scientists. This led to a report (Sale and Szmant 2012) that summarized these scientists' reminiscences on historical reef condition over the last 40 years.

Dr. Szmant also showed photographs of recent changes from 2009 to 2012 in *Montastraea* populations on a coral reef in Curaçao (Watamula) that were caused by a 2010 bleaching event (Figure 2-2). An estimated 50% of previously large healthy coral colonies on Watamula showed partial or complete mortality in less than one year. She also showed photographs of extensive *Acropora cervicornis* beds on Smith Bank (on the south coast of Roatan) near the ones on Cordelia Banks that Dr. McField surveyed (see below). Dr. Szmant has slides of The Buoy and other reef areas in Puerto Rico and the Caribbean from the 1970s that she was willing to share.

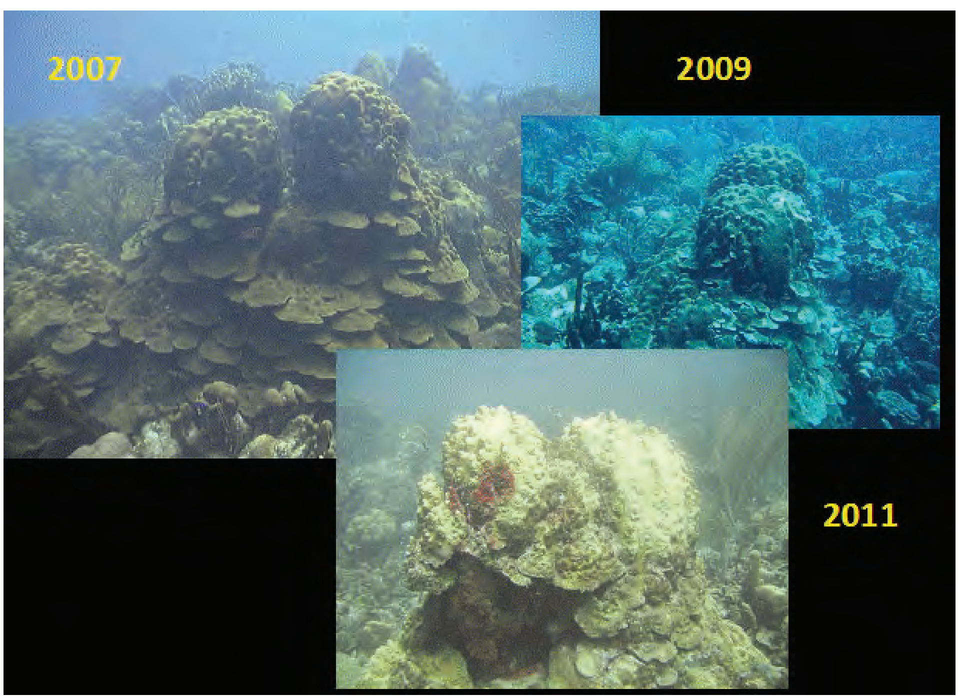


**Figure 2-2. Recent changes from 2009 to 2012 in *Montastraea* populations on a coral reef in Curaçao (Watamula) that were caused by a 2010 bleaching event** (photos: Dr. Alina Szmant).

Dr. McField brought photos from Cordelia Banks on Roatan Island, Honduras (Figures 2-3, 2-4 and 2-5). Cordelia Banks is located near the airport and main port of Roatan, but strong onshore currents likely keep land-based sources of pollution away most of the time. Cordelia Banks is a good candidate for a reference site because it has:

- 52 acres of healthy reef with the highest live coral cover in the Caribbean (up to 73% measured in transects and averaging just over 50%). *Acropora cervicornis*, which is one of the most important reef species for structural reef growth and fish nursery habitat, dominates this reef. Unfortunately, this species and *Acropora palmata* have been reduced by about 98% over the last three decades throughout the Caribbean by disease and bleaching.
- The presence of two important species of sharks – the nurse shark (*Ginglymostoma cirratum*) and the Caribbean reef shark (*Carcharhinus perezii)*.
- Spawning aggregation sites for groupers and snappers.

**Figure 2-3. Two experts suggested Cordelia Banks near Roatan, Honduras, as an example of a reference site for excellent coral condition.** This area contains 52 acres of threatened coral species, high fish abundance and other characteristics important in sustaining healthy reefs (photo: Dr. Melanie McField).

**Figure 2-4. Monitoring of massive *Acropora cervicornis* banks at Cordelia Banks located off a major airport in Roatan, Honduras** (photo: Dr. Melanie McField).

**Figure 2-5. Panoramic view of *Acropora cervicornis* banks at Cordelia Banks, Roatan, Honduras** (photo: Dr. Melanie McField).

Dr. McField also brought copies of the 2012 Report Card for the Mesoamerican Reef. Dr. McField's program, Healthy Reefs for Healthy People Initiative, is an international, multi-institutional effort that tracks the health of the Mesoamerican Reef (MAR), the human choices that shape it and the progress to ensure its long-term integrity. The Healthy Reefs for Healthy People Initiative seeks to address two overarching questions:

1. What is a healthy reef and how can we improve our tracking of reef health through a shared vision and common indicators or yardsticks?
2. How can we best convey consistent, scientific information to policymakers, decision-makers and the public, such that the connections between reef health and human health result in effective conservation action at an unprecedented scale?

The Healthy Reefs for Healthy People Initiative has developed a quantifiable, interpretive framework of measurable indicators and criteria to better understand and assess reef health in the MAR region. The Initiative produces report cards on the condition of the MAR resources, using a five-point grading system from very good to critical for key indicators: fish abundance, fleshy macroalgal index, *Diadema* abundance, herbivorous fish abundance, coral mortality, conch abundance, coral recruitment and coral cover. The report card also describes the main threats to the ecosystem and evaluates management actions. More information about the Initiative can be found at: http://www.healthyreefs.org

Dr. Weil stated that the average rainfall in Puerto Rico has been increasing steadily since 2000, coinciding with changes in land use. Consequently, rain events have a greater impact on the decline in coral reef condition. He has a draft report on this topic that he could send to other attendees. Dr. Weil also reports that in La Parguera, Puerto Rico, the average winter SST has remained elevated over the last decade. He suggests that water visibility is decreasing, and sedimentation is increasing. Yellow-band disease, which affects the *Montastraea annularis* species-complex, is now chronic all year, whereas it used to be seasonal and limited in distribution. Bleaching events in the area are followed by white plague infection, which leads to increased coral mortality with little or no recovery, and bare coral substrate is colonized by macroalgae.

Mr. Ruiz Torres passed around his recent book *Beneath the Waves*, published by the Sea Grant Program at the University of Puerto Rico (Figure 2-6). It contains nearly a hundred photos documenting the marine environment along the entire coast of Puerto Rico, including algae, fish, crustaceans, mollusks and corals. A description of the location, the depth and the characteristics of the organisms accompany each image. The text is written in English and Spanish.

Dr. Appeldoorn commented that good water flow (medium to high constant speed) is important for high quality reefs. He stated that fish trophic structure is impaired in Puerto Rico because of the low number of apex predators.


**Figure 2-6. Cover for the book, *Beneath the Waves*, by Hector J. Ruiz Torres.**

Dr. Vicente said that he has over 500 one-hour videos documenting reefs around Puerto Rico and USVI that he is willing to share with the group. He will send an index so experts can request the videos of interest.

### 2.4.2 Summary Discussion

The experts remarked that gorgonians were present in the videos of the best sites but not in high abundance. At fair condition sites, gorgonians were most abundant, but reduced abundance was seen again at poor coral reef condition (bell-shaped curve). The experts agreed that there is a need to understand the ecology of relationships between these assemblages to predict where we find certain species and abundance of corals and gorgonians, and why they are distributed that way. For example: Are corals replaced by gorgonians when corals die on reefs in lower or poor condition?

## 2.5 Attributes of a Very Good to Excellent Station

Based on the videos and photographs, the experts identified the attributes of a very good - to excellent station, which would be comparable to BCG Level 2: near natural (minimally disturbed). A summary of the attributes is shown in Table 2-5.

The attributes are reorganized in Table 2-6, into a format that can be more efficiently used during future workshops to facilitate establishing numeric criteria ranges.

### 2.5.1 Three-dimensional Topographic Complexity

The experts thought that very good - excellent stations would have high rugosity or three-dimensional topographic complexity, including substantial reef built above the bedrock. High topographic complexity is known to be an important attribute (Friedlander and Parrish 1998; Zawada 2011). Coral reefs with high topographic complexity have high species diversity (Talbot 1965; Risk 1972), primary productivity (Barnes 1988) and biomass density (Luckhurst and Luckhurst 1978; Carpenter et al. 1981). These reefs provide refuge from predation (Steele 1999; Idjadi and Edmunds 2006) and supplement larval settlement space (Idjadi and Edmunds 2006). Topographic complexity also provides hydrodynamic effects, determining water flow around, over and through the reef (Munk and Sargent 1954; Monismith 2007; Hearn 2008; Nunes and Pawlak 2008) and enhancing energy dissipation thereby, nutrient uptake and mass-transfer rates (Shashar et al. 1996; Hearn et al. 2001).

**Table 2-5. Summary of descriptions of four condition categories (very good to poor) based on expert assessments of individual stations.** The descriptions of good to poor condition are comparisons to a very good condition station based on panelists' identifications of aspects missing from expectations for very good stations.

| Condition level | Attribute descriptions |
|---|---|
| **Very Good Excellent**<br><br>**(approximate BCG Level 1–2)** | **Physical structure:** High rugosity or 3D structure; substantial reef built above bedrock; many irregular surfaces provide habitat for fish; very clear water; no sediment, flocs or films |
| | **Corals:** High species diversity including rare; large old colonies (*Montastraea*) with high tissue coverage; balanced population structure (old and middle-sized colonies, recruits); *Acropora* thickets present |
| | **Gorgonians:** Gorgonians present but subdominant to corals |
| | **Sponges:** Large autotrophic and highly sensitive sponges abundant |
| | **Fish:** Populations have balanced species abundances, sizes and trophic interactions |
| | **Large vertebrates:** Large, long-lived species present and diverse (turtles, eels, sharks) |
| | **Other invertebrates:** *Diadema,* lobster, small crustaceans and polychaetes abundant; some large sensitive anemone species present |
| | **Algae:** Crustose coralline algae abundant; turf algae present but cropped and grazed by *Diadema* and herbivorous fish; low abundance of fleshy algae |
| | **Condition:** Low prevalence of disease and tumors; mostly live tissue on colonies |
| **Good**<br><br>**(approximate BCG Level 3)** | **Physical structure:** Moderate to high rugosity; moderate reef built above bedrock; some irregular cover for fish habitat; water slightly turbid; low sediment, flocs or films on substrate |
| | **Corals:** Moderate coral diversity; large old colonies (*Montastraea*) with some tissue loss; varied population structure (usually old colonies, few middle aged and some recruits); *Acropora* thickets may be present; rare species absent |
| | **Gorgonians:** Gorgonians more abundant than Levels 1–2 |
| | **Sponges:** Autotrophic species present but highly sensitive species missing |
| | **Fish:** Decline of large apex predators (e.g., groupers, snappers) noticeable; small reef fishes more abundant |
| | **Large vertebrates:** Large, long-lived species locally extirpated (turtles, eels) |
| | **Other invertebrates:** *Diadema,* lobster, small crustaceans and polychaetes less abundant than Levels 1–2; large sensitive anemone species absent |
| | **Algae:** Crustose coralline algae present but fewer than Levels 1–2; turf algae present and longer, more fleshy algae present than Levels 1–2 |
| | **Condition:** Disease and tumor presence slightly above background level; more colonies have irregular tissue loss |

**Table 2-5 (continued)**

| Condition level | Attribute descriptions |
|---|---|
| **Fair**<br><br>**(approximate BCG Level 4)** | **Physical structure:** Low rugosity; limited reef built above bedrock; erosion of reef structure obvious; water turbid; more sediment accumulation, flocs and films; *Acropora* usually gone or present as rubble for recruitment substrate |
| | **Corals:** Reduced coral diversity; emergence of tolerant species, few or no living large old colonies (*Montastraea*); *Acropora* thickets gone, large remnants mostly dead with long uncropped turf algae |
| | **Gorgonians:** Gorgonians more abundant than Levels 1–3, replacing sensitive coral and sponge species |
| | **Sponges:** Mostly heterotrophic tolerant species and clionids |
| | **Fish:** Absence of small reef fishes (mostly Damselfish remain) |
| | **Large vertebrates:** Large, long-lived species locally extirpated (turtles, eels) |
| | **Other invertebrates:** *Diadema* absent; *Palythoa* overgrowing corals; crustaceans, polychaetes and sensitive anemones conspicuously absent |
| | **Algae:** Some coralline algae present but no crustose algae; turf is uncropped, covered in sediment; abundant fleshy algae (e.g., *Dictyota*) with high diversity |
| | **Condition:** High evidence of diseased corals, sponges, gorgonians; evidence high of mortality; usually less tissue than dead portions on colonies |
| **Poor**<br><br>**(approximate BCG Level 6)** | **Physical structure:** Very low rugosity; no or little reef built above bedrock; no or low relief for fish habitat; very turbid water; thick sediment film and thick floc covering bottom; no substrate for recruits |
| | **Corals:** Absence of colonies, those present are small; only highly tolerant species with little or no live tissue |
| | **Gorgonians:** Small and sparse colonies; mostly small sea fans; often diseased |
| | **Sponges:** Heterotrophic sponges buried deep in sediment; highly tolerant species |
| | **Fish:** No large fishes; only a few tolerant species remain; lack of multiple trophic levels |
| | **Large vertebrates:** Usually devoid of vertebrates other than fishes |
| | **Other invertebrates:** Few or no reef invertebrates; high abundance of sediment dwelling organisms such as polychaetes and holothurians |
| | **Algae:** High cover of fleshy algae (*Dictyota)*; complete absence of crustose coralline algae |
| | **Condition:** High incidence of disease and low or no tissue coverage on small colonies of corals, sponges and gorgonians, if present |

## Table 2-6. Condition levels and associated attributes

| Condition level | BCG level | Physical structure | Corals | Gorgonians | Sponges | Fish | Vertebrates | Other invertebrates | Algae/plants | Condition |
|---|---|---|---|---|---|---|---|---|---|---|
| **Very Good - Excellent** | 1–2 | High rugosity or 3D structure; substantial reef built above bedrock; many irregular surfaces provide habitat for fish; very clear water; no sediment, flocs or films | High species diversity including rare; large old colonies (*Montastraea*) with high tissue coverage; balanced population structure (old and middle-aged colonies, recruits); *Acropora* thickets present | Gorgonians present but sub-dominant to corals | Large autotrophic and highly sensitive sponge species abundant | Populations have balanced species abundance, sizes and trophic inter-actions | Large, long-lived species present and diverse (turtles, eels, sharks) | *Diadema*, lobster, small crustaceans and polychaetes abundant; some large sensitive anemone species | Crustose coralline algae abundant; turf algae present but cropped and grazed by *Diadema* and herbivorous fish; low abundance fleshy algae | Low prevalence of disease or tumors; mostly live tissue on colonies |
| **Good** | 3 | Moderate to high rugosity; moderate reef built above bedrock; some irregular cover for fish habitat; water slightly turbid; low sediment, flocs or film on substrate | Moderate coral diversity; large old colonies (*Montastraea*) with some tissue loss; varied population structure (usually old colonies, few middle-aged and some recruitment); *Acropora* thickets may be present; rare species absent | Gorgonians more abundant than in Levels 1–2 | Autotrophic species present but highly sensitive species missing | Decline of large apex predators (e.g., groupers, snappers, etc.) noticeable; small reef fish more abundant than Levels 1–2 | Large, long-lived species locally extirpated (e.g., turtles, eels) | *Diadema,* lobster, small crustaceans and polychaetes less abundant than Levels 1–2; large sensitive anemone species missing | Crustose coralline algae present but less than Levels 1–2; turf algae present and longer; more fleshy algae present | Disease and tumor prevalence slightly above background level; more colonies have irregular tissue loss |

**Table 2.6 (continued)**

| Condition level | BCG level | Physical structure | Corals | Gorgonians | Sponges | Fish | Vertebrates | Other invertebrates | Algae/plants | Condition |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fair** | 4 | Low rugosity, limited reef built above bedrock; erosion of reef structure obvious; water turbid; more sediment accumula-tion, flocs and films; *Acropora* usually gone or present as rubble for recruitment substrate | Reduced coral diversity; emergence of tolerant species, few or no large old colonies (*Montastraea*) mostly dead; *Acropora* thickets gone; large remnants mostly dead with long uncropped turf algae | Gorgonians more abundant than in Levels 1 - 3; replace sensitive coral and sponge species | Mostly heterotrophic sponges with tolerant species and clionids | Absence of small reef fish (mostly Damsel fish) | Large, long-lived species locally extirpated (e.g., turtles, eels) | *Diadema* absent; *Palythoa* overgrowing corals, crustaceans, polychaetes and sensitive anemones conspicuously absent | Some coralline algae; turf is uncropped covered in sediment; lots of fleshy algae with high diversity (e.g., *Dictyota*); possibly covering sessile invertebrates; no turf or coralline algae; complete absence of crustose coralline algae | High incidence of diseased coral, sponges, gorgonians; evidence of high mortality; usually less tissue than dead portions on colonies |
| **Poor** | 6 | Very low rugosity, no or low reef built above bedrock or poor for fish habitat; very turbid water; thick sediment film and high flocs covering bottom; no substrate for recruits | Absence of colonies, those present are small, only highly tolerant species, little or no tissue | Small and sparse colonies, mostly small sea fans, often diseased | Heterotrophic sponges buried deep in sediment; highly tolerant sponge species | No large fish, few tolerant species, lack of multiple trophic levels | Usually devoid of other vertebrates | Low or no reef invertebrates; high abundance of sediment dwelling organisms (e.g., polychaetes, holothurians) | High cover of fleshy algae (*Dictyota*); possibly covering sessile invertebrates; no turf or coralline algae; complete absence of crustose coralline algae | High incidence disease on small colonies of corals, sponges and gorgonians; if present, low or no tissue coverage |

### *2.5.2 Stony Coral Attributes*

For stony corals, attendees decided that very good - excellent stations would have high species diversity that included large colonies of reef-building corals (i.e., *Montastraea*) and those colonies would have high tissue coverage. The *Montastraea annularis* species-complex (*Montastraea annularis, Montastraea faveolata* and *Montastraea franksi*) was historically one of the primary reef framework builders of the Caribbean coral reefs, characterizing the “buttress zone” or “annularis zone” in the classical descriptions of Caribbean reefs (Goreau 1959). These corals have declined dramatically throughout their range. The *Montastraea annularis* species-complex is susceptible to bleaching (Oxenford et al. 2008; Brandt 2009; Bruckner and Hill 2009; Wagner et al. 2010), disease (Bruckner and Hill 2009; Miller et al. 2009), sediment (Eakin et al. 1994; Carricart-Ganivet and Merino 2001; Torres and Morelock 2002) and nutrients (Marubini and Davies 1996).

The experts believed that the coral reef population should have a balanced size-class structure, including large and middle-sized colonies as well as new recruits. Ecologists consider population demographics to be vital statistics, particularly those statistics that can impact on present and future population size (Hughes 1996; Edmunds 2013; Edmunds and Elahi 2007). Typically, expanding populations have a large percentage of young individuals, while declining populations have a large percentage of older individuals and stable populations have a relatively even size distribution among age groups.

The experts also concluded that *Acropora palmata* thickets should be present. *A. palmata* was formerly the dominant species in shallow water (3–16 ft. deep) throughout the Caribbean and on the Florida Reef Tract, forming extensive, densely aggregated thickets in areas of heavy surf. These coral colonies prefer the exposed reef crest and fore-reef environments in depths of < 20 ft., although isolated corals may occur to depths of 65 ft. Since 1980, populations have collapsed throughout their range from disease outbreaks, with losses compounded locally by hurricanes, increased predation, bleaching, elevated temperatures and other factors (Ruzicka et al. 2013). This species is also particularly susceptible to damage from sedimentation (NOAA 2013b).

### *2.5.3 Gorgonian Attributes*

There was considerable discussion about the relative distribution of gorgonians and stony corals. The experts decided that very good - excellent stations would have gorgonians present, but the station should be dominated by stony corals. Gorgonians form a major benthic component of Caribbean reefs (Bayer 1973; Brazaeu and Lasker 1989) and can be very abundant in some sites where stony corals apparently are unable to proliferate. Factors controlling the distribution of shallow-water gorgonians include water motion and substrate relief (Kinzie 1973; Yoshioka and Yoshioka 1989a, b) and sediment transport (Yoshioka and Yoshioka 1989b, 2009).

### 2.5.4 Sponge Attributes

The experts agreed that very good - excellent stations would have high abundances of large autotrophic and highly sensitive sponge species. Most sponges are heterotrophic organisms, obtaining their food from the open water column. However, 35 species of common Caribbean sponges possess photosynthetic endosymbionts (Vicente 1990) that supply food to their hosts (Wilkinson 1983; Thacker and Freeman 2012). This is similar to the relationship between zooxanthellae and their coral hosts. Roberts et al. (2006) found that exposure to shade and siltation significantly reduced the growth and reproductive status of the temperate photosynthetic reef sponge *Cymbastela concentrica*.

### 2.5.5 Fish Attributes

Workshop participants decided that populations should have balanced distributions of species abundances, sizes and trophic interactions. Caribbean coral reefs can contain as many as 500–700 species of fishes (Lieske and Collins 2001). The mechanisms that lead to these concentrations of fish species on coral reefs have been widely debated over the last 50 years. While many reasons have been proposed there is no scientific consensus on a primary mechanism and it seems likely that a number of factors contribute. These include the rich habitat complexity and diversity inherent in coral reef ecosystems (Luckhurst and Luckhurst 1978; Gladfelter et al. 1980) and the variety and temporal availability of food resources available to coral reef fishes (Randall 1967).

Puerto Rico reef fisheries have shown significant decline since the 1970s, and large reef fishes have virtually disappeared from shallow reefs around Puerto Rico (Garcia-Sais et al. 2008). Fishing may have direct and indirect effects on reef fish trophic structure. Removals of apex predators from the reef complex may result in shifts of species composition (e.g., through trophic and ecological cascades) and for some taxa, increased variability in population dynamics or potential effects on species evolution.

### 2.5.6 Large Vertebrate Attributes

Several groups of large, long-lived vertebrate species (e.g., sea turtles and manatees) are considered important contributors to Puerto Rican coral reef communities. Other groups (e.g., dolphins, whales, seabirds) spend most of their life cycle in other habitat types but are occasionally seen hunting or feeding in waters around coral reefs. Puerto Rico supports five species of marine turtles, two of which (Hawksbill and Leatherback) are critically endangered. Four sharks (Blacktip Shark, Reef Shark, Tiger Shark and Nurse Shark), eight eels (Brown Garden Eel, Sharptail Eel, Goldspotted Eel, Spotted Snake Eel, Green Moray, Golden Moray, Spotted Moray, Purplemouth Moray) and two rays (Spotted Eagle Ray and Southern Stingray) can also be found on Puerto Rico coral reefs. A recent study (Jackson et al. 2012) found that the biomass of apex predators (sharks, large snappers and groupers) was close to zero in Puerto Rico. The experts decided that large long-lived species should be present and diverse at very good - excellent stations.

### *2.5.7 Other Invertebrate Attributes*

Queen conch, spiny lobsters and some crabs are harvested for food and have been declining throughout the Caribbean for decades (Santavy et al. 2012). Conchs are generally acknowledged to be over-exploited (Appeldoorn and Meyers 1993), and Puerto Rico has established catch limits for these mollusks. Sea urchins (especially *Diadema antillarum*) are important herbivores that were decimated by an epizootic throughout the western Atlantic in the 1980s (Lessios et al. 1984; Lessios 1988, 2005). The population status for the Caribbean spiny lobster stock is unknown (NOAA 2013a).

The experts decided that very good - excellent stations would have abundant *Diadema*, lobster, small crustaceans and polychaetes. They also felt that some large sensitive anemone species should be present.

### *2.5.8 Algae Attributes*

Macroalgae and turf algae compete for space with coral, sponge and other sessile species. Excess nutrients may alter competitive interactions and favor algae over coral. Many fishes and invertebrates are key grazers, helping to maintain algal biomass and prevent algae from overgrowing coral. A number of algal species (e.g., calcareous macroalgae and crustose coralline algae) deposit calcium carbonate during growth and may contribute to reef structural strength. Crustose coralline algae may also facilitate recruitment of stony coral. Algae are primary producers and provide habitat and resources for marine fish and invertebrates but often not to the same degree as coral reef habitat (Santavy et al. 2012). The experts decided that very good - excellent stations would have abundant crustose coralline algae, turf algae would be present but cropped and grazed and fleshy algae would occur in low abundance.

### *2.5.9 Condition*

Bleaching, disease or predation can affect health and condition of stony corals, gorgonians and sponges. An indicator of stony coral/gorgonian health is the amount of live tissue on the organism or colony. However, coral reef fish rarely appear to suffer from tumors or lesions (Panek 2005). The experts decided that there should be a very low prevalence of disease on very good - excellent stations, with mostly live tissue on coral colonies and gorgonians, and low prevalence of tumors on coral reef fish.

# Chapter 3. Discussion and Next Steps

## 3.1 Discussion

EPA convened a group of experts to attempt, for the first time, to develop a coral reef BCG. There was a consensus among the experts that this was an important contribution, because "We have been documenting the demise of coral reefs, instead of taking action to change the direction of their existence".

A preliminary BCG based on stony corals, fishes, gorgonians, sponges, vertebrates and other invertebrates has been assembled for shallow-water linear reefs of southwestern Puerto Rico. The experts were able to identify four distinct levels of condition: very good – excellent, good, fair and poor. Additional discussion is needed to develop reference condition for biological integrity (e.g., natural level).

Attribute development during the first workshop relied primarily on viewing videos and photos from individual coral reef monitoring sites. This approach resulted in attributes that were largely species-based, with a single notable addition (e.g., organism condition).

EPA anticipates that ecosystem connectivity is also an appropriate attribute to include in a coral reef BCG, since connectivity among coral reefs, mangroves, sea grass beds and lagoons provides a complex and dynamic mosaic that is well documented as a critical ecosystem attribute (Christensen et al. 2003; Cerveny 2006; Mumby et al. 2004, 2008; Aguilar-Perera and Appeldoorn 2007; McField and Kramer 2007; Meynecke et al. 2008; Sale et al. 2008; Pittman et al. 2011).

EPA would like to suggest that considering the attributes at multiple scales, similar to the approach being developed for estuarine ecosystems, may also be informative for coral reef ecosystems. The estuarine BCG framework considers structure, function, condition, connectivity and non-native species in waterbodies at multiple scales, using measures such as seagrass health, benthic faunal indices and habitat mosaics (Cicchetti and Pryor 2010; EPA in review). This holistic and integrated approach is intended to improve the understanding and management of the cumulative impacts of multiple stressors in complex waterbodies and should work well for coral reefs.

## 3.2 Next Steps

### *3.2.1 Second Workshop*

EPA is planning to hold a second workshop in early 2014. At the second workshop EPA hopes to focus more on: 1) different scales and attributes associated with the entire reef ecosystem, 2) tolerance of coral reef species to various anthropogenic stressors and 3) the process for moving towards a quantitative BCG, including development of a data portal to organize and share all of the available data from Puerto Rican coral reef ecosystems. EPA would also like to continue the discussion of reference condition and try to reach consensus on attributes for the reference condition level.

### *3.2.2 Species Tolerance Database*

In preparation for the first workshop, Ms. Bradley and Dr. Santavy began developing spreadsheets of coral reef taxa for each assemblage (e.g., stony corals, octocorals, sponges, other invertebrates, fishes, reptiles, mammals, mangroves, seagrasses and algae) and their characteristics as related to the ten attributes of the BCG, including tolerance levels to various stressors, vulnerabilities, habitat, etc. Thresholds, when known, were documented.

Species lists for the database rows were derived from Miller and Lugo (2009). Some columns are consistent across assemblages (e.g., scientific name, common name, common/rare, tolerance to pollution, tolerance to temperature change, tolerance to wave energy and susceptibility to disease). Other columns are unique to specific assemblages (e.g., for stony corals: maximum colony size, tolerance to acidity, collection or trade; while for fish: juvenile habitat, adult habitat, food preference, solitary/aggregating). Ms. Bradley and Dr. Santavy began to populate the spreadsheets with data, beginning with information from the Humann and DeLoach field guides (Humann and DeLoach 2002a, b; 2003) and Sefton and Webster (1986).

During the first workshop, Ms. Bradley gave a short presentation to introduce the spreadsheets. The group then moved into a brief facilitated discussion. Workshop participants seemed to respond very positively to the concept and were interested in collaboratively working to complete the spreadsheets. The group will discuss how to go about completing the spreadsheets during the second workshop.

### *3.2.3 Assembling the Monitoring Data*

To complete the BCG, the group will utilize pre-existing data collected by others in laboratory and field studies. In Phase 1, EPA is working with EPA and NOAA data for Puerto Rico and USVI (stony corals, fish and benthic invertebrates). The initial biological data set will include fish measurements from several studies conducted by NOAA and EPA. Both groups used the same survey methods for fish, so standardization will easily occur as existing datasets are compiled. The second data set will include stony coral measurements from the same studies by NOAA and EPA. In this case, the methods are very different and will require discussion with the EPA coral reefs BCG team to extract the most meaningful and comparable data for standardized reporting. The third data set will include benthic invertebrates from the same studies by NOAA and EPA. The two survey methods are quite similar, although NOAA counts lobsters, conch and *Diadema*, while EPA also counts crabs and additional urchin species.

For all datasets, EPA will normalize taxonomic naming protocols to the Integrated Taxonomic Information System (ITIS). The standardized data set will contain data in the original format, a crosswalk with translations for converting data and the final standardized format. The data set will also include a field for the organization that generated the data (data owner).

EPA is planning on completing Phase 1 (as described above) prior to the second workshop and plans to use these data during the workshop.

Phase 2 activities will include direct submission into the STORET Data Warehouse (short for STOrage and RETrieval). STORET is a repository for water quality, biological and physical data and is used by state and territorial environmental agencies for their water quality data under the CWA. Phase 2 will also include incorporation of additional data and fields, when additional datasets from the coral reef BCG partners are provided (Puerto Rico Department of Natural and Environmental Resources, Puerto Rico Environmental Quality Board, USVI Department of Planning and Environmental Resources, University of Puerto Rico, University of the Virgin Islands, US Geological Survey and National Park Service). The EPA Office of Water has agreed to make the necessary modifications to STORET to include these data. Additionally, metadata for the database in STORET (with URL) will be developed for inclusion in NOAA's Coral Reef Information System (CORIS).

### *3.2.4 Calibrating the BCG*

The group will begin calibrating the BCG by using found (or existing) data to confirm the ecological attributes developed during this first workshop. The experts have determined narrative decision rules for assigning stations to a BCG level on the basis of the photographs and videos collected at multiple stations. Documentation of expert opinion in assigning stations to BCG levels is critical to the process. Next, a decision model will be developed that incorporates those rules and will be tested with independent data sets. The decision model using the tested decision rules will provide a transparent, formal and verifiable method for documenting and validating expert knowledge. A quantitative data analysis program can be developed using those rules.

BCG level descriptions in the conceptual model are qualitative (e.g., high diversity, reduced diversity; Table 2-5) to allow for consistent assignments of stations to levels. It is necessary to formalize and quantify the expert knowledge by codifying level descriptions into a set of quantitative rules (e.g., Droesen 1996). If formalized and quantified, any person (with data) can follow the rules to obtain the same level assignments as the group of experts. This makes the actual decision criteria transparent to stakeholders and potentially applicable to similar types of coral reefs in other areas.

Rules are logic statements that experts use to make their decisions, for example: "If taxon richness is high, then biological condition is high." Rules on attributes can be combined, for example: "If the number of highly sensitive coral taxa (Attribute II) is high, and the number of tolerant colonies (Attribute V) is low, then the assignment is to Level 2." The categories high, moderate, low, etc., are ordinal categories: we know that moderate is greater than low; but the boundaries of the categories are fuzzy and somewhat subjective. In iterations of the process, the expert panel is asked to put quantitative boundaries on the categories they have defined. The objective is to derive combined rules, for example, "If there are more than 10 highly sensitive coral taxa, and the percentage of colonies of tolerant taxa is less than 15%, then assignment is Level 2." The quantitative rules preserve the collective professional judgment of the expert group and set the stage for the development of quantitative models that reliably assign stations to levels without having to reconvene the same expert group. In essence, the rules and the models capture the panel's collective decision criteria.

The decision rule for a single level of the BCG does not usually rest on a single attribute (e.g., highly sensitive taxa) and generally includes other attributes (intermediate sensitive taxa, tolerant taxa, indicator species); such rules are termed Multiple Attribute Decision Rules. After verification with independent data, the quantified rules allow users to consistently assess stations according to the same rules used by the expert panel and allow a computer algorithm, or other persons, to obtain the same level assignments as the original panel. Documentation of the rules and algorithm allow new panels to review and modify the decision rules as necessary.

### *3.2.5 Economic Valuation of Coastal Ecosystem Services*

Despite their open-access nature and many contributions to the public good, coral reefs have often been undervalued in decision-making (Brander et al. 2009). The natural features of a coral reef (including physical structure, water quality, biological organisms and ecological functions) provide many natural benefits to human societies, collectively known as ecosystem goods and services. The economic values of some services (e.g., commercial fishing) are established in markets, while other services provide nonmarket value for local, state/regional and national/international segments of the population (Principe et al. 2012). Most ecosystem service studies have focused on market benefits, which are relatively easy to incorporate in trade-off analyses, but coral reefs also provide numerous nonmarket ecosystem services (e.g., existence value and cultural value) that can be estimated using a variety of methods.

Estimates of the global value of coral reefs range from US $30 billion per year (Cesar et al. 2003) to US $377 billion per year (Costanza et al. 1997). However, global estimates are coarse and rarely relevant to local management decisions. Decision contexts differ with reef type and habitat, political climate, stakeholder interests, decision authorities and responsibilities, knowledge, management capacity and expertise. Every decision contains an element of valuation, but values are not always at the forefront of finding optimal decisions (Keeney 1996). Consequences resulting from a decision are often described in terms of value (Hastie 2001). Yet, the values of stakeholders often go ignored before management strategies are implemented. Public and stakeholder values, cares, and priorities should be considered throughout in the focus and design of assessments and management planning and should not be an afterthought in the process.

The BCG effort focuses on how attributes of the coral reef ecosystem change in response to increasing anthropogenic stress. The attributes of the coral reef ecosystem represent the “glue” (Pearce and Moran 1994; Turner et al. 2000) of the properly functioning ecosystem, supporting the growth of reef-building corals for ecosystem services (e.g., shoreline protection, the presence of unique and diverse species to attract tourists, the creation of potentially useful natural products and the maintenance of habitat and nurseries for harvestable fish stocks). The development of concise, rigorous definitions and levels of condition along the human disturbance gradient will provide the fundamental understanding of the factors that affect delivery of ecosystem services.

EPA and NOAA, in partnership with the University of Puerto Rico and the Puerto Rico Sea Grant, are conducting a study to provide the economic valuation of tourism and recreation associated with Puerto Rico's coral reefs to help improve our understanding of the real costs of decisions and management options. Reef-related tourism activities include snorkeling, diving, fishing, viewing wildlife, boating, beach use and surfing. The project will consist of a modified form of the method NOAA used in the Florida Keys National Marine Sanctuary (Leeworthy and Wiley 1996, 1997, 2003; Leeworthy and Bowker 1997; Leeworthy and Vanasse 1999; Park et al. 2002; Bhat 2003; Shivlany et al. 2008), in Southeast Florida (Johns et al. 2001) and in Hawaii (Bishop et al. 2011).

The study is estimating the use and associated market (spending and associated impacts on total output/sales, income and employment) and non-market economic value (consumer's surplus or the net value received by those doing recreation activities on the reef over and above what they pay to undertake the activities) and how those values change with changes in reef attributes. Linking the relationships of how reef attribute values change with changes in the physical/natural levels of those attributes can be used to measure the economic benefits of the changes and thus provide additional performance measures of management actions to protect and restore coral reef ecosystems. Table 3-1 shows coral reef ecosystem services and examples of coral reef attributes that are associated with them.

**Table 3-1. Coral reef ecosystem services and reef attributes** (adapted from Principe et al. 2012).

| Ecosystem service(s) | | Natural features (reef attributes) |
|---|---|---|
| **Final** | **Intermediate** | |
| Recreational fishing opportunity | Production of benthic and aquatic prey for consumption by recreational fish | Fish diversity and abundance |
| Recreational diving/snorkeling opportunity | Coral reef formation and maintenance; maintenance of water clarity; production of benthic and aquatic prey for consumption by recreational fish | Coral diversity, abundance and health; fish diversity and abundance; water clarity |
| Recreational underwater photography opportunity | Coral reef formation and maintenance; maintenance of water clarity; production of benthic and aquatic prey for consumption by recreational fish | Coral diversity, abundance and health; fish diversity and abundance; water clarity |
| Recreational surfing opportunity | Reef breaks | 3-D reef structure |
| Opportunity to view nature and wildlife | Biological integrity | Biodiversity (birds, marine mammals, turtles) |
| Opportunity to sunbathe and swim at the beach | Water quality, shoreline protection, sand production | White coralline sands; calm waters |
| Opportunity to collect objects (beachcombing) | Water quality | Wide sandy beaches, biodiversity, occasional storms |

### *Definitions*

- Final ecosystem service – Output of ecological functions or processes that directly contributes to social welfare or has the potential to do so in the future (*sensu* Boyd and Banzhaff 2007).
- Intermediate ecosystem service – Output of ecological functions or processes that indirectly contributes to social welfare or has the potential to do so in the future.
- Natural features – The biological, chemical and physical attributes of an ecosystem or environment.

Estimates of use and value will be made for five regions in Puerto Rico to provide information on the economic value of reefs in various levels of condition, including present condition. Use and economic information can be used in evaluating the economic benefits of investments in protection and restoration of the coral reef ecosystems. Results can be used by both private businesses and government agencies responsible for managing coral reefs in marketing, education and outreach efforts, including Puerto Rico's coral reef management activities in the four coral reef priority areas (Culebra, the Northeast Reserve, Cabo Rojo and Guánica).

## 3.3 Final Thoughts

The first workshop was a new experience for all involved. While EPA has worked with states and territories to develop BCGs for streams and estuaries, no one has ever attempted to develop a BCG for coral reefs. The experts met the challenge head-on and great progress was made. EPA anticipates that this is just the first of several expert workshops. EPA will host conference calls and webinars as appropriate. EPA has asked that the experts from the first workshop commit to working with us throughout the process. Experts who were not able to attend the first workshop will also be invited to participate in future workshops and webinars.

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# Appendix C. Workshop Agenda

(Workshop was compressed to two days due to Tropical Storm Isaac; times shown below are approximate)

**Goal:** To develop a conceptual, narrative model that describes how biological attributes of coral reefs change along a gradient of increasing anthropogenic stress.

**DAY 1 – Setting the Stage: A Visual Evaluation of Stations**

9:00 **Registration**

9:30 **Purpose of the Workshop**

9:45 **Introductions**

**Purpose:** Who is attending; organization they represent; what scientific expertise?

**Desired Outcomes:** Relaxed atmosphere, prepare to work as a team.

10:00 **Coral Reef Video Evaluations**

**Purpose:** Participants individually review coral reef videos, located throughout the 3 rooms in the conference center.

**Desired Outcomes:** Every participant will have evaluated 8 videos.

12:00 **Lunch**

1:00 **Complete Coral Reef Video Evaluations**

**Purpose:** Complete final 4 stations.

**Desired Outcomes:** Participants have rated EPA stations and documented their rationale.

2:00 **Break**

2:15 **Freshwater Stream and Estuarine Attributes**

**Presenter:** Jeroen Gerritsen (Brief introduction to the attributes developed for freshwater streams and estuaries).

**Purpose:** Introduce the stream and estuarine attributes.

**Desired Outcomes:** Understand where others have been and where we hope to go. Further explore the attribute concept.

2:45 **Presentation of Ratings and Discussion of Rationale**

**Presenter:** Debbie Santavy (ranked stations)

**Purpose:** Try to reach consensus on station assignments stating the rationale for the decision.

**Desired Outcomes:** Share rating of stations; document criteria considered during selection and capture on flip charts.

4:30 **Thresholds**

**Presenter:** Jeroen Gerritsen (management uses of BCG and how to move forward).

**Purpose:** Establish preliminary thresholds for different levels of conceptual model.

**Desired Outcomes:** What relative abundance of sessile invertebrates for each level: hard corals, sponges and gorgonians? What else defines each level? Fish, rugosity, other invertebrates? Any inclusion of water quality factors: both qualitative and quantitative.

5:15 **Adjourn**

**DAY 2 – Biological Integrity**

9:00 **Biological Integrity Discussion**

**Presenters:** Debbie Santavy (results from coral reef video evaluations and attributes discussion); Experts (share their videos and photos that exhibit full biological integrity of a coral reef); Pat Bradley (reference condition); Pat Bradley (list of coral reef taxa).

**Purpose:** Discuss biological integrity and reference condition.

10:30 **Break**

10:45 **Reference Condition Discussion**

**Desired Outcomes:** Preliminary consensus on what the reference station should be. Begin to assemble the attributes.

12:30 **Lunch**

1:30 **Using Data to Rank Stations**

**Presenter:** Debbie Santavy (overview of EPA data).

**Purpose:** Focus thinking about the attributes in breakout groups.

**Desired Outcomes:** Begin thinking about levels of condition and lists of associated attributes.

3:00 **Break**

3:15 **Attributes as Condition Changes**

**Purpose:** Begin to consider different levels of condition along a human disturbance gradient, using visual and data-derived attributes.

**Desired Outcomes:** Begin to compile lists of both visual and data-derived attributes that are not station specific, but more overarching characteristics. Perhaps develop levels of attributes from data metrics to begin populating BCG framework.

5:00 **Thank you and next steps**

5:30 **Adjourn**

# Appendix D.
# Tally Sheet – Rating Condition of Coral Reef Videos (1st)

**Name: ______________________**

**Ballot**

| Station No. | Rating (Good, Fair, Poor) | Rationale (indicate 3 most important characteristics considered in ranking) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

# Appendix E.
# Tally Sheet – Rating Condition of Coral Reef Videos (2nd)

**Name:** ______________________

**Ballot**

| Station No. | Rating (Good, Fair, Poor) | Rationale (indicate 3 most important characteristics considered in ranking) |
|---|---|---|
| **9** | | |
| **10** | | |
| **11** | | |
| **12** | | |

# Appendix F.
# Notes Sheet – Rating Condition of Coral Reef Videos

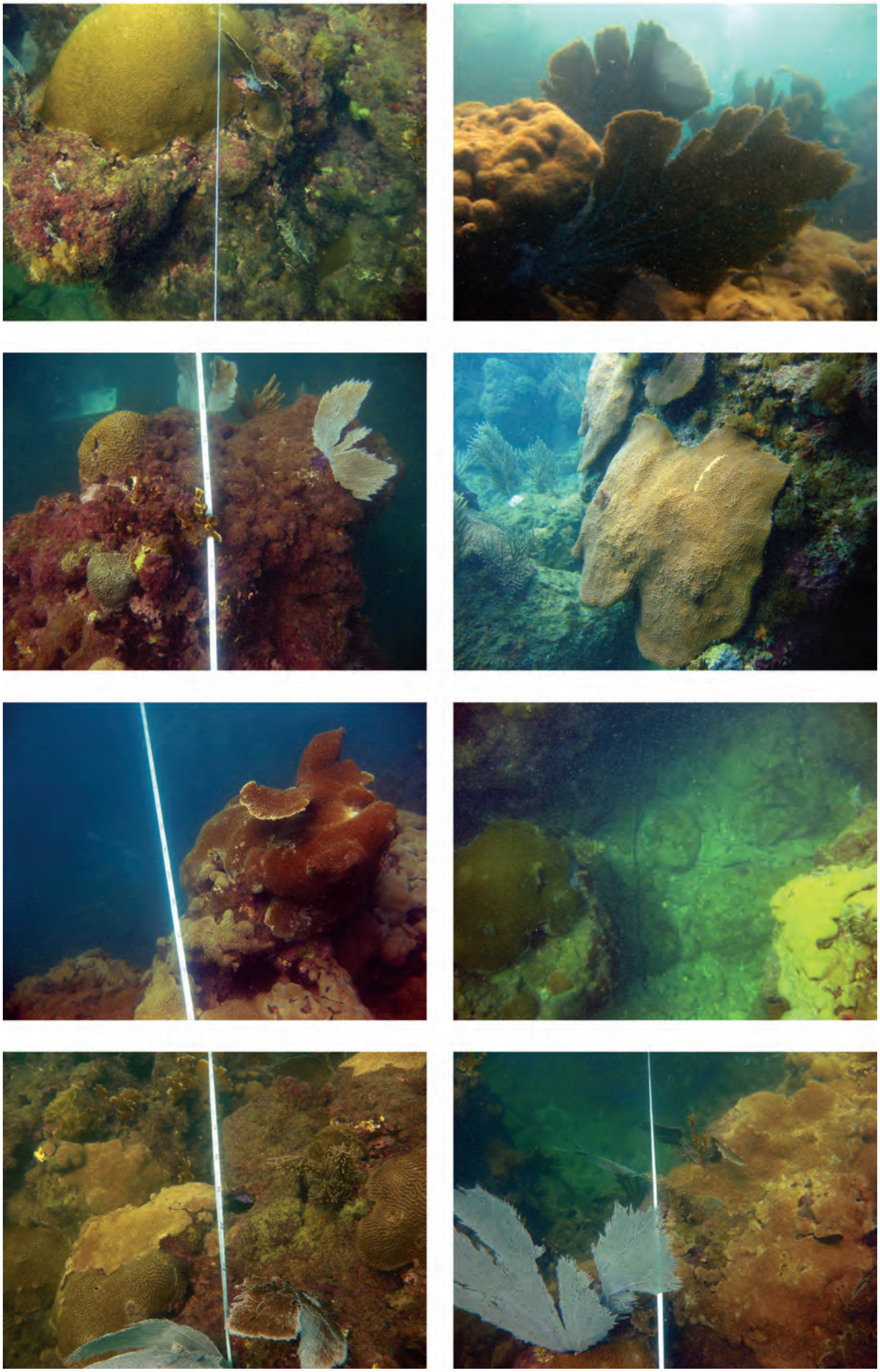
**Notes Sheet - Station 1** **Rating: Good - - - Fair- - -Poor**
(Circle your condition rating)

Use this sheet to capture salient points about this station while viewing the video. You also have a photo handout of key photos to assist you. The salient points should provide your rationale for rating condition as good, fair or poor.

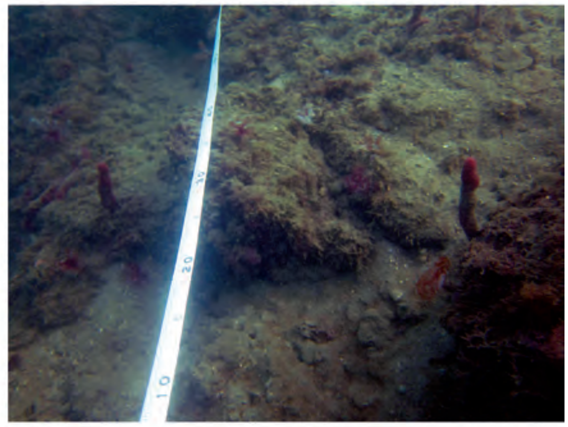
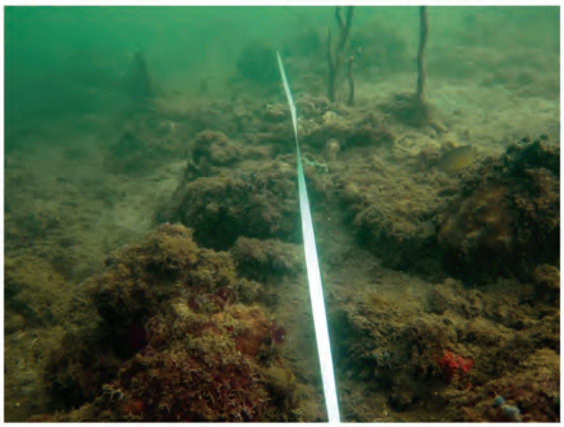
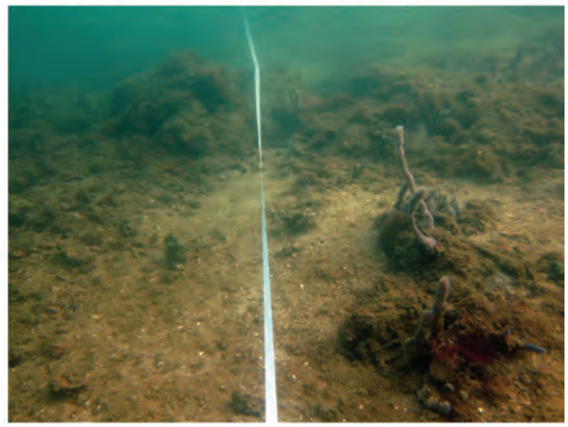
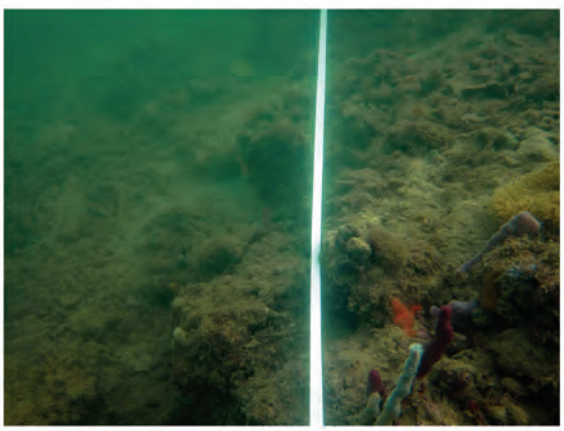
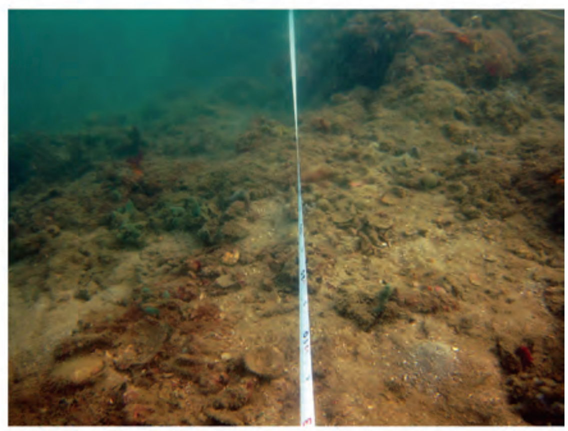
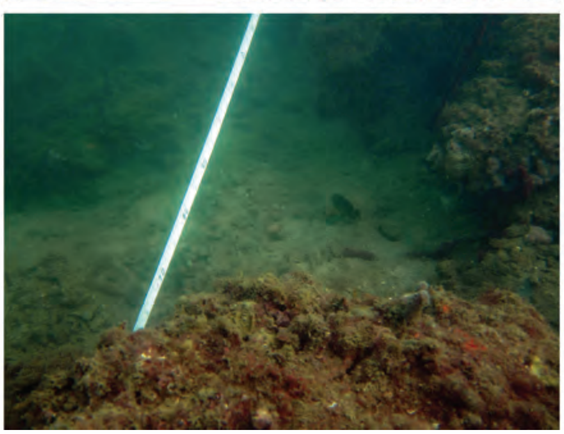
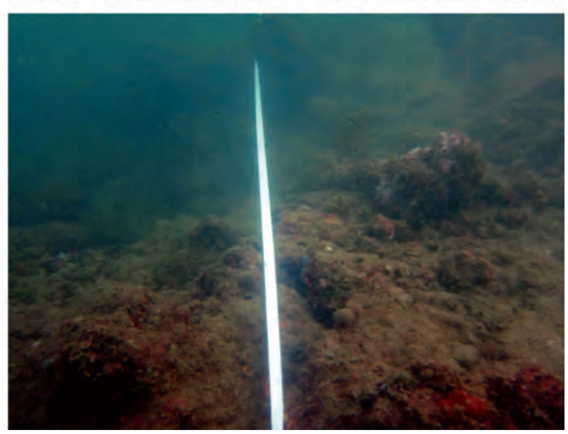
# Appendix G.
# Supporting Photos – Rating Condition of Coral Reef Videos

The following pages show supporting photos for each station (1 page per station). The experts used these as supplemental material to evaluate the videos.

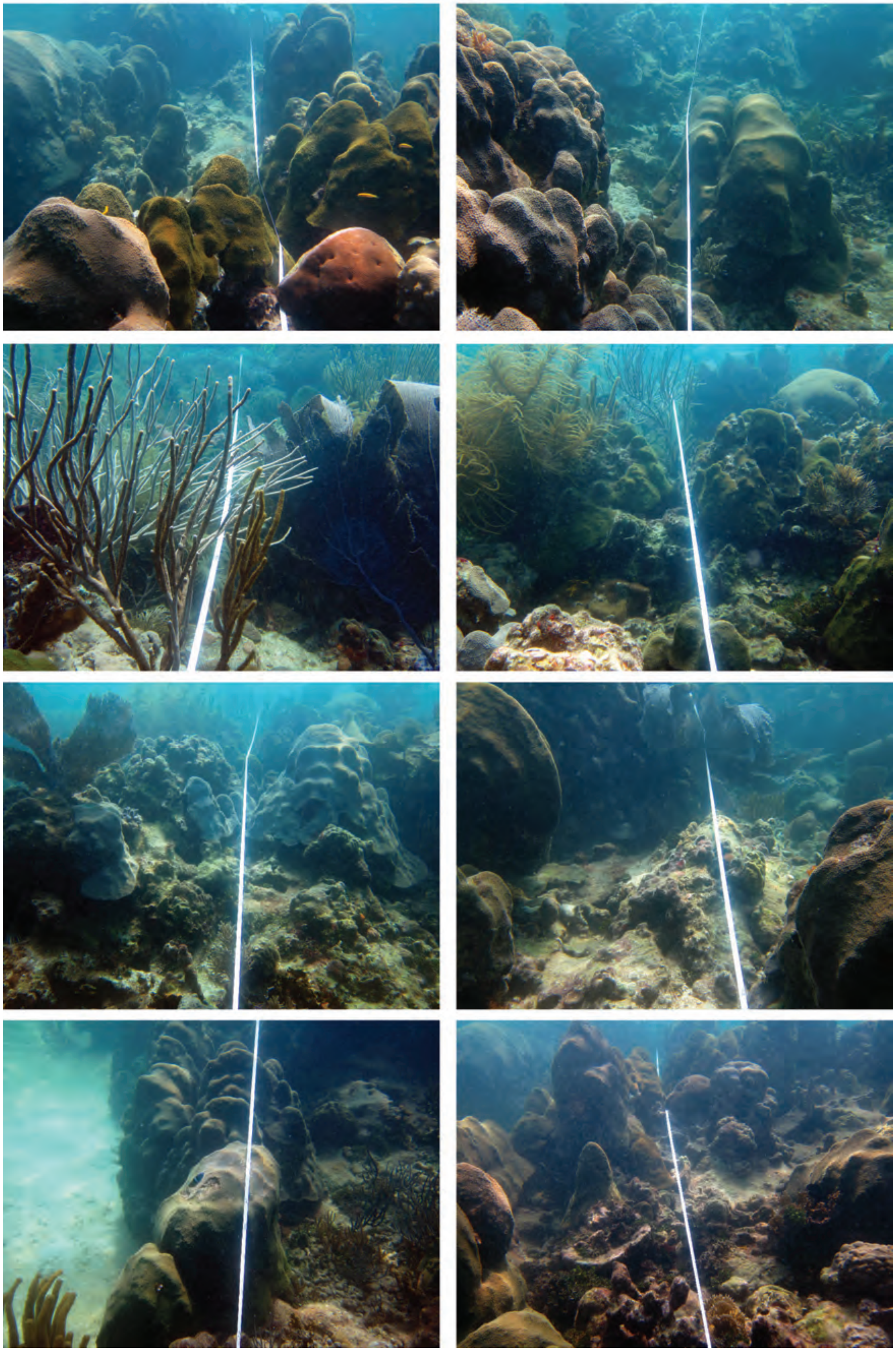
## Station 1



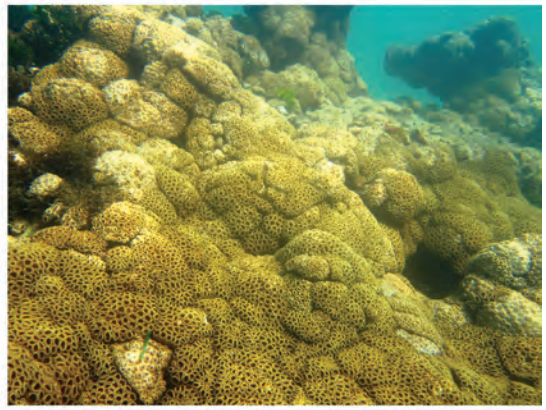
## Station 2

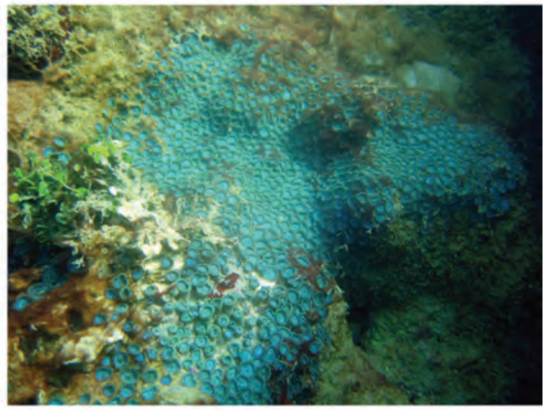
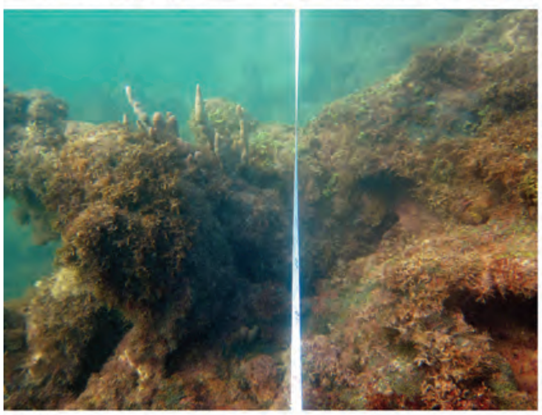









**Station 3**



## Station 4

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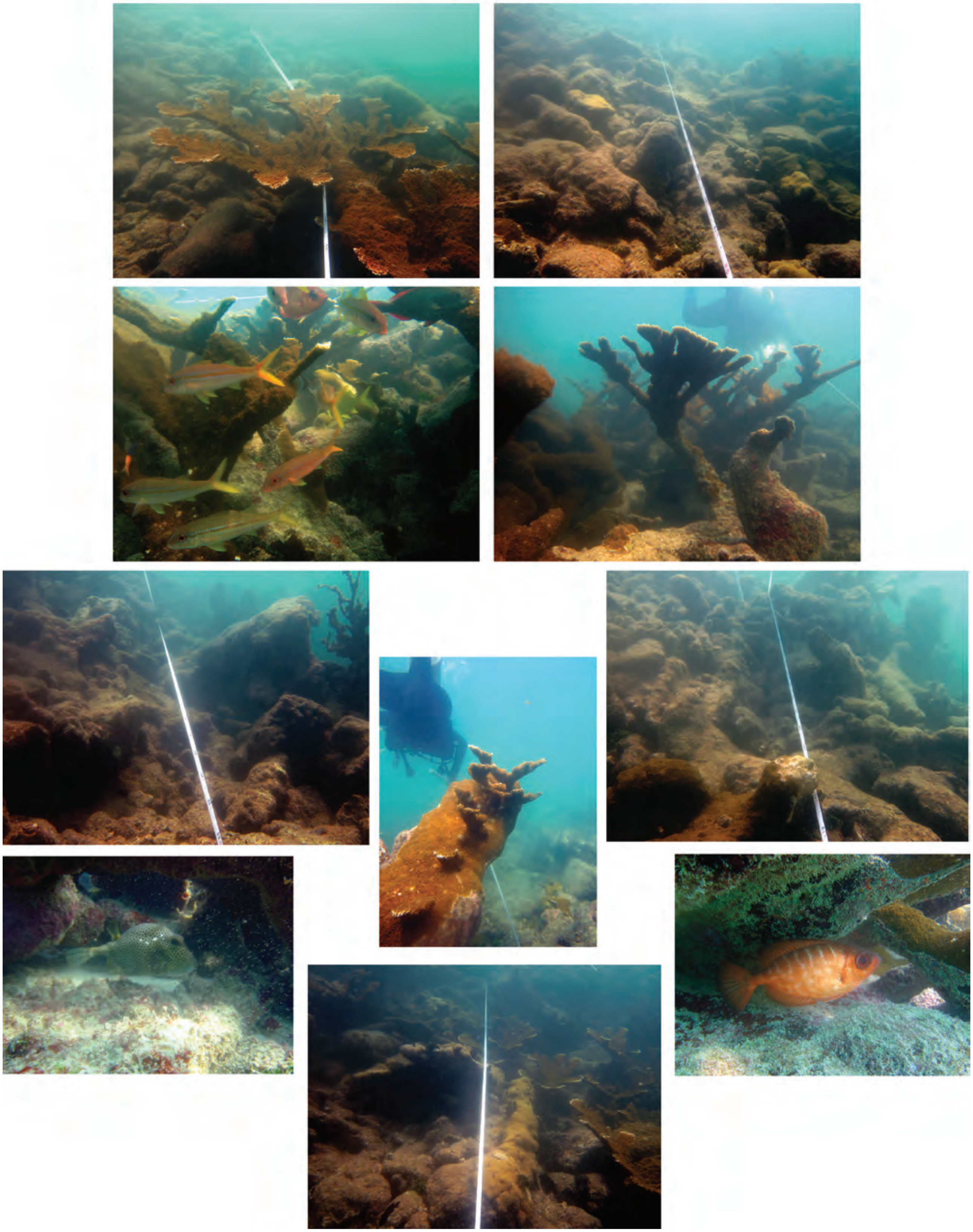

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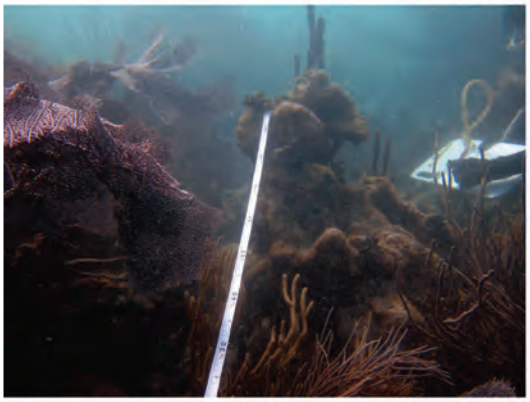
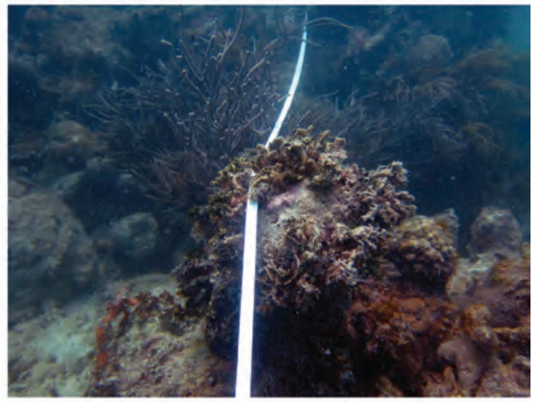
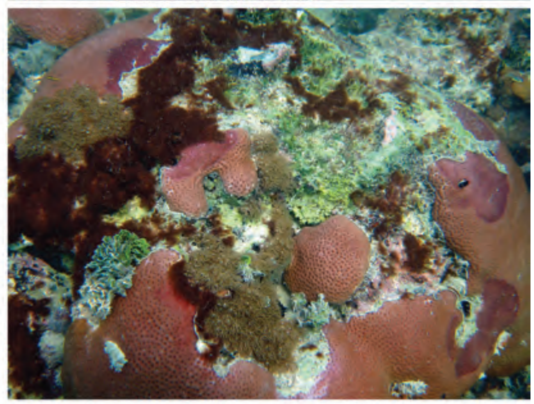
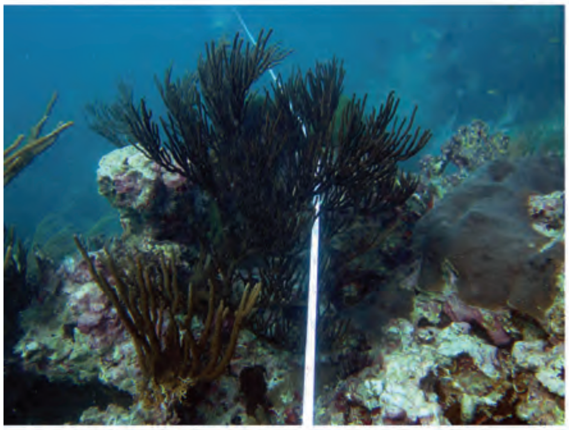
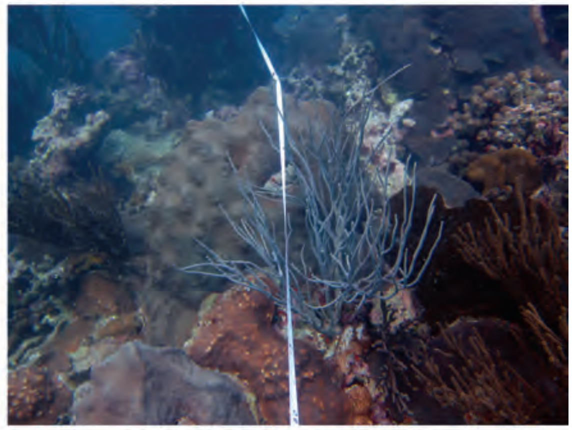



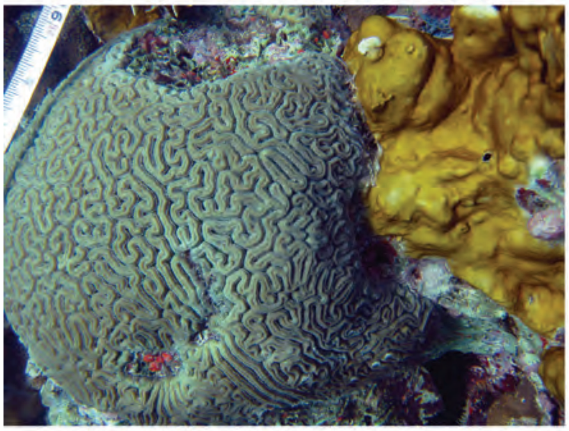


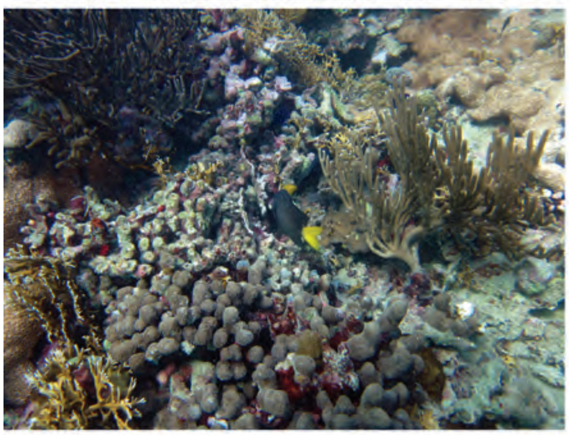


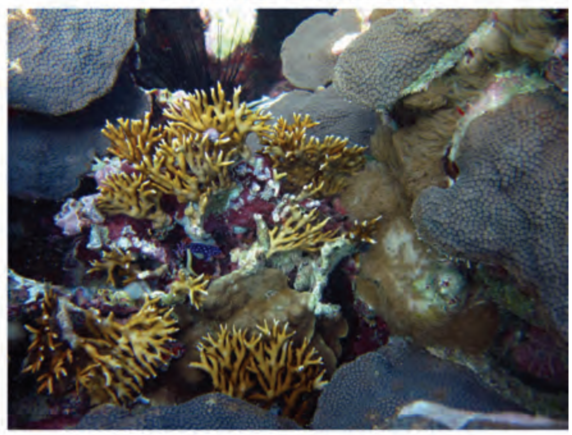
## Station 7

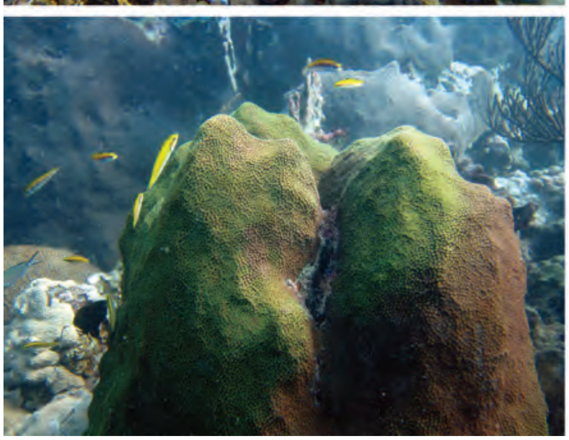




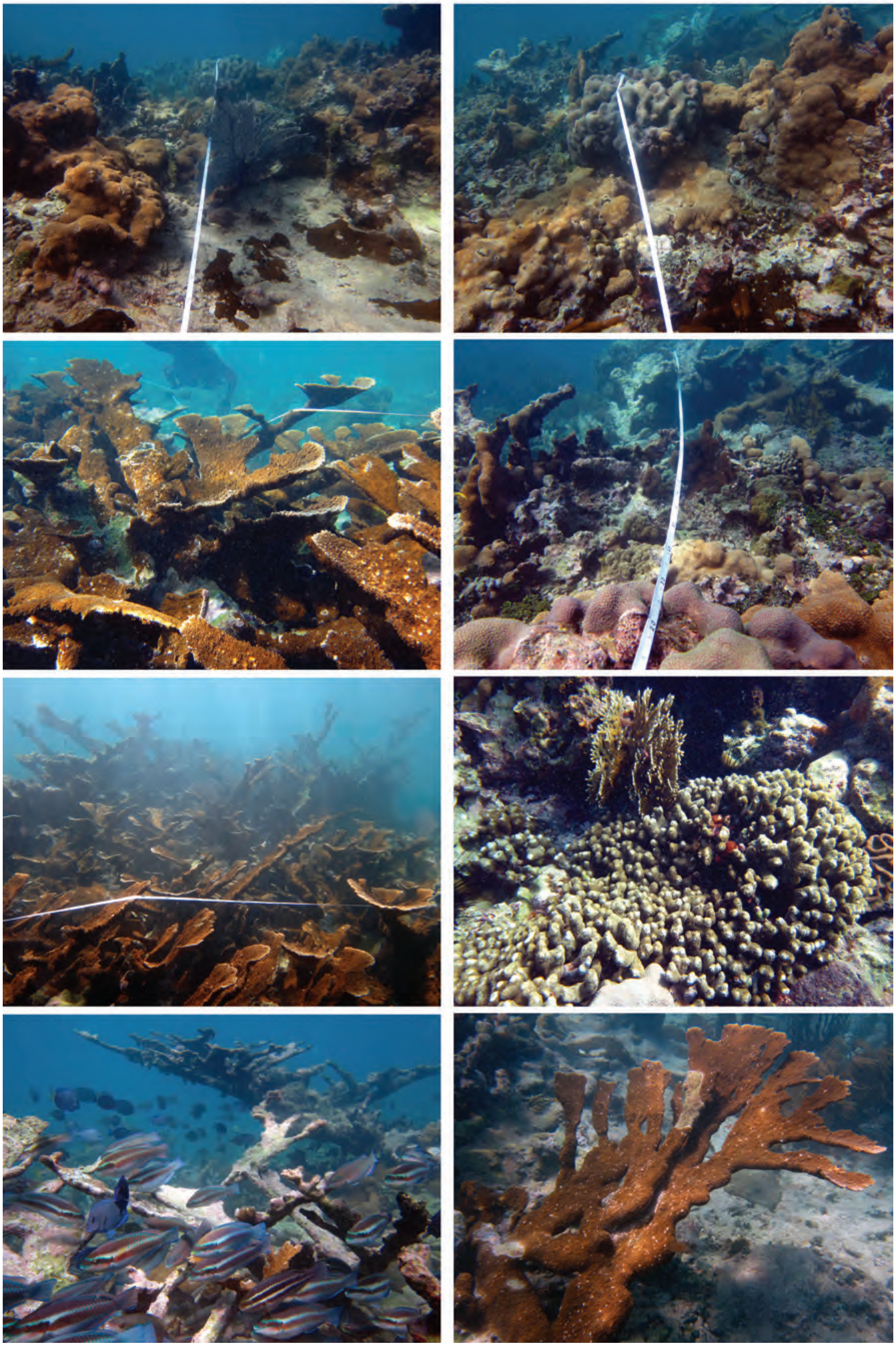








**Station 8**



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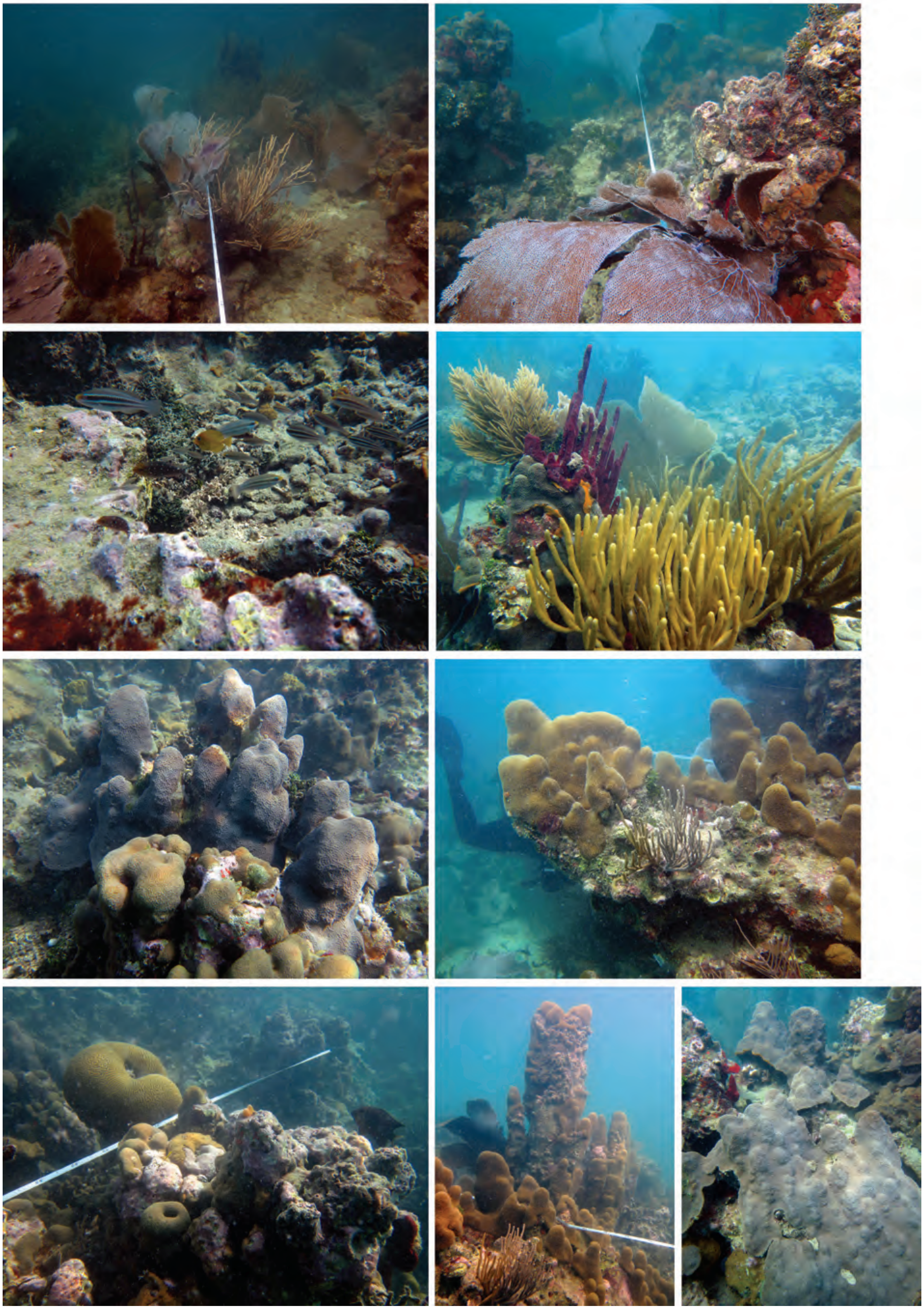

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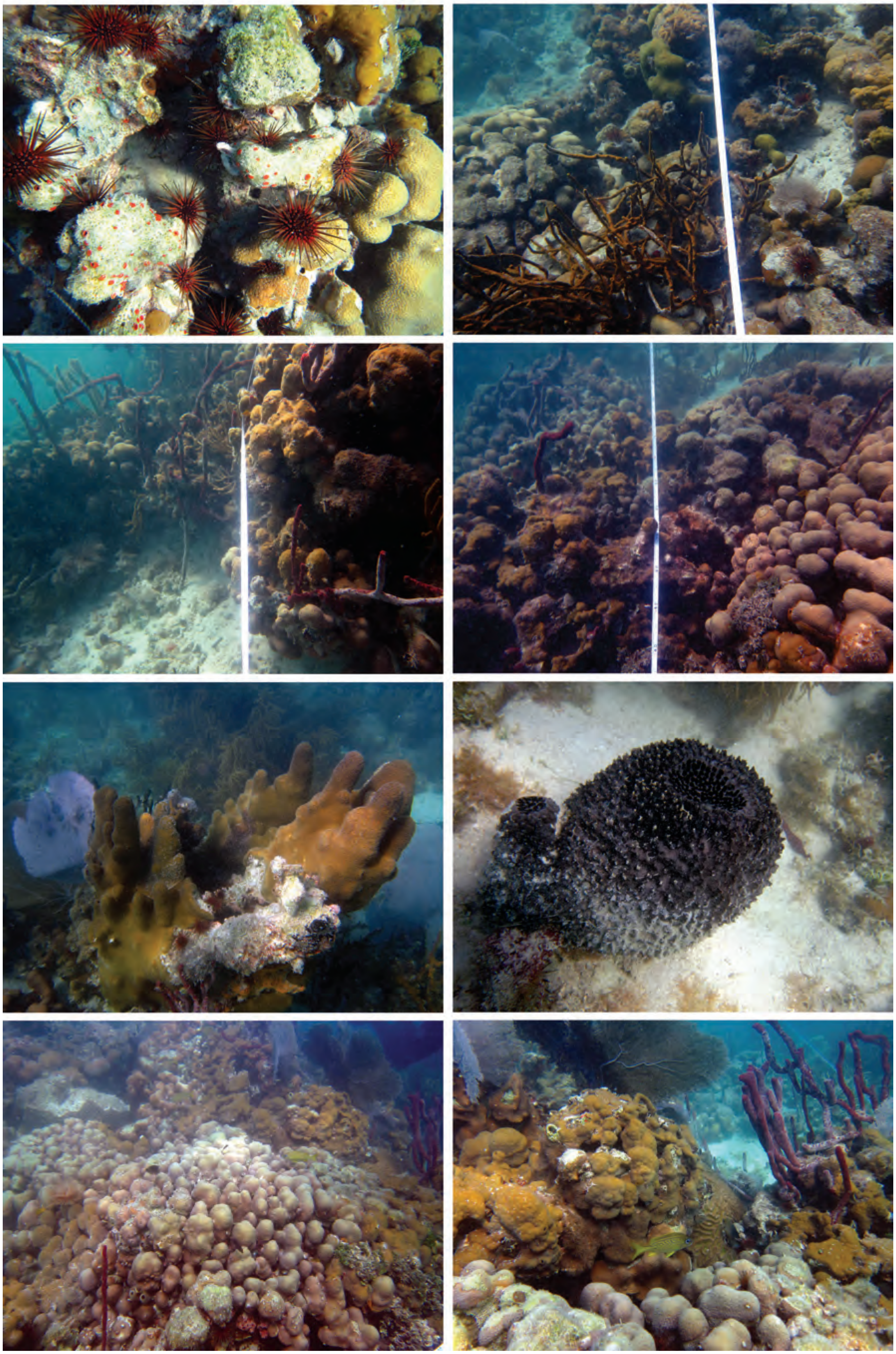
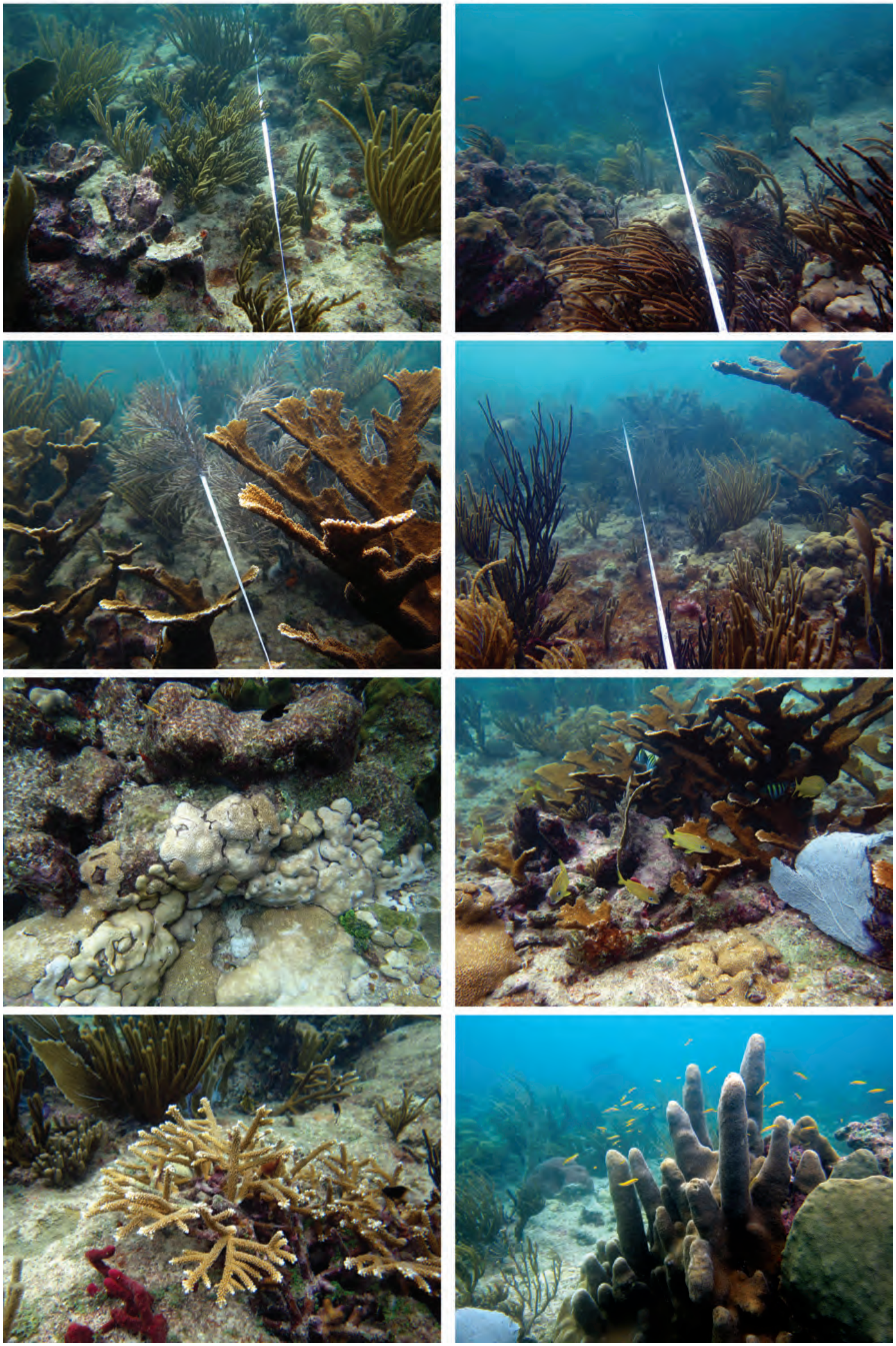
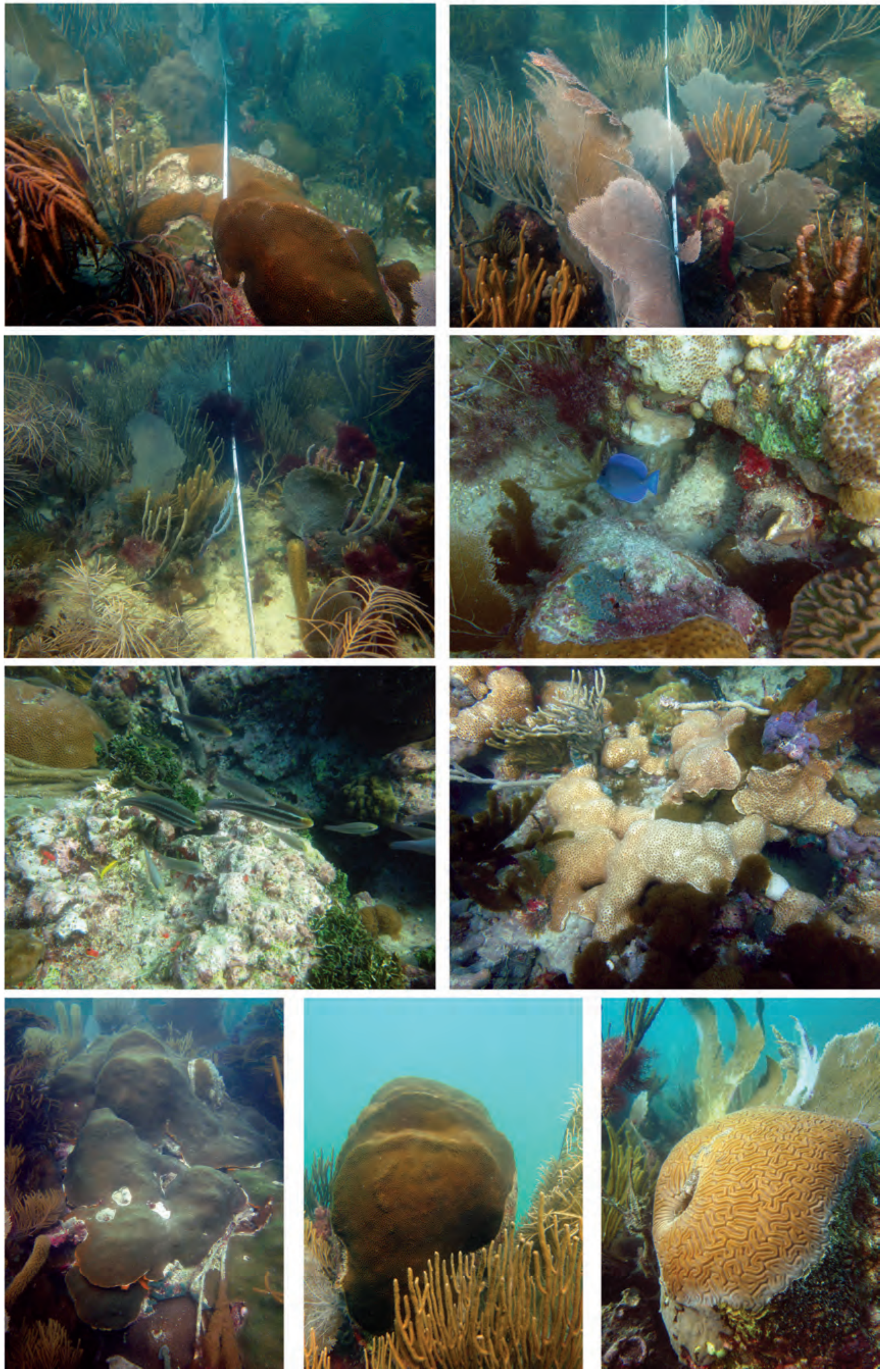


**Station 11**



## Station 12



# Appendix H. Workshop Glossary

**Attribute:** Any measurable component of a biological system (Karr and Chu 1999).

**Best attainable condition:** A condition that is equivalent to the ecological condition of (hypothetical) least disturbed stations where the best possible management practices are in use. This condition can be determined using techniques such as historical reconstruction, best ecological judgment and modeling, restoration experiments, or inference from data distributions.

**Biological integrity:** The ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region.

**Human disturbance:** Human activity that alters the natural state and can occur at or across many spatial and temporal scales.

**Ecosystem-level functions:** Processes performed by ecosystems, including, among other things, primary and secondary production, respiration, nutrient cycling, and decomposition (EPA 2005).

**Historical condition:** The ecological condition at some previous point in history. Conditions reflective of the historic time period may no longer exist in actual ecosystems in an area.

**Least disturbed condition:** The best available existing conditions with regard to physical, chemical, and biological characteristics or attributes of a waterbody within a class or region. These waters have the least amount of human disturbance in comparison to others within the waterbody class, region or basin. Least disturbed conditions can be readily found but may depart significantly from natural, undisturbed conditions or minimally disturbed conditions. Least disturbed condition may change significantly over time as human disturbances change (EPA 2005).

**Minimally disturbed condition:** The physical, chemical and biological conditions of a waterbody with very limited or minimal human disturbance in comparison to others within the waterbody class or region. Minimally disturbed conditions can change over time in response to natural processes (EPA 2005).

**Non-native species:** Any species that is not naturally found in that ecosystem. Species introduced or spread from one region of the US to another outside their normal range are non-native or non-indigenous, as are species introduced from other continents (EPA 2005).

**Reference condition:** The condition that approximates natural, unimpacted conditions (biological, chemical, physical, etc.) for a waterbody. Reference condition (biological integrity) is best determined by collecting measurements at a number of stations in a similar waterbody class or region under undisturbed or minimally disturbed conditions (by human activity), if they exist. Since undisturbed or minimally disturbed conditions may be difficult or impossible to find, least disturbed conditions combined with historical information, models or other methods, may be used to approximate reference condition as long as the departure from natural or ideal is understood. Reference condition is used as a benchmark to determine how much other water bodies depart from this condition due to human disturbance (EPA 2005).

**Reference station:** A station selected for comparison with stations being assessed. The type of stations selected and the type of comparative measures used will vary with the purpose of the comparisons. For the purposes of assessing the ecological condition of stations, a reference station is a specific locality on a waterbody that is undisturbed or minimally disturbed and is representative of the expected ecological integrity of other localities on the same waterbody or nearby waterbodies (EPA 2005).

**Sensitive-rare taxa:** Taxa that naturally occur in low numbers relative to total population density but may make up large relative proportion of richness. May be ubiquitous in occurrence or may be restricted to certain microhabitats, but because of low density recorded occurrence is dependent on sample effort. Often stenothermic (having a narrow range of thermal tolerance) or cold-water obligates, commonly k-strategists (populations maintained at a fairly constant level, slower development, longer life-span), may have specialized food resource needs or feeding strategies. Generally intolerant to significant alteration of the physical or chemical environment; are often the first taxa observed to be lost from a community (EPA 2005).

**Sensitive or regionally endemic taxa:** Taxa with restricted, geographically isolated distribution patterns (occurring only in a locale as opposed to a region), often due to unique life history requirements. May be long lived, late maturing, low fecundity, limited mobility or require mutualistic relationships with other species. May be listed as threatened, endangered or of special concern species. Predictability of occurrence often low, therefore, requires documented observation. Recorded occurrence may be highly dependent on sample methods, station selection and level of effort (EPA 2005).

**Sensitive taxa:** Taxa that are intolerant to a given anthropogenic stress, often the first species affected by the specific stressor to which they are “sensitive" and the last to recover following restoration (EPA 2005).

**Taxa:** A grouping of organisms given a formal taxonomic name such as species, genus, family, etc. (EPA 2005).

**Taxa of intermediate tolerance:** Taxa that comprise a substantial portion of natural communities, which may increase in number in waters which have moderately increased organic resources and reduced competition, but they are intolerant of excessive pollution loads or habitat alteration. These may be r-strategists (early colonizers with rapid turn-over times; boom/bust population characteristics), eurythermal (having a broad thermal tolerance range), or have generalist or facultative feeding strategies enabling them to utilize more diversified food types. They are readily collected with conventional sample methods (EPA 2005).

**Tolerant taxa:** Taxa that comprise a low proportion of natural communities. Tolerant taxa often are tolerant of a broader range of environmental conditions and are thus resistant to a variety of pollution or habitat-induced stress. They may increase in number (sometimes greatly) in the absence of competition. They are commonly r-strategists (early colonizers with rapid turn-over times; boom/bust population characteristics), able to colonize when stress conditions occur. Last survivors (EPA 2005).

# Appendix I. Summary Data Results for BCG Stations

**Table I-1. Scleractinian coral summary statistics for BCG stations** (Puerto Rico surveys in 2010 and 2011). Ave. 3D SA is average 3-dimensional surface area $cm^2/m^2$. SE=standard error of mean.

| BCG Station No. | EPA Station No. | Species Richness | % Total Abundance | No. Colonies | Shannon Diversity Index (H') | Colony Density (#/$m^2$) | 3D Coral Area ($cm^2/m^2$) | 2D Coral Area ($cm^2/m^2$) | Rugosity* | SE Rugosity | Rating by Visual Media | Visual Rating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125 | 13 | 11.61 | 51 | 2.040 | 3.40 | 6,560 | 1,533 | 2.18 | 0.107 | poor/fair | 8 |
| 2 | 15 | 3 | 2.68 | 4 | 1.040 | 0.16 | 185 | 106 | 1.12 | 0.019 | poor (worst) | 12 |
| 3 | 113 | 10 | 8.93 | 79 | 1.657 | 3.16 | 9,518 | 2,843 | 1.52 | 0.107 | good (best) | 1 |
| 4 | 3 | 6 | 5.36 | 21 | 1.234 | 0.84 | 2,706 | 565 | 1.52 | 0.087 | poor | 11 |
| 5 | 19 | 7 | 6.25 | 31 | 1.261 | 1.24 | 18,228 | 3,673 | 1.54 | 0.108 | fair/poor | 9 |
| 6 | 14 | 10 | 8.93 | 54 | 1.793 | 3.6 | 5,359 | 1,530 | 1.71 | 0.106 | poor | 10 |
| 7 | 16 | 11 | 9.82 | 73 | 1.971 | 4.87 | 14,210 | 5,089 | 1.83 | 0.119 | fair | 4 |
| 8 | 108 | 7 | 6.25 | 71 | 1.512 | 4.73 | 19,637 | 4,549 | 1.48 | 0.116 | fair | 6 |
| 9 | 109 | 8 | 8.04 | 87 | 1.410 | 5.80 | 20,080 | 5,917 | 1.88 | 0.134 | fair | 7 |
| 10 | 1 | 11 | 9.82 | 70 | 1.784 | 2.8 | 11,026 | 3,698 | 1.48 | 0.052 | fair | 3 |
| 11 | 46 | 9 | 8.04 | 44 | 1.827 | 1.16 | 11,635 | 2,598 | 1.12 | 0.039 | fair | 5 |
| 12 | 25 | 8 | 7.14 | 95 | 1.469 | 3.8 | 9,199 | 3,498 | 1.25 | 0.086 | fair | 2 |

*Rugosity is the linear ratio of 6m divided by the taut linear distance of a 6m chain draped over the tops of corals and along the bottom. Rugosity is a reef-scale indicator of reef contour or surface heterogeneity. See Appendix J for formulas.

**Table I-2. Gorgonian summary statistics for BCG stations** (Puerto Rico surveys in 2010 and 2011). Ave. 3D SA is average 3-dimensional surface area $cm^2/m^2$ or per individual. Maximum number of morphologies that can be present at one station is nine.

| BCG Station No. | Station No. | Morpho. Richness[a] | No. Individuals | Density #/$m^2$ | Ave. 3D SA[b]/$m^2$ | Ave. 3D SA[c]/ind |
|---|---|---|---|---|---|---|
| 1 | 125 | 4 | 21 | 4.2 | 5,154 | 1,227 |
| 2 | 15 | 0 | 0 | 0 | 0 | 0 |
| 3 | 113 | 7 | 24 | 4.8 | 30,346 | 6,322 |
| 4 | 3 | 0 | 0 | 0 | 0 | 0 |
| 5 | 19 | 0 | 0 | 0 | 0 | 0 |
| 6 | 14 | 6 | 27 | 5.4 | 38,352 | 7,102 |
| 7 | 16 | 8 | 37 | 7.4 | 33,342 | 4,506 |
| 8 | 108 | 2 | 6 | 1.2 | 86 | 71 |
| 9 | 109 | 4 | 7 | 1.4 | 11,229 | 8,021 |
| 10 | 1 | 2 | 10 | 2 | 17,649 | 8,825 |
| 11 | 46 | 7 | 52 | 10.4 | 26,954 | 2,592 |
| 12 | 25 | 8 | 86 | 17.2 | 58,558 | 3,405 |

a: Morphological shapes and regression equations for 3D surface estimation of an individual by morphology in Santavy et al., 2012, pp. 36-38.

b: Ave. 3D SA/$m^2$ = Σ Gorgonian surface area in transect area/total transect area

c: Ave. 3D SA/ind= Σ Gorgonian surface area in transect area/total # Gorgonians in transect. See Appendix J, Table J-2 for formulas

**Table I-3. Sponge summary statistics for BCG stations** (Puerto Rico surveys in 2010 and 2011). Ave. 3D SA is average 3-dimensional surface area $cm^2/m^2$ or per individual. Maximum number of morphologies present at one station is eight.

| BCG Station No. | Station No. | Morpho. Richness[a] | No. Individuals | Density $\#/m^2$ | Ave. 3D $SA^b/m^2$ | Ave. 3D $SA^c$/ind |
|---|---|---|---|---|---|---|
| 1 | 125 | 3 | 22 | 4.4 | 1,615 | 367 |
| 2 | 15 | 3 | 20 | 4 | 1,146 | 286 |
| 3 | 113 | 1 | 5 | 1 | 48 | 48 |
| 4 | 3 | 2 | 7 | 1.4 | 173 | 124 |
| 5 | 19 | 1 | 5 | 1 | 208 | 208 |
| 6 | 14 | 2 | 8 | 1.6 | 410 | 256 |
| 7 | 16 | 0 | 0 | 0 | 0 | 0 |
| 8 | 108 | 0 | 0 | 0 | 0 | 0 |
| 9 | 109 | 3 | 7 | 1.4 | 1,389 | 992 |
| 10 | 1 | 5 | 33 | 6.6 | 10,776 | 1,633 |
| 11 | 46 | 3 | 21 | 4.2 | 53,824 | 12,815 |
| 12 | 25 | 5 | 28 | 5.6 | 6,213 | 1,110 |

a: Morphological shapes and regression equations for 3D surface estimation of an individual by morphology in Santavy et al., 2012, pp. 36-38.

b: Ave. 3D $SA/m^2$ = Σ Sponge surface area in transect area/total transect area.

c: Ave. 3D SA/ind= Σ Sponge surface area in transect area/total # Sponges in transect. See Appendix J, Table J-2 for formulas.

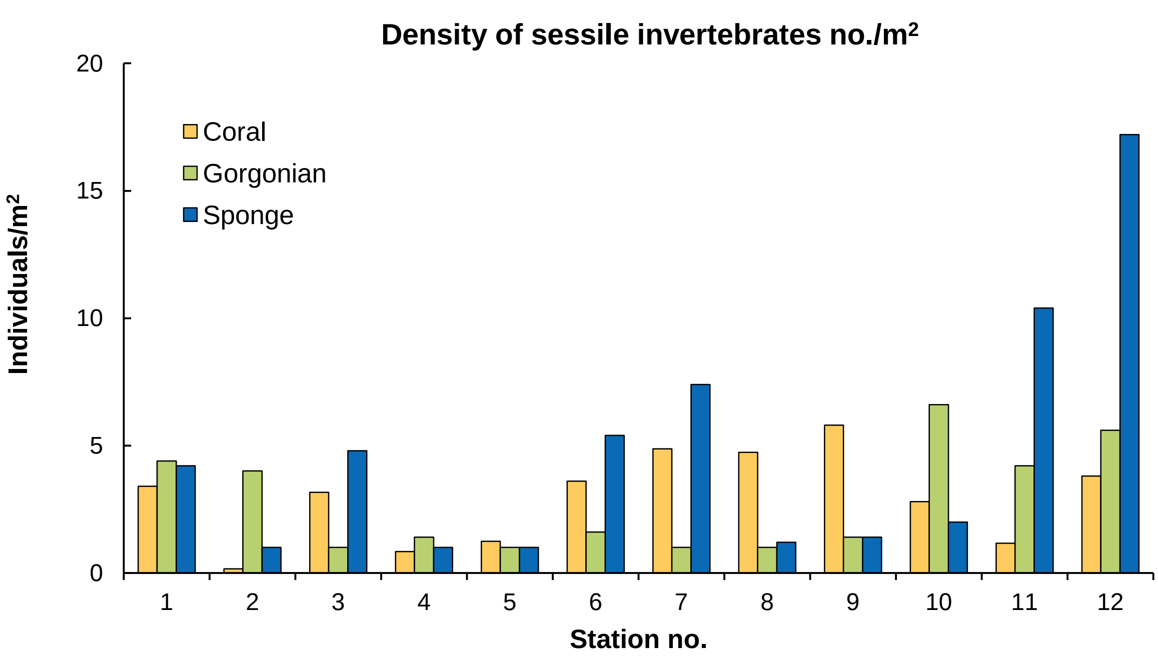



**Figure I-1. Comparison of the density of the major sessile invertebrates assessed in the 12 BCG stations.**

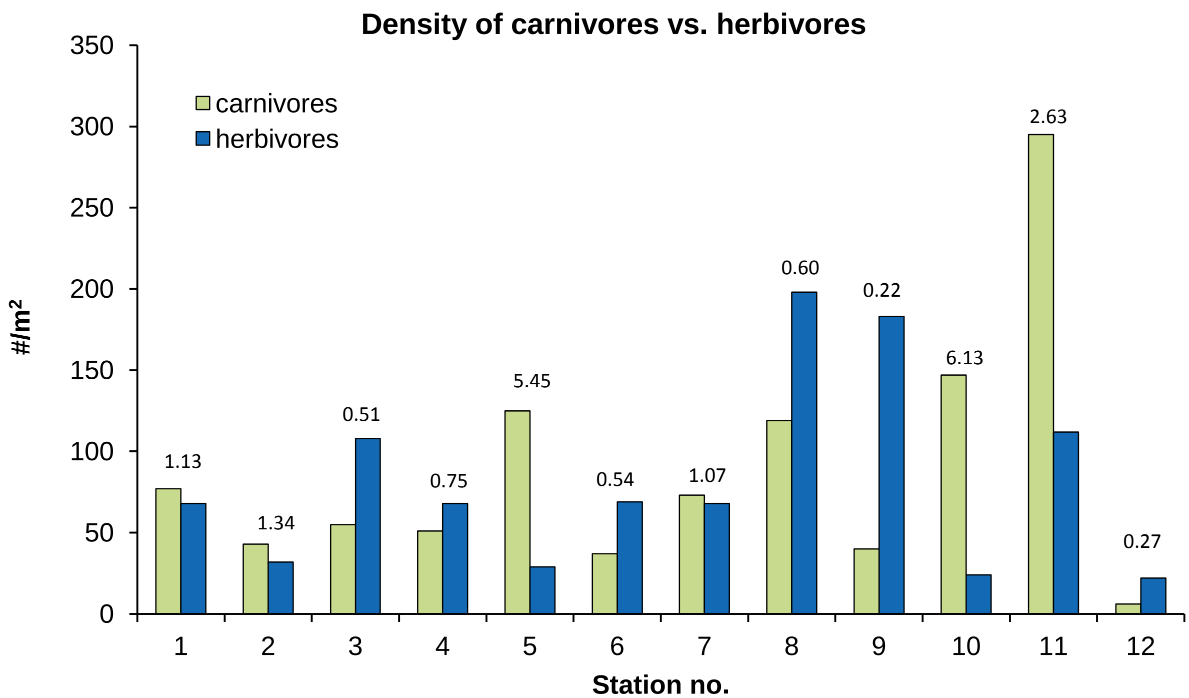



**Figure I-2. Comparison of density for fish carnivores vs. herbivores at BCG stations.** Number above bar pairs is the ratio of carnivore/herbivore density.

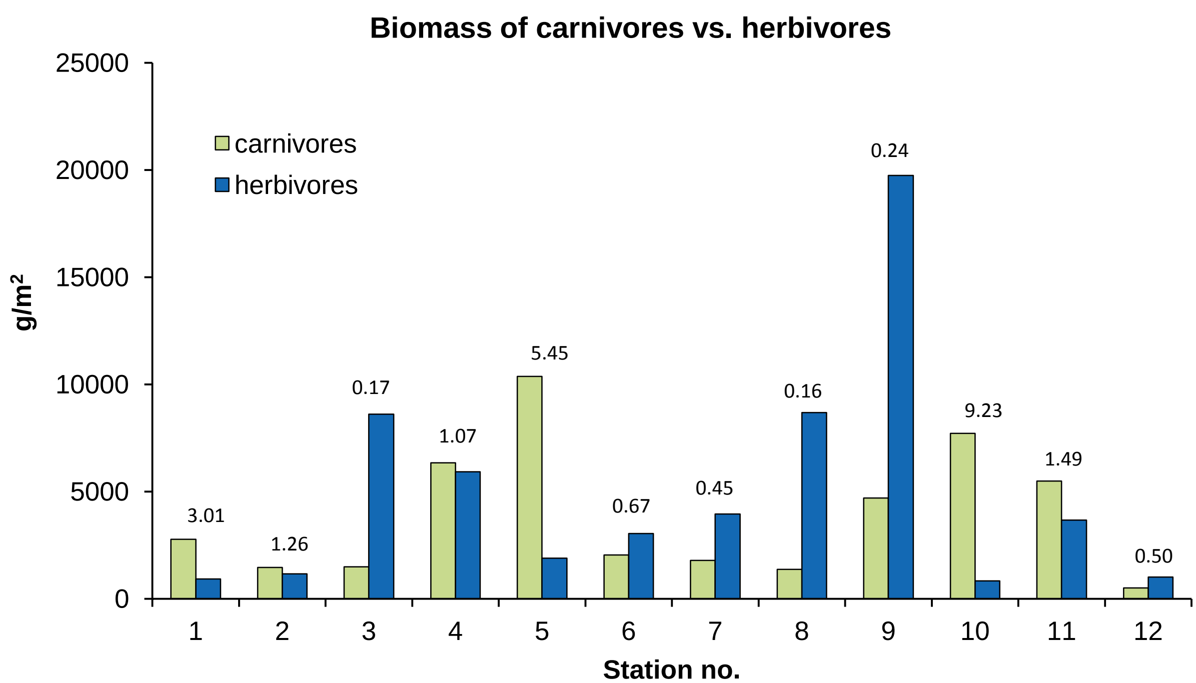
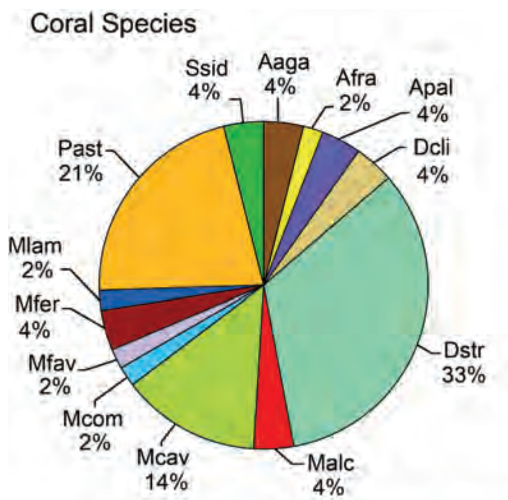


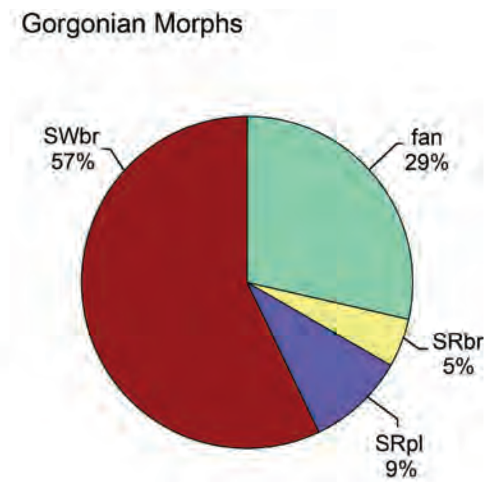

**Figure I-3. Comparison of biomass for fish carnivores vs. herbivores at BCG stations.** Number above bar pairs is the ratio of carnivore/herbivore biomass.

# BCG Station 1
# (Field Station 125_2010)
# Coral Species Richness: 13
# Photo rank and rating: 8, Poor/Fair

**Table I-4. BCG Station 1 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/$m^2$) | 3.40 | 0.53 | 0.13 | 0.13 | 0.73 |
| Ave. 3D colony skeletal area ($cm^2$)/colony | 2,146 | 2,462 | 20,077 | 417 | 435 |
| Ave. 3D colony skeletal area ($cm^2$)/$m^2$ | 7,297 | 1,313 | 2,677 | 56 | 319 |
| Ave. 3D coral tissue area ($cm^2$)/colony | 1,929 | 2,284 | 16,446 | 417 | 435 |
| Ave. 3D coral tissue area ($cm^2$)/$m^2$ | 6,560 | 1,218 | 2,193 | 56 | 319 |
| Ave. 2D coral tissue area ($cm^2$)/$m^2$ | 1,533 | 228 | 198 | 54 | 16 |



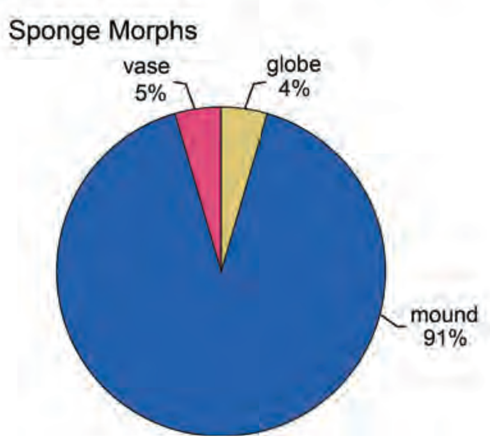




**Figure I -4. Percentages of stony coral species, gorgonian morphologies and sponge morphologies for BCG Station 1.**

**Table I-5. Fish species found in BCG Station 1, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass (g/100 $m^2$) |
|---|---|---|---|
| *Abudefduf saxatilis* | Sergeant Major | 2 | 90 |
| *Acanthurus coeruleus* | Blue Tang | 5 | 167 |
| *Anisotremus surinamensis* | Black Margate | 1 | 1,274 |
| *Anisotremus virginicus* | Porkfish | 1 | 9 |
| *Caranx ruber* | Bar Jack | 1 | 17 |
| *Gramma loreto* | Fairy Basslet | 3 | 1 |
| *Haemulon flavolineatum* | French Grunt | 1 | 40 |
| *Halichoeres poeyi* | Blackear Wrasse | 1 | 5 |
| *Holacanthus bermudensis* | Blue Angelfish | 1 | 11 |
| *Lutjanus analis* | Mutton Snapper | 1 | 637 |
| *Lutjanus apodus* | Schoolmaster | 1 | 215 |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 5 | 174 |
| *Ocyurus chrysurus* | Yellowtail Snapper | 8 | 242 |
| *Ophioblennius macclurei* | Redlip Blenny | 3 | 12 |
| *Pempheris schomburgkii* | Glassy Sweeper | 1 | 33 |
| *Scarus iseri* | Striped Parrotfish | 2 | 15 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 1 | 40 |
| *Sparisoma viride* | Stoplight Parrotfish | 3 | 3 |
| *Stegastes adustus* | Dusky Damselfish | 49 | 510 |
| *Thalassoma bifasciatum* | Bluehead | 55 | 198 |

# BCG Station 2
# (Field Station 15_2011)
# Coral Species Richness: 3
# Photo rank and rating: 12, Poor (Worst)

**Table I-6. BCG Station 2 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/$m^2$) | 0.16 | 0 | 0 | 0.08 | 0 |
| Ave. 3D colony skeletal area ($cm^2$)/colony | 1,248 | 0 | 0 | 980 | 0 |
| Ave. 3D colony skeletal area ($cm^2$)/$m^2$ | 200 | 0 | 0 | 78 | 0 |
| Ave. 3D coral tissue area ($cm^2$)/colony | 1,157 | 0 | 0 | 822 | 0 |
| Ave. 3D coral tissue area ($cm^2$)/$m^2$ | 185 | 0 | 0 | 66 | 0 |
| Ave. 2D coral tissue area ($cm^2$)/$m^2$ | 106 | 0 | 0 | 37 | 0 |

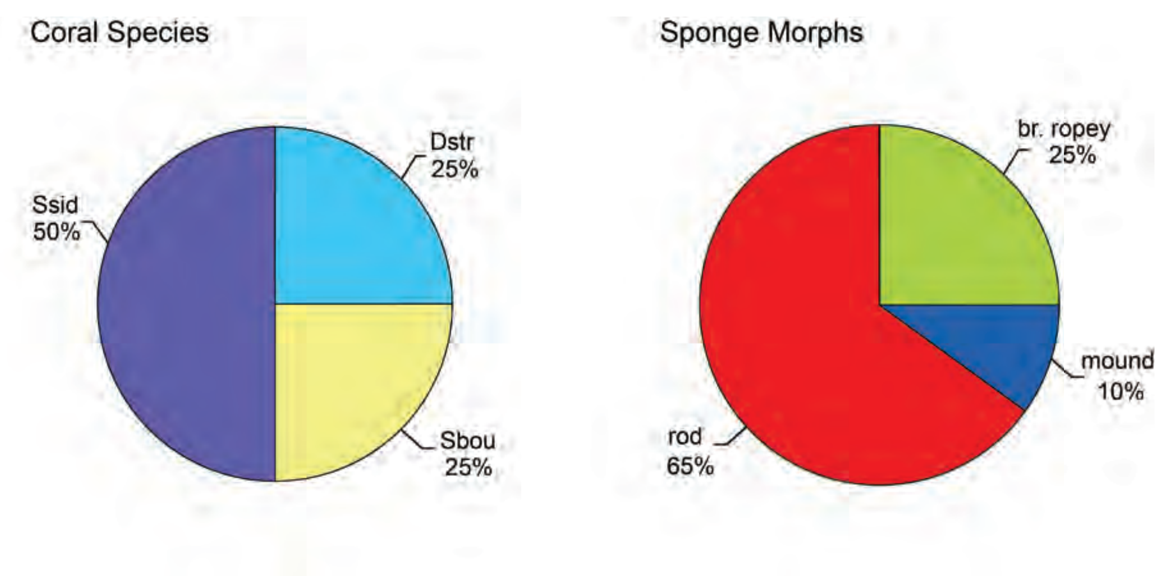



**Figure I-5. Percentages of stony coral species and sponge morphologies for BCG Station 2.** No gorgonians were present at BCG Station 2.

**Table I-7. Fish species found in BCG Station 2, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass (g/100 $m^2$) |
|---|---|---|---|
| *Acanthurus bahianus* | Ocean Surgeonfish | 10 | 457 |
| *Anisotremus virginicus* | Porkfish | 5 | 220 |
| *Canthigaster rostrata* | Sharpnose Puffer | 1 | 0 |
| *Cephalopholis fulva* | Coney | 2 | 68 |
| *Chaetodon capistratus* | Foureye Butterflyfish | 7 | 105 |
| *Elacatinus saucrum* | Leopard Goby | 6 | 298 |
| *Haemulon flavolineatum* | French Grunt | 10 | 404 |
| *Haemulon macrostomum* | Spanish Grunt | 1 | 40 |
| *Halichoeres poeyi* | Blackear Wrasse | 1 | 26 |
| *Lachnolaimus maximus* | Hogfish | 1 | 10 |
| *Mulloidichthys martinicus* | Yellow Goatfish | 2 | 81 |
| *Ocyurus chrysurus* | Yellowtail Snapper | 7 | 212 |
| *Scarus iseri* | Striped Parrotfish | 1 | 33 |
| *Stegastes adustus* | Dusky Damselfish | 8 | 496 |
| *Stegastes diencaeus* | Longfin Damselfish | 4 | 127 |
| *Stegastes partitus* | Bicolor Damselfish | 4 | 2 |
| *Stegastes variabilis* | Cocoa Damselfish | 5 | 49 |

# BCG Station 3
# (Field Station 113_2011)
# Coral Species Richness: 10
# Photo rank and rating: 1, Good (Best)

**Table I-8. BCG Station 3 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/$m^2$) | 3.16 | 0.92 | 0 | 0.48 | 1.36 |
| Ave. 3D colony skeletal area ($cm^2$)/colony | 4,537 | 13,445 | 0 | 949 | 704 |
| Ave. 3D colony skeletal area ($cm^2$)/$m^2$ | 14,337 | 12,369 | 0 | 456 | 957 |
| Ave. 3D coral tissue area ($cm^2$)/colony | 3,012 | 8,646 | 0 | 626 | 609 |
| Ave. 3D coral tissue area ($cm^2$)/$m^2$ | 9,518 | 7,954 | 0 | 300 | 829 |
| Ave. 2D coral tissue area ($cm^2$)/$m^2$ | 2,843 | 2,212 | 0 | 135 | 326 |

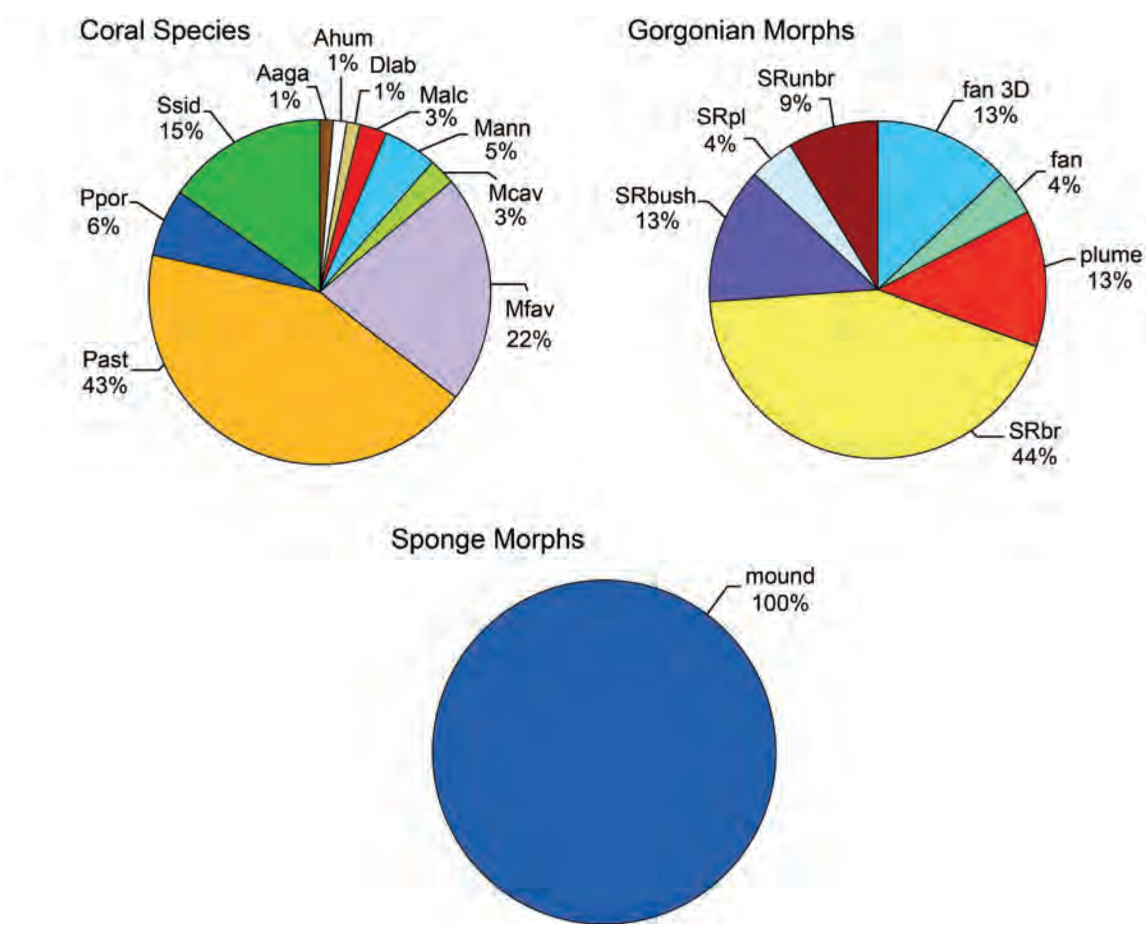



**Figure I-6. Percentages of stony coral species, gorgonian morphologies and sponge morphologies for BCG Station 3.**

**Table I-9. Fish species found in BCG Station 3, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass ($g/100\ m^2$) |
|---|---|---|---|
| *Acanthurus bahianus* | Ocean Surgeonfish | 1 | 46 |
| *Acanthurus coeruleus* | Blue Tang | 9 | 638 |
| *Canthigaster rostrata* | Sharpnose Puffer | 2 | 14 |
| *Caranx ruber* | Bar Jack | 2 | 34 |
| *Chaetodon capistratus* | Foureye Butterflyfish | 1 | 15 |
| *Coryphopterus glaucofraenum* | Bridled Goby | 15 | 10 |
| *Haemulon macrostomum* | Spanish Grunt | 1 | 242 |
| *Halichoeres bivittatus* | Slippery Dick | 5 | 574 |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | 3 | 43 |
| *Lutjanus apodus* | Schoolmaster | 2 | 431 |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 2 | 324 |
| *Scarus iseri* | Striped Parrotfish | 51 | 5,749 |
| *Serranus tigrinus* | Harlequin Bass | 1 | 7 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 5 | 482 |
| *Sparisoma viride* | Stoplight Parrotfish | 6 | 979 |
| *Stegastes adustus* | Dusky Damselfish | 30 | 360 |
| *Stegastes partitus* | Bicolor Damselfish | 4 | 32 |
| *Stegastes planifrons* | Threespot Damselfish | 2 | 13 |
| *Thalassoma bifasciatum* | Bluehead | 21 | 106 |

# BCG Station 4
# (Field Station 3_2011)
# Coral Species Richness: 6
# Photo rank and rating: 11, Poor

**Table I-10. BCG Station 4 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/$m^2$) | 0.84 | 0.12 | 0 | 0 | 0.04 |
| Ave. 3D colony skeletal area ($cm^2$)/colony | 4,251 | 17,387 | 0 | 0 | 157 |
| Ave. 3D colony skeletal area ($cm^2$)/$m^2$ | 3,571 | 2,086 | 0 | 0 | 6 |
| Ave. 3D coral tissue area ($cm^2$)/colony | 3,221 | 10,681 | 0 | 0 | 141 |
| Ave. 3D coral tissue area ($cm^2$)/$m^2$ | 2,706 | 1,282 | 0 | 0 | 6 |
| Ave. 2D coral tissue area ($cm^2$)/$m^2$ | 565 | 315 | 0 | 0 | 4 |

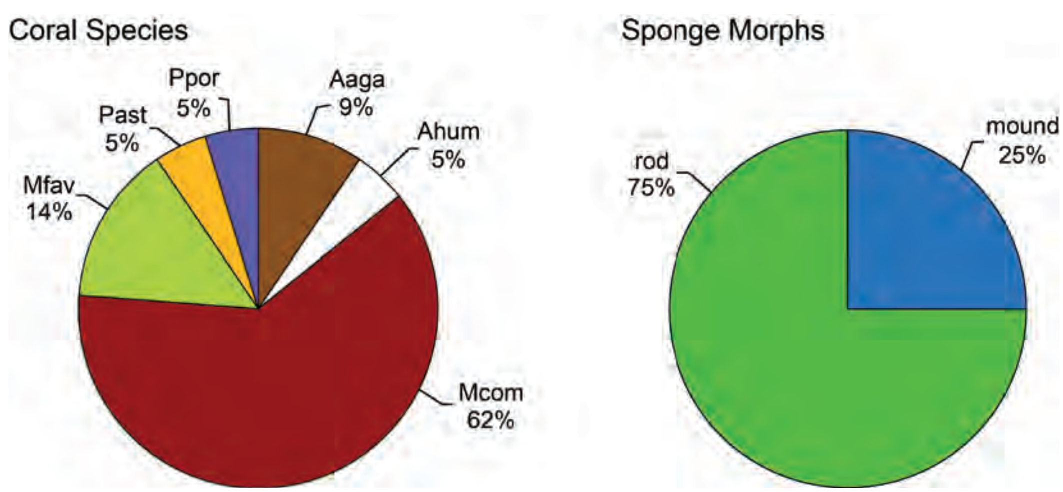



**Figure I-7. Percentages of stony coral species and sponge morphologies for BCG Station 4.** No gorgonians were present at BCG Station 4.

**Table I-11. Fish species found in BCG Station 4, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass ($g/100\ m^2$) |
|---|---|---|---|
| *Acanthurus bahianus* | Ocean Surgeonfish | 1 | 129 |
| *Acanthurus chirurgus* | Doctorfish | 6 | 629 |
| *Acanthurus coeruleus* | Blue Tang | 5 | 1,081 |
| *Aulostomus maculatus* | Trumpetfish | 1 | 256 |
| *Canthigaster rostrata* | Sharpnose Puffer | 1 | 7 |
| *Chaetodon capistratus* | Foureye Butterflyfish | 1 | 15 |
| *Decapterus macarellus* | Mackerel Scad | 2 | 395 |
| *Gymnothorax sp.* | Moray Eel sp. | 1 | 3 |
| *Haemulon carbonarium* | Caesar Grunt | 5 | 1,024 |
| *Haemulon chrysargyreum* | Smallmouth Grunt | 5 | 475 |
| *Haemulon flavolineatum* | French Grunt | 5 | 609 |
| *Haemulon parra* | Sailors Choice | 1 | 404 |
| *Halichoeres radiatus* | Puddingwife | 1 | 168 |
| *Lutjanus apodus* | Schoolmaster | 9 | 2,193 |
| *Malacanthus plumieri* | Sand Tilefish | 13 | 318 |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 8 | 1,296 |
| *Odontoscion dentex* | Reef Croaker | 1 | 21 |
| *Rypticus saponaceus* | Greater Soapfish | 1 | 82 |
| *Scarus iseri* | Striped Parrotfish | 10 | 1,119 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 3 | 580 |
| *Sparisoma rubripinne* | Yellowtail Parrotfish | 1 | 401 |
| *Sparisoma viride* | Stoplight Parrotfish | 1 | 314 |
| *Stegastes adustus* | Dusky Damselfish | 33 | 384 |
| *Synodus intermedius* | Sand Diver | 1 | 339 |
| *Thalassoma bifasciatum* | Bluehead | 3 | 31 |

# BCG Station 5
# (Field Station 19_2011)
# Coral Species Richness: 7
# Photo rank and rating: 9, Fair/Poor

**Table I-12. BCG Station 5 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/m$^2$) | 1.24 | 0.2 | 0.8 | 0.08 | 0 |
| Ave. 3D colony skeletal area (cm$^2$)/colony | 23,116 | 5,030 | 34,248 | 520 | 0 |
| Ave. 3D colony skeletal area (cm$^2$)/m$^2$ | 28,664 | 1,006 | 27,399 | 42 | 0 |
| Ave. 3D coral tissue area (cm$^2$)/colony | 14,700 | 2,950 | 21,764 | 520 | 0 |
| Ave. 3D coral tissue area (cm$^2$)/m$^2$ | 18,228 | 590 | 17,411 | 42 | 0 |
| Ave. 2D coral tissue area (cm$^2$)/m$^2$ | 3,673 | 71 | 3,526 | 16 | 0 |

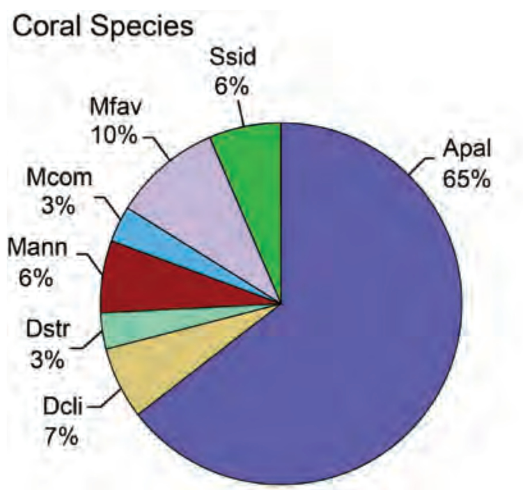




**Figure I-8. Percentages of stony coral species and sponge morphologies for BCG Station 5.** No gorgonians were present at BCG Station 5.

**Table I-13. Fish species found in BCG Station 5, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass ($g/100\ m^2$) |
|---|---|---|---|
| *Acanthurus bahianus* | Ocean Surgeonfish | 1 | 46 |
| *Acanthurus coeruleus* | Blue Tang | 2 | 72 |
| *Anisotremus virginicus* | Porkfish | 1 | 128 |
| *Aulostomus maculatus* | Trumpetfish | 3 | 439 |
| *Bodianus rufus* | Spanish Hogfish | 1 | 32 |
| *Caranx ruber* | Bar Jack | 1 | 17 |
| *Decapterus macarellus* | Mackerel Scad | 2 | 275 |
| *Haemulon carbonarium* | Caesar Grunt | 1 | 41 |
| *Haemulon chrysargyreum* | Smallmouth Grunt | 6 | 570 |
| *Haemulon flavolineatum* | French Grunt | 63 | 6,989 |
| *Haemulon macrostomum* | Spanish Grunt | 1 | 242 |
| *Heteropriacanthus cruentatus* | Glasseye Snapper | 1 | 214 |
| *Holocentrus adscensionis* | Squirrelfish | 1 | 237 |
| *Lutjanus apodus* | Schoolmaster | 2 | 203 |
| *Malacanthus plumieri* | Sand Tilefish | 13 | 300 |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 3 | 486 |
| *Mulloidichthys martinicus* | Yellow Goatfish | 7 | 283 |
| *Myripristis jacobus* | Blackbar Soldierfish | 1 | 107 |
| *Pempheris schomburgkii* | Glassy Sweeper | 5 | 164 |
| *Scarus iseri* | Striped Parrotfish | 3 | 458 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 2 | 151 |
| *Sparisoma viride* | Stoplight Parrotfish | 3 | 521 |
| *Stegastes adustus* | Dusky Damselfish | 14 | 168 |
| *Stegastes partitus* | Bicolor Damselfish | 1 | 1 |
| *Thalassoma bifasciatum* | Bluehead | 16 | 134 |

# BCG Station 6
# (Field Station 14_2010)
# Coral Species Richness: 10
# Photo rank and rating: 10, Poor

**Table I-14. BCG Station 6 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/m$^2$) | 3.6 | 1.2 | 0 | 0.33 | 1.4 |
| Ave. 3D colony skeletal area (cm$^2$)/colony | 5,431 | 14,255 | 0 | 1,400 | 466 |
| Ave. 3D colony skeletal area (cm$^2$)/m$^2$ | 19,552 | 17,106 | 0 | 467 | 653 |
| Ave. 3D coral tissue area (cm$^2$)/colony | 1,489 | 3,298 | 0 | 1,193 | 443 |
| Ave. 3D coral tissue area (cm$^2$)/m$^2$ | 5,359 | 3,958 | 0 | 398 | 621 |
| Ave. 2D coral tissue area (cm$^2$)/m$^2$ | 1,530 | 892 | 0 | 141 | 330 |

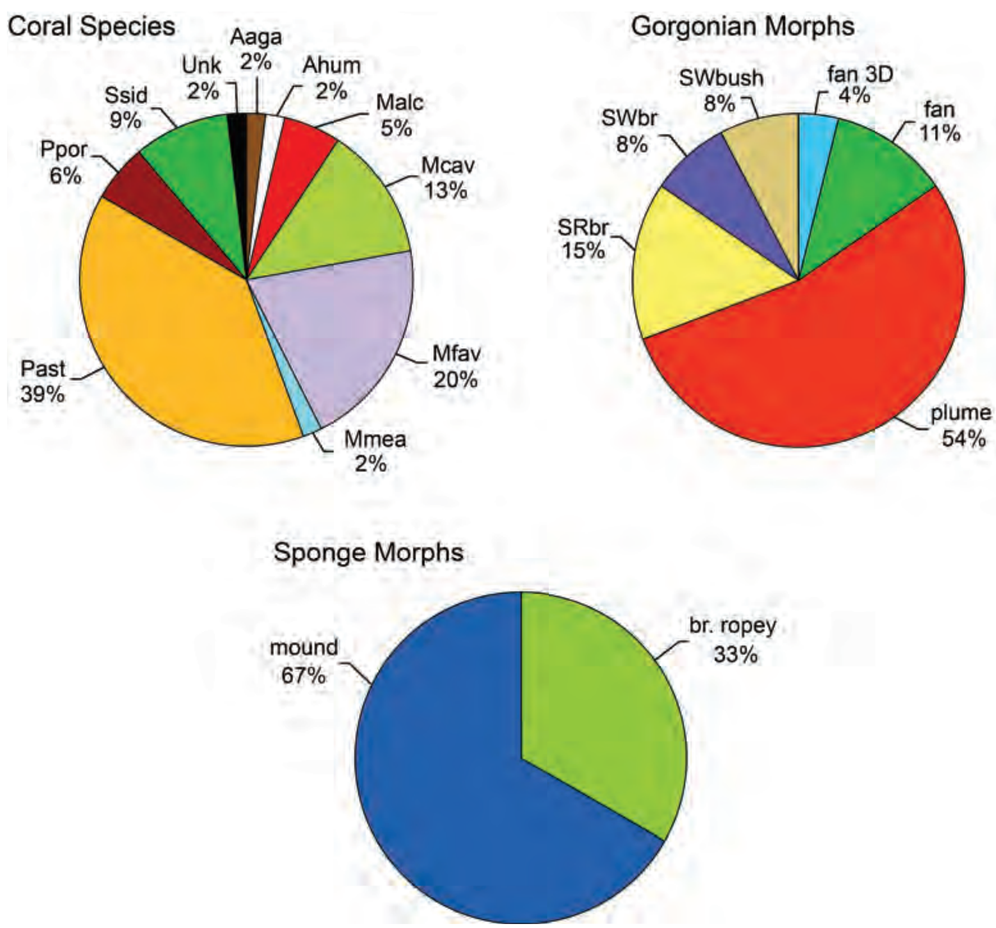



**Figure I-9. Percentages of stony coral species, gorgonian morphologies and sponge morphologies for BCG Station 6.**

**Table I-15. Fish species found in BCG Station 6, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass (g/100 $m^2$) |
|---|---|---|---|
| *Acanthurus bahianus* | Ocean Surgeonfish | 1 | 129 |
| *Acanthurus chirurgus* | Doctorfish | 1 | 121 |
| *Chaetodon capistratus* | Foureye Butterflyfish | 4 | 60 |
| *Elacatinus genie* | Cleaning Goby | 1 | 0 |
| *Epinephelus adscensionis* | Rock Hind | 1 | 174 |
| *Halichoeres garnoti* | Yellowhead Wrasse | 2 | 195 |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | 1 | 19 |
| *Hypoplectrus puella* | Barred Hamlet | 1 | 19 |
| *Lutjanus apodus* | Schoolmaster | 1 | 649 |
| *Mulloidichthys martinicus* | Yellow Goatfish | 2 | 472 |
| *Ocyurus chrysurus* | Yellowtail Snapper | 1 | 177 |
| *Scarus iseri* | Striped Parrotfish | 36 | 632 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 5 | 466 |
| *Sparisoma viride* | Stoplight Parrotfish | 11 | 1,606 |
| *Stegastes diencaeus* | Longfin Damselfish | 3 | 36 |
| *Stegastes leucostictus* | Beaugregory | 4 | 31 |
| *Stegastes partitus* | Bicolor Damselfish | 7 | 24 |
| *Stegastes planifrons* | Threespot Damselfish | 12 | 229 |
| *Thalassoma bifasciatum* | Bluehead | 12 | 55 |

# BCG Station 7
# (Field Station 16_2010)
# Coral Species Richness: 11
# Photo rank and rating: 4, Fair

**Table I-16. BCG Station 7 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/m$^2$) | 4.87 | 1.13 | 0 | 0.53 | 1.53 |
| Ave. 3D colony skeletal area (cm$^2$)/colony | 3,529 | 10,160 | 0 | 895 | 567 |
| Ave. 3D colony skeletal area (cm$^2$)/m$^2$ | 17,173 | 11,515 | 0 | 477 | 870 |
| Ave. 3D coral tissue area (cm$^2$)/colony | 2,920 | 9,057 | 0 | 790 | 469 |
| Ave. 3D coral tissue area (cm$^2$)/m$^2$ | 14,210 | 10,264 | 0 | 421 | 720 |
| Ave. 2D coral tissue area (cm$^2$)/m$^2$ | 5,089 | 3,537 | 0 | 167 | 303 |

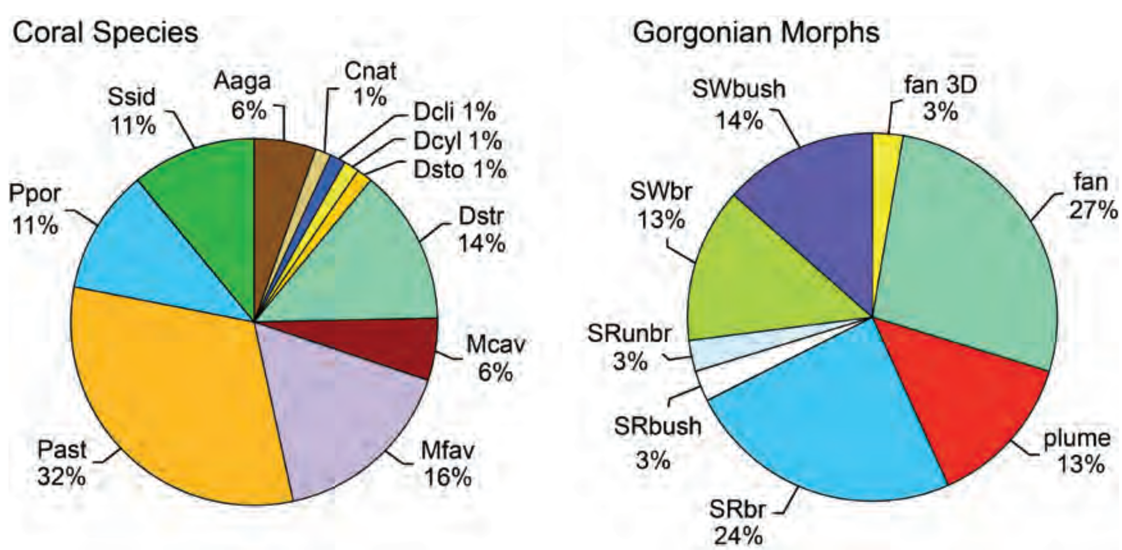



**Figure I-10. Percentages of stony coral species and gorgonian morphologies for BCG Station 7.**

No sponges were present at BCG Station 7.

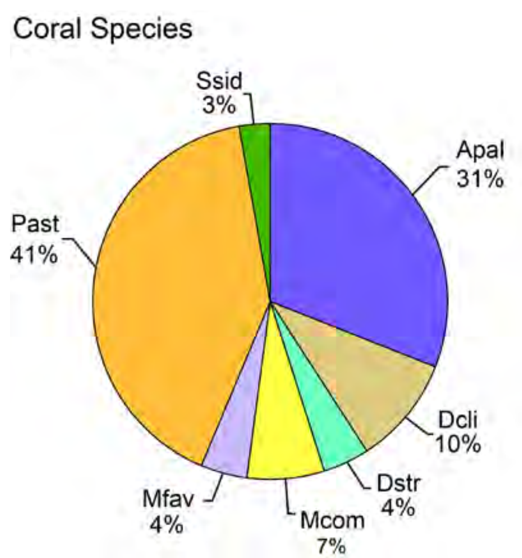
**Table I-17. Fish species found in BCG Station 7, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass ($g/100\ m^2$) |
|---|---|---|---|
| *Acanthurus coeruleus* | Blue Tang | 9 | 414 |
| *Chaetodon striatus* | Banded Butterflyfish | 2 | 124 |
| *Chromis multilineata* | Brown Chromis | 16 | 126 |
| *Haemulon aurolineatum* | Tomtate | 3 | 21 |
| *Haemulon flavolineatum* | French Grunt | 2 | 81 |
| *Holocentrus adscensionis* | Squirrelfish | 2 | 474 |
| *Lutjanus apodus* | Schoolmaster | 1 | 215 |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 13 | 1,133 |
| *Ocyurus chrysurus* | Yellowtail Snapper | 10 | 303 |
| *Pomacanthus paru* | French Angelfish | 1 | 342 |
| *Scarus iseri* | Striped Parrotfish | 16 | 1,515 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 17 | 475 |
| *Stegastes diencaeus* | Longfin Damselfish | 8 | 294 |
| *Stegastes leucostictus* | Beaugregory | 2 | 89 |
| *Stegastes partitus* | Bicolor Damselfish | 3 | 31 |
| *Thalassoma bifasciatum* | Bluehead | 36 | 110 |

# BCG Station 8
# (Field Station 108_2010)
# Coral Species Richness: 7
# Photo rank and rating: 6, Fair

**Table I-18. BCG Station 8 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/$m^2$) | 4.73 | 0.20 | 1.47 | 0.13 | 1.93 |
| Ave. 3D colony skeletal area ($cm^2$)/colony | 4,938 | 1,473 | 14,658 | 157 | 258 |
| Ave. 3D colony skeletal area ($cm^2$)/$m^2$ | 23,372 | 295 | 21,499 | 21 | 499 |
| Ave. 3D coral tissue area ($cm^2$)/colony | 4,149 | 949 | 12,274 | 157 | 239 |
| Ave. 3D coral tissue area ($cm^2$)/$m^2$ | 19,637 | 190 | 18,002 | 21 | 462 |
| Ave. 2D coral tissue area ($cm^2$)/$m^2$ | 4,549 | 52 | 3,964 | 10 | 273 |



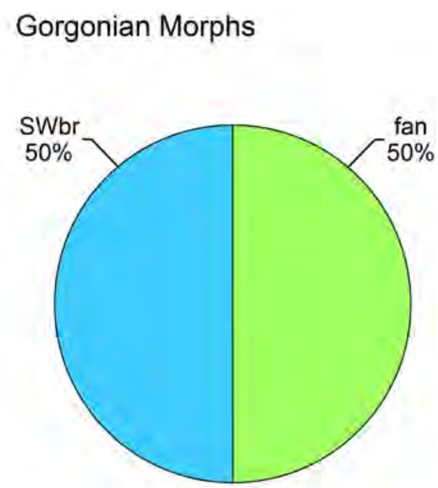




**Figure I-11. Percentages of stony coral species and gorgonian morphologies for BCG Station 8.** No sponges were present at BCG Station 8.

**Table I-19. Fish species found in BCG Station 8, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass ($g/100\ m^2$) |
|---|---|---|---|
| *Abudefduf saxatilis* | Sergeant Major | 3 | 99 |
| *Acanthurus bahianus* | Ocean Surgeonfish | 3 | 386 |
| *Acanthurus coeruleus* | Blue Tang | 31 | 1,479 |
| *Aulostomus maculatus* | Trumpetfish | 1 | 130 |
| *Haemulon flavolineatum* | French Grunt | 1 | 111 |
| *Halichoeres bivittatus* | Slippery Dick | 4 | 182 |
| *Halichoeres maculipinna* | Clown Wrasse | 6 | 24 |
| *Halichoeres radiatus* | Puddingwife | 1 | 0 |
| *Lutjanus apodus* | Schoolmaster | 4 | 341 |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 28 | 961 |
| *Ophioblennius macclurei* | Redlip Blenny | 1 | 4 |
| *Pomacanthus paru* | French Angelfish | 1 | 156 |
| *Scarus iseri* | Striped Parrotfish | 69 | 4,592 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 4 | 332 |
| *Sparisoma viride* | Stoplight Parrotfish | 2 | 326 |
| *Stegastes diencaeus* | Longfin Damselfish | 54 | 603 |
| *Stegastes partitus* | Bicolor Damselfish | 6 | 3 |
| *Thalassoma bifasciatum* | Bluehead | 98 | 331 |

# BCG Station 9
# (Field Station 109_2010)
# Coral Species Richness: 9
# Photo rank and rating: 7, Fair

**Table I-20. BCG Station 9 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/m$^2$) | 5.80 | 3.47 | 0 | 0.53 | 0.67 |
| Ave. 3D colony skeletal area (cm$^2$)/colony | 9,091 | 8,102 | 0 | 806 | 781 |
| Ave. 3D colony skeletal area (cm$^2$)/m$^2$ | 52,731 | 28,088 | 0 | 430 | 521 |
| Ave. 3D coral tissue area (cm$^2$)/colony | 3,462 | 4,040 | 0 | 734 | 739 |
| Ave. 3D coral tissue area (cm$^2$)/m$^2$ | 20,080 | 14,006 | 0 | 391 | 493 |
| Ave. 2D coral tissue area (cm$^2$)/m$^2$ | 5,917 | 4,015 | 0 | 213 | 298 |

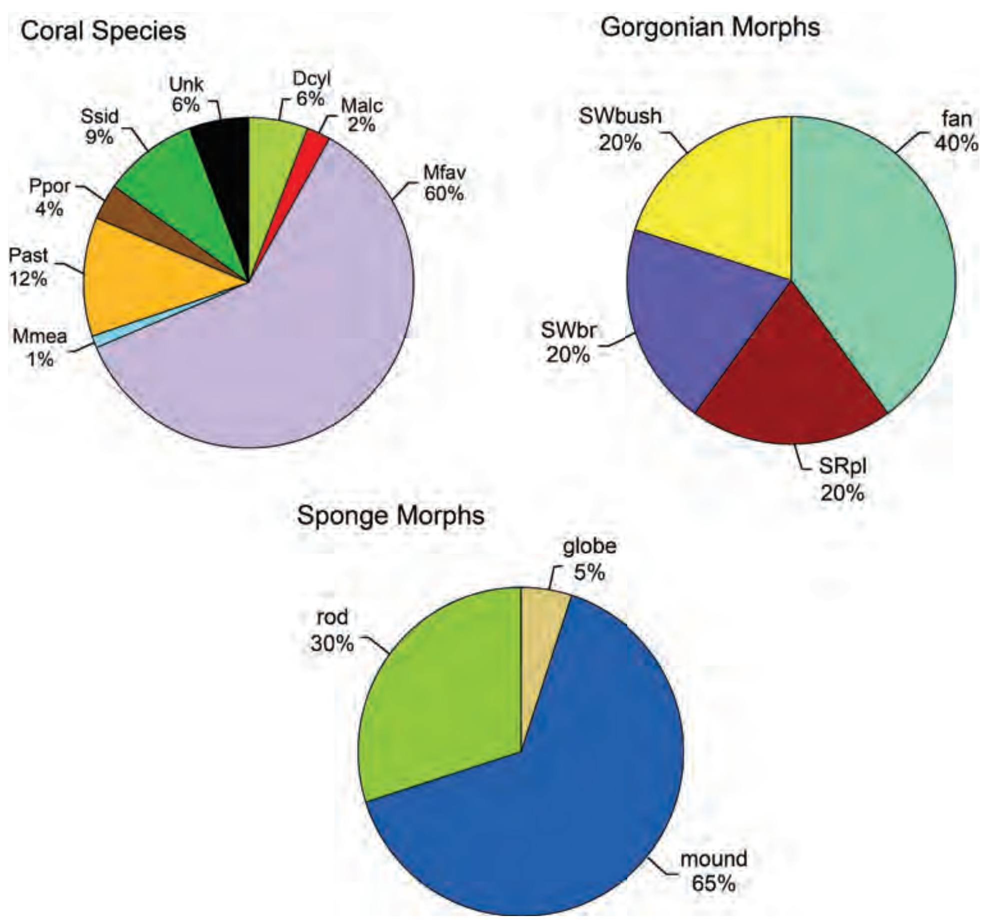



**Figure I-12. Percentages of stony coral species, gorgonian morphologies and sponge morphologies for BCG Station 9.**

**Table I-21. Fish species found in BCG Station 9, with density and biomass for 100 m$^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 m$^2$ | Total Biomass (g/100 m$^2$) |
|---|---|---|---|
| *Abudefduf saxatilis* | Sergeant Major | 4 | 263 |
| *Acanthurus bahianus* | Ocean Surgeonfish | 1 | 129 |
| *Acanthurus chirurgus* | Doctorfish | 10 | 1,206 |
| *Acanthurus coeruleus* | Blue Tang | 76 | 11,429 |
| *Anisotremus virginicus* | Porkfish | 3 | 851 |
| *Aulostomus maculatus* | Trumpetfish | 1 | 442 |
| *Cephalopholis cruentata* | Graysby | 1 | 178 |
| *Chaetodon striatus* | Banded Butterflyfish | 2 | 25 |
| *Coryphopterus glaucofraenum* | Bridled Goby | 10 | 7 |
| *Haemulon carbonarium* | Caesar Grunt | 3 | 915 |
| *Haemulon plumierii* | White Grunt | 1 | 539 |
| *Halichoeres bivittatus* | Slippery Dick | 2 | 342 |
| *Holocentrus adscensionis* | Squirrelfish | 1 | 433 |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | 3 | 12 |
| *Lutjanus apodus* | Schoolmaster | 2 | 431 |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 7 | 402 |
| *Mulloidichthys martinicus* | Yellow Goatfish | 1 | 236 |
| *Scarus iseri* | Striped Parrotfish | 19 | 98 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 4 | 1,008 |
| *Sparisoma viride* | Stoplight Parrotfish | 16 | 5,024 |
| *Stegastes diencaeus* | Longfin Damselfish | 30 | 348 |
| *Stegastes leucostictus* | Beaugregory | 2 | 20 |
| *Stegastes partitus* | Bicolor Damselfish | 18 | 79 |
| *Stegastes planifrons* | Threespot Damselfish | 2 | 24 |
| *Thalassoma bifasciatum* | Bluehead | 4 | 14 |

# BCG Station 10
# (Field Station 2011_1)
# Coral Species Richness: 11
# Photo rank and rating: 3, Fair

**Table I-22. BCG Station 10 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/m$^2$) | 2.8 | 1.88 | 0.04 | 0.08 | 0.4 |
| Ave. 3D colony skeletal area (cm$^2$)/colony | 7,205 | 10,095 | 9,503 | 3,662 | 794 |
| Ave. 3D colony skeletal area (cm$^2$)/m$^2$ | 20,174 | 18,979 | 380 | 293 | 317 |
| Ave. 3D coral tissue area (cm$^2$)/colony | 3,938 | 5,549 | 0 | 1,405 | 640 |
| Ave. 3D coral tissue area (cm$^2$)/m$^2$ | 11,026 | 10,432 | 0 | 112 | 256 |
| Ave. 2D coral tissue area (cm$^2$)/m$^2$ | 3,698 | 3,496 | 0 | 50 | 94 |

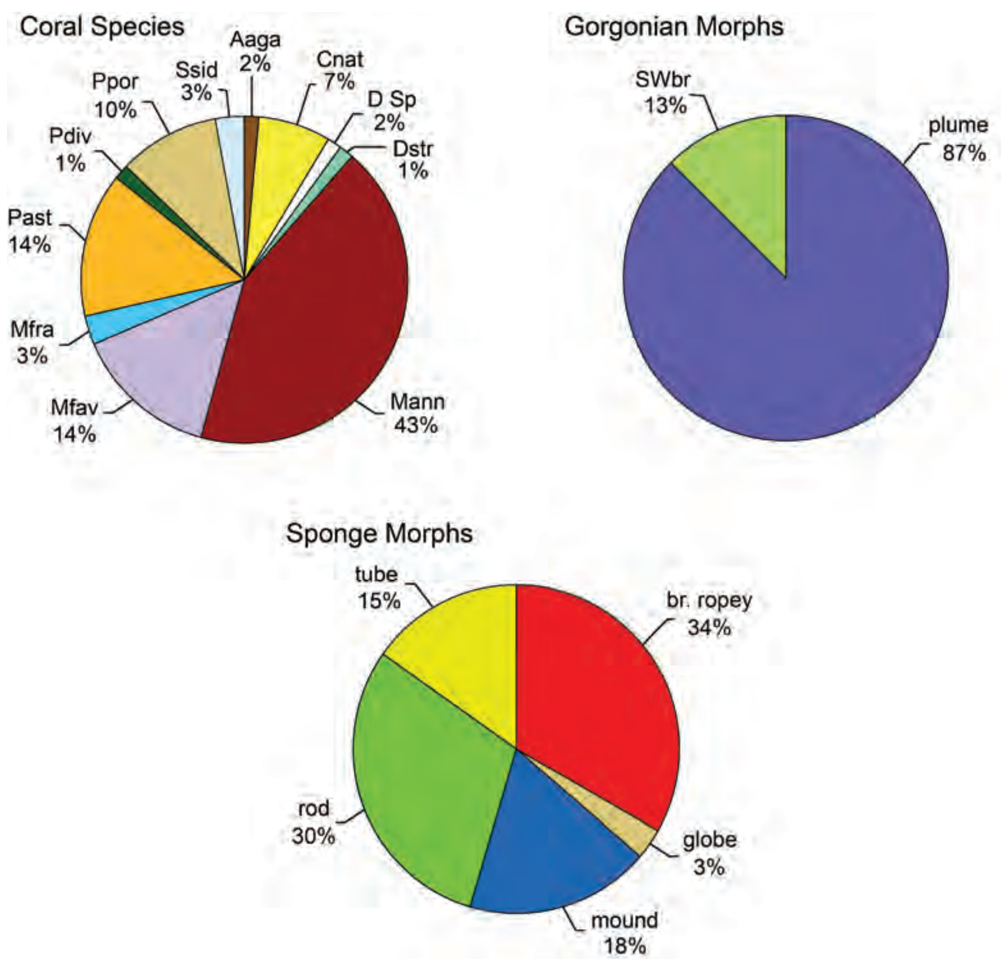



**Figure I-13. Percentages of stony coral species, gorgonian morphologies and sponge morphologies for BCG Station 10.**

**Table I-23. Fish species found in BCG Station 10, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass ($g/100\ m^2$) |
|---|---|---|---|
| *Chaetodon capistratus* | Foureye Butterflyfish | 2 | 30 |
| *Decapterus macarellus* | Mackerel Scad | 4 | 250 |
| *Haemulon flavolineatum* | French Grunt | 22 | 2,441 |
| *Hypoplectrus chlorurus* | Yellowtail Hamlet | 2 | 24 |
| *Malacanthus plumieri* | Sand Tilefish | 1 | 24 |
| *Malacoctenus triangulatus* | Saddled Blenny | 4 | 1 |
| *Odontoscion dentex* | Reef Croaker | 14 | 804 |
| *Pomacanthus paru* | French Angelfish | 2 | 2,161 |
| *Scarus iseri* | Striped Parrotfish | 6 | 45 |
| *Sparisoma viride* | Stoplight Parrotfish | 15 | 789 |
| *Stegastes partitus* | Bicolor Damselfish | 3 | 2 |
| *Stegastes planifrons* | Threespot Damselfish | 96 | 1,982 |

# BCG Station 11
# (Field Station 46_2011)
# Coral Species Richness: 9
# Photo rank and rating: 5, Fair

**Table I-24. BCG Station 11 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/$m^2$) | 1.76 | 0.16 | 0.60 | 0.20 | 0.60 |
| Ave. 3D colony skeletal area ($cm^2$)/colony | 8,236 | 639 | 21,258 | 1,210 | 422 |
| Ave. 3D colony skeletal area ($cm^2$)/$m^2$ | 14,495 | 102 | 12,755 | 242 | 253 |
| Ave. 3D coral tissue area ($cm^2$)/colony | 6,610 | 495 | 16,902 | 491 | 363 |
| Ave. 3D coral tissue area ($cm^2$)/$m^2$ | 11,635 | 79 | 10,141 | 98 | 218 |
| Ave. 2D coral tissue area ($cm^2$)/$m^2$ | 2,598 | 41 | 2,187 | 44 | 96 |

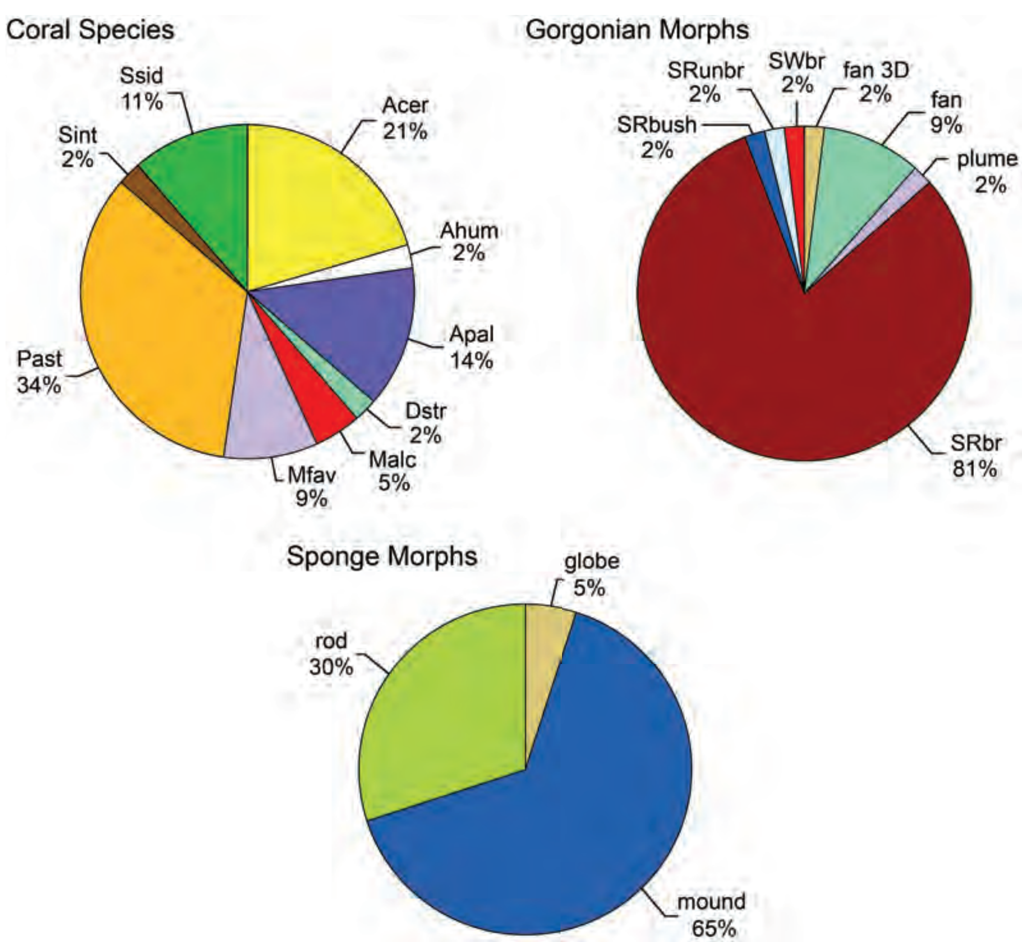



**Figure I-14. Percentages of stony coral species, gorgonian morphologies and sponge morphologies for BCG Station 11.**

**Table I-25. Fish species found in BCG Station 11, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass ($g/100\ m^2$) |
|---|---|---|---|
| *Acanthurus bahianus* | Ocean Surgeonfish | 21 | 959 |
| *Acanthurus coeruleus* | Blue Tang | 7 | 831 |
| *Aulostomus maculatus* | Trumpetfish | 1 | 15 |
| *Caranx ruber* | Bar Jack | 20 | 134 |
| *Cephalopholis cruentata* | Graysby | 1 | 82 |
| *Chaetodon capistratus* | Foureye Butterflyfish | 10 | 150 |
| *Chaetodon striatus* | Banded Butterflyfish | 4 | 247 |
| *Haemulon carbonarium* | Caesar Grunt | 15 | 1,543 |
| *Haemulon chrysargyreum* | Smallmouth Grunt | 30 | 1,011 |
| *Haemulon flavolineatum* | French Grunt | 15 | 606 |
| *Halichoeres garnoti* | Yellowhead Wrasse | 1 | 82 |
| *Halichoeres maculipinna* | Clown Wrasse | 1 | 5 |
| *Halichoeres radiatus* | Puddingwife | 4 | 68 |
| *Holocentrus rufus* | Longspine Squirrelfish | 2 | 190 |
| *Lutjanus apodus* | Schoolmaster | 5 | 185 |
| *Malacanthus plumieri* | Sand Tilefish | 15 | 367 |
| *Microspathodon chrysurus* | Yellowtail Damselfish | 14 | 1,204 |
| *Myripristis jacobus* | Blackbar Soldierfish | 1 | 107 |
| *Scarus iseri* | Striped Parrotfish | 46 | 386 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 2 | 119 |
| *Stegastes adustus* | Dusky Damselfish | 11 | 132 |
| *Stegastes leucostictus* | Beaugregory | 1 | 1 |
| *Stegastes partitus* | Bicolor Damselfish | 10 | 45 |
| *Thalassoma bifasciatum* | Bluehead | 170 | 698 |

# BCG Station 12
# (Field Station 25_2011)
# Coral Species Richness: 8
# Photo rank and rating: 2, Fair

**Table I-26. BCG Station 12 data summary for corals and subgroups.** See Appendix J for formulas used and species abbreviations.

| Coral Parameters | All Species | Massive Species | Acroporid Species | *Siderastrea siderea* | *Porites astreoides* |
|---|---|---|---|---|---|
| Colony density (#/m$^2$) | 3.8 | 1.56 | 0 | 0.36 | 1.72 |
| Ave. 3D colony skeletal area (cm$^2$)/colony | 3,525 | 7,563 | 0 | 592 | 740 |
| Ave. 3D colony skeletal area (cm$^2$)/m$^2$ | 13,396 | 11,799 | 0 | 213 | 1,273 |
| Ave. 3D coral tissue area (cm$^2$)/colony | 2,421 | 5,037 | 0 | 460 | 619 |
| Ave. 3D coral tissue area (cm$^2$)/m$^2$ | 9,199 | 7,857 | 0 | 166 | 1,065 |
| Ave. 2D coral tissue area (cm$^2$)/m$^2$ | 3,498 | 2,928 | 0 | 61 | 472 |

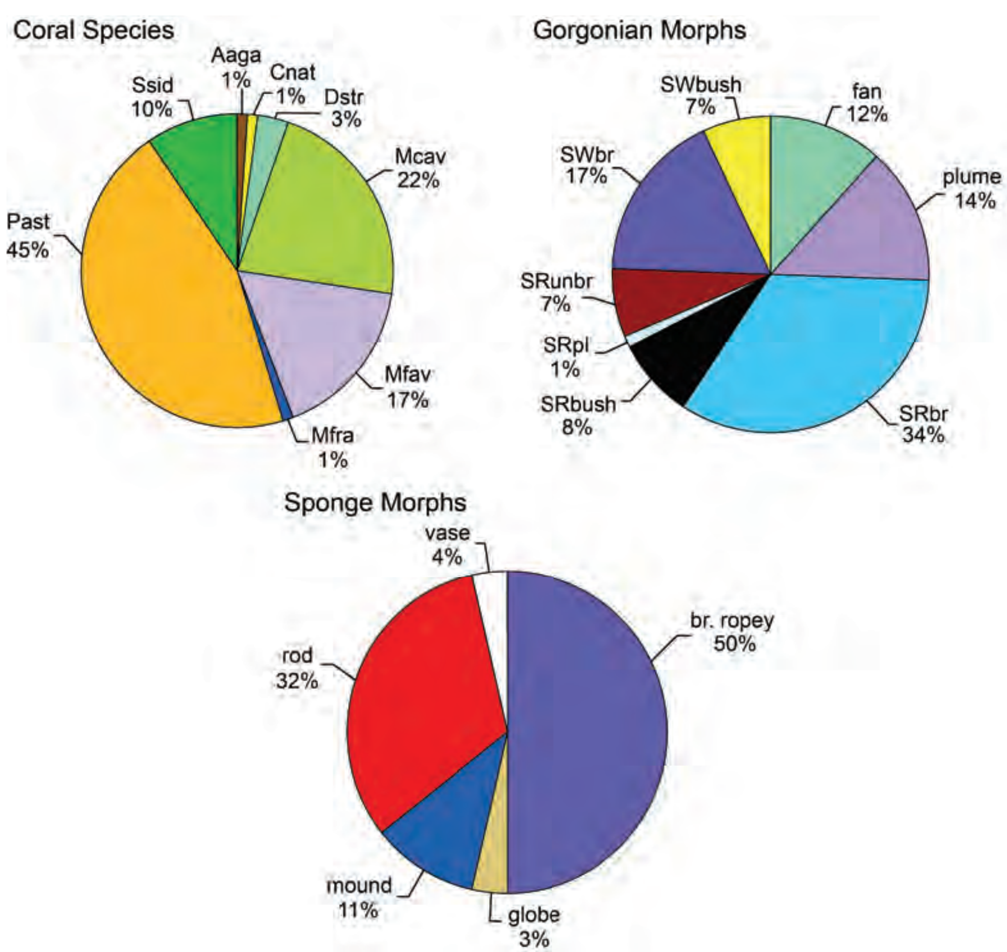



**Figure I-15. Percentages of stony coral species, gorgonian morphologies and sponge morphologies for BCG Station 12.**

**Table I-27. Fish species found in BCG Station 12, with density and biomass for 100 $m^2$ transect.**

| Fish Species | Common Name | Abundance/ 100 $m^2$ | Total Biomass ($g/100\ m^2$) |
|---|---|---|---|
| *Acanthurus bahianus* | Ocean Surgeonfish | 2 | 91 |
| *Acanthurus chirurgus* | Doctorfish | 1 | 44 |
| *Haemulon flavolineatum* | French Grunt | 3 | 262 |
| *Labrisomus nuchipinnis* | Hairy Blenny | 1 | 33 |
| *Lutjanus apodus* | Schoolmaster | 1 | 101 |
| *Myripristis jacobus* | Blackbar Soldierfish | 1 | 107 |
| *Scarus iseri* | Striped Parrotfish | 8 | 85 |
| *Sparisoma aurofrenatum* | Redband Parrotfish | 6 | 247 |
| *Sparisoma viride* | Stoplight Parrotfish | 4 | 534 |
| *Stegastes adustus* | Dusky Damselfish | 1 | 12 |

# Appendix J. Formulas Used for Calculating Condition Metrics
# 1. Stony Corals

## *Coral metrics*

Colony surface area
Coral abundance
Percent live tissue
Live colony three-dimensional surface area
Live colony two-dimensional surface area

## *Colony condition measurements*

Every scleractinian coral within a 25 $m^2$ transect area (25 m x 1 m) and greater than 10 cm was identified to species. The maximum height and diameter of each colony was measured in cms, and the percent of living coral tissue on the skeleton of the colony was estimated in 10% increments. The percent tissue (living coral) was estimated for the entire colony in three dimensions, not only from an aerial planar view. The observations and measurements made for each coral colony included: scleractinian taxon, height (cm), maximum diameter (cm) and percent living colony tissue.

## *Formulas*

*Colony surface area* (CSA) was the total three-dimensional colony surface area ($cm^2$) including both living and dead portions of a single coral colony.

$$CSA = \pi r^2 M$$

r = [colony height (cm) + (colony diameter (cm)/2)] /2

M = morphological conversion factor (values of 1, 2, 3, or 4 depending on coral species morphology), see Table J-1

*Coral abundance* (n) was total number of colonies in the entire transect area

*% Live tissue* (LT) was estimation of percent live tissue on a single coral colony over the entire surface area. It was estimated for every coral colony in transect.

*Live colony 3D surface area* (LCSA_3D) was a calculated value for the total three-dimensional colony surface area ($cm^2$) of only living tissue on a single coral colony.

$$LCSA\_3D = CSA * (LT/100)$$

*Live colony 2D surface area* (LCSA_2D) was a calculated value for the total planar colony surface area ($cm^2$) of living tissue on a single coral colony as though it were viewed from above. This calculation assumes equal distribution of living tissue on a colony, which was initially recorded for three dimensions rather than two. It approximates percent coral cover used as the standard in many historical assessments.

$$LCSA\_2D = \pi\,[\text{colony diameter (cm)}/2]^2 * (LT/100)$$

## *Coral metrics calculated for each BCG station*

Ave. 3D colony skeletal area ($cm^2$)/colony = Σ CSA/n

Ave. 3D colony skeletal area ($cm^2$)/$m^2$ = Σ CSA/area of transect

Ave. 3D coral tissue (live) area ($cm^2$)/colony = Σ LCSA_3D/n

Ave. 3D coral tissue (live) area ($cm^2$)/$m^2$ = Σ LCSA_3D/area of transect

Ave. 2D coral tissue (live) area ($cm^2$)/$m^2$ = Σ LCSA_2D/area of transect

**Table J-1. Stony corals included in Western Atlantic and Caribbean assessments (as provided by Humann and DeLoach 2002) with the three-letter identification code and the morphological conversion factor for calculating 3D surface area** (Santavy et al. 2012).

| Genus and Species | ID Code | Conversion Factor |
|---|---|---|
| *Acropora cervicornis* | Acer | 4 |
| *Acropora palmata* | Apal | 4 |
| *Acropora prolifera* | Apro | 4 |
| *Agaricia agaricites* | Aaga | 1 |
| *Agaricia fragilis* | Afra | 1 |
| *Agaricia humilis* | Ahum | 1 |
| *Agaricia lamarcki* | Alam | 1 |
| *Agaricia tenuifolia* | Aten | 3 |
| *Cladocora arbuscula* | Carb | 2 |
| *Colpophyllia natans* | Cnat | 2 |
| *Dendrogyra cylindrus* | Dcyl | 3 |
| *Dichocoenia stokesii* | Dsto | 2 |
| *Diploria clivosa*[1] | Dcli | 2 |
| *Diploria labyrinthiformis* | Dlab | 2 |
| *Diploria strigosa*[1] | Dstr | 2 |
| *Eusmilia fastigiata* | Efas | 3 |
| *Favia fragum* | Ffra | 2 |
| *Leptoseris cucullata* | Lcuc | 1 |
| *Isophyllastrea rigida* | Irig | 2 |
| *Isophyllia sinuosa* | Isin | 2 |
| *Madracis decactis* | Mdec | 3 |
| *Madracis formosa* | Mfor | 3 |
| *Madracis mirabilis* | Mmir | 3 |
| *Madracis pharensis* | Mpha | 1 |
| *Manicina areolata* | Mare | 2 |
| *Meandrina meandrites* | Mmea | 2 |
| *Millepora complanata* | Mcom | 3 |
| *Montastraea annularis*[2] | Mann | 3 |
| *Montastraea cavernosa* | Mcav | 2 |
| *Montastraea faveolata*[2] | Mfav | 2 |

**Table J-1. (continued)**

| Genus and Species | ID Code | Conversion Factor |
|---|---|---|
| *Mussa angulosa* | Mang | 2 |
| *Mycetophyllia aliciae* | Mali | 1 |
| *Mycetophyllia danaana* | Mdan | 1 |
| *Mycetophyllia ferox* | Mfer | 1 |
| *Mycetophyllia lamarckiana* | Mlam | 1 |
| *Oculina varicosa* | Ovar | 3 |
| *Porites astreoides* | Past | 2 |
| *Porites colonensis* | Pcol | 1 |
| *Porites divaricata* | Pdiv | 3 |
| *Porites furcata* | Pfur | 3 |
| *Porites porites* | Ppor | 3 |
| *Siderastrea siderea* | Ssid | 2 |
| *Solenastrea bournoni* | Sbou | 2 |
| *Solenastrea hyades* | Shya | 3 |
| *Stephanocoenia intersepta* | Sint | 2 |

1: This report does not adopt the new classifications for *Diploria strigosa* and *Diploria clivosa* as the original genus *Pseudodiploria* (Budd et al. 2012).

2: This report does not adopt the new classification for the *Montastraea annularis* species-complex (*Montastraea annularis*, *Montastraea faveolata* and *Montastraea franksi*) which has been reclassified as the original genus *Orbicella* (Budd et al. 2012).

## 2. Rugosity

### *Rugosity measurement and metric*

Rugosity was the linear ratio of a 6 m chain length compared to the taunt linear distance in centimeters of a draped chain. Rugosity is a reef-scale indicator of reef contour. It was determined using a chain-transect method that compares the length of a chain draped along the top of corals and along the bottom of the reef to the length of a taut line across the same linear distance using a separate tape measure, laid parallel but not on top of the transect tape. The linked chain was placed such that it follows the relief of hard bottom substrate. The chain was placed on top of any hard substrate encountered, but not on top of gorgonians or sponges since only hard bottom rugosity was being measured.

### *Formula*

Rugosity was the ratio of the overall length of chain draped over the reef contour divided by the straight horizontal distance between the beginning and the end of the chain. Therefore, if 6 m of chain is laid out over a 4 m horizontal distance, the rugosity is 6/4 = 1.5 for that segment. Rugosity will always be $\geq$ 1. Higher values relate to increased rugosity or reef relief. The average rugosity was calculated per transect.

## 3. Fish

### *Fish metrics*

Abundance at lowest taxonomic level possible

Length in cms

Biomass of fish in g/100 $m^2$

### *Fish measurements*

Fish contained within a 100 $m^2$ transect area, 25 m length x 4 m width (height was water depth) were recorded to the lowest taxonomic level possible. All fish greater than 3 cm in size were included in the assessment. Each fish was scored as 5 cm size class increments up to 35 cm for fork length using visual estimation. If a fish was longer than 35 cm, an estimate of the actual fork length was made. The fork length was measured from the fish snout (with mouth closed) to the fork at the base of the tail or caudal fin. Observations and measurements made for each fish included taxon and size class.

### *Formulas*

*Abundance* (n) was total number of fish in the entire transect area
*Density* was the number of fish of a single taxon per 100 $m^2$
*Biomass* (W) was the weight recorded as g/100 $m^2$ of a single fish

$W = \alpha L^{\beta}$

L = fork length as midpoint between 5 cm increment class (e.g., 10–15 cm class using 12.5 as length in calculation). L > 35 cm uses actual length.

α and β are species specific coefficients obtained from FishBase (www.fishbase.org) for calculating fish biomass (see Appendix A in Santavy et al. 2013). Biomass for species with no published length-weight relationships can be calculated using terms for the closest congener based on morphology.

### *Fish metrics calculated for each BCG station*

Total biomass for each taxon per 100 $m^2 = \sum_{i=1}^{n} \mathrm{W}$

## 4. Gorgonians

### *Gorgonian metrics*

Density was the number of individuals/$m^2$

Average three-dimensional surface area gorgonian/$m^2$

Average three-dimensional surface area gorgonian/individual

### *Gorgonian measurements*

Every gorgonian ≥ 10 cm (in any dimension) that falls within the quadrat was classified as one of ten gorgonian morphologies (Table J-2). If the base of the gorgonian was in the quadrat, it was considered in the transect area. Colony height (greatest distance from substrate) and maximum diameter (parallel to the substrate) were measured in cms. The observations and measurements made for each individual were gorgonian colony shape, height and maximum diameter. Although gorgonians are prominent reef inhabitants, they are often excluded from monitoring programs. This is partially because they are not widely recognized for their important functional contributions to reef environments, and partially because taxonomic distinctions can be difficult. In this approach, classification was based on morphology, categorized by predetermined shapes, which can be easier to apply than taxonomy and still can influence their ecosystem functions.

### *Formulas and BCG station metrics*

*Abundance* (n) was total number of gorgonians in the entire transect area

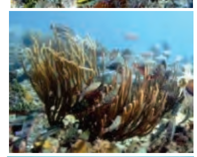
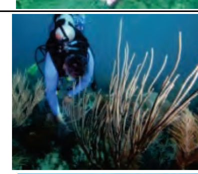
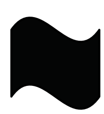
Average three-dimensional surface area of each gorgonian morph/$m^2$ =

$$\sum_{i=1}^{n} \frac{(\text{regression equation for SA in Table J} - 2)}{\text{area of transect}}$$

Average three-dimensional surface area of each gorgonian morph/colony =

$$\sum_{i=1}^{n} \frac{(\text{regression equation for SA in Table J} - 2)}{n}$$

**Table J-2. Gorgonian morphological shapes, abbreviations, simulated model, *in situ* example and regression models to estimate three-dimensional surface area** (Santavy et al. 2013).

| Gorgonian Morphology | Species Example | Simulated Model | *in situ* Example | Surface Area Estimations |
|---|---|---|---|---|
| Sea Fans | Planar (fan pl) *(Gorgonia ventalina, Leptogorgia)* |  |  | $SA=0.68h^2+0.66d^2-3.61$ |
| | Three-dimensional (3D fan) *(Gorgonia flabellum)* |  |  | $SA=0.0113h^3+106d-1190$ |
| Sea Rods<br>branch and branchlet diameter ≥ 15–≤30 mm | Unbranched (SR ub) digitate form *(Briareum)* |  |  | $SA=0.341d^3+11.2h-127$ |
| | Branched (SR br) *(Plexaura)* |  |  | $SA=1.46d^2+399$ |
| | Bushy (SR bush) *(Eunicea fusca)* |  |  | $SA=0.0288h^3+939$ |
| | Planar (SR pl) *(Eunicea tourneforti)* |  |  | $SA=76.4d-806$ |
| Sea Whips<br>branch and branchlet diameter ≥5–≤15 mm | Branched (SW br) *(Pterogorgia)* |  |  | $SA=-0.479h^3+3.37h^2-51.3h+354$ |
| | Bushy (SW bush) *(Pterogorgia guadalupensi)* |  |  | $SA=0.0672d^3+1610$ |
| Sea Plumes<br>smallest branch and branchlet diameter usually ≤5 mm | (Plume) *(Muriceopsis flavida, Pseudopterogorgia)* |  |  | $SA=4.77h^2-2990$ |
| Encrusting Gorgonians | *(Briareum, Erythopodium)* |  |  | $SA=dw$ |

Minimum height (h) and diameter (d) of colony size required for use in the equations. h is the maximum colony height measured in cm, d is the maximum colony diameter measured in cm.

## 5. Sponges

### *Sponge metrics*

Density was the number of individuals/$m^2$

Average three-dimensional surface area of sponges/$m^2$

Average three-dimensional surface area of sponges/individual

### *Sponge measurements*

Every sponge ≥ 10 cm (in any dimension) falling within the quadrat was classified as one of ten sponge morphologies (Table J-3). If the base of sponge was in the quadrat, it was considered in the transect area. Colony height (greatest distance from substrate) and maximum diameter (parallel to the substrate) were recorded in cms. The observations and measurements made for each sponge were colony shape, height and maximum diameter. Although sponges are one of the most prominent sessile invertebrates on coral reefs, they are often overlooked in monitoring programs. This may be in part because sponge taxonomic classification is confounded by high diversity and morphological plasticity. In this approach, classification was based on morphology rather than taxonomy and can influence their ecosystem functions.

### *Formulas and BCG station metrics*

*Abundance* (n) was total number of sponges in the entire transect area

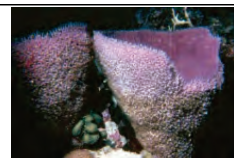
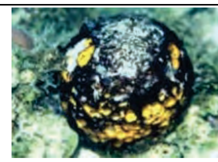
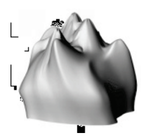
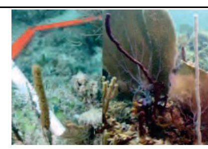
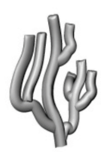
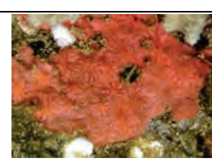
Average three-dimensional surface area of each sponge morph/$m^2$ =

$$\sum_{i=1}^{n} \frac{(\text{regression equation for SA in Table J}-3)}{\text{area of transect}}$$

Average three-dimensional surface area of each sponge morph per individual =

$$\sum_{i=1}^{n} \frac{(\text{regression equation for SA in Table J}-3)}{n}$$

**Table J-3. Sponge morphological shapes, abbreviations, simulated model, *in situ* example and regression models to estimate surface area** (Santavy et al. 2013).

| Sponge Morphology | Species Example | Simulated Model | *in situ* Example | Surface Area Estimations |
|---|---|---|---|---|
| Barrel | *Xestospongia muta, Verongula reiswigi* |  |  | $SA=4.31d^2 + 0.827h^2 +108$ |
| Vase | *Callyspongia plicifera, Callyspongia vaginalis* |  |  | $SA=3.71h^2-161$ |
| Globe | *Iricinia strobilina, Spheciospongia vesparium* |  |  | $SA=1.88h^2 +0.0573d^3+83.3$ |
| Tube | *Aplysina archeri, Aplysina fistularis* |  |  | $SA=0.493d^3+109$ |
| Mound | *Oligoceras hemorrhages, Iricinia felix* |  |  | $SA=30.0h+18.7d-193$ |
| Rod | *Aplysina cauliformis, Niphates erecta* |  |  | $SA=7.69h+1.83d^3-33.5$ |
| Bushy | *Aplysina fulva* |  |  | $SA=0.462h^2+0.834d^2+19.3$ |
| Branched Ropey | *Iotrochota birotulata* |  |  | $SA=18.8d+7.97h-132$ |
| Encrusting | *Amphimedon compressa, Chrondrilla caribensis* |  |  | $SA=dw$ |

Minimum height (h) and diameter (d) of colony size required for use in the equations. h is the maximum colony height measured in cm, d is the maximum colony diameter measured in cm.

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