Calibration of the Biological Condition Gradient (BCG) for Florida's Coral Reef

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FLORIDA'S CORAL REEF

TETRA TECH

Notice and Disclaimer

The Florida Department of Environmental Protection (DEP) funded and collaborated in the research described here through contract WQ168. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This report summarizes calibration of the Biological Condition Gradient (BCG) for the coral/benthic assemblage of Florida's Coral Reef ecosystem. Through an iterative process, scientists from throughout Florida used survey data and expert knowledge to develop quantitative decision rules to describe six Levels of coral reef ecosystem condition.

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Executive Summary

A coral reef Biological Condition Gradient (BCG), which was initially developed for the Caribbean coral reef ecosystem, has been applied to the near shore coral reefs within Florida jurisdictional waters (Florida's Coral Reef), including sites in the Dry Tortugas, the Florida Keys, Biscayne National Park, and up the eastern coast of Florida to Martin County. The BCG is a conceptual model that describes how biological attributes of aquatic ecosystems change along a gradient of increasing human disturbance.

Highly knowledgeable coral reef ecologists from throughout Florida evaluated site-specific quantitative data from diver-based visual surveys on species size-structured abundance, community structure and benthic habitat composition to develop robust decision rules. The experts assigned individual species to BCG attributes; assigned stations to BCG levels based on the sample composition and taxa attribute assignments; developed preliminary narrative decision rules for semi-quantitative BCG models; and developed, reconciled, revised and tested quantitative decision rules for coral/benthic organisms.

In calibrating the BCG, the experts used coral reef condition data from multiple long-term surveys in Florida. The Florida data files were in unique formats, collected using various sampling designs and methodologies, reporting a variety of ecological and environmental parameters, and utilizing different codes and groupings for variables.

Experts characterized coral species attributes based on prevalence, life history traits, susceptibility to bleaching and disease, and sensitivity to pollution. Experts reviewed data for taxa attributes and traits present at each site and developed numeric rules that distinguished between BCG Levels based on measurable sample characteristics. The numeric rules were compiled into a BCG expert decision model that could accurately and transparently replicate the decisions that the experts expressed during sample reviews.

The model includes a cascade of rules for membership at each BCG Level, starting with conceptual rules for Level 2 and proceeding with testable rules for Levels 3 through 5. Samples that failed at all Levels automatically were evaluated as Level 6. No Level 1 rules were developed because Level 1 conditions were unobservable.

The predictive BCG model was accurate, though not perfect, in replicating assessment decisions made by the experts. Predictions of BCG Levels from model application agreed with expert consensus of BCG Levels for 93% of the sites (calibration). All model predictions were within one BCG Level of the expert consensus for all sites. This degree of predictive accuracy is as good or better than examples of other BCG models from different ecological settings.

Florida's Coral Reef BCG can be used to identify high quality reefs, evaluate Best Management Practices (BMP) effectiveness, support biological criteria development and prioritize protection and restoration of coral reef ecosystems.

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Acknowledgements

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Acronyms

BCA – Broward County Site A
BCG – Biological Condition Gradient
CREMP – Coral Reef Evaluation and Monitoring Program
DEMO – Demographic benthic sampling method
DEP – Department of Environmental Protection (Florida)
DRM – Disturbance Response Monitoring
ECA – Ecosystem Conservation Area
EPA – U.S. Environmental Protection Agency
FKNMS – Florida Keys National Marine Sanctuary
FRRP – Florida Reef Resilience Program
FWC – Florida Fish and Wildlife Conservation Commission
LRBC – Large reef-building coral
NCRMP – National Coral Reef Monitoring Program (NOAA)
NOAA – National Oceanic and Atmospheric Administration
NPS – National Park Service
QA/QC – Quality Assurance and Quality Control
SECREMP – Southeast Coral Reef Evaluation and Monitoring Program
SEFCRI – Southeast Florida Coral Reef Initiative
SFCN – South Florida and Caribbean Network (NPS)
SST – Sea Surface Temperature
Tt – Tetra Tech
USA – United States of America

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Chapter 1. Introduction

1.1 BCG Concepts

This report describes the process used to calibrate the coral reef Biological Condition Gradient (BCG) for Florida. The BCG is a conceptual model that describes six levels of biological condition along a gradient of anthropogenic stress, ranging from undisturbed/natural (BCG level 1) to highly disturbed/degraded conditions (BCG level 6) (**Figure 1**) (Davies and Jackson 2006; USEPA 2016). The BCG can be used to characterize condition, regardless of assessment method (Davies and Jackson 2006). This is particularly important in the case of Florida, where multiple monitoring programs are monitoring the coral reef ecosystem, using disparate assessment methods.

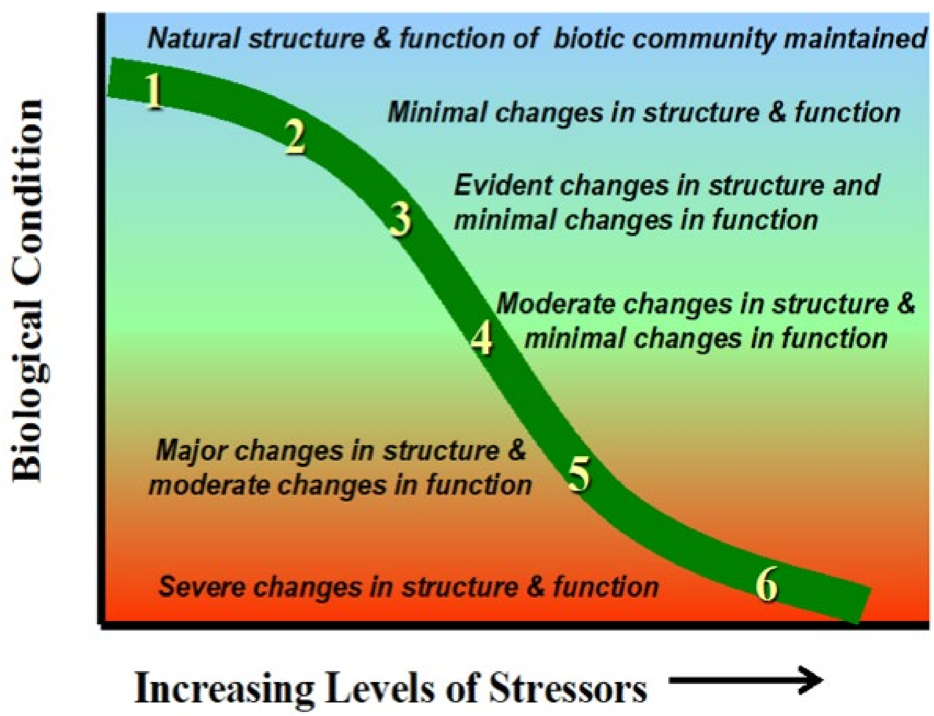

Figure 1. The Biological Condition Gradient (BCG).

The BCG was originally developed for freshwater ecosystems in the USA to support state biological assessment and criteria programs (Davies and Jackson 2006) and recently adapted for the US Caribbean coral reef ecosystems of Puerto Rico and US Virgin Islands (Bradley et al. 2020; USEPA 2021; Santavy et al. 2021, 2022).

The BCG framework includes two important concepts: Attributes and Levels.

- **BCG Attributes** include properties of the aquatic communities (e.g., tolerance, rarity, native-ness) and organisms (e.g., condition, function). As part of the model-development process the experts assign individual taxa to BCG Attributes I – VI. Attribute I taxa are specialist, historically important, or endemic taxa. Attributes II – V are generally related to taxa endemism and pollution tolerance (**Figure 2**). Non-native taxa are assigned to Attribute VI. Attributes VII – X pertain to organism condition, system performance, and physical-biotic interactions, and these have not typically been used in model development. BCG attribute descriptions are provided in **Appendix A**.
- **BCG Levels** describe the six levels of biological response to increasing amounts of stress. Level 1 conditions occur when human disturbance is entirely or almost entirely absent; these conditions are rarely found in aquatic environments, especially given ubiquitous stressors introduced by global phenomena such as climate change and atmospheric deposition. Levels 2 – 5 reflect successively reduced biological condition; these are the Levels most often observed during BCG calibration exercises. Level 6 communities have severely altered structure and function compared to natural expectations. BCG Level descriptions are provided in **Appendix B.**

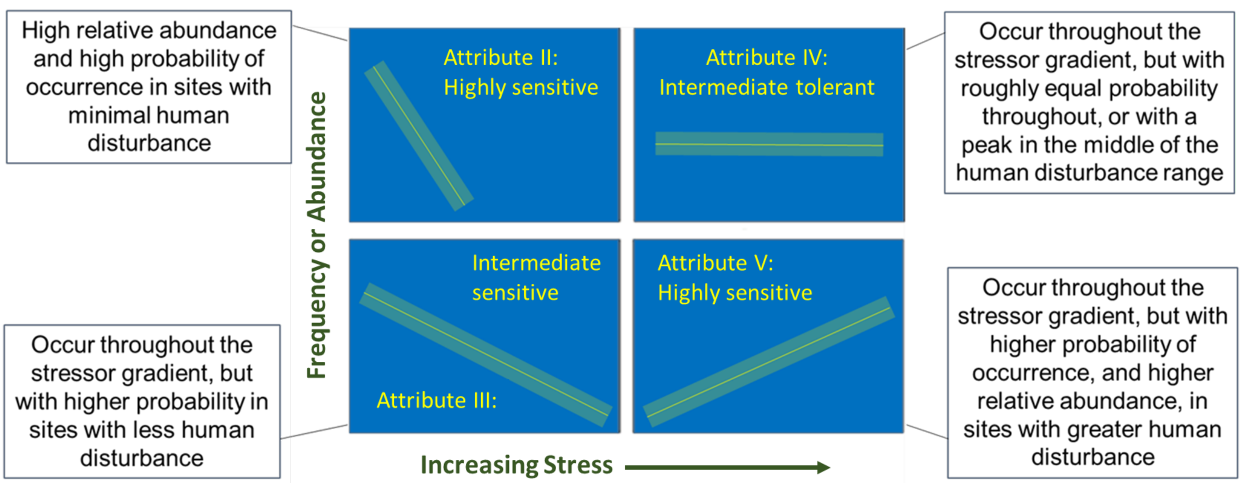

Figure 2. Patterns of frequency or abundance in relation to increasing stress associated with the BCG Attributes assigned to stony coral taxa. Attributes II – V are based on taxa prevalence and stressor tolerance. Attributes I (endemic, specialist species) and VI (non-native species) are not shown in the Figure because they are not necessarily associated with the stressor intensity shown on the x-axis.

1.2 Why Coral Reefs?

Florida has the only nearshore coral reef ecosystem in the continental United States, stretching nearly 350 miles from the St. Lucie Inlet to the Dry Tortugas. Coral reefs in Florida have natural, historical characteristics that vary by reef region, where regions can be defined by location along the coastline and by natural habitat type. Reefs in the Dry Tortugas and Florida Keys were historically dominated by the reef-building coral taxa, including all *Acropora* species, *Colpophyllia natans*, *Diploria labyrinthiformis*, all *Meandrina* species, *Montastraea cavernosa*, all *Orbicella* species, all *Pseudodiploria* species, and *Siderastrea siderea*. Corals of the genus *Orbicella* are critical for the biodiversity of fish and invertebrates (Beets and Friedlander 1998; Mumby et al. 2008). *A. palmata* and *A. cervicornis,* were listed as a threatened Caribbean species in 2006 under the National Marine Fisheries Service (NMFS). They significantly contribute to reef growth and development, and also provide essential habitat for fish (NOAA 2012).

Stony corals, octocorals, sponges, and gorgonians form the three-dimensional reef habitat that supports a multitude of fish, crustaceans, mollusks, and other animals. Undisturbed coral reef habitats possess a wide range of morphologies that provide habitable surface areas for fish and other organisms (Alvarez-Filip et al. 2009; Lirman 2013). Crustose coralline algae are also important because they bind coral skeletons and provide settling sites for coral larvae. Coral reefs have also been shown to protect coastlines from erosion, flooding, and storm damage (UNEP- WCMC 2006; WRI 2009; Principe et al. 2012; Ferrario et al. 2014; Yee et al. 2015; Storlazzi et al. 2019; Storlazzi et al. 2021a; Storlazzi et al. 2021b;).

Some organisms on the reef can kill and overgrow corals and crustose coralline algae, or prevent coral larvae from settling (e.g., macroalgae, cyanobacteria and peyssonnelids). In thriving reefs, these organisms are naturally present at low proportions of the reef community. Impacts to water quality (e.g., increased nitrogen, phosphorous, iron) can enable these faster-growing organisms to out-compete many other benthic species by overgrowth and reduction of larval settlement. This can cause phase shifts to algal-dominated communities that are difficult to re-establish as thriving reefs.

The benthic BCG focuses on the structural and functional importance of benthic organisms including reef-building corals, algae, and other invertebrates, how they interact, and how they indicate overall reef condition. Through the process of model development, all benthic organisms were addressed as potential metrics of biological condition. However, as the model was refined from narrative to numeric characteristics, coral species and metrics became prominent and other benthic organisms were rarely used. We continue to describe all benthic organisms because the narrative expectations were discussed by the experts, regardless of utility in the models.

1.3 Problem Statement

Of the total population of 21.5 million in Florida, approximately 6.4 million people live in counties with coastal reefs (Martin, Palm Beach, Broward, Miami-Dade and Monroe) (2020 U.S. census), subjecting the coral reefs to a variety of anthropogenic stressors (e.g., polluted runoff from agriculture and land-use practices, over-fishing, ship groundings, coastal development and climate change). Additionally, the reefs are threatened by several natural stressors including tropical storms, bleaching events, and disease events (**Appendix C**). The Florida Department of Environmental Protection (DEP) would like to characterize the biological conditions of Florida's Coral Reef using a BCG model as an assessment tool. Once calibrated and finalized, Florida's Coral Reef BCG can be used to identify high quality reefs, evaluate Best Management Practices (BMP) effectiveness, support biological criteria development and prioritize protection and restoration of coral reef ecosystems.

1.4 Description of the study area

Florida, located at the convergence of the subtropical and temperate climate zones, is the southernmost state in the conterminous US. Florida, has 65,758 sq. mi (170,312 km^2) of land area, and a 1,350 mi (2,170 km) of coastline. Florida's Coral Reef occurs along most of the Atlantic coastline and can be separated into two distinct regions: Southeast Florida (Martin, Palm Beach, Broward, and Miami-Dade counties) and the Florida Keys, which extend south and west into the Gulf of Mexico down to the Dry Tortugas.

- Florida Keys. Coral reefs in the Florida Keys are protected, with the extreme northern end (Biscayne National Park) and the far southwest (Dry Tortugas National Park) managed by the National Park Service, and the remainder of the reef tract managed by NOAA and the State of Florida as the Florida Keys National Marine Sanctuary (FKNMS).
- Southeast Florida. Southeast Florida's Kristin Jacobs Coral Reef Ecosystem Conservation Area (Coral ECA) includes the northernmost portion of Florida's Coral Reef across sovereign submerged lands and state waters offshore of Martin, Palm Beach, Broward, and Miami-Dade counties from the St. Lucie Inlet to the northern boundary of Biscayne National Park. The coastal counties of southeast Florida are highly developed, containing approximately one third of Florida's population of 21.5 million people (2020 U.S. census). The reef in southeast Florida is managed by DEP's Coral Reef Conservation Program.

All coral reef habitats within Florida jurisdictional waters (Florida Coral Reef) were considered valid for evaluation in the BCG project. This included western sites in the Dry Tortugas, through the Florida Keys, Biscayne National Park, and up the eastern coast of Florida up to Martin County (**Figure 3**). The data sets compiled for the project spanned this entire range (**Figures 4 and 5**). Several studies distinguish geopolitical reef regions that might also reflect distinguishable natural reef characteristics. These regions include the Dry Tortugas, the Florida Keys, and Southeast Florida. The Marquesas and Biscayne areas are transition zones between these regions. Sites were limited to those shallower than 30m.

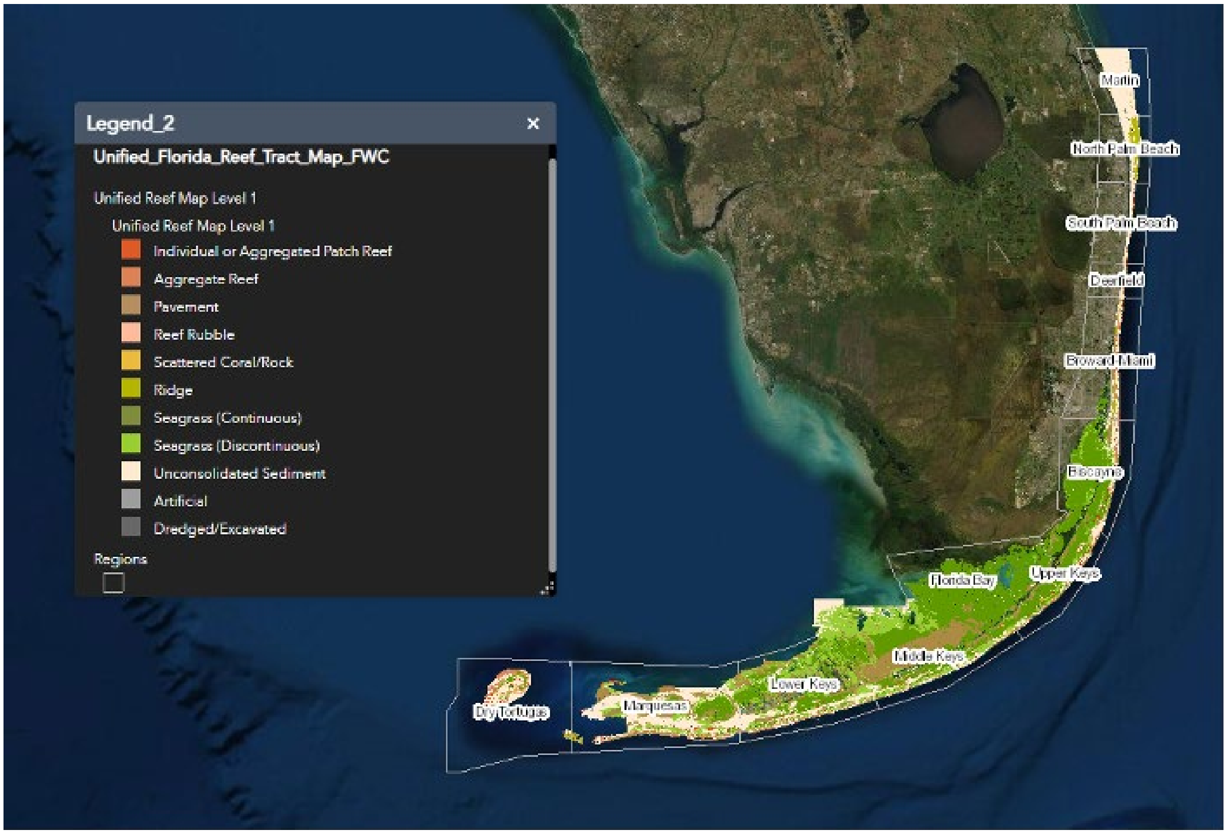

Figure 3. The Unified Reef Map (Florida FWC) identifies benthic habitats throughout Florida's Reef Tract from the Dry Tortugas, through the Florida Keys, and up the Atlantic Coast to Martin County. [*Florida's Unified Reef Map | FWC (myfwc.com)*](https://myfwc.com)

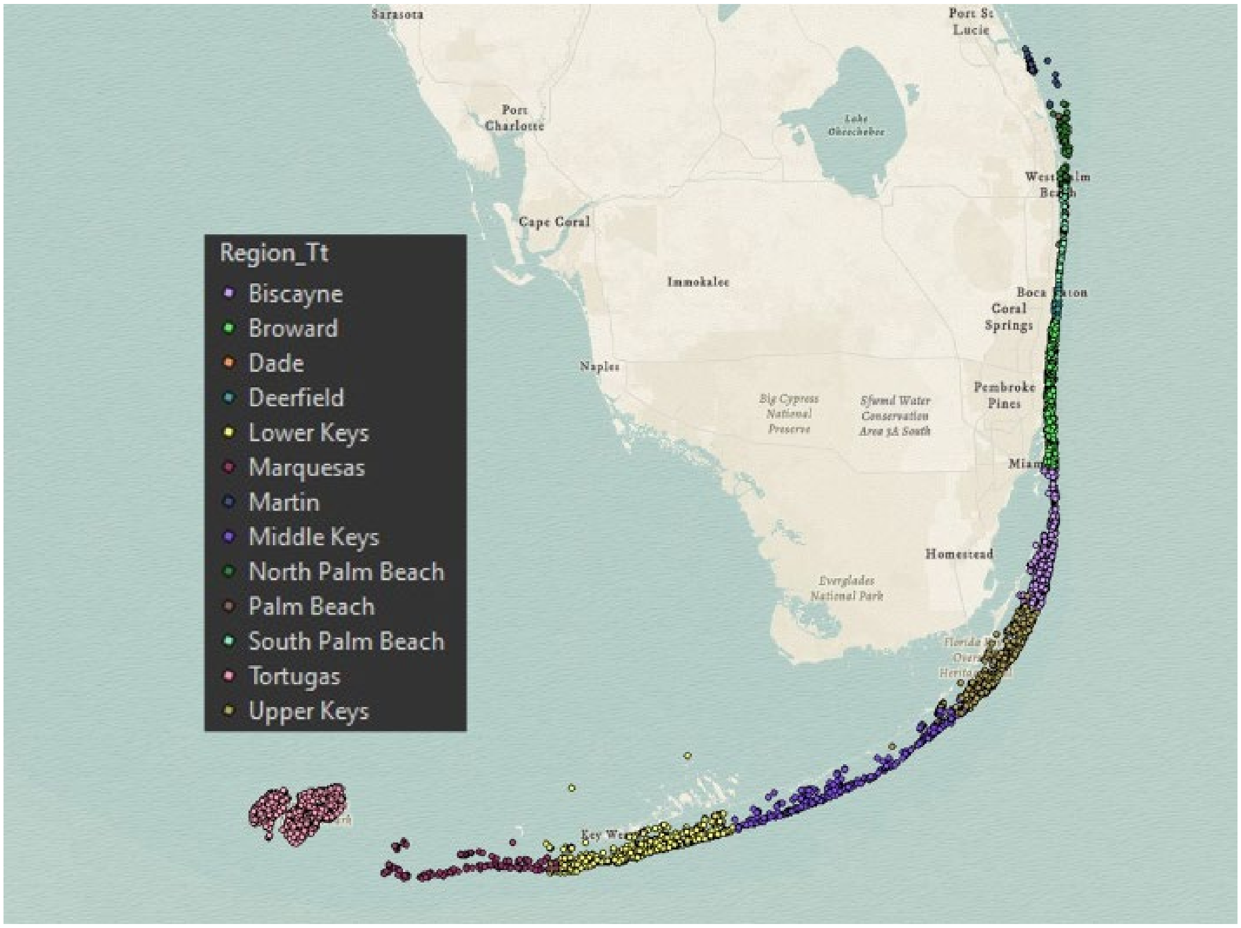

Figure 4. Locations of sampling sites by reef region.

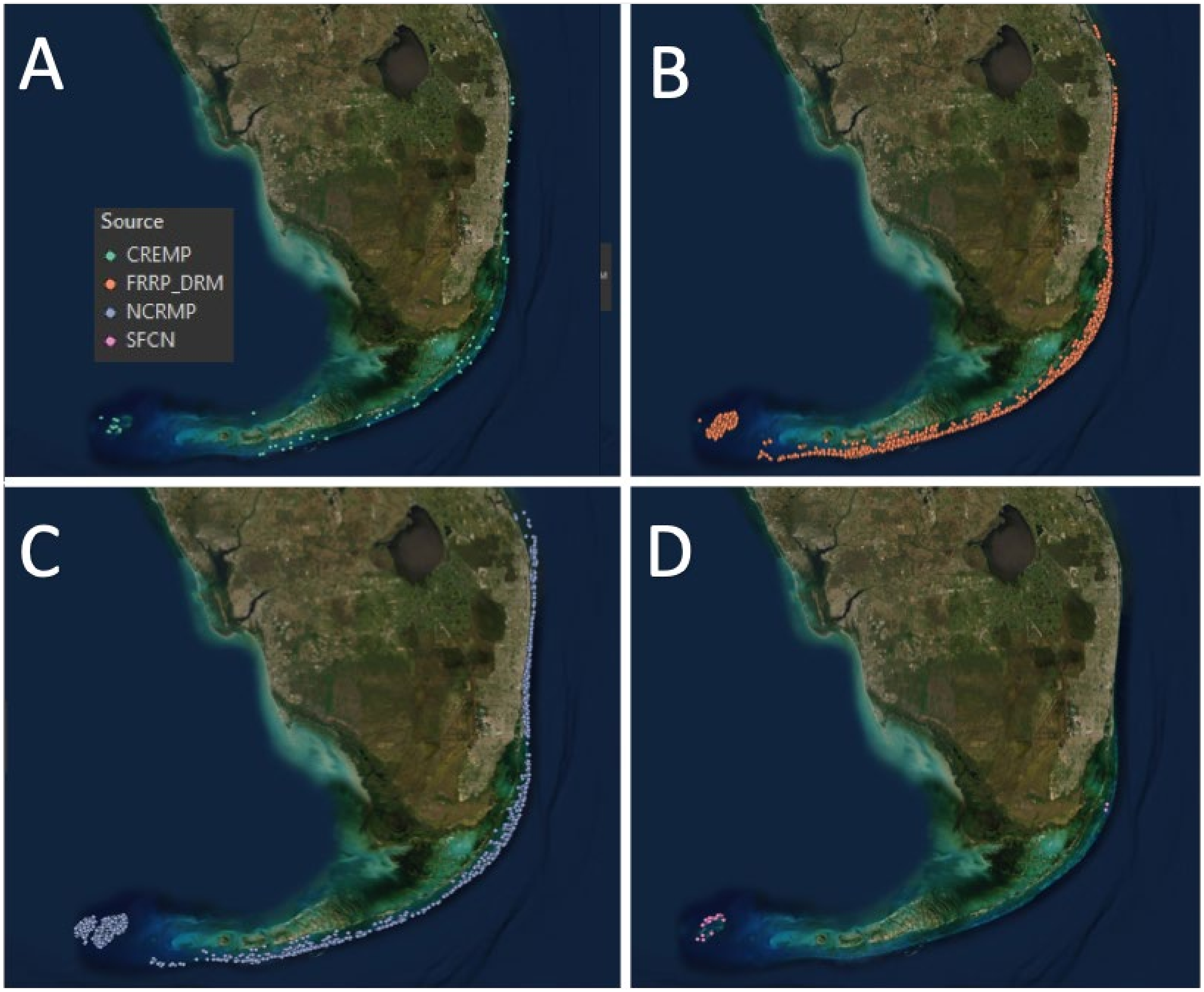

Figure 5. Locations of sampling sites by data source: A – CREMP (SECREMP, FKNMS, and CREMP-DT), B – FRRP_DRM, C – NCRMP, D – SFCN.

Reef Regions and Habitat Distinctions

Habitat classification is generally required to establish reference conditions and benchmarks for biological assessments. Coral reef communities are zoned by differences in depth, wave energy, temperature, and light (Stoddard 1973; Zitello et al. 2009). Reef types, geographic zones, and geomorphological structures are important determinants of expected species composition (Costa et al. 2009, Costa et al., 2013; Hubbard 1997; Hubbard et al. 2009; Stanley 2003; Zitello et al. 2009).

The recommended preliminary classification scheme was by reef region and habitat type. Reef regions were generally defined from west to east as the Dry Tortugas, Marquesas, Lower Keys, Middle Keys, Upper Keys, Biscayne, and Southeast Florida (SEF). More refined regions in SEF were defined by Walker (2012) and were perceived south to north by latitude. The northern-most region, approximately from the Bahamas Fault Zone near West Palm Beach to the St.

Lucia Inlet, had distinctive coral composition as shown in Walker's study. The Biscayne region also had distinct coral composition compared to other SEF regions. The Biscayne region is generally recognized as a transition zone between SEF and the Upper Keys.

Andy Bruckner, Brian Walker, and other experts recommended that there are distinct habitat types within and among the geographic regions. The complexity of regions and types was simplified, though the simplification does not account for all of the distinct reef types that the experts recognized. In SEF, the recommended habitat types were nearshore ridge complex, inner reef, middle and outer reef (combined), and deep ridge complex. In the Keys, the five main reef zones include the nearshore patch reefs, mid channel patch reefs (mostly associated with Hawks Channel), offshore aggregate patch reefs, and the main bank barrier reef system (fore reef) (**Figure 6**). The Marquesas do not have spur and groove reefs and were preliminarily classified separately from the Lower Keys. Based on expert deliberations, the classification shown in **Table 1** was proposed for preliminary stratification of sites.

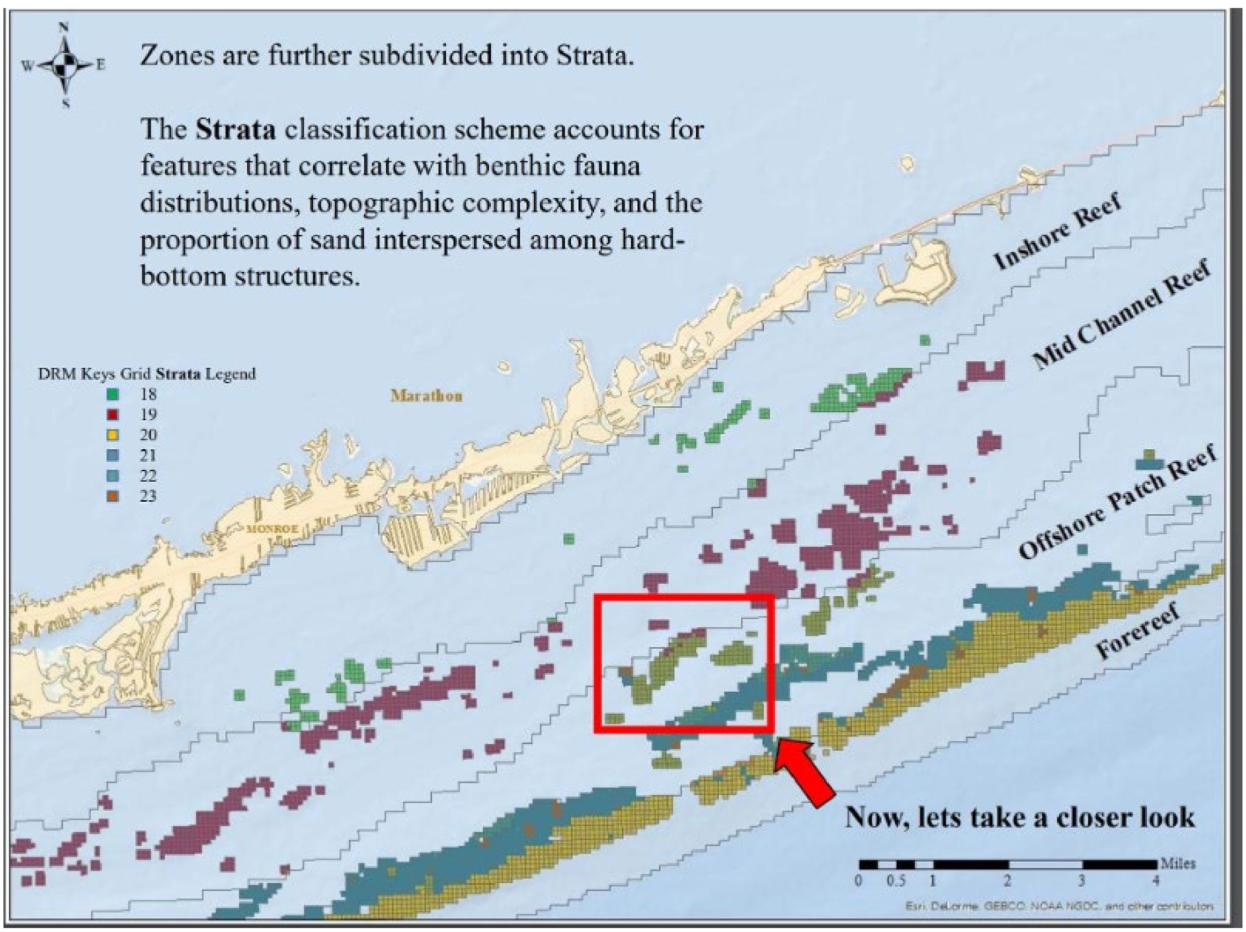

Figure 6. Habitat types of the cross-shelf gradient.

Table 1. Proposed reef classification.

Dry Tortugas	Marquesas	Florida Keys	SE Florida
Fringe reef	Off-shore patch	Nearshore patch reef Mid channel patch reefs (mostly associated with Hawks Channel) Offshore aggregate patch reef Main bank barrier reef (fore reef)	Reef Regions: North Palm Beach South Palm Beach Deerfield Broward-Miami Biscayne Habitat Types Nearshore ridge complex Inner reef Middle and outer reef Deep ridge complex

1.5 The BCG Calibration and Model Development Process

BCG calibration and model development for the Florida benthic assemblages followed a series of steps described in technical guidance for development of a BCG (EPA 2016). Constraints included availability and consensus of benthic assemblage experts and availability and applicability of sample data. The basic process included 1) organization of sample data into interpretable presentations, 2) orientation of the expert panel to BCG concepts and project objectives, 3) assignment of taxa to BCG attributes, 4) expert rating of biological samples into BCG Levels, and 5) translating sample ratings into narrative rules and responsive metric values into quantitative models (**Figure 7**). Model validation is intended for future project phases.

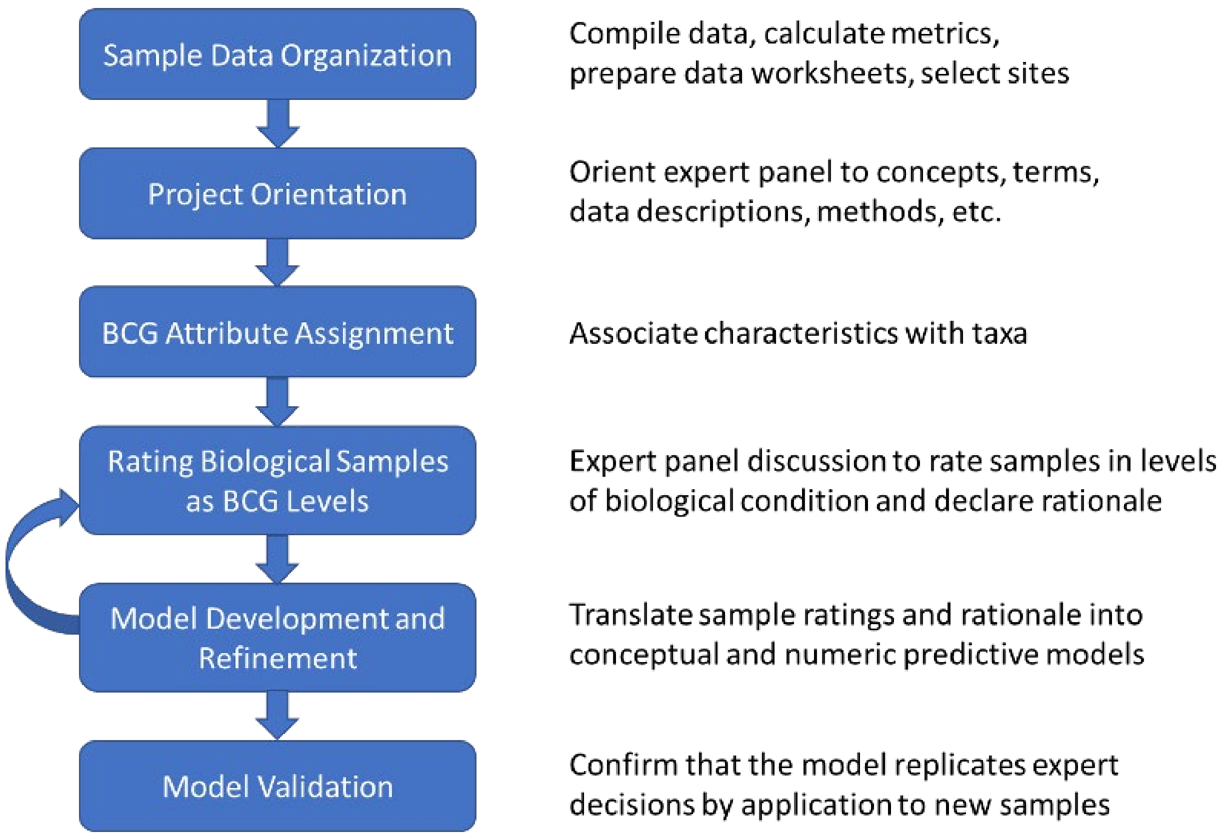

Figure 7. *Steps for BCG calibration and model development.*

Chapter 2. Approach to Reef BCG Calibration and Model Development

2.1 Data Compilation

Tetra Tech compiled the basic data files and worked with data providers to ensure proper interpretations of the data as it relates to biological condition levels of the BCG. The data files from each of the data providers were in unique formats, collected using various sampling designs and methodologies, reporting a variety of ecological and environmental parameters, and utilizing different codes and groupings for variables (**Table 2**). The earliest datasets were collected in 1996 by CREMP and did not include Demographic (DEMO) data. Data from 5815 sampling events were organized for the project.

Table 2. Data Files Compiled for Florida Coral/Benthic BCG.

Acronym	Program Name and Organization Conducting the Monitoring	Site Selection
SECREMP	Southeast Coral Reef Evaluation and Monitoring Project (SECREMP) monitored by the National Coral Reef Institute at Nova Southeastern University Oceanographic Center	Fixed sites selected as representative of the four reef habitats located off of southeast Florida (Palm Beach, Broward, Dade, and Martin counties)
CREMP	Coral Reef Evaluation and Monitoring Project (CREMP) managed by the Florida Fish and Wildlife Conservation Commission (FWC)	Fixed stations selected using a stratified, random sampling procedure based on habitat type; Florida Keys National Marine Sanctuary (FKNMS)
CREMP DT	Coral Reef Evaluation and Monitoring Project Dry Tortugas (CREMP DT) managed by the FWC	Sites were selected as representative samples of the coral reefs of the Dry Tortugas and with the intention of targeting certain coral species
NCRMP	National Coral Reef Monitoring Program (NCRMP), managed by the National Oceanic and Atmospheric Administration (NOAA)	Single stage stratified random design across entire Florida reef tract; previously a two-stage stratified random survey design
FRRP_DRM	Florida Reef Resiliency Program (FRRP) Disturbance Response Monitoring (DRM), managed by the FWC	Stratified Random Sample Design based on benthic habitat classification, bathymetry and satellite data; < 60 ft deep
SFCN	South Florida and Caribbean Network (SFCN), monitored by the National Parks Service (NPS)	Fixed stations with permanent pins

Survey data underwent thorough QA/QC to eliminate uncorrectable, unmatched, or conflicting data, sites deemed to be in non-target habitat types, and to correct older taxonomic names or synonyms. The data were then entered into an Excel workbook for use by the experts. The workbook included a series of linked worksheets:

- Notes, including descriptions of the other worksheets and metadata
- Status Page, that provides a summary of stations and expert consensus BCG Level assignments
- A master table of taxonomic attributes and characteristics that provides species information, including scientific and common names, classification, BCG attribute, and assemblage-specific traits.
- A data habitat worksheet, that provides other information by sample (e.g., exercise ID, collection date, collection method (CREMP, SECREMP, FRRP DRM, NCRMP, SFCN), region, latitude/longitude, survey year, reef type, whether in an MPA, habitat (NOAA benthic maps), etc.
- Data sheets from individual monitoring sites, including site and sample information, taxa lists, attribute-based metrics, coral cover metrics, and metrics of other cover types.

Tetra Tech used R code to generate taxa spatial distribution maps (**Figure 5**). Distributions for all species are shown in **Appendix D**. The distribution maps were available for the experts to review when considering BCG attribute assignments.

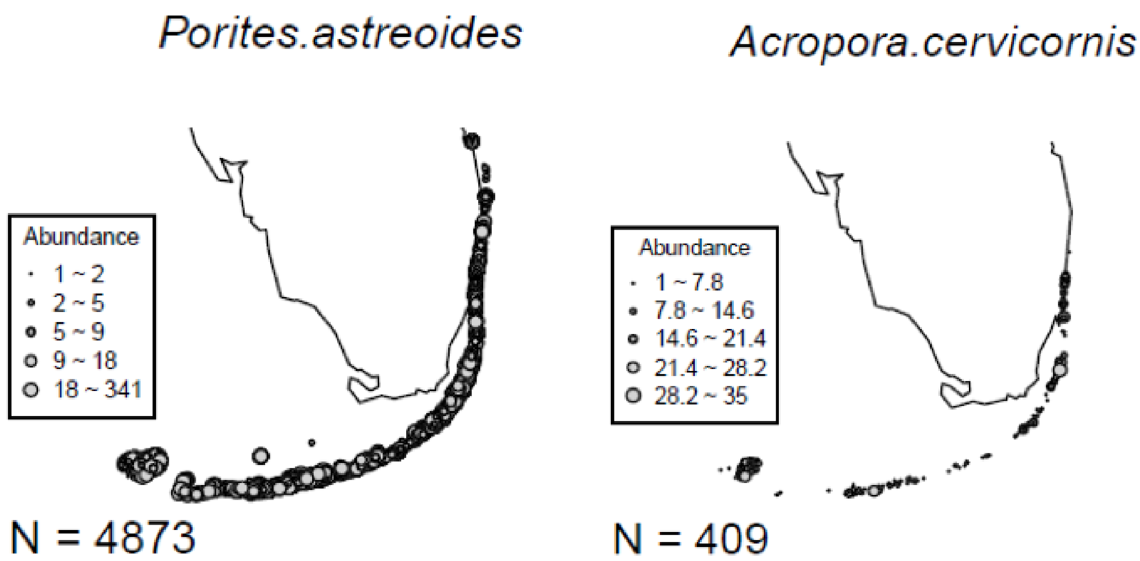

Figure 8. Examples of distribution maps that Tt is generating for all coral taxa across all 5815 project samples. See all coral distributions in: Appendix D.

2.2 The Expert Panel.

A panel of experts familiar with the taxonomy and ecology of the aquatic biota is an essential component of the BCG process. The panel assesses biological conditions of sample data and relates these to the BCG model (EPA 2016). As detailed in EPA (2016), professional expert consensus has been used in the medical and environmental fields. Scientific research includes the results of professional judgment and assumptions throughout the research process (Scardi et al. 2008; Steedman 1994).

When calibrating a BCG and developing a model, the experts make judgments on the biological significance of changes in the BCG attributes. In development of prior BCGs, experts have been highly concordant in their ratings of sites for various ecosystems, including marine benthic invertebrate communities in California bays (Weisberg et al. 2008), marine coastal benthic communities from four widely separated geographic regions (Teixeira et al. 2010), freshwater systems throughout the United States (EPA 2016; Gerritsen et al. 2017); and coral reefs in Puerto Rico and USVI (Bradley et al. 2020; EPA 2021; Santavy et al. 2021, 2022).

Working in coordination with FL DEP, Tetra Tech assembled a local expert panel, from Florida and surrounding regions, of expert staff biologists and representatives to serve as a BCG expert panel. The Florida BCG expert panel is comprised of experts with a wide and deep breadth of knowledge and expertise from multiple organizations, which helps to minimize internal bias.

The expert logic in developing the decisions was fully documented so the rules would be transparent and understandable to those that were not engaged in the expert panel. Experts were invited to participate in the entire BCG process, from orientation to report writing, as advisors and reviewers (**Appendix E**).

2.3 Assignment of BCG Attributes to Stony Coral Species

The benthic experts were oriented to and discussed the terminology used in the BCG Attribute definitions (**Appendix A**). During a series of webinars, the BCG coral experts assigned 65 Scleractinian and hydrozoan coral species found in Florida and the Caribbean region to one of six BCG attribute categories that represented specialized or endemic taxa (I), degree of sensitivity to pollution (II-V) and non-native taxa (VI).

While assigning BCG attributes to taxa, the experts considered the previously assigned BCG attribute values and previously identified sensitivities from the Caribbean BCG, Ernesto Weil's summary of coral traits related to taxa morphology, growth rates, reproductive strategy, and susceptibility to sedimentation, bleaching, and disease (Weil 2020), susceptibility to Stony Coral Tissue Loss Disease (SCTLD; **Appendix F**) and expert knowledge of historic bleaching and disease events for Florida's coral/benthic species.

The experts revised the example traits to align with specific conditions and characteristics known for Florida reefs. For example, susceptibility to SCTLD was not discussed during development of the Caribbean BCG, since it was not present there until after that BCG calibration process. Also, the importance of large reef-building coral (LRBC) was emphasized for the Florida reef system. The experts identified those species considered to be LRBC, including *Acropora* cervicornis, *Acropora palmata*, *Colpophyllia natans*, *Diploria labyrinthiformis*, all *Meandrina* species, *Montastraea cavernosa*, all *Orbicella* species, all *Pseudodiploria* species, and *Siderastrea siderea*. Two species that had been identified as LRBC for the Caribbean (Weil 2020), were not considered to be LRBC for Florida (e.g., *Acropora prolifera* and *Dendrogyra cylindrus),*

The experts associated one taxon species with Attribute I (*Dendrogyra cylindrus*) and one species was associated with Attribute VI (non-native taxa, *Tubastraea coccinea*). Seven species and the genus *Meandrina* were associated with Attribute II (sensitive, rare). Assignments to other attributes are as follows: Attribute III – 17 species, Attribute IV – 15 species, Attribute V – 14 species. Sixteen coral species were not associated with attributes because little is known of their sensitivity or they were not expected to occur in Florida. The complete list of species and assigned BCG Attributes is shown in **Appendix G**.

2.4 Model Development (in-person meeting and webinars)

The facilitation team selected a set of 200 sites from the Florida surveys (NCRMP, CREMP, SECREMP, FRRP_DRM and SFCN) to span the full range of the Florida's Coral Reef and across a range of stress from land-based sources of pollution (Low Stress – Dry Tortugas and Marquesas, Medium Stress – Lower Keys, Upper Keys, Biscayne, and Palm Beach County, and High Stress – Middle Keys, and Miami - Dade County). Sampling protocols for the monitoring programs and the ecological measurements that could be made from the data were discussed with the expert panel to describe the metrics, data limitations, and characteristics of each dataset. For example, the FRRP DRM surveys did not record point-based coverage measures and the SFCN used only point-based measures and did not record demographic measures. The expert opinion was that the demographic data critical for sample interpretation and therefore the SFCN data were not assessed.

The model was developed during an in-person 3-day in-person meeting and several webinars. The basic ideas of reef assessment were discussed in relation to BCG terminology. The Excel workbook was used throughout the process. Experts were asked to assign BCG Levels to sites based on their interpretation of taxa lists, assemblage metrics, and site information provided in the Workbook. An example of the information evaluated by the expert panel for a single site is shown as screenshots of an Excel workbook (**Figures 9 and 10**). Metrics were calculated as in **Appendix H**.

ExerciseID	Samp2506	Best Tier	NA	Rating	Rationale
Collection Date	8/15/20	Median Tier	NA		
Collection Method	Demo & Image Analysis	Worst Tier	NA		

CORAL ATTRIBUTE SUMMARY - DEMO

BCG Attribute	Number of Taxa	Colonies/m²	% Taxa	LCSA 2D (cm^2/m^2)	CSA 3D (cm^2/m^2)	LCSA 3D (cm^2/m^2)	% Cover
1	0	0.00	0%	0	0	0	0.0%
2	1	0.08	8%	4	9	9	0.0%
3	5	0.85	38%	2128	16323	6572	3.0%
4	4	2.60	31%	217	847	584	0.7%
5	3	0.70	23%	35	121	99	0.1%
6	0	0.00	0%	0	0	0	0.0%
NA	0	0.00	0%	0	0	0	0.5%
Total	*13*	*4.23*	*100%*	*2384*	*17300*	*7263*	*4.4%*

Coral Cover

Live 2D cm^2	Live % 2D cover	Live 3D cm^2	Live % cover
2384	23.8%	7263	4.4%

Taxa Demo

CORAL TAXA LIST - DEMO

		Demo	% Mean Mortality			Max			Height							
BCG Attribute	Scientific Name	Colonies	Colonies/m²	Old	New	Min	Avg	Max	Max (cm)	LCSA_2D cm^2/m^2	CSA_3D cm^2/m^2	LCSA_3D cm^2/m^3	# Bleached (part/total)	# Diseased (colonies)	# Damaged	x Tissue Isolat
3	Acropora cervicornis	26	0.65	26.1	2.7	12.0	76.3	425.0	29.9	2082.8	16111	6438.9	0	0	11	2
4	Agaricia agaricites	31	0.78	1.6	0.1	4.0	5.9	8.0	3.3	21.4	26	25.0	5PL	0	2	2
3	Colpophyllia natans	1	0.03	0.0	0.0	7.0	7.0	7.0	3.0	1.0	2	1.7	0	0	0	1
3	Eusmilia fastigiata	4	0.10	1.3	0.0	5.0	8.8	11.0	7.0	6.3	33	32.7	0	0	0	1
2	Meandrina meandrites	3	0.08	0.0	0.0	6.0	8.3	11.0	4.0	4.3	9	8.6	0	0	0	1
4	Montastraea cavernosa	1	0.03	70.0	0.0	18.0	18.0	18.0	11.0	1.9	16	4.7	0	0	0	1
5	Oculina diffusa	4	0.10	6.3	0.0	6.0	7.8	9.0	6.0	4.5	34	30.7	2PL	0	0	1
3	Orbicella faveolata	1	0.03	50.0	0.0	53.0	53.0	53.0	35.0	27.6	149	74.3	0	0	0	1
5	Porites astreoides	19	0.48	11.9	0.2	5.0	7.8	16.0	4.8	20.1	71	52.9	2PL	0	3	2
4	Porites porites	51	1.28	21.8	1.6	4.0	13.2	48.0	7.1	152.4	716	473.9	5PL	0	14	1
3	Pseudodiploria strigosa	2	0.05	11.0	0.0	15.0	17.0	19.0	10.0	10.0	29	24.4	0	0	1	1
4	Siderastrea siderea	21	0.53	5.8	1.3	5.0	9.2	30.0	4.5	41.6	90	80.5	2PL	1	11	4
5	Stephanocoenia intersepta	5	0.13	3.0	0.0	5.0	10.0	14.0	3.6	10.5	16	15.2	1PL	0	0	1
	Total	169	4.2													

Coral Taxa List - % cover

BCG Attribute	Scientific Name	% Cover
3	Acropora cervicornis	2.35
4	Agaricia agaricites	0.03
3	Colpophyllia natans	0.09
2	Meandrina meandrites	0.03
NA	Millepora alcicornis	0.54
4	Montastraea cavernosa	0.32
3	Orbicella annularis	0.55
5	Porites astreoides	0.08
4	Porites porites	0.21
3	Pseudodiploria strigosa	0.03
4	Siderastrea siderea	0.15
5	Stephanocoenia intersepta	0.06

Figure 9. Screenshot of the benthic organism data sheet (MS Excel workbook) used in assessing Florida data: This view shows the taxa list, including the assigned BCG attribute, scientific and common names, density, % mortality, and various calculated metrics.

STATION AND SAMPLE CHARACTERISTICS	
Site ID	1P1
Site Name	White Shoal
Latitude	24.641625
Longitude	-82.896425
Source/Program	CREMP - NPSDT
Region	DT
Habitat Code	P
Habitat Description	Patch or Pinnacle (Dry Tortugas)
Meters sampled (total)	40
Depth (avg feet)	21.5
Total number of LPI Points	3462
Percent Cover	
MACRO ALGAE	**24.6**
CYANOBACTERIA	**3.4**
SEAGRASS	**0.0**
BARE SUBSTRATE	**46.6**
SPONGES	**4.1**
SCLERACTINIAN CORALS	**4.4**
OCTOCORALS	**16.6**
ZOOANTHIDS	**0.0**
OTHER SPP	**0.0**
)ctocorals (num (min avg max height))	
Eunicea calyculata	0
Eunicea flexuosa	35 (3-18-43)
Gorgonia ventalina	18 (7-17-48)
Pseudoplexaura porosa	3 (4-9-15)
Pseudopterogorgia americana	84 (2-23-63)
Pseudopterogorgia bipinnata	0

Figure 10. Example data from Excel worksheet: Station and sample characteristics used in assessing CREMP Florida Keys data. This view shows information about the station and metrics calculated at the site scale.

Whether site reviews were conducted as a group during the in-person meeting or web-assisted webinars, experts would first individually rate the site (**Figure 11**). The facilitator then called on each expert to propose a BCG level for the site and provide the critical or most important information they used to inform the decision (EPA, 2016; Gerritsen et al., 2017). Decision rationale expressed by the experts generally included a statement about the critical components of the sample such as overall taxa richness, organism density, taxa that indicated stress or lack of stress, organism condition and other measurable metrics (**Table 3**).

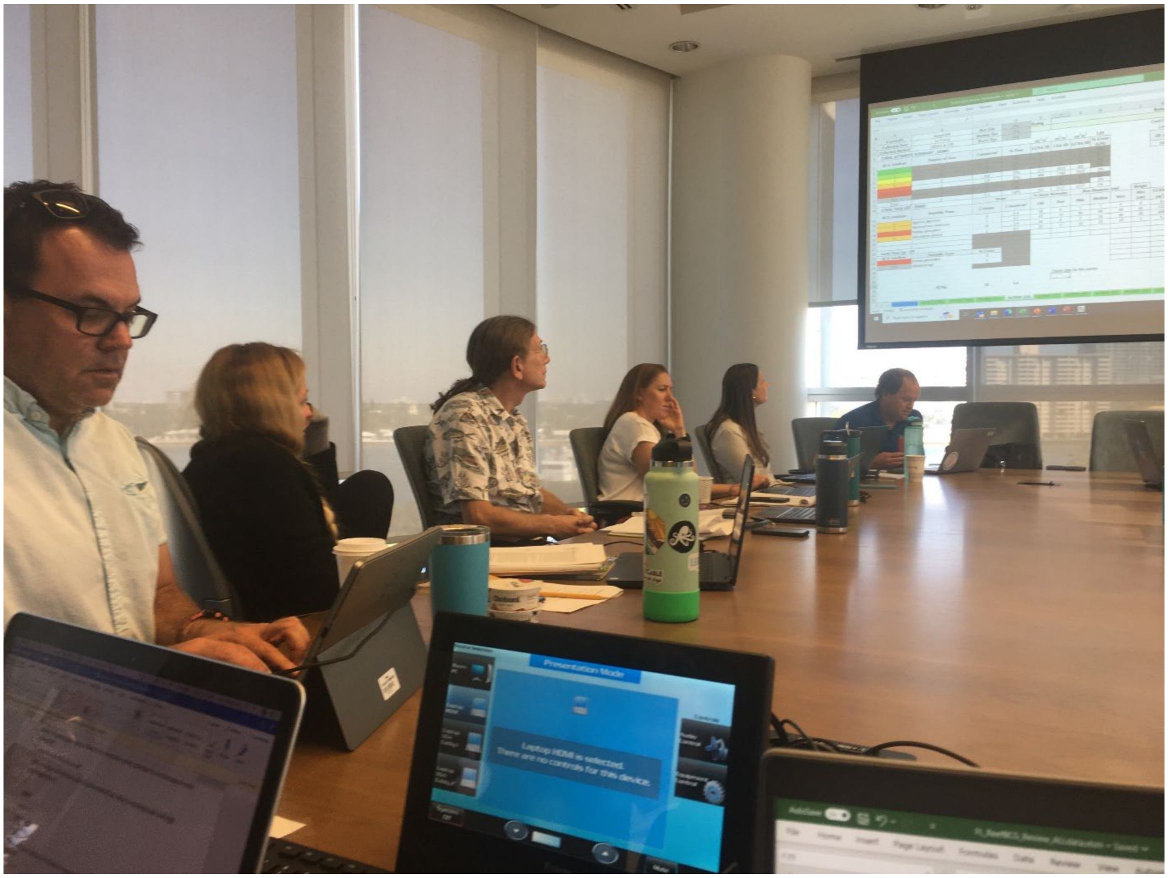

Figure 11. Expert panel reviewing the sample data, comparing sample characteristics to standard expectations for BCG Levels, assigning a BCG Level, and providing rationale for the BCG Level Assignment.

While experts were asked to provide an integer rating for the BCG Level, they were sometimes unwilling to do so, and intermediate Levels were as assigned as “+” (exhibiting characteristics of the next best Level but not enough to rate the site at that better Level) or “-“ (exhibiting characteristics that suggest somewhat worse conditions but not enough to rate the site in the worse Level). For example, a site was rated as “4+” because the site was “a better 4 but not as good as a 3”. In each case, the expert’s decision logic (rationale) was documented. This decision logic was extremely important information that indicated what shifts in the community structure and function signaled that the site was approaching another BCG Level. Articulating these thresholds and uncertainties allowed interpretation of ecologically meaningful decision rules in the BCG model.

Table 3. Hypothetical example of expert panel ratings and rationale for a single benthic reef site with summary rating of BCG Level 3.

Expert	**Rating**	**Rationale**
Expert #1	2	Good diversity including 2 BCG attribute 2 species; low disease, low bleaching - though some paling. Good % cover at 12%
Expert #2	3	Low old mortality. Some larger colonies. More attribute III's than attribute 4's and attribute 5's which is great. 12.4% coral cover is decent and the macroalgae cover is less than 25%.
Expert #3	2- or 3+	2011 before 2014-2015 bleaching episode. Dry Tortugas, patch or pinnacle reef, 38' deep, 48% bare substrate, 22% macroalgae (same problem cannot separate the "beneficial or good algae" from the "nuisance".
Expert #4	3-	Pre 2014/2015 bleaching and SCTLD; moderate depth on pinnacle; expected slightly higher cover. High diversity, wide size range of corals, a number of larger colonies; moderate to low amount of old mortality, some recent mortality; many of the less common species susceptible to SCTLD and medium sized healthy corals.
Expert #5	3+	Good diversity; relatively high cover; low disease and bleaching/paling; lots of attribute 2 and attribute 3 species.
Expert #6	3+	Good diversity including *Acropora cervicornis* and two BCG attribute 2 species. Minimal disease and minimal beaching. A few of the larger reef building corals were represented by a higher number of colonies than we have been seeing in other samples. Maximum height was low for most species, but there were still a few larger colonies.
Expert #7	4+	High number of species and colonies. High cover, some large colony sizes, lowish partial mortality, high weedy species, disease present.
Expert #8	4+	For the Tortugas this is pretty good. These pinnacle reefs in the Tortugas can have spectacular coral assemblages. The amount of old mortality is lower at this site in comparison to sites in the Keys or Southeast FL so this is a positive, however there still is A LOT of partial mortality on these corals. This is why I would go no higher than a 4+. Good diversity with some large to medium size colonies occurring across a range of species. Overall abundance is not as high as some of the best patch reefs in Florida.

Once all experts had provided their individual ratings, the experts discussed the ratings and rationale, and revised their individual ratings, if desired. The BCG assignments ranged from Level

3 (evident changes in structure of the biotic community and minimal changes in ecosystem function) to Level 6 (fully degraded). No sites were rated as Level 2 (minimal changes in structure and function). The experts felt that Level 1 conditions (natural) were no longer present in Florida.

2.5 Narrative Descriptions of Florida Reef BCG Levels

The narrative BCG rules were derived after rating BCG Levels for 55 reef sites from four surveys (NCRMP, CREMP, SECREMP, and FRRP_DRM). As the reef condition decreased with deteriorating environmental conditions, moving down the gradient from BCG Levels 3 or 4 to Levels 5 and 6, coral richness and the richness of large reef-building corals decreased, mortality increased, and nuisance species became more prevalent (Table 4). As reefs degraded, the number of rules or descriptors of condition decreased until BCG Level 6 was defined as not meeting the rules for BCG Level 5.

Table 4. Florida Reef BCG Conceptual Narrative Rules.

• Coral richness is greater with less stress
• *Acropora* and *Orbicella* can dominate with less stress even when richness is low
• Richness of non-tolerant coral (Attribute I, II, III (IV?)) is greater with less stress
• Richness of large reef-building corals is greater with less stress (see **Appendix I** for list of Large Reef Building Corals)
• Relative richness of tolerant taxa (% attribute IV and/or V taxa) is lower with less stress
• Mortality is low with less stress, especially on large colonies
• The percent of live tissue area of total coral area is greater with less stress
• The percent of colonies that are weedy is small with less stress
○ Conversely (or in addition), the percent of colonies that are large and >50% live is greater with less stress
○ Weedy colonies are defined by "weedy" designation of taxa (see **Appendix J**)
○ *Siderastrea siderea* and *Stephanocoenia intersepta* are weedy when diameter <30cm and height <10cm
○ Large colonies have diameter >75cm
• Nuisance species are prevalent with more stress
• Nuisance species include *Palythoa*, clionid sponges, *Millepora alcicornis*, *Dictyota*, *Lobophora*, cyanobacteria, encrusting *Peyssonnelia*, encrusting gorgonians (*Erythropodium* and *Briareum*)
• If bleaching is high and recent tissue loss is high or disease is prevalent, this indicates stress
○ Bleaching without recent tissue loss or disease does not necessarily indicate stress
○ Disease without recent tissue loss or bleaching does not necessarily indicate stress

Chapter 3. Numeric Model Calibration

3.1 Derivation of BCG Model Rules

To facilitate consistent assignment of sites to BCG Levels, it is necessary to quantify the narrative rules into a set of quantitative rules (e.g., Droesen 1996). Once the rules have been quantified, a knowledgeable person can follow the rules to obtain the same BCG Level as the group of experts, while the decision criteria remain transparent for managers and stakeholders. Rules are robust to missing information and can be nonlinear or non-montonic.

The narrative rules were converted to numeric metrics. These metrics and several more that were implied by the experts as they expressed rationale for rating samples were tested for discrimination between rated BCG levels. For example, the concept that 'Coral richness is greater with less stress' was quantified in the 'Total Coral Taxa' metric, which is a count of hard coral and hydrocoral taxa in each sample. From this concept and metric, we expect that the set of samples rated Level 3 would have more taxa per sample than the samples rated Level 4, 5, or 6. Each metric was plotted to show its values distributed among sites within BCG Levels as rated by the experts. The plots were used to confirm the narrative rules and to identify quantitative thresholds.

Membership of a site in a given BCG level was interpreted according to rules applicable to each attribute or metric that the panel deemed important for the BCG level. For example, the narrative rule that metric *live coral cover is high* was translated to a numeric range for the 3-dimensional live coral tissue cover per square centimeter (cm^2) or square meter (m^2). For the BCG Level 3 rule, numeric limits ranged from 5000-8000 cm^2/m^2 for CREMP Keys sites and 2000-4000 cm^2/m^2 for SECREMP sites. This meant that the panel agreed that the rule for the metric *live coral cover is high* in the CREMP Florida Keys dataset is definitely true when the metric value is greater than 8000. The rule is not met when the metric value is less than 5000. With values between 5000 and 8000, the rule is partially met and the sample exhibits some of the expected characteristics for that BCG Level. Hence, membership of the sample in BCG level 3 would be 0 (zero) when the metric *live 3-D coral cover* was less than or equal to 5,000, 50% when the metric was 6,500 and 1 (100%) when the value equaled or exceeded 8,000. The panel also specified other rules expressed in the same way. Rules for individual metrics were combined with logical "AND", i.e., the minimum value of all the memberships was taken as the final membership. Some rules were considered Flags, such as *percent colonies Acropora,* to recognize Acropora stands, which would be considered good condition even though coral taxa richness was low.

The quantitative BCG model was formulated by applying the rule thresholds in combination at each Level. Not all conceptual rules were used in the final models. This was the case when the concepts were not confirmed in the empirical metrics. Either the metrics did not adequately represent the concepts, the experts were not consistent in applying rationale, or secondary factors were not recognized to modify metrics and refine expectations. The secondary factors might include natural site types that were uncommon in the rated data set (such as *Acroporid* stands), in which cases the model was not refined enough to recognize specific types. Other factors might include interactions among metrics that were not appropriately captured in rule combination strategies. For example, low 'Total Coral Taxa' might not indicate stress if the few taxa are monotypic stands of reef-building coral, as might be expected in a natural *Acropora* thicket. This would need to be modeled to describe *either* high taxa richness *or* a high percentage of reef-building coral.

When separation between Levels showed that the better Level had consistently better metric values, the rule was developed so that there were few errors in identifying the better Level. In these cases, all the rules were required, the rules were combined with "AND" logic, and the minimum membership value for the set of rules was the membership value for each site and Level. In other cases (not yet encountered in the model calibration), when the panel was clearly considering an either/or situation, alternative rules could be applied using "OR" logic. Panelists may not be aware that they did this – it typically becomes apparent when the draft numeric model yields poorer BCG predictions than the panel, i.e., the numeric model is too stringent. To accommodate model accuracy, the panel can consider and approve such alternative rule applications.

At Level 3, six rules were included in the model. There is also a Flag for *Acroporid* stands. At Level 4, six rules were used to describe biological conditions. At Level 5, three rules were defined. Because the rules are applied in order from Level 2 to Level 5, any site not meeting any of the Level 5 rules is automatically predicted to be Level 6. Rules for the draft model as of June 2023 are as described in **Exhibit 1** and illustrated in **Figures 12 – 14**. BCG Level 1 was not expected to occur and was not described conceptually or with model rules. BCG Level 2 was not observed and was not described with model rules.

The following explains the BCG predictive model rules for the coral reef benthic assemblage (first generation), showing the Level definition (details in **Appendix B**), narrative rules, quantitative rules, and rule combinations. In application, sample metrics were tested first at Level 2. Level 3 rules were applied next, but only if Level 2 rules were not met with 100% membership. The rules were likewise applied at Levels 4 and 5 until site membership was established. If rules were not met at Level 5, then the site was determined to be Level 6 by default. In the quantitative rules, the numeric range is shown so that partial membership can be determined for each rule at each Level.

Exhibit 1. ***BCG predictive model rules for the coral reef benthic assemblage***

BCG Level 1

Definition: Natural or native condition—native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability

Narrative: Level 1 and 2 narratives were not distinguished for the BCG exercise. No quantitative rules were developed for Level 1

BCG Level 2

Definition: Minimal changes in structure of the biotic community and minimal changes in ecosystem function - virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability

Narrative: Coral species are highly diverse, including rare species and susceptible species; large old colonies of reef-building species (e.g., *Acropora* and *Orbicella*) with high live tissue cover; balanced population structure (old and middle-aged colonies, recruits). No quantitative rules were developed for Level 2

BCG Level 3

Definition: Evident changes in structure of the biotic community and minimal changes in ecosystem function—Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but intermediate sensitive taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system

Narrative: Live coral cover is high; *Acropora* or *Orbicella* colonies are numerous; Live large reef-building coral cover is high; small and weedy colonies are not hyper-dominant; sensitive taxa are represented; and *Acropora* thickets may be present (Flag)

BCG Metrics	Narrative Rules	Quantitative Rules (FL Keys)	Quantitative Rules (SEFL)
sampLCSA_3dm2	3-D Live Coral Surface Area (LCSA) is high (cm^2/m^2)	5,000 – 8,000	2,000 – 4,000
ncol_AcrOrb_M2	The number of *Acropora* or *Orbicella* colonies per square meter is high (# colonies/m^2)	0.1 – 0.3	0.0 – 0.1
LRBC_LCSA_3d_M2	3-D LCSA of large reef-building corals is high (cm^2/m^2)	4,000 – 8,000	1,000 – 4,000
LCSA1234_3d_M2	3-D LCSA of non-tolerant coral taxa is high (cm^2/m^2)	2,000 – 4,000	2,000 – 4,000
pcol_Small/Weedy	Small and weedy colonies are not hyper-dominant	65 – 75	
nt_BCG123	itive taxa are represented	2 - 3	2 - 3
Pcol_Acropora	FLAG to recognize Acroporid Stands	15 -25	

BCG Level 4

Definition: Moderate changes in structure of the biotic community and minimal changes in ecosystem function—moderate changes in structure due to replacement of some intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes

Narrative: Reduced live coral cover compared to Level 3; reduced live large reef-building coral cover compared to Level 3; sensitive taxa are represented; emergence of tolerant species; small and weedy colonies are more dominant than at Level 3; *non-tolerant taxa are moderately diverse*

BCG Metrics	Narrative Rules	Quantitative Rules (FL Keys)	Quantitative Rules (SEFL)
sampLCSA_3dm2	3-D Live Coral Surface Area (LCSA) is moderate (cm^2/m^2)	4,000 – 6,000	0 – 1,000
LRBC_LCSA_3d_M2	3-D LCSA of large reef-building corals is moderate (cm^2/m^2)	4,000 – 6,000	0 – 1,000
nt_BCG123	Sensitive taxa are represented	1 - 3	1 - 3
Pt_Att5	Tolerant taxa are relatively sparse	30 - 40	30 – 40
pcol_Small/Weedy	Small and weedy colonies are dominant	80 - 90	80 – 90
nt_BCG1234	Non-tolerant taxa are moderately diverse	4 - 6	4 - 6

BCG Level 5

Definition: Major changes in structure of the biotic community and moderate changes in ecosystem function—Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials

Narrative: Algae and bare substrate are not hyper-dominant; non-tolerant taxa are minimally diverse; all coral taxa are minimally diverse

BCG Metrics	Narrative Rules	Quantitative Rules	
Pcvr_AlgSub	Algae and bare substrate are not hyper-dominant	*85 - 95*	*Cannot be applied to DRM data*
nt_BCG1234	Non-tolerant taxa are minimally diverse	*1 - 4*	
Nt_TotalCoralTaxa	All coral taxa are minimally diverse	*1 - 4*	

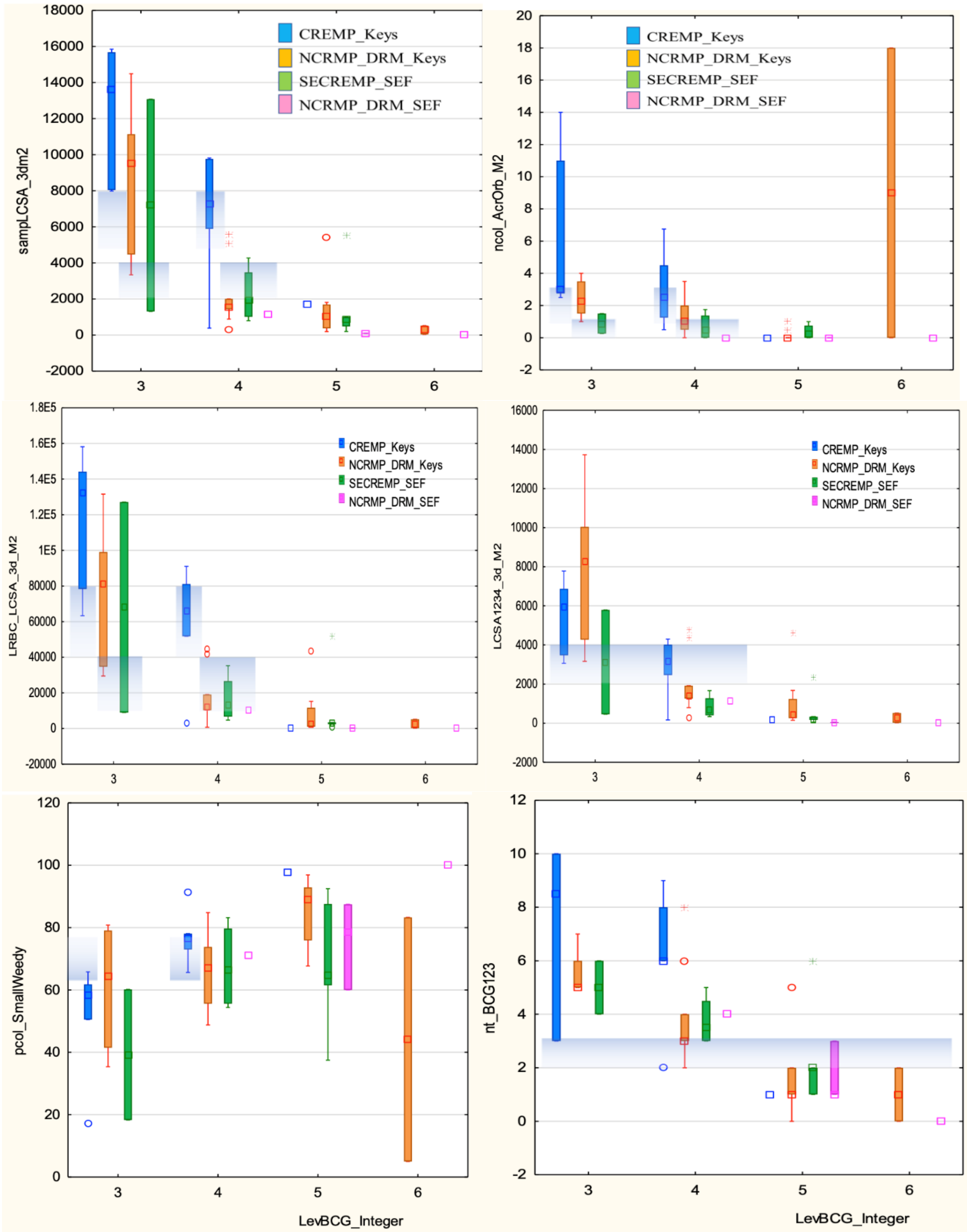

Figure 12. Distributions of metrics used in model rules for discriminating benthic BCG Levels 3 and 4, showing the rule ranges (color-shaded region). Metric names and numeric rule ranges are described in the text and in Exhibit 1. Distributions include the median (central square), interquartile range (rectangular box), non-outlier ranges (whiskers), and outliers (circular marks).

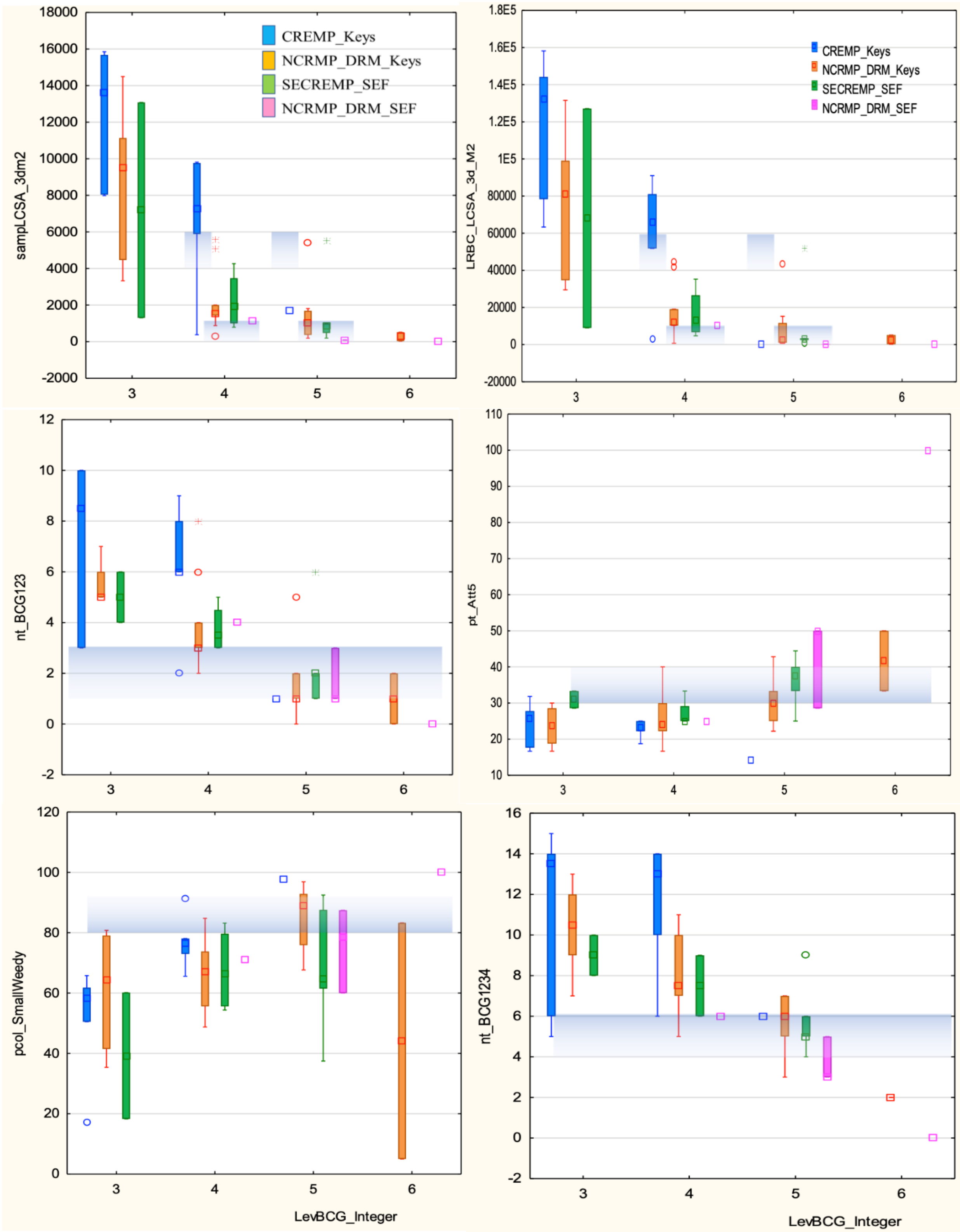

Figure 13. Distributions of metrics used in model rules for discriminating Benthic BCG Levels 4 and 5, showing the rule ranges (color-shaded region). Metric names and numeric rule ranges are described in the text and in Exhibit 1. Distributions include the median (central square), interquartile range (rectangular box), non-outlier ranges (whiskers), and outliers (circular marks).

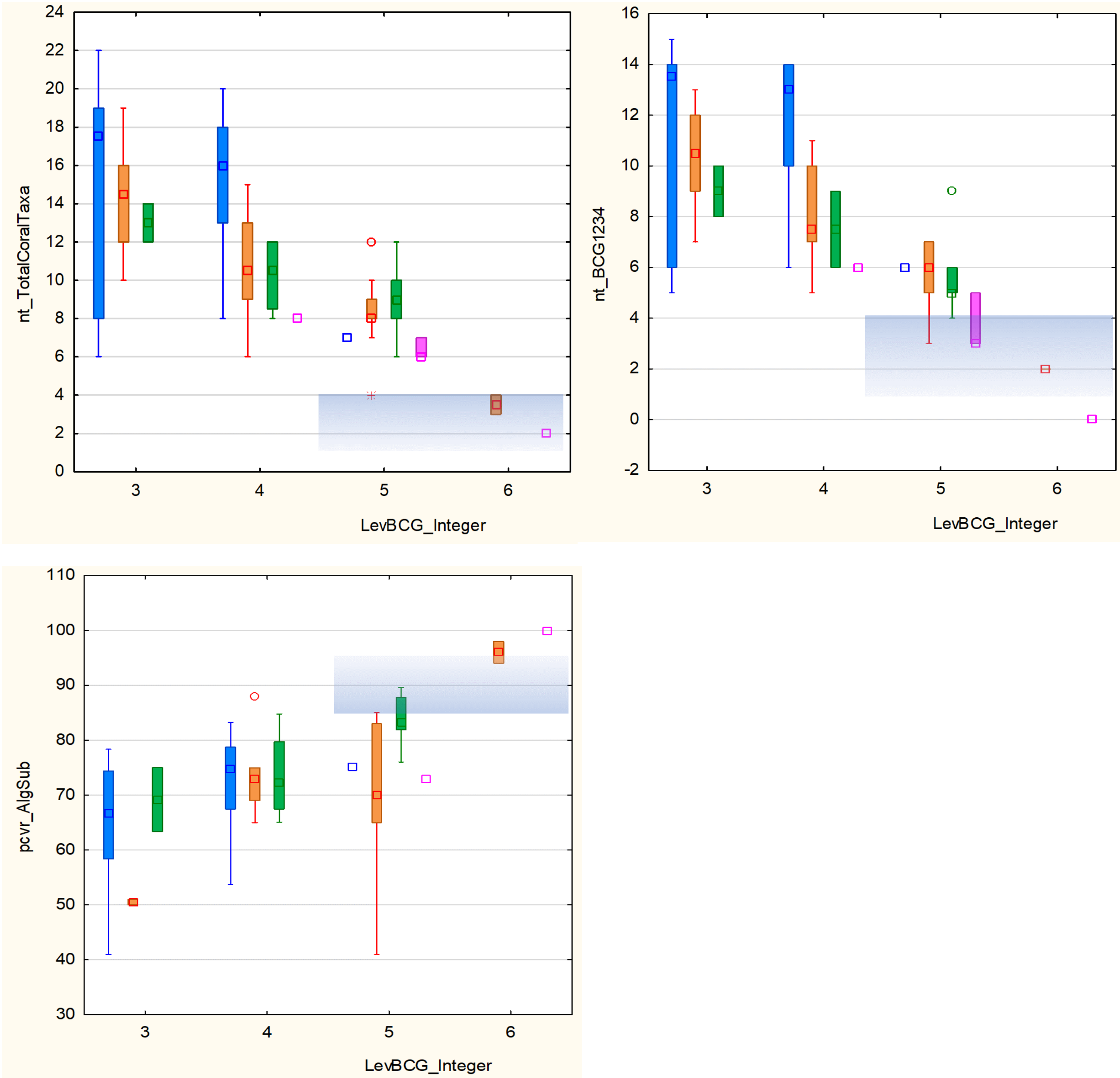

Figure 14. Distributions of metrics used in model rules for discriminating Benthic BCG Levels 5 and 6, showing the rule ranges (color-shaded region). Metric names and numeric rule ranges are described in the text and in Exhibit 1. Distributions include the median (central square), interquartile range (rectangular box), non-outlier ranges (whiskers), and outliers (circular marks).

3.2 Model Predictive Performance

Model performance is described in terms of agreement between model results and the median of expert ratings per site. We assessed the number of sites where the draft BCG decision model's level rating exactly matched the experts' median opinion ("exact match") and the number of sites where the model predicted a BCG level that differed from the median expert opinion ("mismatch" sites). For the mismatched sites, the BCG level rating differences between the experts and the model were examined to determine whether there was a bias.

Model performance is summarized in **Table 5** showing number and percent of model assessments compared to expert panel assessments. Of the 55 sites evaluated by the experts, the model (first generation) predicted the same BCG Level as assigned by the experts for 51 sites. The model accuracy is therefore 93%. No prediction was more than one Level different than the assignment. There were 5 predictions counted as correct that were tied between Levels either in expert assignment or model prediction. For 4 sites, the prediction was counted as an error although the difference from the assignment was very similar. For example, an assigned Level 3- is very similar to a predicted Level 4+, but because they are in different core BCG Levels, the prediction was counted as an error.

Table 5. Comparison of expert assignment of BCG Levels for benthic calibration of reef sites compared to BCG Levels predicted by the model, indicating where there was agreement (within boxes) and model error (highlighted cells).

		Model Predictions													
		3+	3	3-	34tie	4+	4	4-	45tie	5+	5	5-	56tie	6+	6
Expert Ratings	3+		2	1											
	3		3	2	1			1							
	3-		2	1											
	34tie		1												
	4+		1				3	1							
	4		1			2	2	2	1						
	4-						2	1			1				
	45tie										1				
	5+								1		2				
	5									1	7	1			
	5-										4	3	1		
	56tie														
	6+														1
	6													1	1

3.3 Model Precision among Experts

The experts assigned BCG Levels with the qualifiers "+" for a condition at the better end of a Level and "-" for a condition edging towards the next worse Level. The span of Level assignments was evaluated for the degree of agreement among experts for each site. The evaluation included comparison of each individual Level assignment to the median for each site. To convert the assignments to numeric differences, the core BCG assignment was the integer representing the Level. The "+" and "-" qualifiers were counted as 1/3 of a level (0.33). For example, if an expert rated a sample as a 4+ and the median/consensus for that sample was a 4-, then the difference would be 0.67. Comparisons that included ties between Levels were rounded to represent closer agreement (a difference of 0.33 instead of 0.5). Positive differences meant that the individual expert considered the biological condition to be better than the median of ratings from all experts.

The agreement among experts was high, with 89% of 422 individual ratings for 55 samples being within 1/3 of the median BCG assignment (Figure 15). Very few individual ratings were different than the median by 1 whole BCG Level or more. Most sample ratings were assigned during the in-person meeting, with expert interactions to describe rationale for their ratings. Ten (10) samples were rated as homework, where experts did not share rationale until after all ratings were assigned. The ratings given with interaction were more precise (better expert agreement) than the ratings assigned independently. This was demonstrated by calculating the Root Mean Square Error (RMSE) for ratings within samples. For in-person ratings, the RMSE (an approximation of average standard deviation) was 0.26 BCG Level units. For independent ratings, the RMSE was 0.50. The difference in precision is also evident graphically (Figure 16).

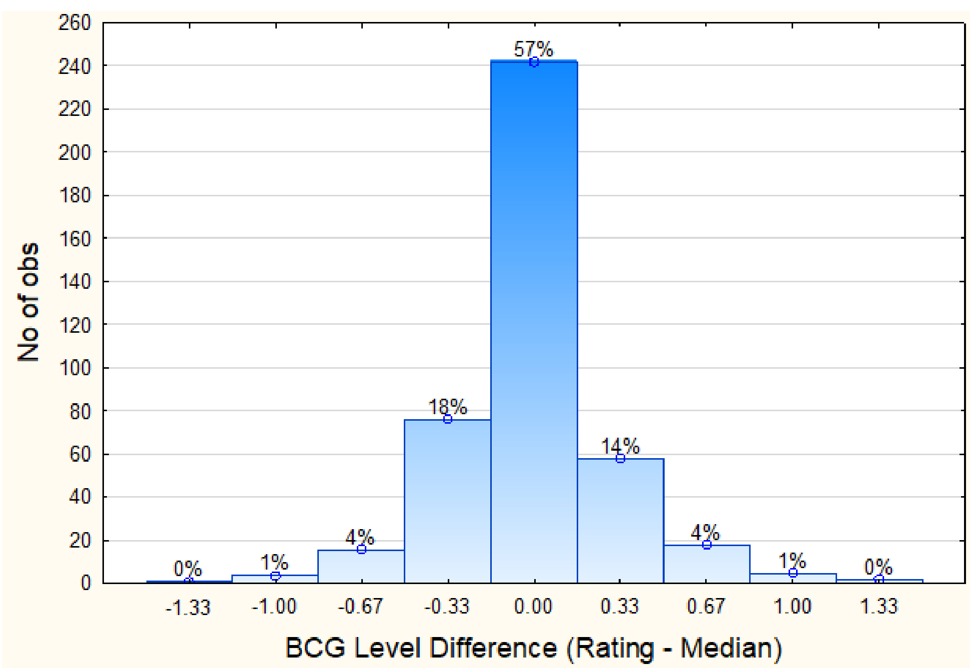

Figure 15. Differences in BCG Level assignment given by individual experts compared to the median rating for each sample (showing percentages for the difference categories). Level qualifiers are represented by 1/3 of a BCG Level. Positive values indicate that the individual expert gave a rating indicating conditions better than the median.

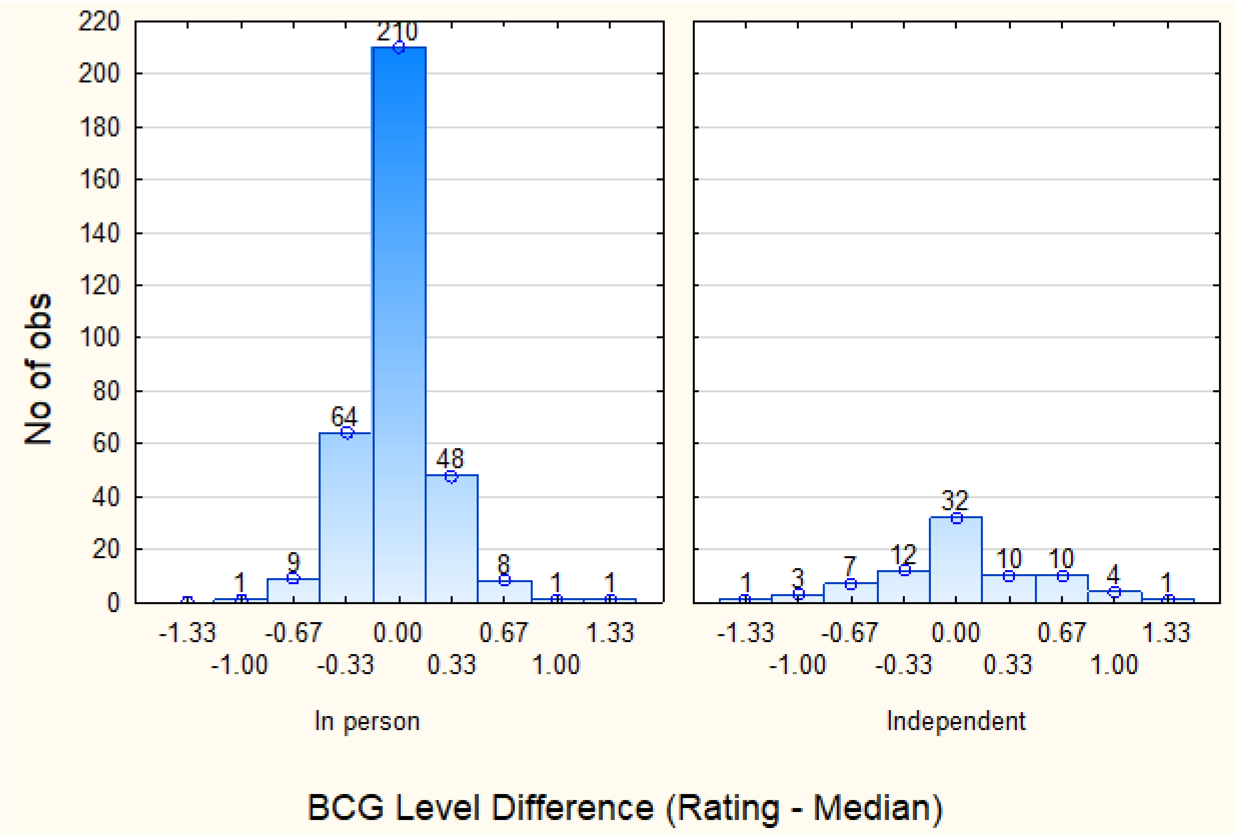

Figure 16. Differences in BCG Level assignment given by individual experts compared to the median rating for each sample, distinguishing ratings assigned in-person and those assigned without expert discussion (showing numbers of ratings in the difference categories).

Chapter 4. Benthic Model Discussion and Next Steps

The experts determined that the first-generation benthic BCG model can be used to quantitively interpret Florida reef conditions ranging from BCG Level 3 to BCG Level 6. The model was based on expert derived numeric decision rules. The model has not been validated. Validation will be undertaken in Validation Phase (upcoming) of the project.

During the calibration of the Florida coral BCG, the coral/benthic expert panel was assembled, a database was developed for coral/benthic sample and site data, and preliminary decision rules for coral/benthic assemblages were developed by subject matter experts for the Florida's Coral Reef using data from several Florida monitoring programs. The database included information on coral taxa traits, composition of samples collected using multiple programs and sampling methods, and queries for calculating metrics of the coral and benthic communities. The database allows analysis of data from multiple monitoring programs, taxonomic traits for metric calculations, and assessment of indicators in relation to natural and stressor site characteristics.

The frequency and severity of Scleractinian diseases and syndromes are being documented and evaluated as potential BCG indicators of reef organism conditions. Conditions include bleaching, black band disease, dark spots disease, white plague, yellow band (blotch) disease, and Stony Coral Tissue Loss Disease (SCTLD), among others. Biochemical, genomic, and physiological factors contribute to species susceptibility or resistance to diseases, variations in temperature, or other environmental factors. The experts' combined knowledge of such factors is incorporated into the BCG model. In the current model, metrics based on measured incidence of disease and on disease susceptibility were tested for consistent indication of reef biological condition. While anecdotal examples were evident for some samples, the signals from disease-based metrics were not consistent enough to apply as model rules.

In the reef classification discussions, it was recommended that SECREMP should really end at Lake Worth Inlet (latitude 27.0) for purposes of the BCG; that's the limit for historical reef structure. The North Palm Beach region and Martin County have substantially different coral composition compared to more southern areas (Walker 2012).

Several metrics were discussed that could potentially provide additional rules, but these were either not uniformly collected by the programs or were not collected by any of the programs. Tissue isolates could be used to determine if large reef-building corals were fragmenting over time; this would possibly need to be a temporal exercise. Sponge and gorgonian assemblages could provide additional information about reef condition but are generally excluded from Florida's monitoring programs. A possible monitoring approach would be to estimate the three-dimensional (3D) surface area (SA) of marine gorgonians and sponges from field measurements of colony height, diameter, and morphology was developed as an indicator of habitat availability for fish and invertebrates (Santavy et al. 2012, 2013). It was also suggested that documenting crustose coralline algae is important to include in monitoring programs because it provides reef structure and promotes coral larval settlement.

While model development was based on the preliminary site classification scheme, the experts also discussed ways to better refine the model to address reef variability between regions and habitats. Several flags were suggested, including depth and a spatial areal extent for branching species.

Because it is a long-term, fixed site monitoring program, the experts also recommended that we apply the BCG model to CREMP sites to observe trends over time. This could be important in teasing out rules for bleaching and disease. This will be developed during the Validation Phase (upcoming) of the project.

Next Steps:

In the Validation Phase, the quantitative coral/benthic BCG model will be finalized by validating the model with independent samples and incorporating expert review comments from the

Phase 1 report. The experts will review and rate at least 10 independent samples and Tetra Tech will then calculate model validation performance and precision statistics for the model for ratings among experts.

Tetra Tech will present the finalized BCG model to the SCTLD Disease Advisory Committee and other groups as invited by FL DEP. The presentation will include BCG model concepts, model development process, model results, and practical application addressing restoration potential and stony coral tissue loss disease. Tetra Tech will prepare a web-enabled StoryMap intended for both technical and non-technical audiences. The StoryMap will include explanations of BCG model concepts, development procedures, and results; links to project reports; and links to model application tools. Model application tools will be developed in R-Shiny to simplify data input, model calculation, and model reporting. Instructions for tool application will be incorporated into the R-shiny application. Hosting of the model code is to be determined.

A Glossary of terms is provided in **Appendix K**.

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Appendix A – BCG Attributes

Attribute	Description
I. Historically documented, 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. They may be long-lived and late maturing and have low fecundity, limited mobility, multiple habitat requirements as with diadromous species, or require a mutualistic relationship with other species. They may be among listed Endangered or Threatened (E/T) or special concern species. Predictability of occurrence is often low, and therefore requires documented observation. The taxa that are assigned to this category require expert knowledge of life history and regional occurrence of the taxa to appropriately interpret the significance of their presence or absence. Long-lived species are especially important as they provide evidence of multi-annual persistence of habitat condition. Florida Coral Examples (from initial expert assignments): *Dendrogyra cylindrus* (Pillar coral)
II. Highly sensitive taxa	Taxa that are highly sensitive to pollution or anthropogenic disturbance. Tend to occur in low numbers relative to total population density, but they might make up a large relative proportion of richness. In high quality sites, they might be ubiquitous in occurrence or might be restricted to certain micro-habitats. They often have slow growth – long-lived (K-strategists) vs. short-lived—fast growth (r-strategists). In coral reef ecosystems, large-bodied, slow-growing, late-maturing fishes (K-strategists) are generally more sensitive to fishing pressure and environmental stress than faster-growing, shorter-lived species. The distinguishing characteristic for this attribute category was found to be sensitivity and not relative rarity, although some of these taxa might be uncommon in the data set (e.g., very small percent of sample occurrence or sample density), therefore, these are the first to disappear with disturbance or pollution. Florida Coral Examples (from initial expert assignments): *Acropora palmata* (elkhorn coral), *Isophyllastrea rigida* (Rough cactus coral), *Isophyllia sinuosa* (Sinuous cactus coral), *Meandrina danae* (Butterprint rose coral), *Meandrina jacksoni* (White valley maze coral), *Meandrina meandrites* (Maze coral), *Mycetophyllia ferox* (Rough cactus coral)

Attribute	Description
III. Intermediate sensitive taxa	Taxa that are 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 in reduced density and richness in moderately disturbed or polluted stations. These taxa often comprise a substantial portion of natural communities. Florida Coral Examples (from initial expert assignments): *Agaricia lamarcki* (Whitestar sheet coral), *Colpophyllia natans* (Boulder brain coral), *Eusmilia fastigiata* (Smooth flower coral), *Helioseris cucullata* (Sunray lettuce coral), *Mussa angulosa* (Atlantic mushroom coral), *Mycetophyllia lamarckiana* (Ridged cactus coral)
IV. Intermediate tolerant taxa	Taxa that commonly comprise a substantial portion of an assemblage in undisturbed habitats, as well as in moderately disturbed or polluted habitats. They exhibit physiological or life-history characteristics that enable them to thrive under a broad range of thermal, light, or oxygen conditions. Many have generalist or facultative feeding strategies enabling utilization of diverse food types. These species have little or no detectable response to moderate stress, and they are often equally abundant in both reference and moderately stressed sites. Some intermediate tolerant taxa may show an "intermediate disturbance" response, where densities and frequency of occurrence are relatively high at intermediate levels of stress, but they are intolerant of excessive pollution loads or habitat alteration. Florida Coral Examples (from initial expert assignments): *Agaricia agaricites* (Low relief lettuce coral), *Favia fragum* (Golfball coral), *Montastraea cavernosa* (Great star coral), *Mycetophyllia aliciae* (Knooby cactus coral), *Orbicella franksi* (Boulder star coral), *Porites porites* (Clubtip finger coral), *Siderastrea sidereal* (Massive starlet coral)

Attribute	Description
V. Tolerant taxa	Tolerant taxa are those that typically comprise a low proportion of natural communities. These taxa are more tolerant of a greater degree of disturbance and stress than other organisms and are, thus, resistant to a variety of pollution or habitat induced stress. They may increase in number (sometimes greatly) under severely altered or stressed conditions. They may possess adaptations in response to organic pollution, hypoxia, or toxic substances. These are the last survivors in severely disturbed systems and can prevail in great numbers due to lack of competition or predation by less tolerant organisms, and they are key community components of level 5 and 6 conditions. Florida Coral Examples (from initial expert assignments): *Cladacora arbuscula* (Tube coral), *Madracis decactis* (Ten ray star coral), *Manicina areolata* (Rose coral), *Oculina diffusa* (Diffuse ivory coral), *Siderastrea radians* (Lesser starlet coral), *Solenastrea bournoni* (Smooth star coral), *Solenastrea hyades* (Knobby star coral), *Stephanocoenia intersepta* (Blushing star coral)
VI. Non-native or intentionally introduced species	Any species not native to the ecosystem. Species introduced or spread from one region to another outside their normal ranges are non-native, non-indigenous, or alien species. This attribute represents both an effect of human activities and a stressor in the form of biological pollution. The BCG identifies the presence of native taxa expected under undisturbed or minimally disturbed conditions as an essential characteristic of BCG level 1 and 2 conditions. The BCG only allows for the occurrence of non-native taxa in these levels if those taxa do not displace native taxa and do not have a detrimental effect on native structure and function. Condition levels 3 and 4 depict increasing occurrence of non-native taxa. Extensive replacement of native taxa by tolerant or invasive, non-native taxa can occur in levels 5 and 6. Florida Coral Examples (from initial expert assignments): *Tubastraea coccinea* (Orange cup coral)
VII. Organism condition	Anomalies of the organisms; indicators of individual health (e.g., coral bleaching, coral disease, fish deformities, lesions, tumors).

Attribute	Description
VIII. Ecosystem function	Ecosystem function refers to processes required for the performance of a biological system expected under naturally occurring conditions (e.g., primary and secondary production, respiration, nutrient cycling, and decomposition). Assessing ecosystem function includes consideration of the aggregate performance of dynamic interactions within an ecosystem, such as the interactions among taxa (e.g., food web dynamics) and energy and nutrient processing rates (e.g., energy and nutrient dynamics) (Cairns 1977). Additionally, ecosystem function includes aspects of all levels of biological organization (e.g., individual, population, and community condition). Altered interactions between individual organisms and their abiotic and biotic environments might generate changes in growth rates, reproductive success, movement, or mortality. These altered interactions are ultimately expressed at ecosystem-levels of organization (e.g., shifts from heterotrophy to autotrophy, onset of eutrophic conditions) and as changes in ecosystem process rates (e.g., photosynthesis, respiration, production, decomposition).
IX. Spatial and temporal extent of detrimental effects	The spatial and temporal extent of stressor effects includes the near-field to far-field range of observable effects of the stressors on a water body. Such information can be conveyed by biological assessments provided the spatial density of sampling sites is sufficient to convey changes along a pollution continuum (U.S. EPA 2013). Use of a continuum provides a method for determining the severity (i.e., departure from the desired state) and extent (i.e., distance over which adverse effects are observed) of an impairment from one or more sources.

Attribute	Description
X. Ecosystem connectivity	Access or linkage (in space/time) to materials, locations and conditions required for maintenance of interacting populations of aquatic life. It is the opposite of fragmentation and is necessary for persistence of metapopulations and natural flows of energy and nutrients across ecosystem boundaries. Ecosystem connectivity can be indirectly expressed by certain species that depend on the connectivity, or lack of connectivity, within an aquatic ecosystem to fully complete their life cycles and thus maintain their populations. There are two commonly recognized categories of connectivity based upon the typical life history (i.e., two-phase life cycle) of most reef associated fishes: (1) pre-settlement connectivity through larval dispersal and (2) post-settlement connectivity (Aguilar-Perera 2004). Transport of larval reef fish around Puerto Rico, the United States Virgin Islands, and the uninhabited island of Navassa, which comprise the Caribbean portion of the US-EEZ, is poorly understood, and is not reflected in current fish monitoring programs. Post-settlement connectivity involves 1) juveniles that settle in nursery areas and progressively migrate using intermediate habitats as they grow (e.g., mangroves, lagoons and seagrass beds) until reaching deeper adult habitats; or 2) other kinds of migrations, such as those related with feeding and spawning. The BCG Fish experts recommended additional research to better understand the connectivity between sampling locations and non-coral reef habitats and the necessity of such habitats for each fish species. The knowledge gained from such research would support the future development of useful metrics.

Appendix B - BCG Levels

The six Levels of the BCG are described as follows (modified from EPA 2016).

Level 1, Natural or native condition—Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability. Level 1 represents biological conditions as they existed (or still exist) in the absence of measurable effects of stressors and provides the basis for comparison to the next five Levels. The Level 1 biological assemblages that occur in a given biogeophysical setting are the result of adaptive evolutionary processes and biogeography. For this reason, the expected Level 1 assemblage of a coral reef from the Caribbean will be very different from that of a coral reef in the Pacific. The maintenance of native species populations and the expected natural diversity of species are essential for Levels 1 and 2. Non-native taxa (Attribute VI) might be present in Level 1 if they cause no displacement of native taxa, although the practical uncertainties of this provision are acknowledged (see section 2.2). Attributes I and II (i.e., historically documented and sensitive taxa) can be used to help assess the status of native taxa when classifying a site or assessing its condition.

Level 2, Minimal changes in structure of the biotic community and minimal changes in ecosystem function—Most native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability. Level 2 represents the earliest changes in densities, species composition, and biomass that occur as a result of slight elevation in stressors (e.g., increased temperature regime or nutrient pollution). There might be some reduction of a small fraction of highly sensitive or specialized taxa (Attribute II) or loss of some endemic or rare taxa as a result. The occurrence of non-native taxa should not measurably alter the natural structure and function and should not replace any native taxa. Level 2 can be characterized as the first change in condition from natural, and it is most often manifested in nutrient-polluted waters as slightly increased richness and density of either intermediate sensitive and intermediate tolerant taxa (Attributes III and IV) or both.

Level 3, Evident changes in structure of the biotic community and minimal changes in ecosystem function—Evident changes in structure due to loss of some highly sensitive native taxa; shifts in relative abundance of taxa, but sensitive-ubiquitous taxa are common and relatively abundant; ecosystem functions are fully maintained through redundant Attributes of the system. Level 3 represents readily observable changes that, for example, can occur in response to organic pollution or increased temperature. The “evident” change in structure for Level 3 is interpreted to be perceptible and detectable decreases in highly sensitive taxa (Attribute II) and increases in sensitive-ubiquitous taxa or intermediate organisms (Attributes III and IV).

Level 4, Moderate changes in structure of the biotic community with minimal changes in ecosystem function—Moderate changes in structure due to replacement of some intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant traits. Moderate changes of structure occur as stressor effects increase in Level 4. A substantial reduction of the two sensitive Attribute groups (Attributes II and III) and replacement by more tolerant taxa (Attributes IV and V) might be observed. A key consideration is that some Attribute III sensitive taxa are maintained at a reduced Level, but they are still an important functional part of the system (i.e., function is maintained). While total abundance (density) of organisms might increase, no single taxa or functional group should be overly dominant.

Level 5, Major changes in structure of the biotic community and moderate changes in ecosystem function—Sensitive taxa are markedly diminished or missing; conspicuously unbalanced distribution of major groups from those expected; organism condition shows signs of physiological stress; ecosystem function shows reduced complexity and redundancy; increased build-up or export of unused materials. Changes in ecosystem function (as indicated by marked changes in food-web structure and guilds) are critical in distinguishing between Levels 4 and 5. This could include the loss of functionally important sensitive taxa and keystone taxa (Attribute I, II, and III taxa), such that they are no longer important players in the system, though a few individuals may be present. Keystone taxa control species composition and trophic interactions, and are often, but not always, top predators. As an example, removal of keystone taxa by overfishing has greatly altered the structure and function of many coastal ocean ecosystems (Jackson et al. 2001). Additionally, tolerant non-native taxa (Attribute VI) may dominate some assemblages, and changes in organism condition (Attribute VII) may include significantly increased mortality, depressed fecundity, and/or increased frequency of lesions, tumors, and deformities.

Level 6, Severe changes in structure of the biotic community and major loss of ecosystem function—Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism condition is often poor; ecosystem functions are severely altered. Level 6 systems are taxonomically depauperate (i.e., low diversity and/or reduced number of organisms) compared to the other Levels. For example, extremely high or low densities of organisms caused by temperature anomalies, overfishing, and/or severe habitat alteration may characterize Level 6 systems. Non-native taxa may predominate.

Appendix C:

Partial listing of environmental conditions and disturbances in Florida's Coral Reef.

The following chronological listing of natural and anthropogenic disturbances to Florida's Coral Reef includes representative events that are presumed to affect reef biological conditions. The list is not yet comprehensive and focuses on reefs in the Florida Keys.

Select Perturbations That Have Affected Florida's Coral Reef Ecosystem

1973 – Antonius published first incidence of coral diseases in Florida Keys. (Antonius 1973).

1977 – Coral plague affecting non-Acroporid species first reported in Florida Keys, slow disease progression on tissue (Dustan 1977). Others later referred to this as white plague I (Richardson et al. 1998a, b).

1979 – Extraordinarily warm waters flowed from the Gulf of Mexico across the reefs, resulting in massive loss of the barrel sponge, *Xestospongia muta* on Big Pine Shoal, south of Big Pine (Causey 2008).

1980 – Doldrum-like weather patterns replaced the normal summer trade winds resulting in a 6-week warm water event. This caused a reef fish die-off throughout the Keys and minor coral bleaching on offshore colonies (Causey 2008).

1981 – Antonius published occurrence of white band disease in Florida Keys. (Antonius 1981)

1981 – Discolored water, algal blooms, and seagrass die-off reported by fishermen in western Florida Bay (DeMaria 1996).

1983 – Massive coral bleaching from Big Pine Key to Sand Key Reef off Key West. Coral bleaching was most severe on the shallow fore-reef habitats, particularly on the shallow outer reefs which have the greatest exposure to currents from the warmer waters of the Gulf and Florida Bay. Shallow fore reef habitats were most affected, but with minimal mortality (Turgeon et al. 2002).

1983 – *Diadema* die-off beginning (Lessios et al. 1984). About 95% of these important algal grazers died in a single year.

1986 – Black band disease outbreak on fore reef colonies from Big Pine Key to Key West. Colonies of all sizes were affected, and the disease killed coral colonies that were more than 200 years old (Causey 2008).

1987 – Doldrum-like weather in June, followed by a mass coral bleaching event along the seaward margin and on the outer reef tract of the entire Florida Keys. Corals at greater depths also significantly, but still restricted to the same area (outer reef tract). Corals from very shallow water down to depths of 30 m were almost uniformly white. Coral bleaching occurred throughout the Caribbean in September, followed by bleaching in the Indo-west Pacific in October. This was the first global, synchronized bleaching event (Causey 2008).

1989 – Minor bleaching of the genus *Agaricia* on the fore reef limited to Looe Key. Agaricia bleaching also occurred in Puerto Rico the Bahamas (Causey 2008).

1990 – Doldrum-like weather patterns with calm seas in the Florida Keys in July 1990. First bleaching observed in the zoanthid, *Palythoa caribaeorum,* then corals began to bleach on the outer reef tract starting at Looe Key Reef. By mid-August, corals were bleaching on the inshore patch reefs and in the tidal passes. This bleaching event was significant, because it was the first time that mass coral bleaching extended to inshore waters, which have acclimated to tolerate a broader range of temperatures. As a result, there was a substantial loss of live coral, and more than 65% mortality of fire coral *(Millepora complanta)* on the shallow reef crest (Causey 2008).

1991 – Mass mortality of the tropical seagrass *Thalassia testudinum* in Florida Bay (Roblee et al. 1991; LaPointe et al. 2019).

1992- 1993 – Back Band Disease has become chronic in Upper Keys (Kuta and Richardson 1996).

1994-1995 – Stable isotope analyses reveal nutrient rich groundwater percolated on to reefs near Palm Beach causing blooms of *Codium isthmocladum* (LaPointe 1997).

1995 – Caribbean yellow blotch disease (Santavy et al. 1999, 2001)/yellow band disease (Hayes and Bush 1990) observed by C. Quirolo in Key West reefs (Cervino et al. 2001, 2004).

1995 -1997 – White plague type II characterized by rapid tissue loss (up to 2cm/day) first reported in Florida Keys between June and October 1995, infected 17 scleractinian species. The most sensitive species, *Dichocoenia stokesi* experienced 38% complete mortality. Range was >400 km in Florida Keys (Richardson et al. 1998b).

1995 – Historic red tide *Karenia brevis* event in Florida Keys Steinman (1995).

1995-1996 – Sea fan disease epizootic reported in Keys. Aspergillosis identified as pathogen for sea fan disease in Keys (Smith et al. 1996, 1998)

1996 – Severe reductions in *Acropora palmata* populations caused by new disease, white pox, occurred in Eastern Dry Rocks, Florida (Holden, 1996; Porter et al., 2002).

1997 – Doldrum-like weather conditions began in the Florida Keys July 1997, with subsequent widespread mass coral bleaching event in August. Once again, the bleaching event was widespread and long-lasting, affecting both offshore and inshore corals, with many remaining bleached or mottled well into 1998 (Causey 2008; Sommerfield et al. 2008).

1997 – Description of White band disease Type II in acroporid corals only found in Bahamas (Ritchie and Smith 1998).

1997 – Dark spot disease associated with *Siderastrea siderea* reported in Keys.

1998 – Outbreak of coral disease white plague type II in the Florida Keys (Richardson et al. 1998a).

1998 – The waters of the Florida Reef Tract did not cool much during the winter of 1997-98 and a particularly strong El Niño event caused yet another bleaching in 1998. The blade fire coral suffered 80-90% mortality and has remained low in abundance throughout most of the Florida Keys (Turgeon et al. 2002).

1998 – The Florida Keys were hit by Hurricane Georges in September. Large branching Elkhorn and Staghorn corals were broken (USGS 1998; AOML 1999; Waddell et al. 2005).

1998 – Aspergillosis identified as pathogen for sea fan disease in Keys (Smith et al. 1998).

2002 – Etiology study of White pox disease reported affecting *Acropora palmata* in Florida Keys, showed disease caused by the bacterium *Serratia marcescens* (Patterson et al. 2002).

2003 – White plague type II in Florida caused by new genus bacterium *Aurantimonas coralicida* (Denner et al. 2003).

2003 – *Acropora cervicornis* affected by rapid tissue loss disease White Bank Dry Rocks outbreak. Disease is transmissible (Dana and Miller 2005).

2004 – Hurricane Charley caused moderate damage to coral reefs at Dry Tortugas and off Broward County. Hurricanes Francis and Jeanne caused damage to coral reefs off Palm Beach and Martin Counties (Waddell et al. 2005).

2005 – Hurricanes Katrina and Wilma hit the Florida Keys, overturning coral colonies and scouring the bottom (Waddell et al. 2008). While elevated SSTs occurred in the Florida Keys there was only minor to patchy coral bleaching. Florida's corals escaped the severe coral bleaching that was recorded throughout much of the Wider Caribbean (Causey 2008).

2006 – Elkhorn (*Acropora palm*ata) and staghorn coral (*Acropora cervicornis*) were listed as threatened species under the Endangered Species Act.

2006 – BBD reportedly transferred by butterfly fish *Chaetodon capistratus* after feeding on infected corals, with presumptive transmission occurring orally and fecally by fish (Aeby and Santavy 2006).

2008 – Tortugas multispecies rapid tissue loss disease (TMRTL) in Dry Tortugas National Park (DTNP) (Brandt et al. 2012). Affecting 14 scleractinian species. Disease signs most similar white plague (sensu Richardson et al. 1998b, 2001; figs. 2-3). Included thin white film on denuded skeleton.

2010 – A cold front passed through the Florida Keys, suddenly reducing seawater temperature. Corals with narrow thermal tolerance sustained high mortality (e.g., *Acropora cervicornis*, *Orbicella annularis, O. faveolata, Porites astreoides* and *Colpophyllia natans*, *Dendrogyra cylindrus)* on inshore reefs. *Siderastrea siderea,* which has a wide thermal tolerance, was not affected by this cold anomaly (Kemp et al. 2016).

2014 – The boulder star coral (*Orbicella franksi*), mountainous star coral (*Orbicella faveolata*), lobed star coral (*Orbicella annularis*), rough cactus coral (*Mycetophyllia ferox*) and pillar coral (*Dendrogyra cylindrus)* were listed as threatened species under the Endangered Species Act.

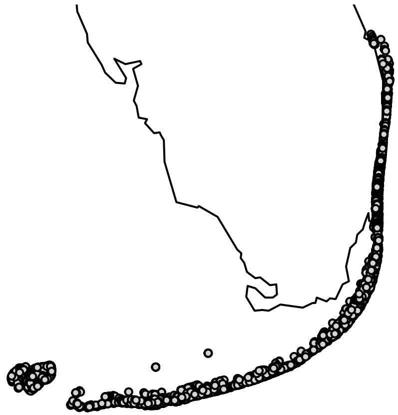
2014 – An intense bleaching event occurred during the summer, followed by a new emergent disease, Stony Coral Tissue Disease (SCTLD), which was first reported off the coast of Miami-Dade County in September (Precht et al., 2016; Precht, 2019; FEDP, 2019). SCTLD affects more than 20 species of scleractinian (stony) corals (Lunz et al. 2017), destroying the corals' soft tissue, killing them within weeks or months of becoming infected (Meiling et al. 2021).

2014 – Stony Coral Tissue Disease ISCTLD) reported off the coast of Miami-Dade County. The disease spread rapidly throughout Florida's Coral Reef, reaching Broward County and Biscayne National Park in 2015; Palm Beach County and the upper Keys in 2016; Martin County and the middle Keys in 2017; the lower Keys in 2018 and 2019 and the Dry Tortugas in 2021. Half of Florida's 45 reef-building coral species had been affected by 2017, including five species listed under the Endangered Species Act.

2017 – Hurricanes Irma and Maria damaged corals, most particularly the ESA listed coral species, *Acropora cervicornis* and *Orbicella annularis (NOAA NCCOS 2023).*

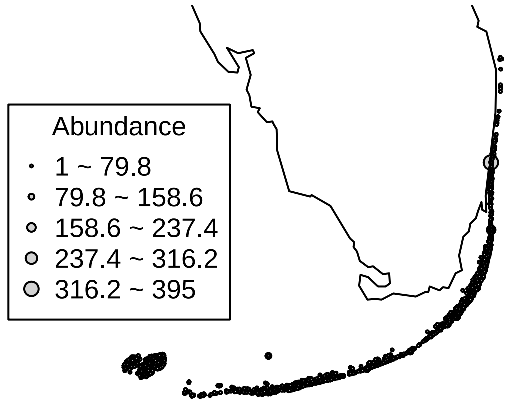
Appendix D: Species Distributions

Sample Distribution



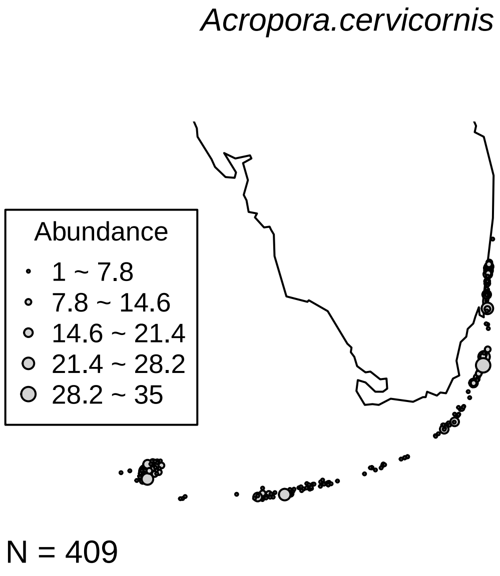
N = 5815

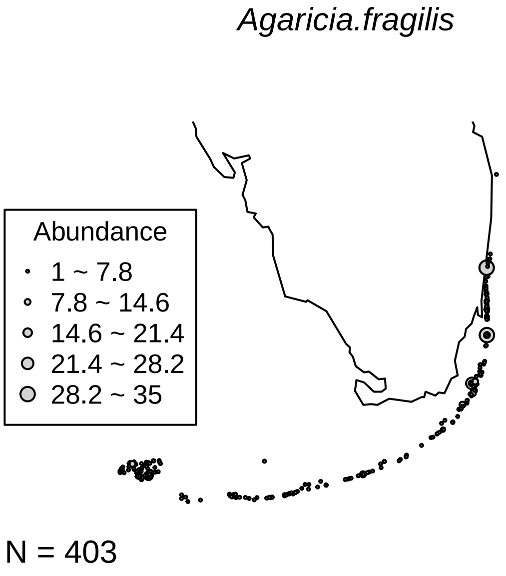
Agaricia.agaricites



N = 2880

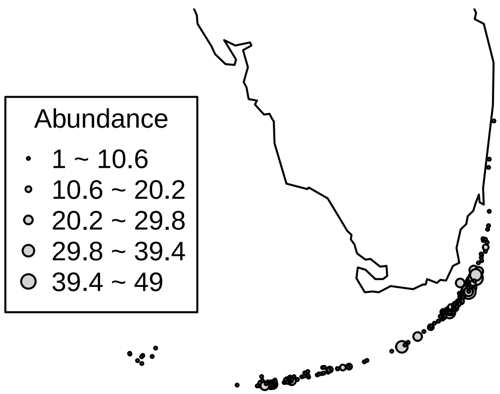
Appendix D: Species Distributions





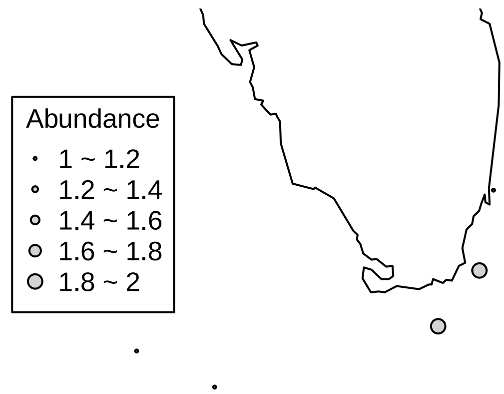
Appendix D: Species Distributions

Agaricia.sp.



N = 218

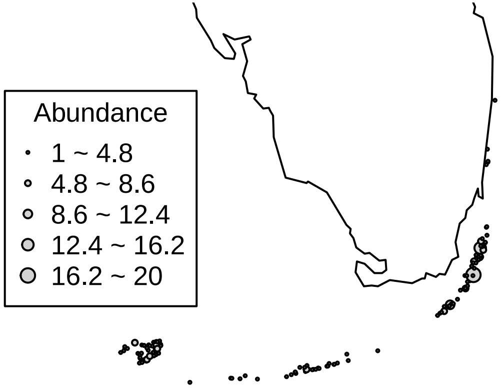
Agaricia.grahamae



N = 5

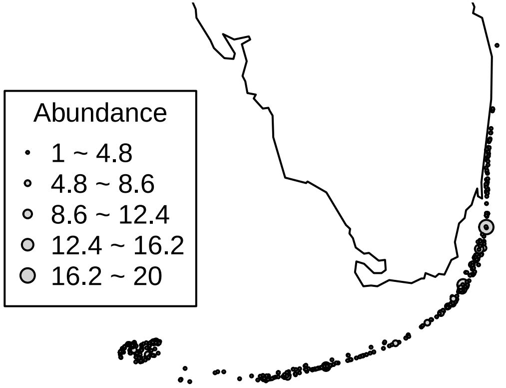
Appendix D: Species Distributions

Agaricia.Humilis



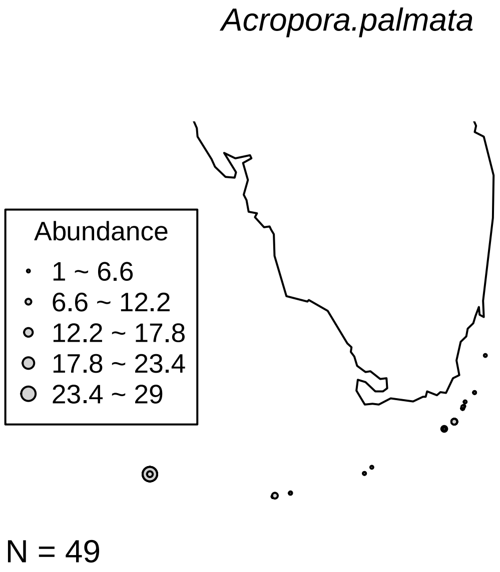
N = 152

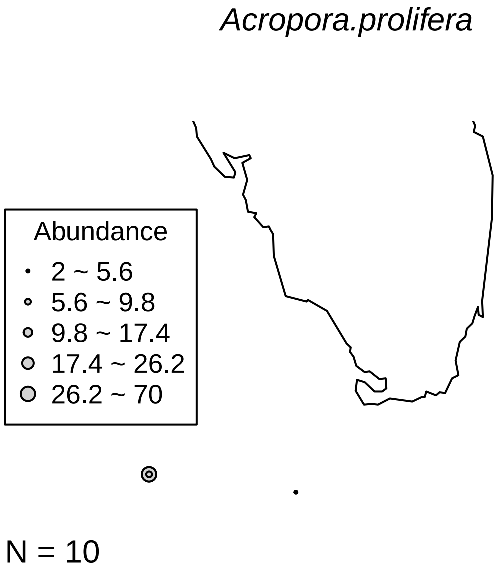
Agaricia.lamarcki



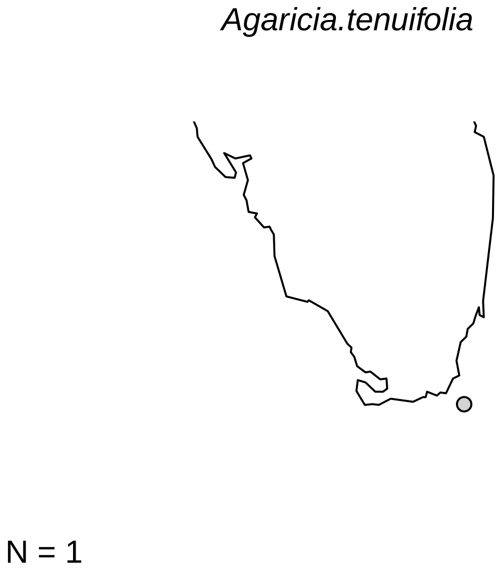
N = 496

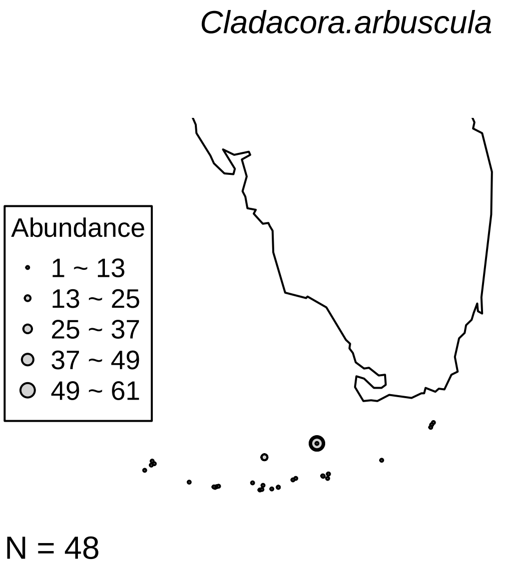
Appendix D: Species Distributions



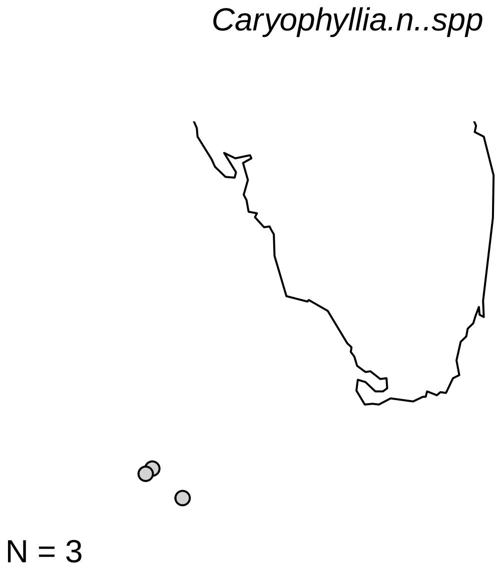


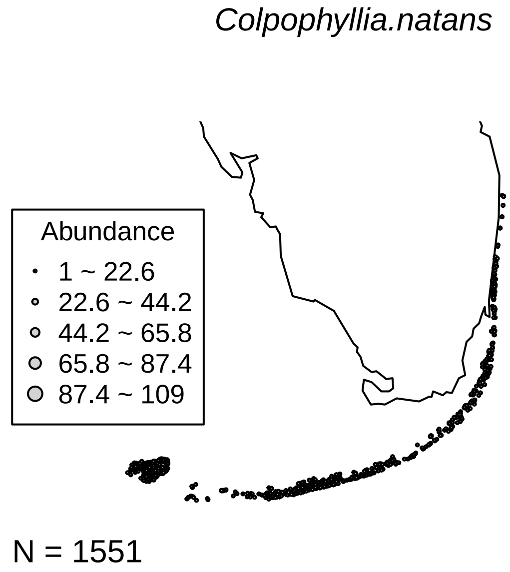
Appendix D: Species Distributions





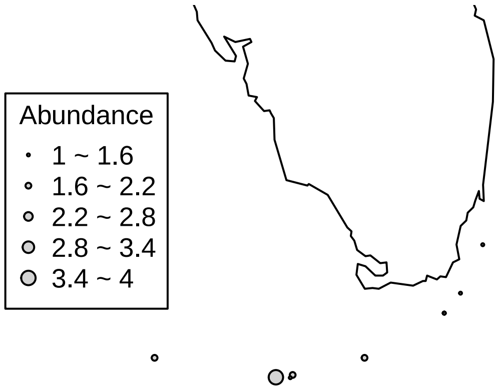
Appendix D: Species Distributions





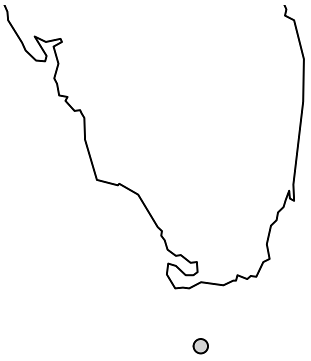
Appendix D: Species Distributions

Dendrogyra.cylindrus



N = 14

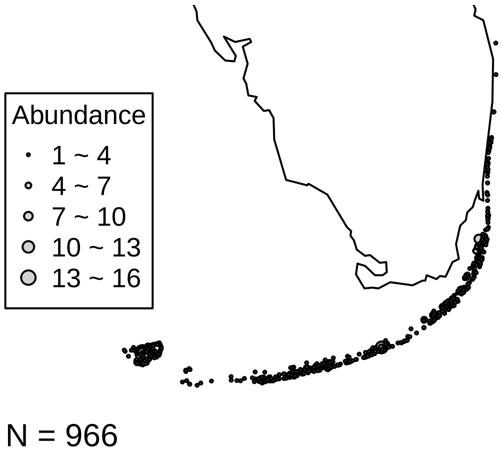
Diploria.sp.



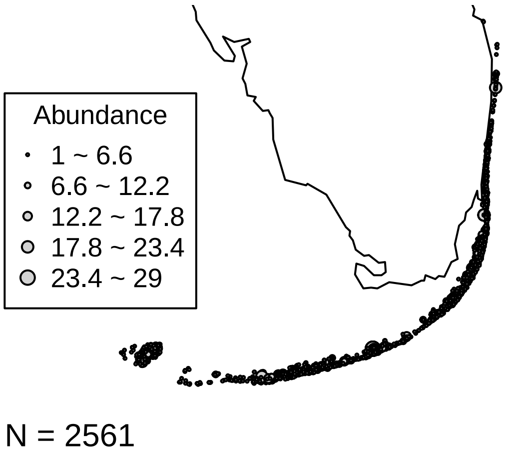
N = 1

Appendix D: Species Distributions

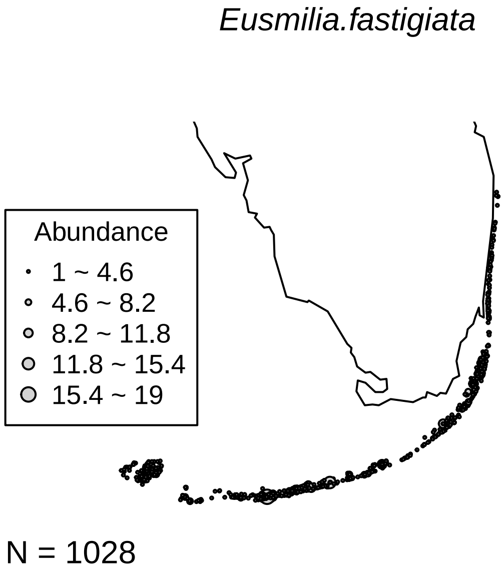
Diploria.labyrinthiformis

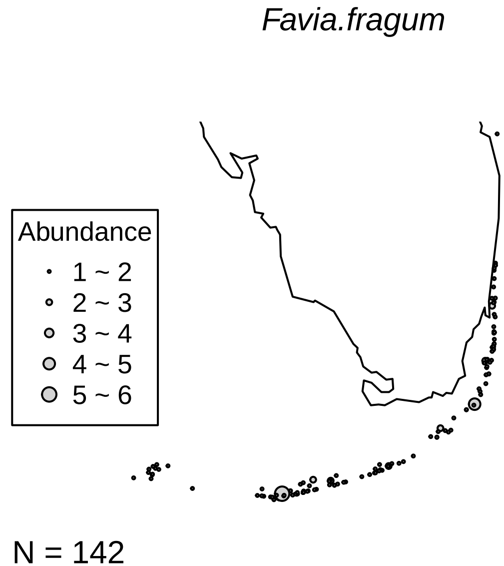


Dichocoenia.stokesii

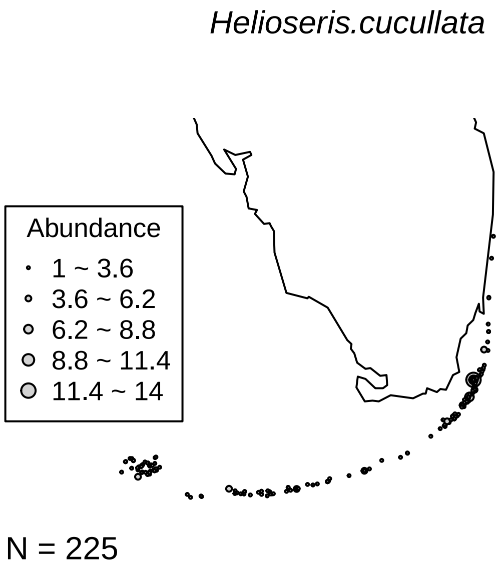


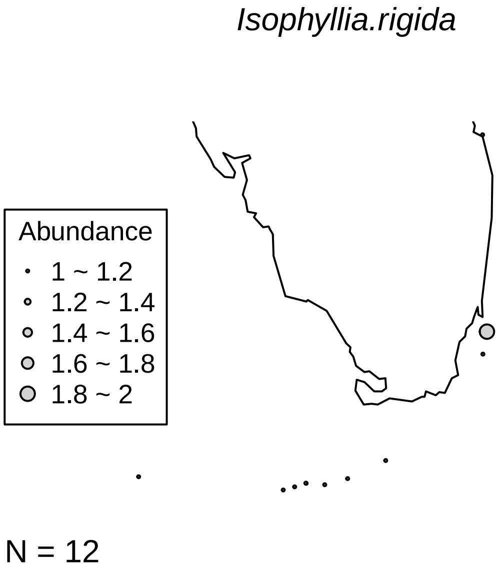
Appendix D: Species Distributions





Appendix D: Species Distributions





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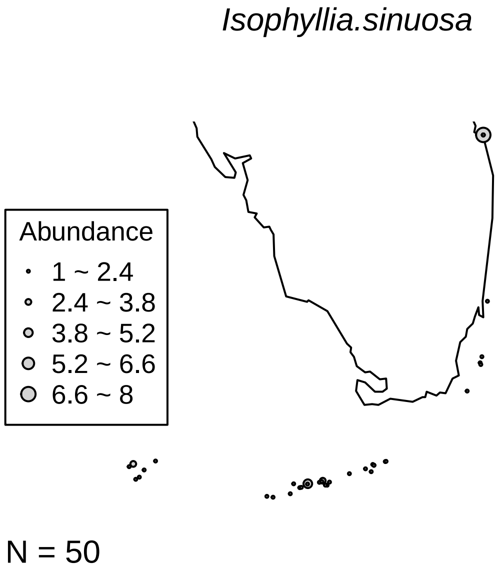
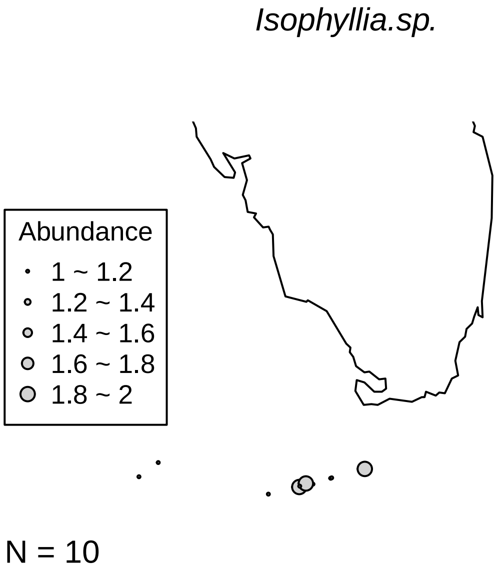
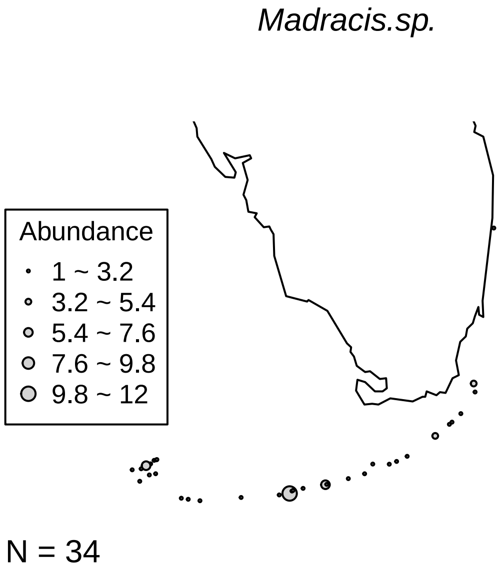
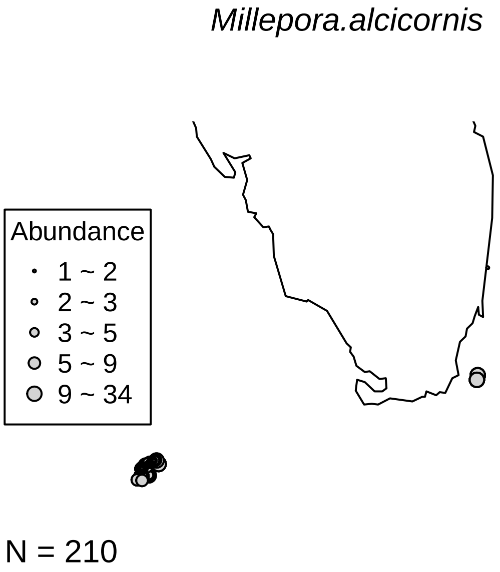




Appendix D: Species Distributions





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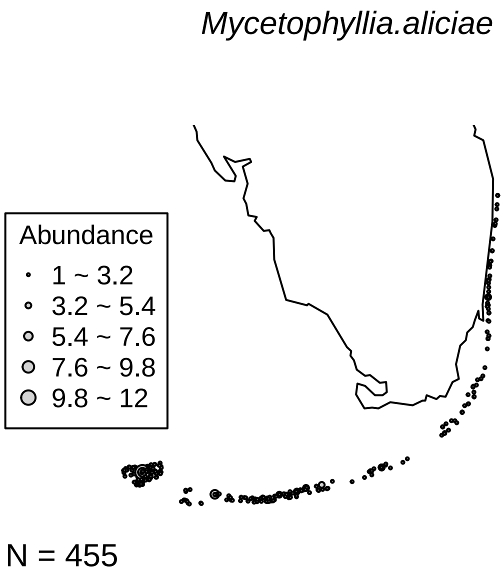

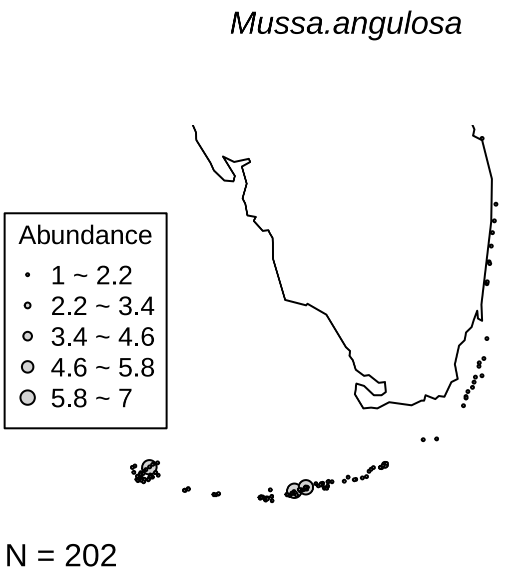

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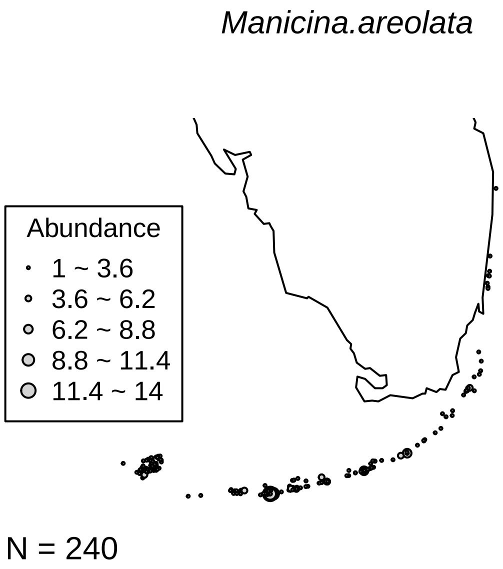

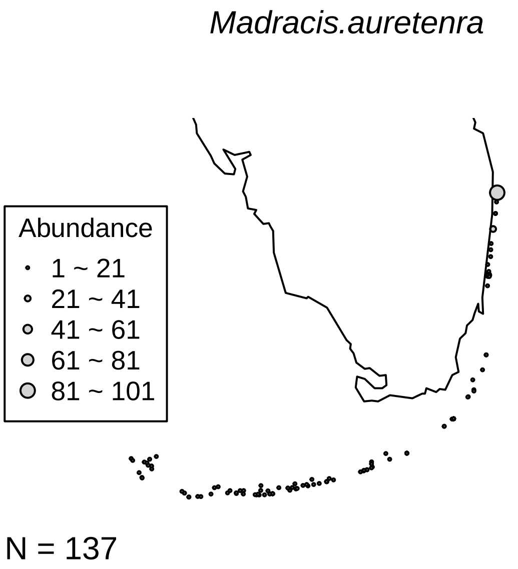

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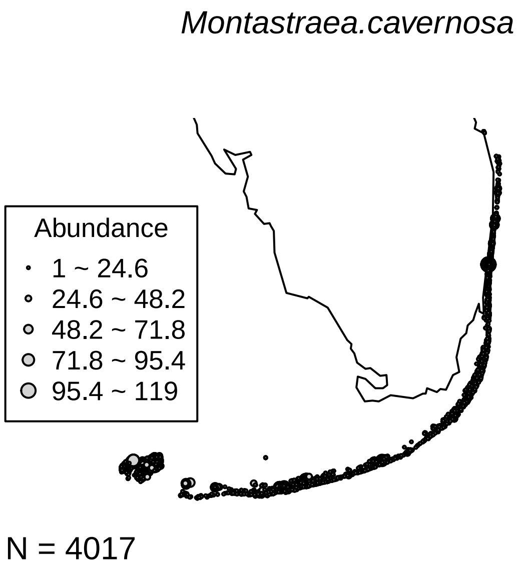
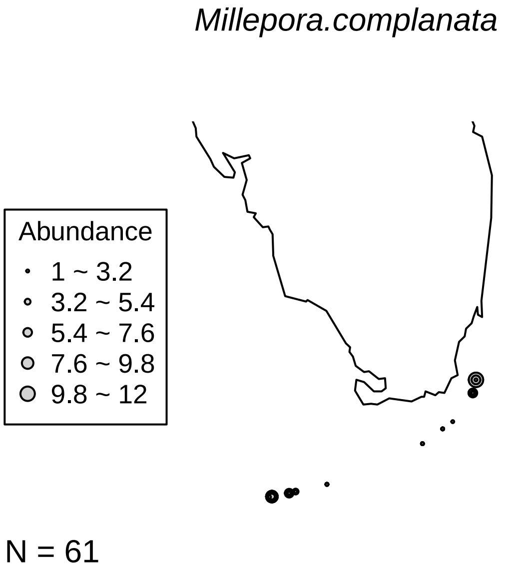
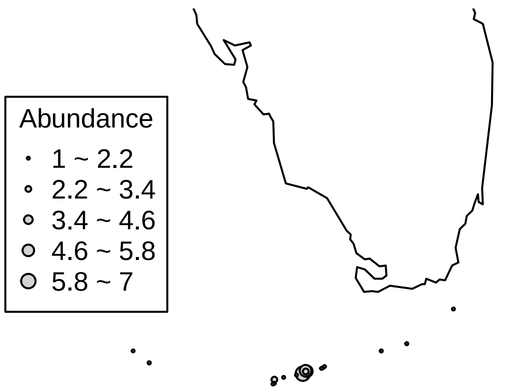




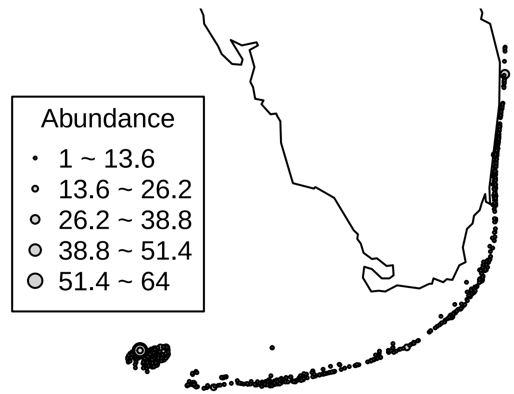
Appendix D: Species Distributions

Mycetophyllia.danaana



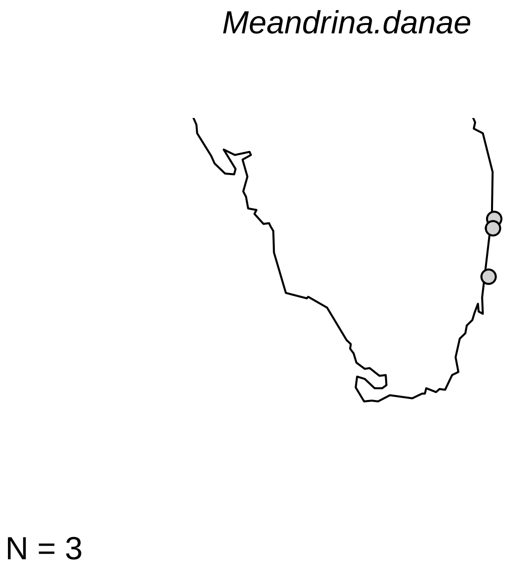
N = 23

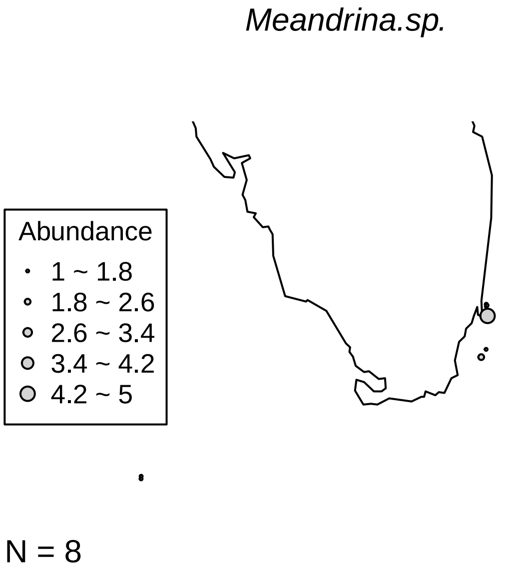
Madracis.decactis



N = 1144

Appendix D: Species Distributions





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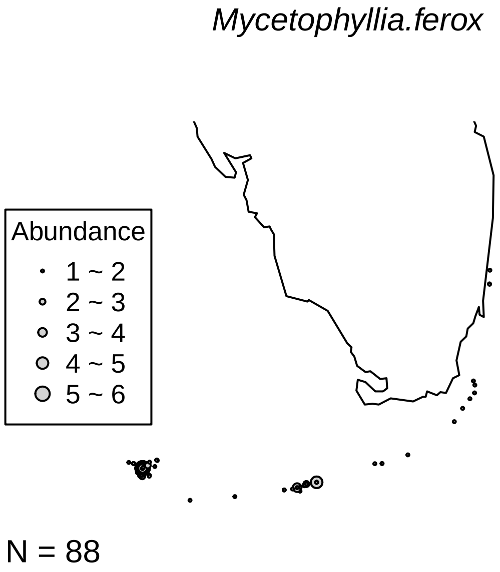

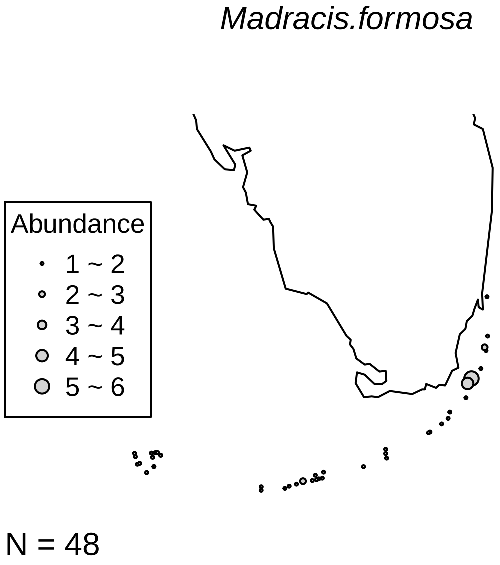

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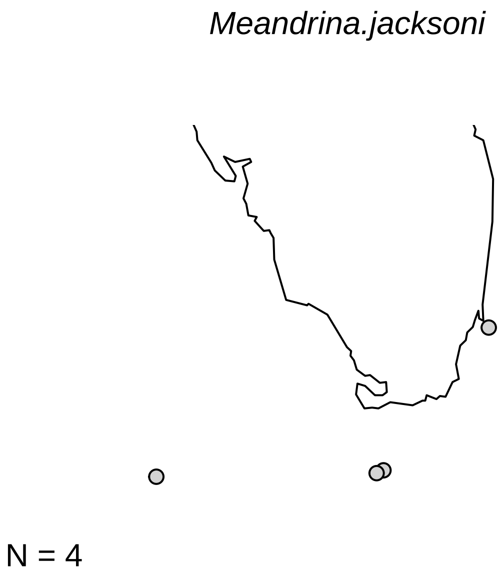

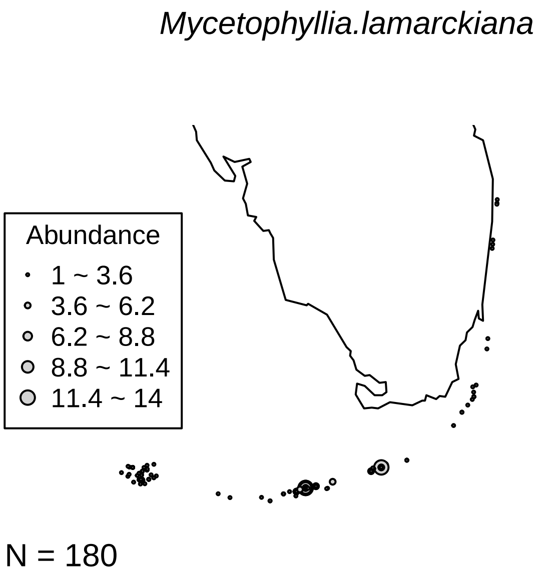

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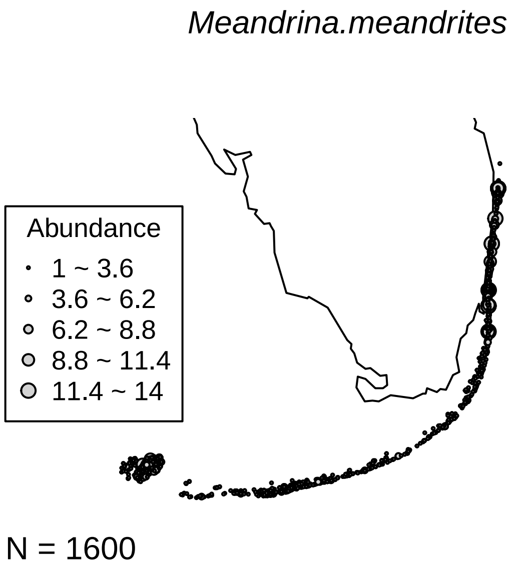
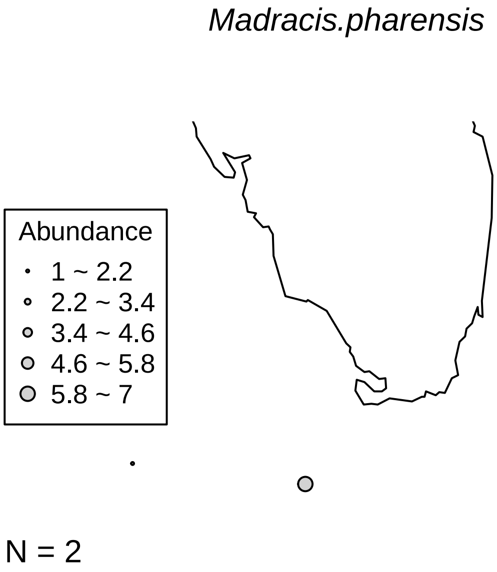
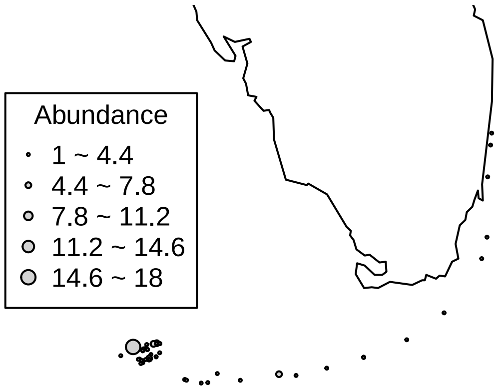




Appendix D: Species Distributions

Madracis.senaria



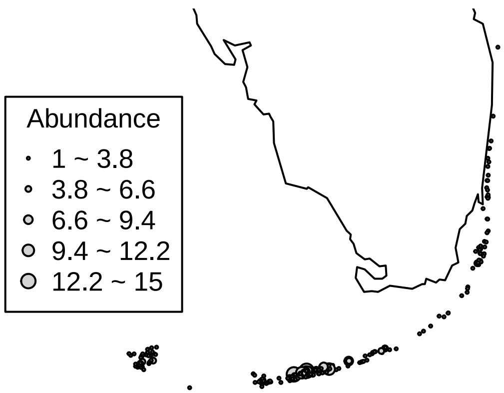
N = 66

Millepora.squarrosa

N = 1

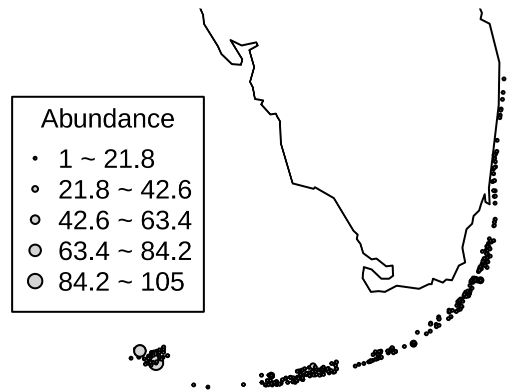
Appendix D: Species Distributions

Mycetophyllia.sp.



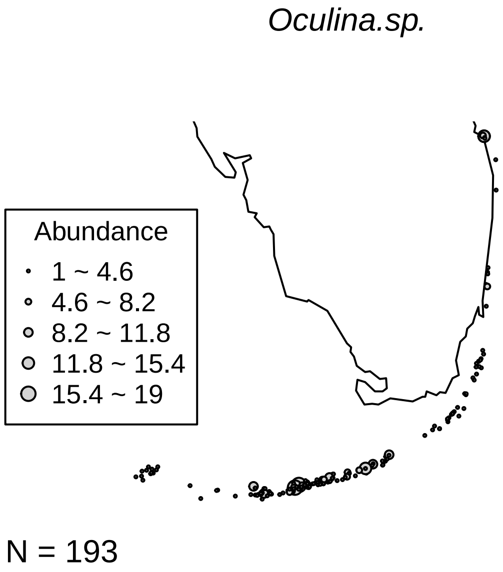
N = 252

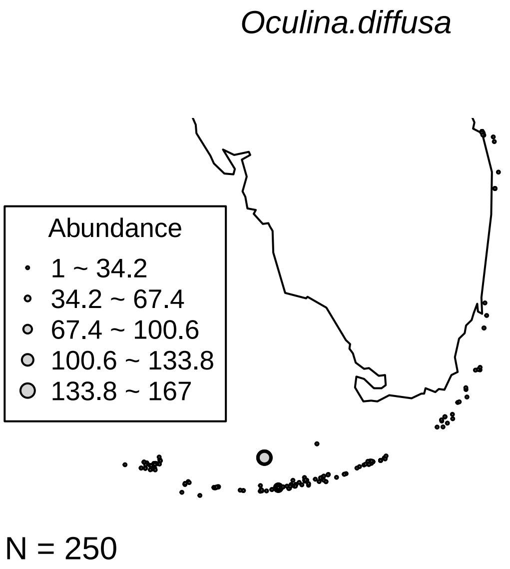
Orbicella.annularis



N = 577

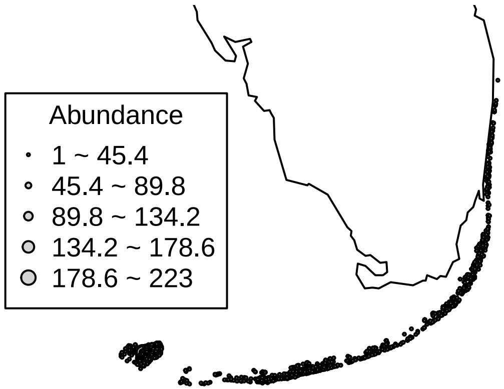
Appendix D: Species Distributions





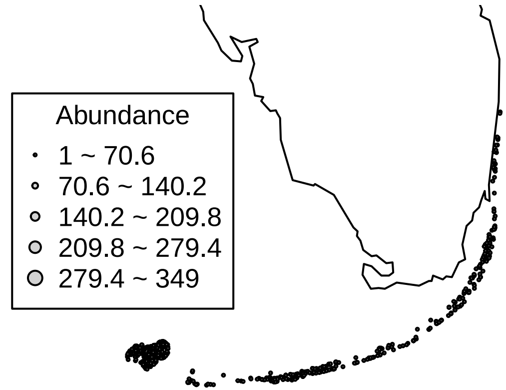
Appendix D: Species Distributions

Orbicella.faveolata



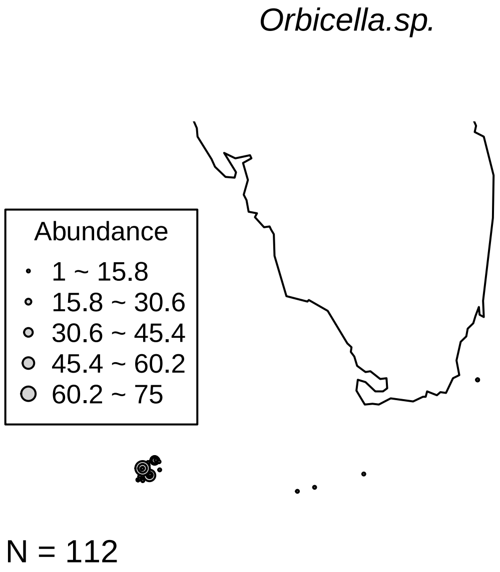
N = 2023

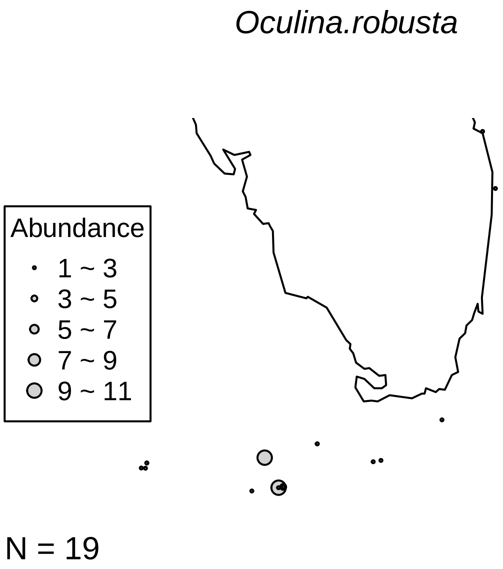
Orbicella.franksi



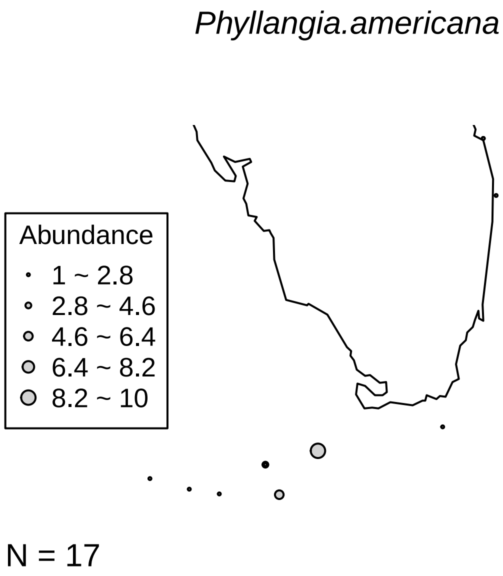
N = 1004

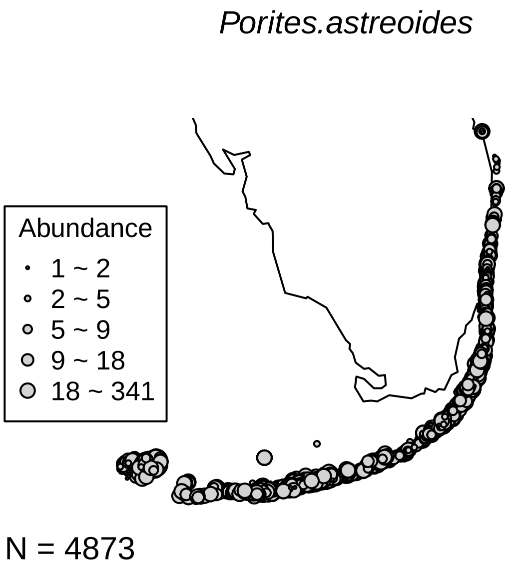
Appendix D: Species Distributions



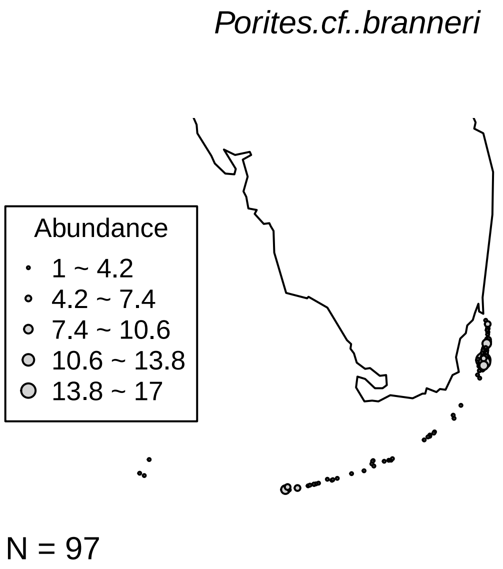


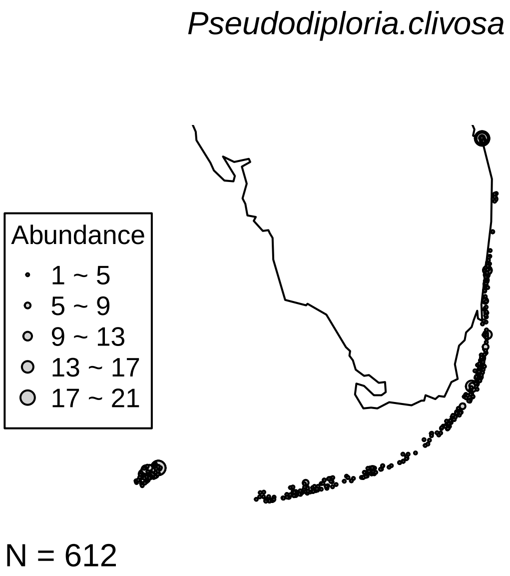
Appendix D: Species Distributions



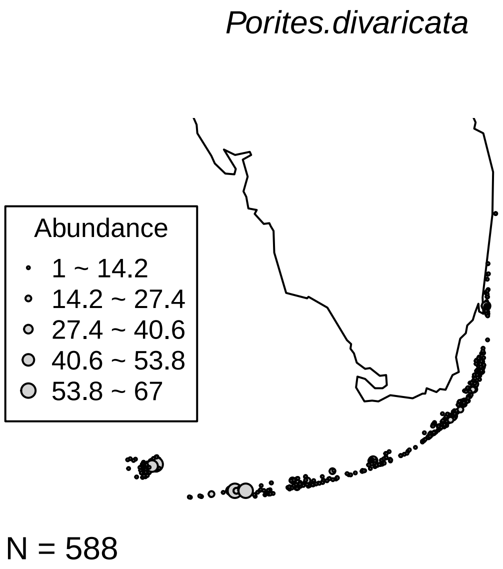


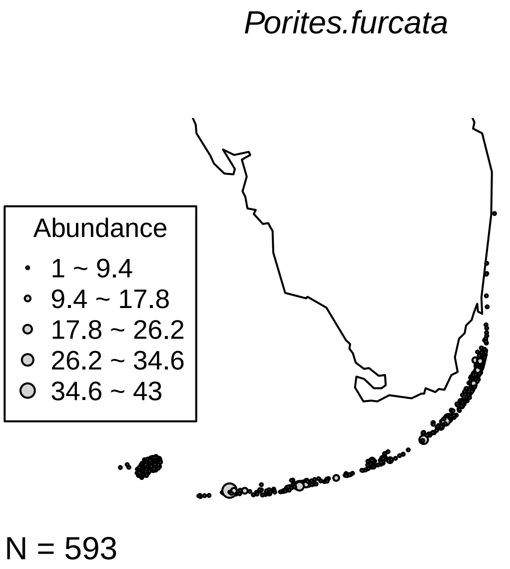
Appendix D: Species Distributions



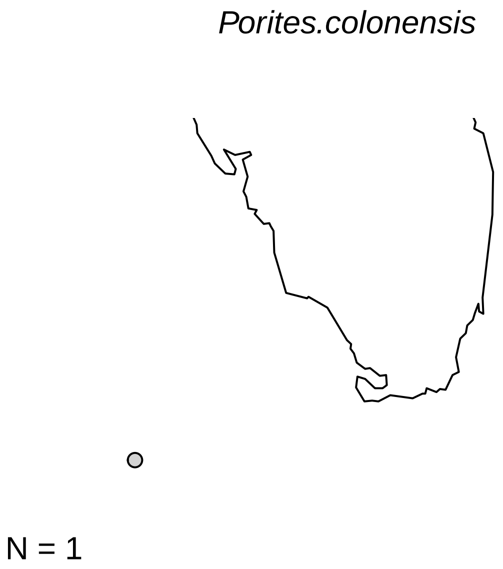


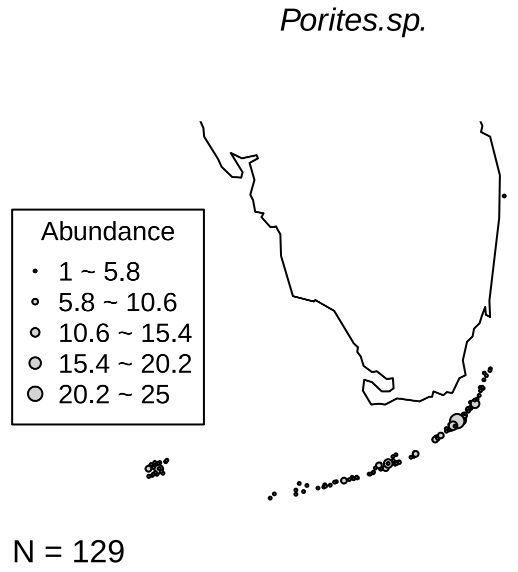
Appendix D: Species Distributions





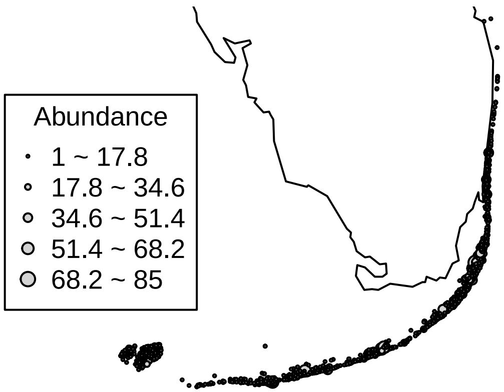
Appendix D: Species Distributions





Appendix D: Species Distributions

Porites.porites



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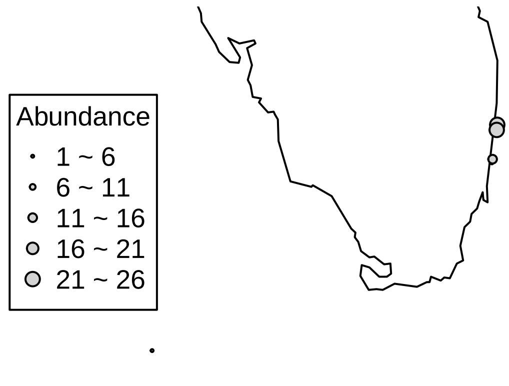

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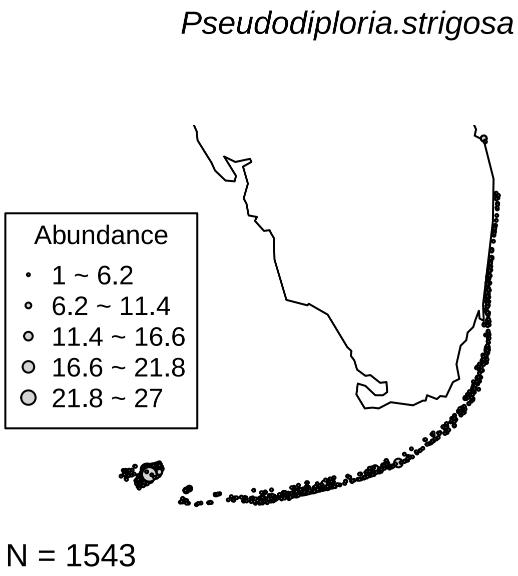
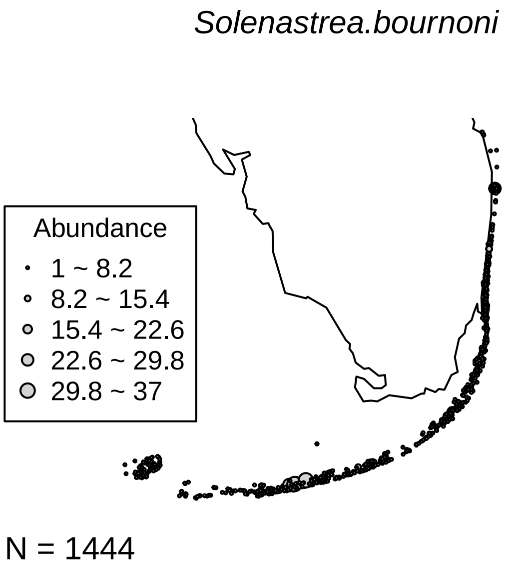
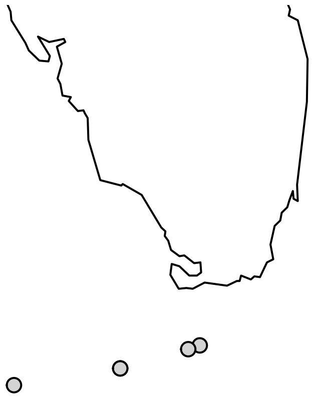
Appendix D: Species Distributions





Appendix D: Species Distributions

Scleractinia



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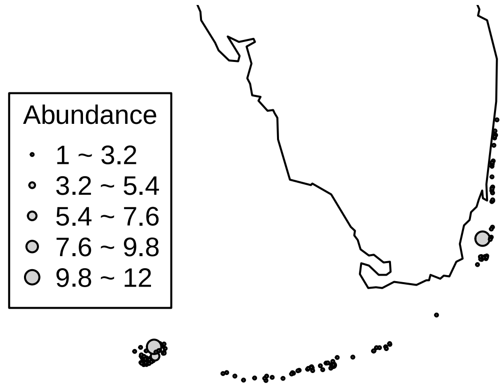
Scolymia.sp.



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Appendix D: Species Distributions

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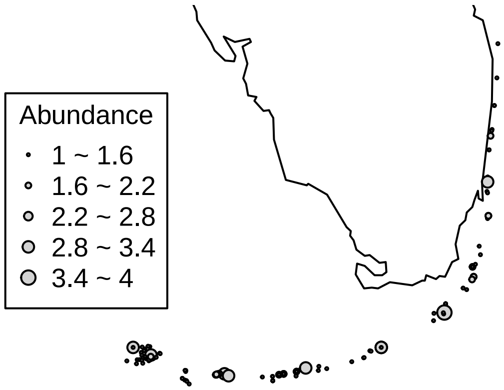

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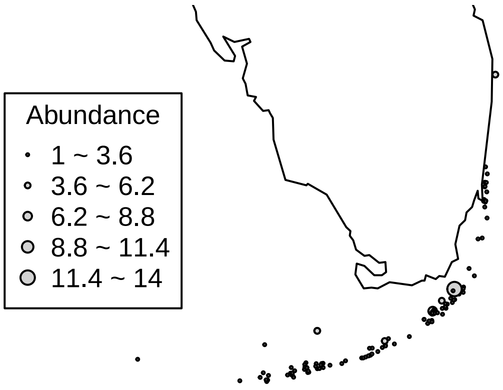
Solenastrea.hyades



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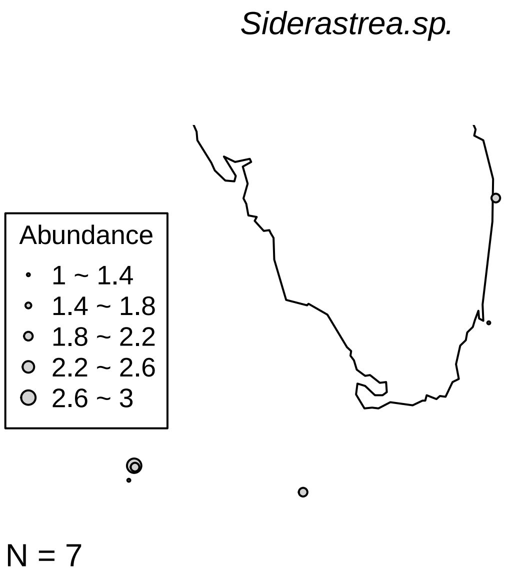
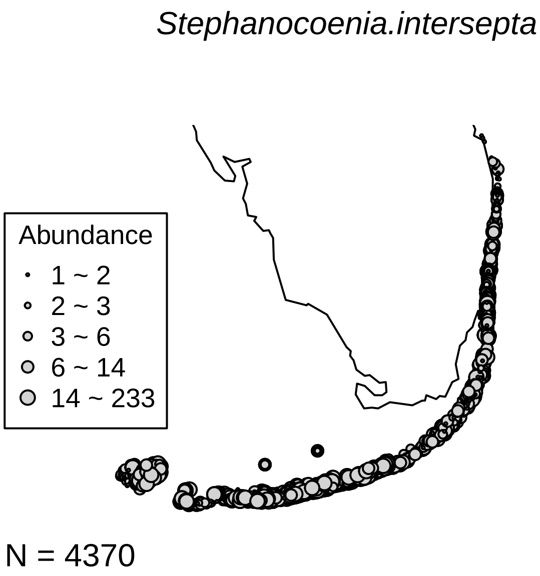
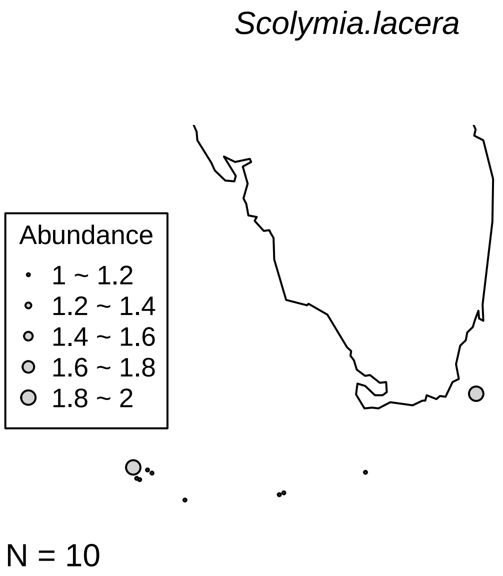
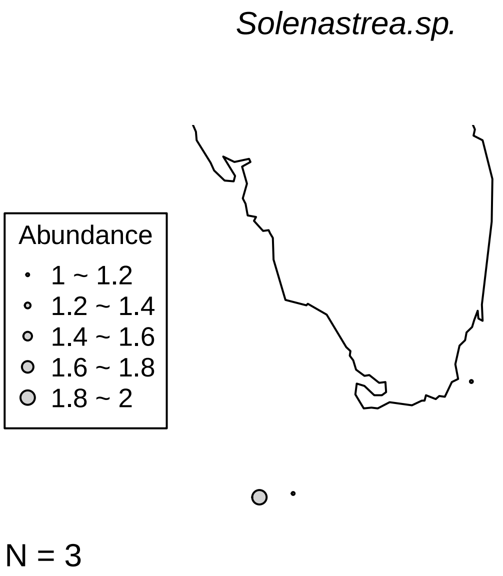
Appendix D: Species Distributions



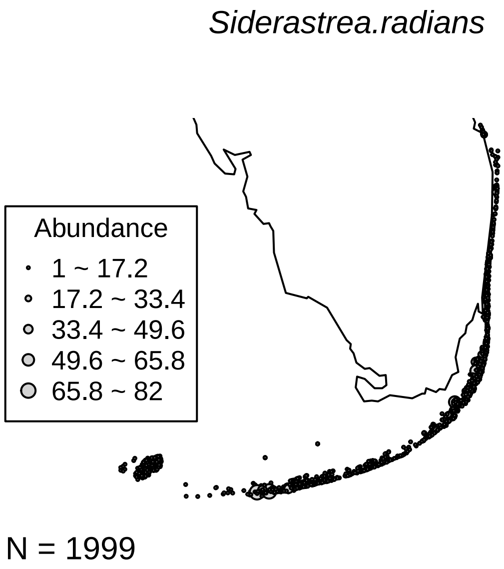


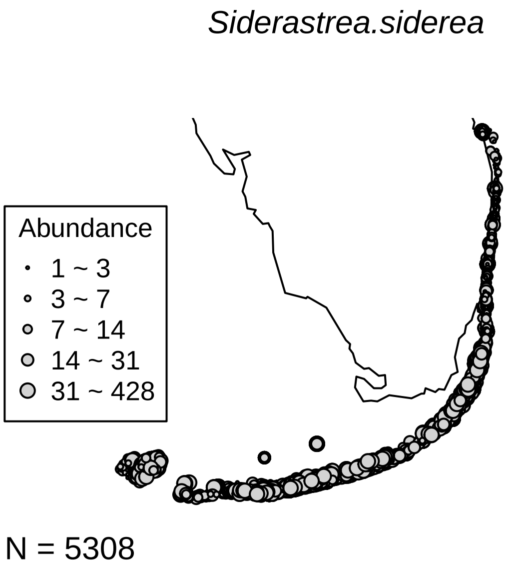
Appendix D: Species Distributions





Appendix D: Species Distributions





Appendix D: Species Distributions

Undaria.tenuifolia

N = 1

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- Pat Bradley, Tetra Tech

Observers

- Tori Barker, Florida Sea Grant, *in support of Florida DEP*
- Katie Lizza, Florida DEP
- Joanna Walczak, Florida DEP

Appendix F

Stony Coral Tissue Loss Disease Susceptibility in Florida

This list is intended to provide a general guide for SCTLD susceptibility by species in Florida. Designations may differ through space and time.

Highly Susceptible: Species that experience early onset of SCTLD during an outbreak and experience relatively rapid tissue loss and high prevalence and mortality rates. Several species are considered 'canaries in the coal mine' that help determine if SCTLD is affecting a given reef.

Susceptible Species: Species that succumb to SCTLD, but the onset of tissue loss typically occurs several weeks after onset in highly susceptible species (nb: lower numbers may also show disease signs along with highly susceptible species).

Presumed Susceptible: Presumed susceptible but insufficient data to categorize onset.

Normally unaffected: During outbreaks, corals that are rarely or not affected by SCTLD

Species	Notes
Highly Susceptible Species	
Colpophyllia natans (boulder brain coral)	
Dendrogyra cylindrus (pillar coral)*	
Dichocoenia stokesii (elliptical star coral)	
Diploria labyrinthiformis (grooved brain coral)	
Eusmilia fastigiata (smooth flower coral)	
Meandrina jacksoni (whitevalley maze coral)	
Meandrina meandrites (maze coral)	
Pseudodiploria clivosa (knobby brain coral)	
Pseudodiploria strigosa (symmetrical brain coral)	
Susceptible Species	
Agaricia agaricites (lettuce coral)	
Montastraea cavernosa (large-cup star coral)	"Highly Susceptible" in some jurisdictions.
Mussa angulosa (spiny flower coral)	
Mycetophyllia aliciae (knobby cactus coral)	
Mycetophyllia ferox (rough cactus coral)	
Mycetophyllia lamarckiana (ridged cactus coral)	
Orbicella annularis (lobed star coral)*	
Orbicella faveolata (mountainous star coral)*	
Orbicella franksi (boulder star coral)*	
Porites astreoides (mustard hill coral)	"Normally Unaffected" in some jurisdictions.
Siderastrea siderea (starlet coral)	"Highly Susceptible" in some jurisdictions.
Solenastrea bournoni (smooth star coral)	

Species	Notes
Stephanocoenia intersepta (blushing star coral)	
Species Presumed to be Susceptible	
Agaricia tenuifolia (thin leaf lettuce coral)	
Favia fragum (golfball coral)	
Helioseris cucullata (sunray lettuce coral)	
Isophyllia spp. (cactus corals)	
Madracis auretenra (pencil coral)	"Normally Unaffected" in some jurisdictions.
Scolymia spp. (disc corals)	
Siderastrea radians (lesser starlet coral)	
Acropora cervicornis (staghorn coral)*	
Acropora palmata (elkhorn coral)*	
Acropora prolifera (fused staghorn coral)	
Cladocora arbuscula (tube coral)	
Oculina spp. (bush corals)	
Tubastraea coccinea (orange cup coral)	
Porites divaricata (thin finger coral)	
Porites furcata (branched finger coral)	
Porites porites (finger coral)	

Appendix G
BCG Attribute Assignments

Scientific Name	Common English Name	Family	Synonym	Rationale
I - Historically documented, sensitive, long-lived or regionally endemic taxa				
Dendrogyra cylindrus	Pillar coral	Meandrinidae		near extirpation, sensitivity to SCTLD, early collections ; ESA listed
II - Sensitive-rare taxa				
Acropora palmata	elkhorn coral	Acroporidae		uncommon now, but used to be very common; Only offshore and bank barrier
Isophyllastrea rigida	Rough cactus coral	Mussidae	*Isophyllia rigida*	SCTLD, WP, rare, few recruits; has always been fairly rare
Isophyllia sinuosa	Sinuous cactus coral	Mussidae		SCTLD, WP, rare, few recruits; has always been fairly rare
Meandrina danae	Butterprint rose coral	Meandrinidae	*Meandrina brasiliensis*	Similar to other Meandrites
Meandrina jacksoni	White valley maze coral	Meandrinidae	*Meandrina meandrites, M. memorialis*	SCTLD susceptible, not recovering; really sensitive (bleaching, white plague)
Meandrina meandrites	Maze coral	Meandrinidae	*Meandrina memorialis*	SCTLD susceptible, not recovering
Meandrina sp.	Maze coral	Meandrinidae	*Meandrina meandrites*	Was common before SCTLD, juveniles are coming back
Mycetophyllia ferox	Rough cactus coral	Mussidae		rare and sensitive - ESA listed - more rare than congeners; SCTLD
III - Sensitive-ubiquitous taxa				
Acropora cervicornis	staghorn coral	Acroporidae		good condition in Broward County; rarely see disease
Acropora prolifera	fused staghorn	Acroporidae	*A. cervicornis*	rare; is a hybrid; Can cross with other Acroporids, but not with other A. proliferas; it is not a listed species (ESA); in Dry Tortugas, Turtle Rocks Pennekamp, Looe Key and Broward County
Agaricia fragilis	Fragile saucer coral	Agariciidae	*Agaricia fragilis*	not as common as other Agariscias; more cryptic

Scientific Name	Common English Name	Family	Synonym	Rationale
Agaricia lamarcki	Whitestar sheet coral	Agariciidae		used to see big slopes of them; 2nd most common species on reef before disease and bleaching
Colpophylia spp		Mussidae		See C. natans
Colpophyllia natans	Boulder brain coral	Mussidae		Now rare and not rebounding; was common in the 1990s; wiped out by SCTLD
Dichocoenia stokesii	Elliptical star coral	Meandrinidae	*Dichocoenia stokesi*	rebounds; papers from Richardson lab documented that it was one of the most susceptible species to white plague disease type 2 (1990s)
Diploria labyrinthiformis	Grooved brain coral	Mussidae		like *Colpophyllia natans*, rare and sensitive; declined with SCTLD, but still common in some locations; recruits present
Eusmilia fastigiata	Smooth flower coral	Meandrinidae		declined with SCTLD, but a lot of recruitment and survivors; most now small; large colonies gone
Helioseris cucullata	Sunray lettuce coral	Agariciidae	*Leptoseris cucullata or Helioceris cucullata*	declined with SCTLD, less likely to bleach due to habitat (sides of spurs; deeper areas; shaded); uncommon
Millepora complanata	Blade fire hydrocoral	Milleporidae		near extirpation from 2014/2015 bleaching but good recovery; extremely sensitive to temperature
Mussa angulosa	Atlantic mushroom coral	Mussidae	*Scolymia lacera*	declined with SCTLD, but never really common
Mycetophyllia danaana	Deep valley cactus coral	Mussidae	*Mycetophyllia daniana*	not a species now (?)
Mycetophyllia lamarckiana	Ridged cactus coral	Mussidae	*Mycetophyllia danaana*	declined with SCTLD, but few reports; recruits seen
Orbicella annularis	Lobed star coral	Merulinidae	*Montastrea annularis*	doesn't recruit, sensitive to sedimentation, bleaching, and disease; was very common but is now ESA listed
Orbicella faveolata	Mountainous star coral	Merulinidae	*Montastrea faveolata*	was very common but is now ESA listed

Scientific Name	Common English Name	Family	Synonym	Rationale
Pseudodiploria strigosa	Symmetrical brain coral	Mussidae	*Diploria strigosa*	susceptible to SCTLD and other stressors
IV – Taxa of Intermediate Tolerance				
Agaricia agaricites	Low relief lettuce coral	Agariciidae	*Undaria agaricites*	sensitivity to bleaching, but recovers; generally not tolerant to environmental pressures but is prolific and does reproduce; it is weedy - not tolerant
Agaricia humilis	Low relief lettuce coral	Agariciidae	*Undaria humilis*	common but small; also sensitive top bleaching
Agaricia tenuifolia	Thin leaf lettuce coral	Agariciidae	*Undaria tenuifoli*	not in Florida; where you have it, it is a large reef builder (elsewhere in Caribbean); it takes wave action, bleaching and recovers
Favia fragum	Golfball coral	Mussidae		not as common now as it was; has shown recovery since near extirpation during 2014-2015 bleaching; very specialized habitat (shallow reef crest)
Madracis auretenra	Yellow pencil coral	Pocilloporidae	*Madracis mirabilis*	on walls in SE FL; pretty hardy; used to be common, now rare, sensitive; does not reproduce a lot; lots prior to 1997/98 El Nino event
Montastraea cavernosa	Great star coral	Montastraeidae		ubiquitous; susceptible to disease, but recruits well, replaces Orbicella when sedimentation is the stressor; specially adapted with large polyps to deal with sediments, can tolerate freshwater and ship channels; disease susceptibility; can shift symbionts (more tolerant)
Mycetophyllia aliciae	Knobby cactus coral	Mussidae		sensitivity to SCTLD, but not highly susceptible; most common Mycet now; recruits seen

Scientific Name	Common English Name	Family	Synonym	Rationale
Orbicella franksi	Boulder star coral	Merulinidae	*Montastrea franksi*	was very common but is now ESA listed; rigid skeletal structure (tolerant of fish predation)
Porites divaricata	Thin finger coral	Poritidae	*Porites porites*	tolerant and successful reproducer
Porites furcata	Branching finger coral	Poritidae	*Porites porites*	tolerant and successful reproducer
Porites porites	Clubtip finger coral	Poritidae		tolerant and successful reproducer
Pseudodiploria clivosa	Knobby brain coral	Mussidae	*Diploria clivosa*	Susceptible to SCTLD and other stressors
Siderastrea siderea	Massive starlet coral	Siderastreidae		best recruiting corals; hit by diseases; large colonies are less common than small
Siderastrea spp		Siderastreidae		see S. siderea
Undaria tenuifolia	Thin leaf lettuce coral	Agariciidae	*Agaricia agaricites*	see Agaricia tenuifolia
V - Highly tolerant taxa				
Cladacora arbuscula	Tube coral	Faviidae	*Cladocora abruscula*	stress tolerant coral commonly found in the colder and more turbid Gulf of Mexico, but also on some poor- quality patch reefs
Madracis decactis	Ten ray star coral	Pocilloporidae		small, but common; in shaded areas, less frequently bleaches, not reported with SCTLD
Madracis senaria	Six-ray star coral	Pocilloporidae	*Madracis scenaria*	similar distribution to M. decactis but is not as common
Oculina diffusa	Diffuse ivory coral	Oculinidae		stress tolerant - found in turbid areas; in dirtiest nearshore habitats, common in the Marquesas
Manicina areolata	Rose coral	Mussidae		less susceptible to SCTLD, can occur in non-reef habitats, small colonies on reef; tolerant and weedy and becoming more common

Scientific Name	Common English Name	Family	Synonym	Rationale
Phyllangia americana		Caryophylliidae		stress tolerant - found in turbid areas; relatively common under ledges and cave entrances; disease/bleaching susceptibility unknown
Porites astreoides	Mustard hill coral	Poritidae		declines with warm events but readily reproduces - prolific
Scolymia cubensis	Solitary disk corals	Mussidae		cryptic, common, tolerant, difficult to distinguish
Scolymia lacera	Solitary disk corals	Mussidae		cryptic, common, tolerant, difficult to distinguish
Scolymia spp		Mussidae		cryptic, common, tolerant; probably susceptible to SCTLD
Siderastrea radians	Lesser starlet coral	Siderastreidae		weedy, in worst environment; shallow, on sea-walls; does not grow to large sizes - encrusting
Solenastrea bournoni	Smooth star coral	Faviidae		generally stress tolerant but somewhat rare; in shallow hardbottom and seagrass or in perimeter of reef
Solenastrea hyades	Knobby star coral	Faviidae		stress tolerant, found in turbid areas and the back country; common in the Gulf of Mexico; cold tolerant
Stephanocoenia intersepta	Blushing star coral	Astrocoeniidae	*Stephanocoenia michelini*	is somewhat susceptible but very abundant and reproduces; survives bleaching
VI - Non-native taxa				
Tubastraea coccinea	Orange cup coral	Dendrophylliidae	*Tubastraea aurea; T. tenuillamellosa*	non-native - generally found on artificial substrates in FL
N– Taxa not assigned to an attribute				
Acropora sp.	Thick staghorn coral	Acroporidae	*A. cervicornis*	no reason to group Acroporids by genus
Agaricia grahamae	Dimpled sheet coral	Agariciidae	*Agaricia sp.*	not in FL
Agaricia undata	Scroll plate coral	Agariciidae		not in FL
Madracis carmabi	Ten ray finger coral	Pocilloporidae	*Madracis formosa*	not in FL
Madracis formosa	Eight-ray star coral	Pocilloporidae	*Madracis decactis*	not in FL

Scientific Name	Common English Name	Family	Synonym	Rationale
Madracis spp		Pocilloporidae		not in FL
Millepora alcicornis	Branching fire hydrocoral	Milleporidae		encrusting on something else - difficult to understand
Millepora squarrosa	Box fire hydrocoral	Milleporidae	*Millepora complanata*	not identified separately
Mycetophyllia reesi	Ridgeless cactus coral	Mussidae	*Mycetophyllia resii*	not in FL
Oculina robusta	Robust ivory coral	Oculinidae		not really found on the reef, found in turbid areas
Oculina valenciennesi	Small ivory coral	Oculinidae		not in FL
Oculina varicosa	Large ivory coral	Oculinidae	*Oculina diffusa*	not commonly found in Florida
Porites branneri	Blue crust coral	Poritidae	*Porites branneri*	not still considered a species
Porites colonensis	Honeycom plate coral	Poritidae	*Porites astreoides*	not in FL
Scleractinia spp				no designation at genus
Scolymia wellsi	solitary disk corals	Mussidae	*Scolymia cubensis*	not in FL

Appendix H - Coral Metric Calculations

The coral demographic metrics (adapted from Santavy et al. 2012; Bradley et al. 2014) were Colony Surface Area (CSA), Live tissue area on Colony Surface Area (LCSA), based on both 2-dimensional and 3-dimensional calculations. The CSA_3D was the total surface area (cm2) of a single colony, which includes both living tissue covering the skeleton and dead portions on the three-dimensional skeletal surface, such that:

$$CSA = \pi r^2 M \quad (1)$$

$$\text{where, } r = [h\_cm + (d\_cm/2)] / 2 \quad (2)$$

The variables used to calculate r were: h_cm=maximum colony height (cm), d_cm=maximum colony diameter (cm), and M = morphological conversion factor. In general, morphological types and relative values included flat (M=1), hemisphere (M=2), overlapping plates and lobes (M=3), and branched (M=4) colonies. The LCSA_3D was the total surface area (cm2) of a single colony including only the living tissue that covered the skeletal surface and was calculated as:

$$LCSA = CSA\ (\%LT/100) \quad (3)$$

Where %LT was the estimated percent of colony surface area that contained live tissue. In 2 dimensions, surface area was an estimated value of the total planar colony surface area (cm2) as though it were viewed only from directly above the colony. The total colony area (CSA_2D) and the area of living tissue (LCSA_2D) were estimated as:

$$CSA\_2D = \pi\ [2r\ (cm)/2]^2 \quad (4)$$

$$LCSA\_2D = \pi\ [2r\ (cm)/2]^2 * (\%LT/100) \quad (5)$$

Metrics were calculated based on surface area and prevalence of colonies based on species BCG attributes and ecological traits. Metrics were formulated to replicate the narrative rules expressed by the expert panel. For a metric example, LCSA_2D of large, reef building coral was calculated by limiting the surface area calculations to those species that are typically massive enough to add structure to the reef. In this example, the large reef building coral include *Acropora cervicornis, Acropora palmata, Acropora prolifera, Colpophyllia natans, Diploria labyrinthiformis, Dendrogyra cylindrus, Montastraea cavernosa, Orbicella annularis, Orbicella faveolata, Orbicella franksi, Pseudodiploria clivosa, Pseudodiploria strigosa* and *Siderastrea siderea*.

Appendix I- Florida Large Reef Building Corals (LRBC)

Scientific Name	**Common Name**
Acropora cervicornis	Staghorn coral
Acropora palmata	Elkhorn coral
Acropora sp.	Thick Staghorn coral
Colpophyllia natans	Boulder brain coral
Diploria labyrinthiformis	Grooved brain coral
Meandrina jacksoni	White valley maze coral
Meandrina meandrites	Maze coral
Meandrina sp.	Maze coral
Montastraea cavernosa	Great star coral
Orbicella annularis	Lobed star coral
Orbicella faveolata	Mountainous star coral
Orbicella franksi	Boulder star coral
Pseudodiploria clivosa	Knobby brain coral
Pseudodiploria strigosa	Symmetrical brain coral
Siderastrea siderea	Massive starlet coral

Appendix J – Weedy Species

Siderastrea siderea and *Stephanocoenia* are weedy when D <30cm and H <10cm

Scientific Name	**Common Name**
Agaricia agaricites	Low relief lettuce coral
Agaricia fragilis	Fragile saucer coral
Agaricia grahamae	Dimpled sheet coral
Agaricia humilis	Low relief lettuce coral
Agaricia lamarcki	Whitestar sheet coral
Agaricia tenuifolia	Thin leaf lettuce coral
Agaricia undata	Scroll plate coral
Helioseris cucullata	Sunray lettuce coral
Isophyllastrea rigida	Rough cactus coral
Isophyllia sinuosa	Sinuous cactus coral
Madracis auretenra	Yellow pencil coral
Madracis carmabi	Ten ray finger coral
Madracis decactis	Ten ray star coral
Madracis formosa	Eight ray star coral
Madracis senaria	Six-ray star coral
Manicina areolata	Rose coral
Meandrina danae	Butterprint rose coral
Meandrina jacksoni	White valley maze coral
Meandrina meandrites	Maze coral
Meandrina sp.	Maze coral
Millepora squarrosa	Box fire hydrocoral
Mussa angulosa	Atlantic mushroom coral
Mycetophyllia aliciae	Knobby cactus coral
Mycetophyllia danaana	Deep valley cactus coral
Mycetophyllia ferox	Rough cactus coral
Mycetophyllia lamarckiana	Rough cactus coral
Mycetophyllia reesi	Ridgeless cactus coral
Oculina diffusa	Diffuse ivory coral
Oculina robusta	Robust ivory coral
Oculina valenciennesi	Small ivory coral
Oculina varicosa	Large ivory coral
Porites astreoides	Mustard hill coral
Porites branneri	Blue crust coral
Porites colonensis	Honeycomb plate coral
Porites divaricata	Thin finger coral
Porites furcata	Branching finger coral
Porites porites	Clubtip finger coral
Scolymia cubensis	Solitary disk corals
Scolymia lacera	Solitary disk corals
Scolymia wellsi	Solitary disk corals
Siderastrea radians	Lesser starlet coral
Tubastraea coccinea	Orange cup coral
Undaria tenuifolia	Thin leaf lettuce coral

Appendix K - Glossary

abundance: An ecological concept referring to the relative representation of a species in a particular ecosystem.

anthropogenic: Originating from man, not naturally occurring.

assemblage: An association of interacting populations of organisms in a given waterbody.

attribute: Any measurable component of a biological system (Karr and Chu 1999). The BCG describes how ten biological attributes of natural aquatic systems change in response to increasing pollution and disturbance. The ten BCG attributes are in principle measurable, although several are not commonly measured in monitoring programs. The BCG attributes are:

- Historically documented, sensitive, long-lived or regionally endemic taxa
- Sensitive and rare taxa
- Sensitive but ubiquitous taxa
- Taxa of intermediate tolerance
- Tolerant taxa
- Non-native taxa
- Organism condition
- Ecosystem functions
- Spatial and temporal extent of detrimental effects
- Ecosystem connectivity

benthic: Living in or on the bottom of a body of water.

Biological Condition Gradient (BCG): A scientific model that describes how biological attributes of aquatic ecosystems (i.e., biological condition) might change along a gradient of increasing anthropogenic stress.

biological criteria: Narrative expressions or numerical values that define an expected or desired biological condition for a waterbody and can be used to evaluate the biological integrity of the waterbody. When adopted by the U.S. jurisdictions, they become legally enforceable standards.

community: All the groups of organisms living together in the same area, usually interacting or depending on each other for existence (EPA 2009).

condition: The relative ability of an aquatic resource to support and maintain a community of organisms having a species composition, diversity, and functional organization comparable to reference aquatic resources in the region.

coral bleaching: When corals are stressed by changes in conditions such as temperature, light, or nutrients, they expel the symbiotic algae living in their tissues, causing them to turn completely white.

coral reef: any reefs or shoals composed primarily of corals and formed by coral growth.

decision rules: Logic statements that experts use to make their decisions.

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

fore reef: The area along the seaward edge of the reef crest that slopes into deeper water on the barrier or fringing reef type (Costa et al. 2013).

gorgonians: Corals having a horny or calcareous branching skeleton (e.g., Sea Fans).

habitat: A place where the physical and biological elements of ecosystems provide a suitable environment including the food, cover, and space resources needed for plant and animal livelihood (EPA 2009).

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

indicator: A measured characteristic that indicates the condition of a biological, chemical or physical system.

integrity: The extent to which all parts or elements of a system (e.g., an aquatic ecosystem) are present and functioning.

intermediate sensitive 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 mutualist relation with other species. May be listed as threatened, endangered (under federal or local threatened and endangered species laws) or species of special concern. Predictability of occurrence often low, therefore, requires documented observation. Recorded occurrence may be highly dependent on sample methods, site selection and level of effort (EPA 2005).

intermediate tolerant taxa: 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 turnover 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).

levels: In the context of this report, levels are the discrete ratings of biological condition along a stressor-response curve (e.g., BCG Level 1 = excellent condition, BCG Level 6 = completely degraded).

live coral cover: a measure of the proportion of reef surface covered by live stony corals.

metadata: Structured information that describes, explains, locates, or otherwise makes it easier to retrieve, use, or manage data.

metric: Measurable quantity of an attribute empirically shown to change in value along a gradient of human influence. A dose-response context is documented and confirmed.

model: A physical, mathematical, or logical representation of a system of entities, phenomena, or processes; i.e., a simplified abstract view of the complex reality. For example, meteorologists use models to predict the weather.

monitoring: A periodic or continuous measurement of the properties or conditions of something, such as a waterbody.

non-native species: Any species that is not naturally found in that ecosystem. Species introduced or spread from one region 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 sites in a similar waterbody class or region under undisturbed or minimally disturbed conditions (by human activity), if they exist. Reference condition is used as a benchmark to determine how much other water bodies depart from this condition due to human disturbance (EPA 2005).

richness: The number of different species represented in an ecological community, landscape or region.

Scleractinina: Scleractinia, also called stony corals or hard corals, are marine animals in the phylum Cnidaria that build themselves a hard skeleton. The individual animals are known as polyps and have a cylindrical body crowned by an oral disc in which a mouth is fringed with tentacles.

seagrass: Flowering plants from one of four plant families (Posidoniaceae, Zosteraceae, Hydrocharitaceae, or Cyomodoceaceae), all in the order Alismatales (in the class of monocotyledons), which grow in marine, fully-saline environments (Wikipedia 2009).

sediment: Particles and/or clumps of particles of sand, clay, silt, and plant or animal matter that are suspended in, transported by, and eventually deposited by water or air.

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).

species: A category of taxonomic classification, ranking below a genus or subgenus and consisting of related organisms capable of interbreeding. Also refers to an organism belonging to such a category.

species composition: All of the organisms within a specific ecosystem or area; usually expressed as a percent contribution of individual species or species groups.

sponge: A multicellular organism that has a body full of pores and channels allowing water to circulate through it; usually occur in sessile colonies.

stony corals: A group of coral species known as hard coral that form the hard, calcium carbonate skeleton (e.g., brain corals, fungus or mushroom corals, staghorn, elkhorn, table corals).

stressors: Physical, chemical and biological factors that adversely affect aquatic organisms (EPA 2009).

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

taxa richness: The number of different species represented in an ecological community, landscape or region.

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 turnover times; boom/bust population characteristics), able to colonize when stress conditions occur. Last survivors (EPA 2005).

water quality: A term for the combined biological, chemical, and physical characteristics of water with respect to its suitability for a beneficial use.