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Field Manual for Coral Reef Assessments

Office of Research and Development
National Health and Environmental Effects Research Laboratory
Gulf Ecology Division

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Table of Contents

Notice and Disclaimer ii
List of Figures v
List of Tables vi
Acknowledgements vii
1.0 Introduction 1
1.1 Biological Water Quality Standards 2
1.2 Ecosystem Services 4
1.3 Measuring Coral Reef Condition 7
1.4 References 11
2.0 Visual Assessment of Reef Fish 14
2.1 What is measured? 14
2.2 Why is it measured? 14
2.3 What do we need? 15
2.4 How are data collected? 16
2.5 How are data managed? 18
2.6 How are indicators calculated? 18
2.7 References 19
3.0 Stony Coral Assessment 21
3.1 What is measured? 21
3.2 Why is it measured? 21
3.3 What is needed? 22
3.4 How are data collected? 24
3.5 How are data managed? 29
3.6 How are indicators calculated? 29
3.7 References 31
4.0 Marine Gorgonian Assessment 33
4.1 What is measured? 33
4.2 Why is it measured? 33
4.3 What do we need? 34
4.4 How are data collected? 37

4.5 How are data managed? 38
4.6 How are indicators calculated? 38
4.7 References 39
5.0 Marine Sponge Assessment 40
5.1 What is measured? 40
5.2 Why is it measured? 40
5.3 What do we need? 41
5.4 How are data collected? 42
5.5 How are data managed? 45
5.6 How are indicators calculated? 45
5.7 References 46
6.0 Reef Rugosity, Live Coral Cover and Macroinvertebrate Assessments 47
6.1 What is measured? 47
6.2 Why is it measured? 47
6.3 What do we need? 48
6.4 How are data collected? 49
6.5 How are data managed? 50
6.6 How are indicators calculated? 51
6.7 References 51
Appendix A: Other Coral Reef Assessment Programs 53
Appendix B: Survey Data Sheets and Data Check List 55
Appendix C: Fish Species Codes, Biomass Coefficients and Trophic Guild Assignments 69
Appendix D: Estimating Surface Area of Gorgonians and Sponges 79

List of Figures

Figure 1-1: Coral reef communities provide benefits to humans 1
Figure 1-2: Coral reefs provide coastal protection 5
Figure 1-3: Benthic hard bottom maps 7
Figure 2-1: Fish contribute valuable ecological and economic services 14
Figure 2-2: Fish must be identified to species 15
Figure 2-3: Diagram of fish survey transect using two divers 17
Figure 2-4: Fork length for different types of fish 17
Figure 3-1: Stony corals assessments document the surface area 21
Figure 3-2: Examples of bleaching corals 23
Figure 3-3: Examples of coral disease 23
Figure 3-4: Boring clionid sponges on corals 23
Figure 3-5: Predation on coral tissue 24
Figure 3-6: Colony size and tissue estimates 25
Figure 3-7: Minimum size of coral colony 25
Figure 3-8: All coral colonies ≤1 m in diameter 26
Figure 3-9: All coral colonies > 1 m in diameter 27
Figure 3-10: Intact coral skeletons with no tissue 27
Figure 4-1: Marine gorgonian assessment for ecosystem services 33
Figure 5-1: Marine sponge assessment for ecosystem services 40
Figure 6-1: Rugosity is a measure of reef surface complexity 47
Figure 6-2: Examples low and high rugosity reefs 48
Figure 6-3: Macroinvertebrates included in the survey 49
Figure 6-4: Adult and juvenile forms of queen conch 50
Figure B-1: Fish Survey Data Sheet 56
Figure B-2: Stony Coral Survey Data Sheet 58
Figure B-3: Gorgonian Survey Data Sheet 60
Figure B-4: Gorgonian and Sponge Survey Data Sheet 62
Figure B-5: Sponge Survey Data Sheet 64
Figure B-6: Rugosity, Biosurvey and LPI Data Sheet 66
Figure B-7: Check List for Data Sheet Actions 67

List of Tables

Table 1-1: Examples of biophysical measurements 6
Table 2-1: Potential fish indicators 19
Table 3-1: Examples of benefits derived from coral reef ecosystem services 22
Table 3-2: Stony Corals included in Western Atlantic and Caribbean assessments 28
Table 3-3: Regression equations for estimating 3D surface area of corals 31
Table 4-1: Gorgonian morphological shapes 36
Table 4-2: Regression equations to estimate surface area of gorgonians 38
Table 5-1: Sponge morphological shapes 44
Table 5-2: Regression equations to estimate surface area of sponges 45
Table A-1: Some current coral reef monitoring and assessment programs 54
Table C-1: Table of fish species, α and β coefficients and trophic guilds 70

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1.0 Introduction

Figure 1-1: Coral reef communities provide many important benefits to humans but they are subject to impairment through human activities.

The U.S. Environmental Protection Agency (EPA) is concerned over the decline of coral reefs in U.S. jurisdictions[1] and around the world. Coral reefs provide citizens a variety of aesthetic and tangible benefits. When human activity impairs the physical, chemical or biological integrity of a waterbody containing a coral reef, it contradicts the goals of the Clean Water Act[2] (Figure 1-1). Many national, state and local policies protect the quality of water and habitat in U.S. watersheds and coastal zones. Despite these policies, reefs have declined dramatically over the last forty years, particularly in the Caribbean and western Atlantic Ocean (Gardner *et al*. 2003). EPA has initiated two research programs with potential to improve coral reef protection.

The Safe and Sustainable Water Resources Program (SSWR) supports development of coral reef biological criteria. Research is focused on developing methods and tools to support implementation of legally defensible biological standards for maintaining biological integrity, which is protected by the Clean Water Act (CWA). Under CWA authority and following national guidelines established by EPA (CWA §303), States and other jurisdictions[3] promulgate water quality standards to protect the physical, chemical and biological integrity of the nation's water bodies. States currently apply physical and chemical standards at levels intended to be protective of aquatic biological inhabitants. More recently, the importance of biological standards are gaining acceptance. Biological standards have the benefit of directly measuring the cumulative effects of good and poor environmental conditions on the biological community. Because the CWA is intended to protect aquatic resources from changes generated by human activities (not from natural changes in the environment), the anticipated outcome is regulatory protection that sustains reef condition equal or similar to a natural state.

The Sustainable and Healthy Communities Program (SHC) is founded on the recognition that natural ecosystems, despite the many goods and services afforded, are undervalued by human society. The services that ecosystems provide are too often considered free and limitless; consequently, their values and benefits to humans are not routinely considered in policies and decisions (MEA 2005). Because we

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[1] U.S. jurisdictions with coral reefs include American Samoa, Commonwealth of Northern Mariana Islands, Florida, Guam, Hawaii, Puerto Rico, Texas (Flower Garden Banks) and U.S. Virgin Islands.

[2] Federal Water Pollution Control Act [As Amended Through P.L. 107-303, November 27, 2002] 33 U.S. Code 1251 et seq.; also known as: The Clean Water Act Public Law 92-50033 U.S. Code 1251 et seq.

[3] For the purpose of this document,when the term "State" is used it is intended to represent any U.S. jurisdiction, which includes States, Territories, tribes and Commonwealths.

generally protect only what we value, the goal of SHC is to quantify market and nonmarket values of ecosystem services and incorporate them into decision-making processes at local, regional and national levels. The anticipated outcome for coral reefs is a better understanding and recognition of reef value, which should lead to decisions that are more protective of the coastal zone. In both EPA research programs, development of appropriate reef assessment methods is critical.

1.1 Biological Water Quality Standards

EPA Assessment Needs. One of the most influential mechanisms available for aquatic resource protection is the U.S. Clean Water Act. Unfortunately, the label "clean water" can mislead people to think that only water quality is protected by the CWA. Protection of the nation's waters also includes protection of biological systems such as coral reefs. States are responsible under the CWA to establish water quality standards that define the goals and pollution limits for all waters within their jurisdictions, including waters of the territorial seas[4]. In essence, water quality standards translate CWA goals into measurable objectives, such as the protection and propagation of fish, shellfish and wildlife, or recreation in and on the water (EPA 1994). Water quality standards support the goal of the CWA to maintain the physical, chemical and biological integrity of water bodies. States are responsible for water quality criteria, but EPA provides national guidelines and oversight. There are three components of water quality standards: designated uses, criteria, and antidegradation implementation plans. Most important for this document is the development of criteria, although coral reef biocriteria cannot be developed without formal recognition of coral reef protection as a designated use for the water body (Bradley *et al.* 2010). Designated uses identify what you want to protect and criteria set the levels (whether physical, chemical or biological) deemed necessary to achieve that protection.

Historically, jurisdictions have relied on enforcement of chemical and physical criteria to protect biological integrity (Yoder and Rankin 1998). Yet, some chemical pollutants are hard to measure. In addition, chemical and physical criteria do not reflect the cumulative impacts of multiple stressors on biota. A better approach for measuring biological integrity is to assess biological changes. However, states have been slow to adopt methods for evaluating biological integrity because the measurements are generally more difficult, and variability is often greater than physical and chemical approaches. Many of these challenges have now been overcome (EPA 2002) and biological criteria are used regularly in freshwater and estuarine water bodies[5] (EPA 1990, 2000). However, biological criteria are not currently in place for marine resources, so the full potential of the CWA to protect coral reefs has not been realized.

Biological criteria may refer to thresholds for expected or desired biological condition. Used in a regulatory context, biocriteria are narrative or numeric thresholds adopted by states as legally enforceable standards of water quality. As such, biological criteria are no different than chemical criteria for toxicants that establish concentration limits—if the criteria are not met, the water body must be reported as impaired (CWA §305b) and restorative actions undertaken (CWA §303d). An important requirement for measurements used in biological criteria is that they are able to detect changes in condition caused by human action. The

Designated Uses:
What you want to protect
Criteria:
Levels or thresholds necessary to achieve that protection

[4] The CWA identifies territorial seas as a belt of ocean waters extending three miles (or more in some states) from shore.
[5] For examples, see EPA's biocriteria web site at <http://www.epa.gov/waterscience/biocriteria>.

purpose of the CWA is to maintain water bodies in a natural condition free from impairment by anthropogenic stresses. Serving this purpose, biological criteria are established to set a legal threshold that distinguishes natural from impaired condition. The measurements used to identify impairment must, therefore, be responsive (sensitive) to human disturbances. They must also be relevant to the designated uses, which is why establishing designated uses for coral reef protection is so important. Designated uses and biological criteria must be vetted through a public discussion, and methods and measurements must be scientifically defensible and relevant. Anticipating that U.S. jurisdictions will eventually incorporate coral reef protection as a designated use for marine waters, EPA has initiated studies to identify reef measurements that reflect ecological integrity and are sensitive to human-generated disturbances.

Water Quality Standard Measurement Needs. There are two critical requirements for measurements used in biocriteria: 1) significance to biological integrity and 2) responsiveness to human disturbances. Biological integrity was first defined as a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitat of a region (Karr and Dudley 1981). Many facets of an ecosystem are incorporated into the concept of biological integrity. Not all of them can be measured, so measurements or sets of measurements are selected to serve as indicators. The indicators are selected on the presumption that if these few indicator measurements are equal or similar to the natural condition, then the water body as a whole supports biological integrity and is attaining its designated uses. In freshwater biocriteria programs, there are particular taxonomic groups (assemblages) recognized to have these characteristics (fish, phytoplankton and insects). Selection of a variety of reef organisms would also reflect overall reef biological integrity, and a few taxa are sure to be included. Stony corals, for example, provide much of the structural habitat needed for a diverse reef community. Other key taxa, such as octocorals, sponges and fish may also serve as indicators of reef biological integrity.

Water quality criteria, whether physical, chemical or biological, must be measured with indicators that distinguish anthropogenic effects from natural changes in the environment. There are two approaches for evaluating whether an indicator will distinguish human disturbance—controlled laboratory exposure-response studies and empirical relationships drawn from field studies. Exposure-response studies can be especially useful for characterizing specific effects of particular stressors on key organisms such as stony corals. They are not, however, effective for quantifying effects of multiple stressors and cumulative stresses over time. Moreover, relationships established in laboratory settings must be validated in the field before they can be applied in a regulatory process.

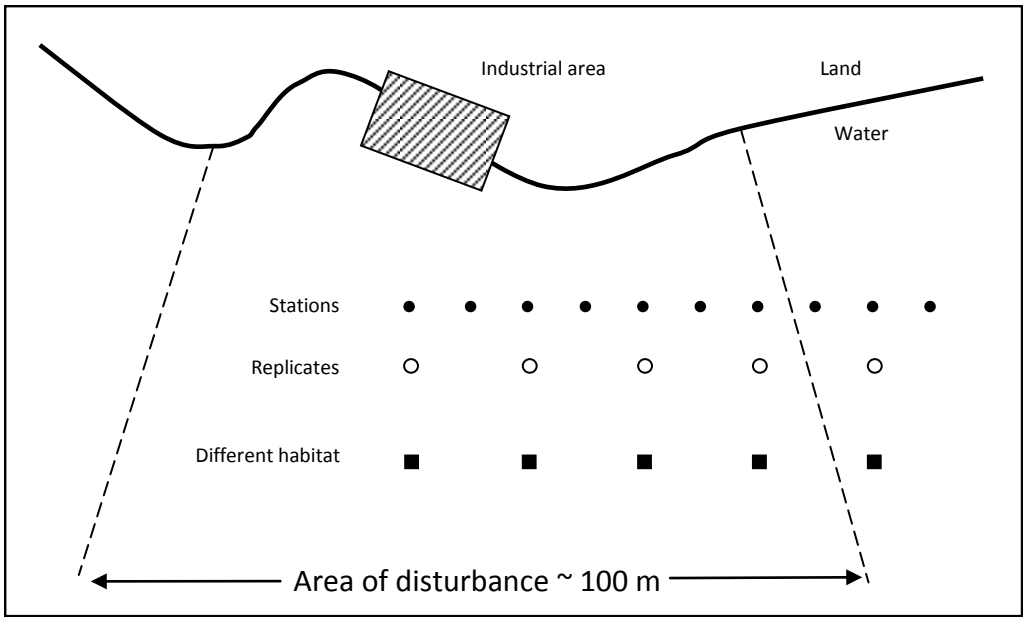
Biological Integrity

A natural, fully functioning living system of organisms and communities, plus the processes that generate and maintain them. The "living system" incorporates a variety of scales—from individuals to landscapes—and is embedded in a dynamic evolutionary and biogeographic context (Karr 2006).

An acceptable field method for testing the sensitivity of indicators to human disturbance is to perform the candidate measurement at various locations across (inside and outside) an area affected by known (or measured) human activity. A consistent and logical response across the disturbance gradient implies a sensitive indicator, at least for those particular disturbances at that particular location. Consistent response means that the indicator values are in relative proportion to the distance from the center of the disturbance, and logical response means that the direction of the response makes sense considering our state of knowledge (e.g., taxa richness is expected to decrease, not increase, with greater human

Human Disturbance Gradients

An effective approach for identifying biological indicators that are responsive to human disturbance is to apply candidate indicators across a zone of human disturbance. For example, an industrial point source along the shore provides an opportunity to test and evaluate candidate indicators. Those indicators that reflect a consistent and logical change with distance from the center of disturbance can be considered responsive. The causative agent of change does not need to be known to identify responsive indicators (metrics).



<http://www.epa.gov/bioiweb1/coral/biological_sampling.html>

disturbance). Ultimately, validation at other locations and for other stressor profiles is required for an indicator to be considered a metric, acceptable for use in a state biocriteria monitoring program. It is also important to examine co-varying factors, such as salinity and depth, which might influence biological responses.

1.2 Ecosystem Services

EPA Assessment Needs. Although we have a great appreciation for coral reefs, society generally fails to understand and appreciate the benefits they provide. Consequently, reefs and the services they provide are not always considered in decisions that might affect them. Drawn by the diverse community of unique and colorful marine organisms, coral reefs attract millions of tourists annually. Coral reefs also provide very practical goods and services, including food products, aquarium fish, construction material, beach nourishment, shoreline erosion control, flood protection and potential pharmaceutical products which all support diverse economic opportunities. These services have led to numerous studies to estimate the monetary worth of coral reefs[6] (Spurgeon 1992; Costanza *et al.* 1997; Cesar *et al.* 2003; Leeworthy *et al* 2004; Pendleton 2009; TEEB 2009).

[6] Estimated global monetary value for coral reefs vary dependent on methods used; some examples are \$377B y^{-1} (Costanza *et al.* 1997), \$30B y^{-1} (Cesar *et al.* 2003) and \$172 B y^{-1} (TEEB 2009).

Several key reef attributes are responsible for the delivery of these ecosystem services (Principe *et al.* 2012). Stony corals form a strong barrier to wave and tidal energy that would otherwise erode shorelines and damage valuable coastal property (Figure 1-2). They also provide a three-dimensional (3D) structure that serves as habitat for the diverse biological community that has evolved with them. Fish and shellfish harvested for food depend on the stony coral as habitat and nursery grounds. Pharmaceuticals developed from natural products are most often discovered in reef areas with high biological diversity (Fenical 1996). Stony corals, and the reef community that they harbor, can generate a strong tourism economy by attracting visitors, boaters, recreational anglers and recreational divers.

Figure 1-2: Coral reefs provide coastal protection by serving as a barrier to wave and tidal energy.

Although stony corals are probably the greatest contributor, other reef organisms provide ecosystem services. Fish and shellfish populations drive economies based on commercial, recreational and subsistence fisheries. Octocorals and sponges, like stony corals, provide substantial habitat for rich reef communities. In fact, some reef systems supporting recreational fisheries are composed primarily of octocorals and sponges (e.g., southeast Florida). Sponges are commercially harvested, as are other marine invertebrates such as lobsters, crabs and conchs.

Reef assessments to support quantification of ecosystem services must incorporate measurements of those organisms that are relevant to the service endpoint. Reef protection of shorelines, for example, depends on reef height, width, topography, depth and distance to shore among other variables (Lowe *et al.* 2005). Provision of habitat, as another example, can be quantified as surface area and topography (Dahl 1973; Alcala and Vogt 1997; Fisher 2007). Anticipating that highly valued ecosystem services will influence decisions to protect coral reefs, EPA has initiated studies to identify and test potential measures that can indicate or be transformed into indicators of ecosystem services.

Ecosystem Services Measurement Needs. Measurements to quantify ecosystem services need to focus on key organisms or processes responsible for providing the service. Stony corals may well be the most important reef inhabitant to benefit humans. To be useful in the context of ecosystem services, measurement of stony corals should quantify those particular attributes that provide the services. For example, measures of stony coral extent, distribution, colony size and topographic heterogeneity (reef "roughness") are useful measurements for quantifying shoreline protection because they are all factors in attenuating the shoreward energy of tides, waves and currents (Lowe *et al.* 2005; Monismith 2007). Measures of stony coral surface area and topographic heterogeneity might be used to quantify the amount of habitat and microhabitat provided by a coral reef to support an abundant and diverse community of organisms (Dahl 1973; Alcala and Vogt 1997; Fisher *et al.* 2007; Monismith 2007). Additional examples for stony coral attributes are provided in Table 1-1.

Table 1-1: Examples of biophysical measurements supporting quantitative estimates of coral reef ecosystem services (human benefits) and the conceptual linkage between them.

Biophysical Measurement	Linkage	Ecosystem Service
Reef dimensions, topographic complexity, roughness and spatial arrangement; colony size and height	Stony corals provide structures that attenuate wave and current energy, protecting shorelines from erosion	*Shoreline protection*: More coastal land, higher land value, lower insurance rates, security against storms and flooding, protection against human injury
Surface area and size; heterogeneity of stony corals, octocorals, and sponges; reef topographic complexity	Biogenic habitat provides substrate for fish and invertebrates harvested for food; reef architecture traps sediment (increased clarity for photosynthesis and fish predation) and aggregates zooplankton for fish predation.	*Fisheries*: More harvestable fish and invertebrates, stronger commercial and recreational fisheries
	Increased reef rugosity increases abundance of unique fish and invertebrates	*Tourism/Recreation*: Greater attraction for tourists, increased tourism industry
Taxa richness, unique taxa	High density and biodiversity adds to interspecies competition and results in unique chemical products	*Natural products*: Diverse biota increases potential for medical or pharmaceutical discoveries, leads to reduction in human pain, suffering and death
	Increased diversity of flora and fauna with more unique taxa	*Tourism/Recreation*: Diverse and rare flora and fauna are aesthetically pleasing
	Unique flora and fauna harvested for aquarium industry	*Fisheries*: Unique flora and fauna are available in the ornamental fish/aquarium trade
Abundance and density of organisms	Biological abundance increases predator-prey interactions	*Fisheries*: Larger harvestable fish and invertebrates, stronger more sustainable fishing industry *Tourism/Recreation*: greater attraction for tourists, stronger tourism industry *Natural products*: Greater potential for novel discoveries

Other reef species that are good assessment candidates include organisms that are harvested for food or profit (food fish, ornamental fish, sponges, lobsters, crabs, conchs, urchins and algae) or that provide biogenic habitat (sponges and octocorals). A species selected for estimating ecosystem services does not have to represent a critical function of the ecosystem (a requirement for regulatory applications) but does need to have a strong connection to benefits derived from the reef.

1.3 Measuring Coral Reef Condition

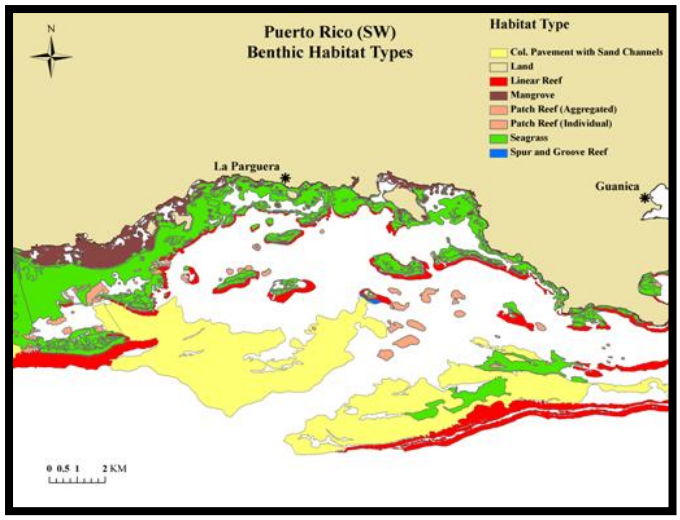


Figure 1-3: Benthic hard bottom maps for SW Puerto Rico.

Benthic Habitat Maps. To measure the condition of coral reefs, we must first know where they are located. Stony coral and other reef-building organisms need hard substrate ("hardbottom") to settle and grow, and, therefore, are present in patterns across the sea floor where hardbottom substrate occurs. When assessing coral condition, time spent visiting locations without hardbottom translates into wasted time and resources. Until recently, little was known about the exact locations of coral reefs. Sonar mapping technology developed and in use since 2000 has been used to create benthic habitat maps that accurately depict hardbottom substrate (Rohmann *et al.* 2005; NOAA 2009). These maps are useful because they delineate the extent of potential coral reef areas and provide an essential tool to identify coral reef monitoring locations (Figure 1-3). The benthic maps of hardbottom substrate can also be used for CWA reporting. EPA recommends that states report water body condition by providing an estimate of the nearshore area that supports designated uses. For example, a state's report of the biennial integrated water quality assessment might conclude, "70% of hardbottom areas support the designated uses for coral reef habitat." To make this calculation, the area of hardbottom substrate must be known. Hardbottom is specified because it is not particularly useful to report coral reef condition for areas, such as soft sediment, that are incapable of supporting reefs.

Sampling Design. The most comprehensive assessment of any resource is a census, which counts every member of the population. A census, however, is usually impractical because it is prohibitive in time and expense, so different sampling designs are implemented to select a subset of the population (or sample). How sampling locations are selected depends on the purpose of the survey. If the results from the subset of locations are intended to represent all locations without bias, then a random selection of sampling locations is necessary. A random design ensures that every location has an equal and known probability of being included in the survey. If the purpose of the study is to address a specific question (not represented by all locations), then sampling random locations is not appropriate. Instead, locations should be "targeted" or selected based on a judgment of which locations will best address the

Sampling Designs

Random sampling **is the selection of representative stations such that every location has an equal chance of being selected. Each station is considered representative of the entire region sampled.**

Probabilistic sampling **is a spatially balanced random design employed to avoid station clumping that can sometimes occur in randomization procedures.**

Targeted sampling **is the selection of stations at specific locations to address particular questions. Information from targeted sampling cannot be extended to represent other locations or the region sampled.**

question. For example, asking if greater numbers of herbivorous fish aggregate at reefs with high rugosity can be answered by counting herbivorous fish at targeted locations with widely varying rugosity.

Monitoring design. Monitoring programs are usually designed for status and trend reporting. Status monitoring assesses the current condition of the resource and answers questions like "What is the size distribution of stony corals in the region?" Trend monitoring detects change over time and will answer questions like "Has taxa richness declined in the region during the last five years?" Surveys to address status and trend questions must use randomly selected sampling locations to obtain a subset, which is intended to represent all locations across the region. For trend sampling, the same stations are usually revisited each year to reduce temporal variability, but sometimes new stations are selected for each survey using a modified random sampling design. For regional reporting, EPA recommends "probabilistic sampling", a specific type of random sampling which incorporates random locations spatially balanced across the region (Peterson *et al.* 1999; Larsen *et al.* 2001; EPA 2008). This avoids clumping of locations that can sometimes occur with simple random sampling. More details on probabilistic sampling designs can be found in Bradley *et al.* 2010 and EPA's Aquatic Resource Monitoring website (EPA 2008).

Monitoring Designs

Status monitoring **assesses current condition and answers questions such as "What is the percent living coral?"**

Trend monitoring **assesses change in status over time or space and can answer questions such as "Have reef fish declined over the last ten years?"**

Both random and targeted sampling designs can be used in development of coral reef biocriteria. For example, a targeted site selection is used to determine which indicators are responsive to human disturbance. Sampling stations are targeted inside, across and outside an area of high human activity (like a port, city or an industrial area) to ensure responses will be measured from both impacted and unimpacted locations (Fore *et al*. 2006; Fisher *et al.* 2008). Targeted site selection can also be used during survey development to identify tradeoffs in data needs and monitoring efficiency. Random site selection can be used to establish regional baselines for future comparison in long-term monitoring programs and is recommended for regional reporting requirements under the CWA (i.e., 305[b] reporting; see Brown *et al.* 2005). Examples of regional monitoring programs for coral reef assessment include the Coral Reef Environmental Monitoring Program (CREMP 2010), Florida Keys coral disease surveys (Santavy *et al.* 2005), the Florida Reef Resilience Program (FRRP 2010) and the EPA survey of Hawaiian bays and estuaries (Nelson *et al.* 2007). (See Appendix A)

Survey Plan. Coral reef surveys, especially those to be used in a long-term monitoring program, are expensive. Assessments usually require on-site, underwater visits, which entail dive boats, scuba equipment, trained divers and extensive survey time. An efficient survey plan should be a high priority for any reef assessment program. For long-term monitoring programs, inefficiencies are replicated year after year, taking an unnecessary toll on time and resources. A competent and efficient survey plan may require many preliminary tests and analyses, but the time is well spent.

Survey Plan

1. **Define target population**
2. **Define sampling frame**
3. **Define sampling unit**

The first step in establishing a survey plan is to define the target population, the sampling frame and sampling unit. To measure trends in a long-term monitoring program for coral reef condition, the target population might include all stony corals in the region, but because a census is unobtainable for most coral surveys, a subset of the population is sampled that is representative of the entire population. A sampling frame characterizes which members of the target population will be used as a basis for sampling. The sampling frame might identify different strata such as depth ranges, the distance from shoreline or reef type classification (e.g., patch reef) to balance any bias in the target population. A sampling unit is one of the elements into which the target population has been divided for purpose of sampling. Each unit is considered individual and indivisible. If, for example, a station location is a sampling unit, then the number of sites visited at that station must be aggregated for a station value. A survey plan attempts to achieve an optimum balance between the objectives of the survey, the responsiveness of the indicators (see below) and the available expertise and resources (monetary and personnel needs).

Indicator Selection. Central to addressing a particular survey question are the measurements that are made and the calculations (indicators) that stem from them. There are many potential indicators to choose from (e.g., Jameson *et al.* 2001; Cooper *et al.* 2009), but not every indicator will be appropriate for the intended purpose of the survey. For example, live coral cover may be suitable for assessing trends in coral health but might not be suitable for estimating a reef's contribution to fish habitat or shoreline protection. Each study might address a different set of questions, and each indicator measurement will likely require different resources and expertise.

Selecting indicators should be a planned, iterative process of review, testing and analysis. Following published guidelines for indicator development and evaluation can be very useful, and documenting how each guideline is met will lend defensibility to later interpretation of results. Jackson *et al.* (2000) present four phases of indicator evaluation—conceptual foundation, feasibility of implementation, response variability and interpretation and utility. These phases describe an idealized progression for indicator development that flows from fundamental concepts to methodology, to examination of data from pilot or monitoring studies and lastly to how the indicator serves the program objectives.

Indicator Evaluation

1. **Conceptual foundation**
2. **Feasibility of implementation**
3. **Response variability**
4. **Interpretation and utility**

(Jackson *et al*. 2000)

Bradley *et al.* (2010) characterized a subset of guidelines that were important for coral reef biocriteria development. Similarly, Hallock *et al.* (2003) used these guidelines to evaluate the foraminiferan (FORAM) index as an indicator of biological condition of coral reef communities. A brief summary of how EPA stony coral indicators described in Fisher (2007) are believed to meet these guidelines is provided below:

(1) *Relevance to purpose*: The condition of a reef ecosystem can be characterized by the physical and biological condition of stony corals. The pivotal role that stony corals play in reef ecology, stemming from provision of habitat, is well known and amply addressed in the scientific literature[7].

(2) *Relevance to ecosystem structure and function*: Stony corals provide the infrastructure of the reef and create a physical and biological environment that attracts other species. Most reef organisms depend on stony corals in some manner[8].

[7] For example, Loya 1972; Birkeland 1987; Brown 1988; Jones and Kaly 1996; Done 1997; Kramer 2003.

[8] Dahl 1973 states: "The production, occupation, and destruction of surface area are, therefore, basic reef processes, and the balance between them is an essential aspect of the reef ecosystem. The efficient production of surface is a primary function of

(3) *Power to detect differences:* Useful indicators have the statistical power to demonstrate change for the number of stations surveyed. Measurement errors for stony coral calculations were found to be smaller than natural variability across the stations (Fisher *et al.* 2007) and are expected to detect differences among stations.
(4) *Responsiveness to human influence*: Stony coral indicators will respond in a consistent and logical manner to a human disturbance gradient. Several indicators tested at St. Croix, USVI, were found sensitive to a human disturbance gradient (Fisher *et al.* 2008).
(5) *Feasibility of implementation*: Stony coral indicator measurements can be easily obtained by divers during a single dive. However, the number of stations that can be visited each year is dependent on staff and resources. A rotating panel design for regional coverage can be used (Fore *et al.* 2006).
(6) *Interpretation and utility for management*: Management is supported when measurements reflect the features that people value. Stony coral species richness, colony size and tissue condition are defensible as surrogates for ecosystem integrity. Greater reef integrity supports fish nurseries, shoreline protection and reef community habitat. Stony coral abundance and diversity provide a significant attraction for snorkelers and divers (tourism)[9].

Assessment Procedures. Clearly, there are two monitoring objectives for EPA—condition assessments for setting useful thresholds as water quality standards and ecosystem services assessments to estimate benefits provided from reef existence and function. There are numerous approaches available for characterizing reef condition (see Appendix A) but not for ecosystem services. Both objectives can be met with similar sampling designs and monitoring approaches, but the indicators and measurements made to generate those indicators may differ (Principe *et al.* 2012). Recently, EPA has attempted to develop a suite of indicators and measurements that could meet both objectives. The procedures are outlined here with guidance on measurements and indicators for reef fish, stony corals, gorgonian octocorals, sponges and macroinvertebrates, as well as reef rugosity and live coral cover. Although some of the condition measurements (fish, stony corals, rugosity and live coral cover) are not new, they have been adapted for an efficient survey plan that includes new services indicators (octocorals and sponges).

Survey Approach

1. **Fish surveyor lays transect tape and counts fish (25 x 4 m, 15 minutes) while buddy diver estimates live coral cover and counts macroinvertebrates.**
2. **Upon return, the fish surveyor and buddy diver perform rugosity measurements.**
3. **After 15-20 minutes (leaving enough time for completion of the fish survey), the stony coral and octocoral/sponge surveyors enter the water to begin surveys along the transect tape.**
4. **If available, a fifth diver can photograph or video the transect and surrounding reef area.**

The manual presents assessment methods as chapters in the order that the EPA Coral Assessment Team conducts a survey. The fish assessment is completed first so the fish will not be disturbed prior to counting. The fish surveyors lay the transect tape that is subsequently used for other surveys. During the

many reef organisms, and the control of surface by secondary occupants is a basic competitive force and a major determinant of reef communities." (p. 240)

[9] In a dive site preference study, divers were able to distinguish sites with greater fish species richness and abundance, stony coral richness, abundance, tissue and structural complexity (Uyarra *et al.* 2009). In a choice-based valuation, degraded reef attributes (including abundance and diversity of fish and coral, and water clarity) at Eilat (Israeli Red Sea) represent a $2.86M annual loss from recreational diving (Wielgus *et al.* 2003).

fish count, the buddy diver can survey macroinvertebrates and estimate live coral cover using the linear point intercept method. Once complete, the fish counter and buddy diver can conduct rugosity measurements on their return to the marker buoy. Once the fish survey is complete, the stony coral counter and octocoral/sponge counter can enter the water and complete their surveys. If available, it is beneficial to have a fifth diver to take video or photographs, record transects and capture interesting and unusual features at each study site.

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2.0 Visual Assessment of Reef Fish

2.1 What is measured?

Reef fish are surveyed visually to document the species, numbers and sizes of all reef fishes within a 25 m x 4 m underwater transect (100 m^2). Data are used to estimate abundance, species richness and biomass for the fish populations, which can be subsequently classified by taxonomy and trophic guilds (Randall 1967). This protocol is a noninvasive, rapid underwater assessment and is similar to that performed by the National Oceanic and Atmospheric Administration (Menza *et al.* 2006; Caldow *et al.* 2009).

Figure 2-1: Fish on reefs contribute valuable ecological and economic services.

2.2 Why is it measured?

Reef fish are major components of coral reef ecosystems and provide valuable economic and ecological services, particularly food provisioning via subsistence and commercial fishing (Figure 2-1). The World Health Organization (WHO 2010) reports that the protein derived from seafood (fish, crustaceans and mollusks) accounts for 13-16% of the animal protein consumed by people globally. Reef fish are also a major attraction for recreational anglers, snorkelers and divers, supporting lucrative tourism and recreational industries (Hall 2001; Brander *et al.* 2007). Additionally, reef fish are harvested for the aquarium trade (Chan and Sadovy 2000).

Fish play an important ecological role in maintaining the stability and sustainability of coral reefs. They have a primary role in the trophodynamics of the reef system: fish consumption of algae and predation on other fish is critical to maintaining a trophic balance across the reef ecosystem. For example, herbivores (e.g., parrotfishes, damselfishes, and surgeonfishes) crop algae that might otherwise overgrow corals and sustain the infrastructure of reefs (Burkepile and Hay 2008). Invertivores (e.g., grunts, angelfish) aid in balancing the proliferation of corallivores (e.g., butterflyfishes, snails), which consume coral tissue. Overfishing of all these trophic groups can be attributed as major threats to the persistence of coral reefs and could provide mechanisms for ecological phase shifts, for example, from coral to algal-dominated communities (Sale 1977; Jackson *et al.* 2001). While various programs have been established to generate policies for sustainable reef fisheries (e.g., Ault *et al.* 2005, 2006), an increased understanding of fish on reefs as indicators of coral reef ecosystem condition will provide greater protection for coral reef ecosystems.

Figure 2-2: Fish must be identified to species, and abundance and size class estimations made while swimming 25 m in 15 minutes.

2.3 What do we need?

2.3.1 Surveyor skills

Surveyors must be able to count and identify reef fishes to the genus and preferably species level. They also have to be able to make size estimates quickly while swimming along a 25 m transect (Figure 2-2). Expertise is acquired through reference materials and field training (e.g., Humann and DeLoach 2006). Familiarity with local species can be obtained from region-specific literature. Resources for fish identification provide comprehensive descriptions, diagrams, behavioral characteristics and photographic records of the targeted species (Humann and DeLoach 2002). Additional training to refine identification skills is acquired by underwater training with an experienced surveyor who highlights target species, prominent physical characteristics, habitat preferences and behavioral patterns for accurate identification.

Surveyors are trained to estimate fish size under water, using premeasured objects as calibration tools. Training should include pacing the 25 m swim for a duration of 15 minutes. Measurement bias will occur if the survey time is substantially over or under the required 15 minutes. If there is more than one fish surveyor, then variability among surveyors (measurement error) must be determined. Each surveyor collects data independently, while they simultaneously swim side-by-side in the same transect. Differences in surveyor experience and training are common causes of measurement bias. Increased training should minimize this error (Menza *et al.* 2006).

2.3.2 Equipment

- Fish Survey Data Sheets printed on underwater paper (Figure B-1)
- Fish species codes (Appendix C for Caribbean species)
- Underwater slate or clipboard
- Underwater pencils[10] or pens with surgical tubing or rubber bands to attach to slate
- Flexible fiberglass metric measuring tape at least 30 m in length on reel
- Optional: underwater digital camera

The metric measuring tape is on a reel to allow deployment during the fish survey and is clearly marked at 1 m increments. A convenient way to attach the tape to the substrate is to modify the end of the tape with a small diameter bungee cord and snap clip. The bungee cord is wrapped around an object on the substrate and clipped back on itself to secure the tape in place. If there are substantial currents and the transect will be used for other types of surveys (e.g., stony coral assessment), it is recommended that the tape be weighted with a thin lead line to reduce movement. An underwater camera is useful for recording fish with questionable identities for later verification with existing literature.

[10] Recycled wood pencils will disintegrate. Always bring multiple pencils or pens.

2.4 How are data collected?

1) Preparation: Record survey information on the Fish Survey Data Sheet (Figure B-1), ensuring each page is numbered consecutively and taking care to transcribe the date, location, and surveyor name prior to entering water. Set a weighted marker buoy from the surface at the desired sampling location using GPS coordinates. If multiple assessments for other organisms and measurements will be made, the fish survey should always be completed first. The fish surveyor and buddy diver enter the water with slate, pencils, data sheets, transect line (30 m tape), and fish species codes (optional: lead line and camera). Divers descend slowly and avoid movements that would disturb fish and take care to adjust buoyancy. No other divers should be present during the fish survey to reduce fish disturbance, herding or congregating. The transect location and direction is selected as the best available reef habitat (usually based on stony coral coverage) within 20 m of the marker buoy weight. The transect tape is attached securely to the sea floor, and a visual reference point 25 m at the other side of the selected habitat should be estimated as a target to swim towards. The depths at the 0 m and 25 m marks of the transect tape are recorded.
2) Transect: The fish surveyor begins swimming, documenting fish abundance, species and size classes while reeling out the 25 m tape along a single direction across the best available habitat. Depending on current, swimming is at a medium pace so that the measuring tape is deployed at a relatively constant rate and reaches 25 m in about 15 minutes. Longer or shorter swimming periods could affect comparison of results across stations. The buddy diver remains behind the fish surveyor and can perform other tasks such as coral cover (LPI) or macroinvertebrate counts (See Chapter 6).
3) Procedure: Completion of the survey should take 15 minutes regardless of habitat type or number of fish present to standardize data collection among sites. The fish surveyor looks forward at all times and documents only those fish that occur within 2 m to each side (delineating the 4 m width of the transect perimeter) in the entire water column. Fish above or below the surveyor's line of sight should be documented as far as visibility allows, but not past the 25 m length or the 4 m width of the transect (Figure 2-3). The surveyor may move off the centerline to check for fish under ledges or in holes, but should never look back to the transect area already surveyed.
4) Measurements:
   a) *Species abundance*: Fish within the 100 m^2 transect area are recorded to the lowest taxonomic level possible. All fish greater than 1 cm in size are included in the assessment. Four letter codes, consisting of the first two letters of the genus and the first two letters of the species, are used for reporting (Caribbean species in Appendix C). If common names are recorded on the data sheet under water, then corresponding scientific codes need to be transcribed on data sheet and used for data entry purposes. In the case that two species have the same four-letter code, letters are added to the species name until a unique code occurs. If the fish cannot be classified to at least family level, then a brief description is taken and the fish is photographed for later identification. All procedures must be standardized prior to the survey.

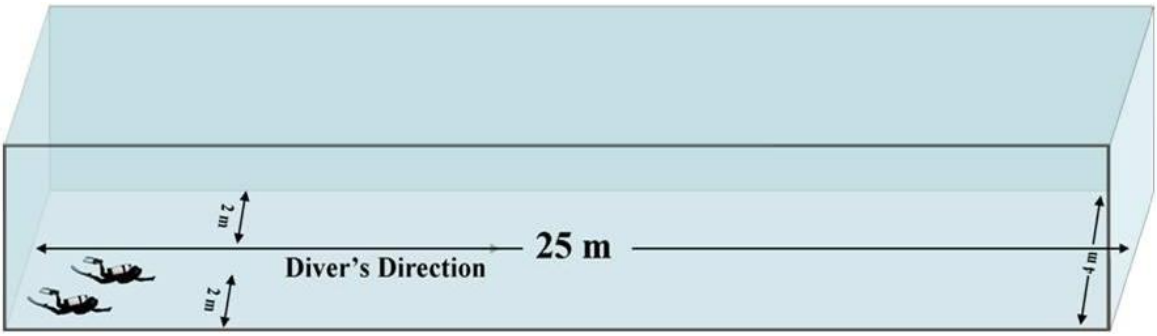

Figure 2-3: Diagram of fish transect using two divers in a 4 m x 25 m belt transect (100 m²). All fish encountered in the water column or on the reef are included in the visual assessment.

b) *Fish size*: Each fish is scored in 5 cm size class increments up to 35 cm using visual estimation of fork length. If an individual is greater than 35 cm, an estimate of the actual fork length is made. The fork length is measured from the snout (with closed mouth) to the fork at the base of the tail or caudal fin (Figure 2-4).

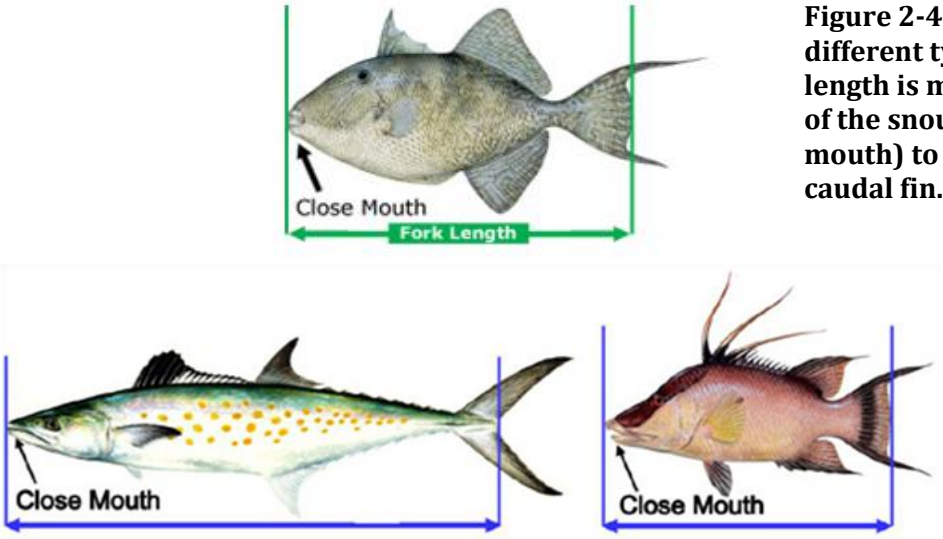

Figure 2-4: Fork length for different types of fish. The fork length is meaured from the tip of the snout (with closed mouth) to the base of the caudal fin.

5) Post-Survey: The survey is complete at the 25 m mark and the depth is recorded again. If additional surveys will follow (e.g., stony corals) the transect tape is secured beyond the 25 m mark and, if needed, a lead line is installed to anchor it down. Otherwise, the tape is reeled back to the starting point and all equipment retrieved. After the dive all data sheets are verified for completeness and any questionable records reconciled by the surveyor. Data sheets are rinsed with freshwater and dried.

2.5 How are data managed?

Surveyors must review data sheets for legibility, completeness, and correct use of standardized fish codes. Changes are made to the data sheet and should be initialed. A checklist for data sheet review is provided in Figure B-7. Any photographs taken to verify taxonomic description are examined and archived with an appropriate file name. Data are delivered to the data recorder who transcribes it from the underwater data sheets into electronic spreadsheets for archiving and data analysis. After data have been electronically entered, they are reviewed for accuracy and verified simultaneously by the surveyor and recorder. When complete, both the recorder and the surveyor sign and date the data sheets, which are scanned and archived.

2.6 How are indicators calculated?

All data are summarized and procedures are applied to identify outliers, errors, and inconsistencies to be considered prior to data analyses. These procedures can include summary statistics, box plots and stem and leaf plots. Fish community ecological attributes such as species richness, abundance, density, length distributions, biomass and diversity indices can be calculated at different taxonomic levels and by trophic guilds (Table 2-1).

Biomass (W) for each fish (equation 2-1) is calculated using the measured length (L) in cm and published length-weight relationships specific for species, represented as values for α and β coefficients that were obtained from FishBase (Froese and Pauly 2007; Table C-1).

$$W = \alpha L^{\beta} \qquad \text{(equation 2-1)}$$

Population biomass is estimated by pooling all individuals of one species by either abundance or density. Biomass estimations for species with no published length-weight relationships are calculated using terms for the closest congener based on morphology. Additionally, fish classified by trophic guild are compared by abundance and biomass. These trophic guilds include: herbivores, piscivores, invertivores, detritivores and zooplanktivores (Randall 1967)[11].

[11] Herbivores: fish that eat algae and vegetation. Piscivores: carnivorous fish that eat other fish. Invertivores: fish that eat invertebrates usually separated by sessile [corals (corallivores), sponges, etc.)] and mobile forms (crustaceans, polycheates, mollusks, etc.). Detritivores: fish that eat bottom materials and detritus. Zooplanktivores: fish that eat zooplankton.

Table 2-1: Potential fish indicators used to describe characteristics of reef fish. Most indicators can be expressed as total or mean values classified by species or other taxonomic level and trophic guilds. (Equations detailed in Caldow *et al*. 2009 and Mensa *et al*. 2006).

Indicator	Description	Units	Formula
Species richness (total or mean)	# of fish species at site		S=Σ species
Density (total or mean)	# fish /area=relative abundance	#/ 100 m^2	No. fish/ 100 m^2
Length size (mean or frequency)	Fork length, total length, body length	cm	L
Biomass (total or mean)	Total weight of all individuals, estimated wet weight	g / 100 m^2	$W = \alpha L^{\beta}$ [1]
Shannon diversity index (H)	Index of richness & abundance	Unitless	H' =
Pielou evenness index (J)	Index of biodiversity	Unitless	J' = H' / ln S
Abundance (total or mean)	Total # individuals	# individuals	
Frequency of occurrence	Proportion of sampled sites that a given species is present	Unitless	

[1] α and β are coefficients obtained from FishBase (Froese and Pauly 2007) for calculating biomass (see Appendix C). Biomass for species with no published length-weight relationships can be calculated using terms for the closest congener based on morphology.

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3.0 Stony Coral Assessment

3.1 What is measured?

Stony coral surveys document the taxa, 3D size, amount of tissue on coral colonies and the occurrence of adverse health conditions such as bleaching, disease or overgrowth by boring sponges. These characteristics can provide estimates of stony coral abundance, density, species diversity, richness, reef surface area and complexity, and relative health of coral colonies. This method is an update of EPA's Stony Coral Rapid Bioassessment Protocol (Fisher 2007).

Figure 3-1: Stony coral assessments document the surface area of corals and provide important information about ecosystem and ecological services.

3.2 Why is it measured?

Stony corals form the permanent architecture of coral reefs. Because stony corals provide habitat for many other types of organisms, humans benefit from the opportunity for tourism, recreation, and fishing (Figure 3-1). Stony corals also provide shoreline protection from erosion and inundation during storms or even normal high wind and wave conditions. They also support high abundances of extremely diverse organisms that produce secondary metabolites potentially useful for pharmaceuticals and other biochemical needs. Stony corals are a main attraction for divers and snorkelers, who enjoy the beautiful colors and interesting shapes. Protection of stony corals and the services they provide, are critical for future provision of coral reef ecosystem services (Table 3-1).

The coral reef infrastructure supports many of the ecological interactions and functions characteristic of a dynamic reef ecosystem. It also contributes to biodiversity by providing essential habitat for sponges, octocorals, fish and a myriad of invertebrate and plant species. The stony coral assessment procedure characterizes the biophysical condition of stony corals by comparing species and populations across reef types, study areas and geographic regions (Fisher 2007). The condition of stony corals and the reef is related to water quality and human disturbances in watersheds and coastal zones (Fisher *et al.* 2006, 2008). Moreover, data from these measurements can be used to determine whether stony corals attain established thresholds (biocriteria) or to estimate the type and quantity of ecosystem services they provide.

Table 3-1: **Examples of benefits derived from coral reef ecosystem services that rely on a stony coral infrastructure (in economic categories, Principe *et al*. 2012).**

Direct Extractive Uses	Direct Non-extractive Uses
Commercial fishing	Scuba diving
Subsistence fishing	Snorkeling
Aquarium fish	Boating
Sport fishing	Pharmaceutical chemicals
Coral jewelry	Non-pharmaceutical natural products
Pharmaceutical harvesting	
Non-pharmaceutical harvesting	
Indirect Uses	**Non-uses**
Fish habitat	Existence value
Nutrients	Cultural value
Reduced flooding	Option value
Less storm damage	Quasi-option value
Fewer deaths from storms and flooding	Bequest value
Reduced erosion from storms and flooding	Instrumental value
Mangrove and seagrass protection	Intrinsic value
Sealife nursery protection	Scientific value
Global life support	Scarcity value

3.3 What is needed?

3.3.1 Surveyor skills

Surveyors must be able to identify corals to genus and species, measure coral colony dimensions and estimate the proportion of tissue in relation to the overall size of the colony. Surveyors can note any bleaching (Figure 3-2), disease (Figure 3-3), and invasive growth of clionid sponges (Figure 3-4), taking care to distinguish from predation damage (Figure 3-5). (For detailed disease, predation, bleaching and overgrowth descriptions see regional specific websites: GCDD 2012; NOAA CDHC 2012; NOAA CORIS 2012). If more than one surveyor is required, then variability among surveyors (measurement error) must be determined.

3.3.2 Equipment

- Stony Coral Survey Data Sheets printed on underwater paper (Figure B-2)
- Species (Table 3-2) and disease code sheets
- Underwater slate or clipboard
- Underwater pencils or pens[12] with surgical tubing or rubber bands to attach to slate
- Flexible fiberglass metric measuring tape on reel at least 30 m in length
- 1 m length rod or PVC pipe to delineate transect width
- 0.5 m or 1 m measuring tool marked in 5 cm increments (e.g., PVC tube)
- Optional: underwater digital camera

[12] Recycled wood pencils will disintegrate. Always bring multiple pencils or pens.

Bleached Corals

Figure 3-2: Examples of bleaching corals, including paling (left), partially (center) and severely bleached (right) colonies.

Diseased Corals

Figure 3-3: Examples of coral disease, black band disease (left), white plague (center), and white pox (right).

Boring Sponges on Corals

Figure 3-4: Boring clionid sponges on corals. Dark brown sponge (left) and orange boring sponges (center and right) dissolve coral skeletons.

Predation on Corals

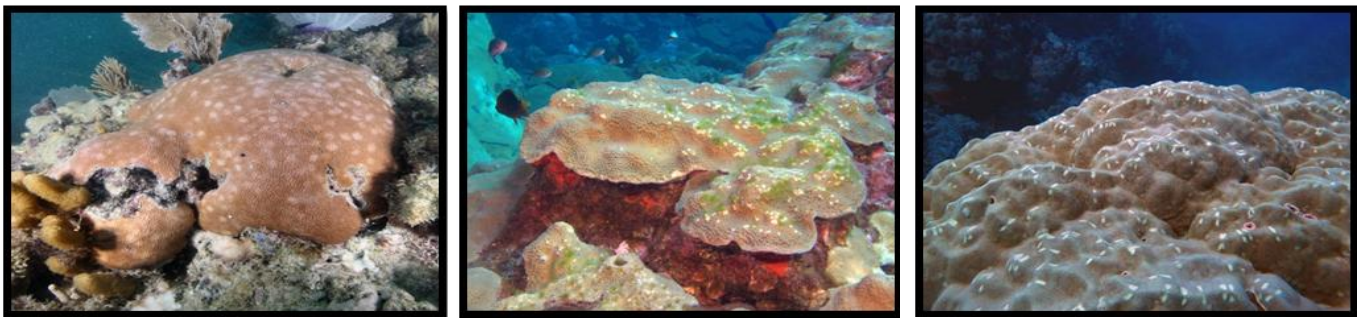


Figure 3-5: Predation on coral tissue by snails (left), damselfish (center) and parrotfish (right).

The metric measuring tape should be on a reel to allow easy deployment and should be clearly marked at 1 m increments. If the fish survey was conducted, the tape will have been previously deployed. The tape can be attached to the substrate with a small diameter bungee cord and snap clip on the end of the tape. The bungee cord is wrapped around an object on the substrate and clipped back on itself. An underwater camera is beneficial to record corals of uncertain identity for later verification with existing literature.

3.4 How are data collected?

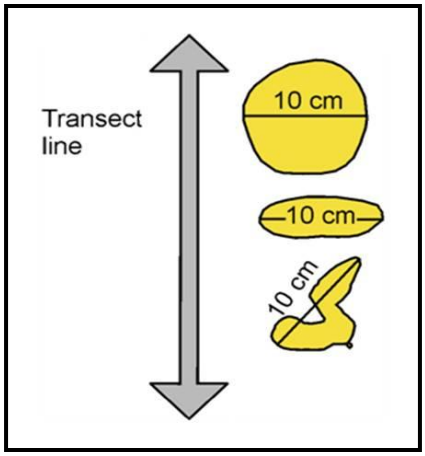
1. Preparation: Record survey information on the Stony Coral Survey Data Sheet (Figure B-2), ensuring that each page is numbered consecutively and taking care to enter the date, location, and surveyor name prior to entering water. Set a weighted marker buoy from the surface at the desired sampling location using GPS coordinates. If multiple assessments for other organisms and measurements are made, the fish survey should always be conducted first and then the transect tape will be in place. If only a coral survey is performed, the coral surveyor and dive buddy enter the water with transect line (30 m tape on reel), slate, pencils, 1 m rod, measuring tool, data sheets, and stony coral species codes, (optional lead line and camera). The transect location and direction is selected as the best available reef habitat, (usually based on stony coral coverage) within 20 m of the marker buoy weight. The transect tape is securely fastened to the seafloor and deployed 25 m in a straight line. Depth is recorded and colony measurements begin at the 0 m mark of the transect tape. If strong currents exist, the transect line can be secured by tie wrapping the lead line to it. If there is very high coral coverage, the transect length can be reduced, but changes must be clearly noted on each data sheet.
2. Transect: Position the 1 m rod on the right side (looking forward) and orthogonal to the transect tape, parallel to the seafloor. As the survey progresses, the 1 m rod is moved along the transect tape to delineate the 1 m transect width. If the rod can be laid directly on the seafloor, it can be used to mark the surveyors progress along the transect line.
3. Procedure: The surveyor records all stony coral data from the transect on the data sheet by identifying each colony to genus and species (Table 3-2), measuring the maximum height and diameter of the colony, and estimating the percent of coral tissue (as opposed to bare skeleton) on the colony. Hydrocorals *Millipora complanata* and *Millipora alcicornis* can be included in the assessment of Caribbean corals. Colony height is the greatest distance of the colony from the substrate and maximum diameter is the greatest distance parallel to the substrate. All measurements are recorded to the nearest 5 cm with appropriate rounding.

4. Percent tissue (living coral) is estimated for the whole colony in 3D, not simply from the aerial planar view and is recorded in 10% increments (Figure 3-6). If condition indicators are included, the surveyor can note any disease, bleaching, or clionid boring sponges on the colony.

Figure 3-6: Colony size and tissue estimates are made from the entire colony surface, not merely from an overhead planar view.

5. <u>Rules for inclusion</u>: Certain conventions have been adopted to determine which colonies are included within the survey transect.
    a. The entire coral colony skeleton, including live and dead areas, must have one dimension greater than 10 cm (any dimension—height, diameter, or length) to be included in survey (Figure 3-7). Smaller coral colonies can be assessed if recruitment data are desired.

Figure 3-7: Minimum size of coral colony is 10 cm in any dimension, including length, diameter, or height. Yellow color denotes coral skeleton, which may or may not be covered by tissue.



b. If greater than fifty percent of the colony falls within the transect perimeter, the entire colony is included in the survey transect, even in cases where the tissue falls outside the transect perimeter (Figure 3-8).

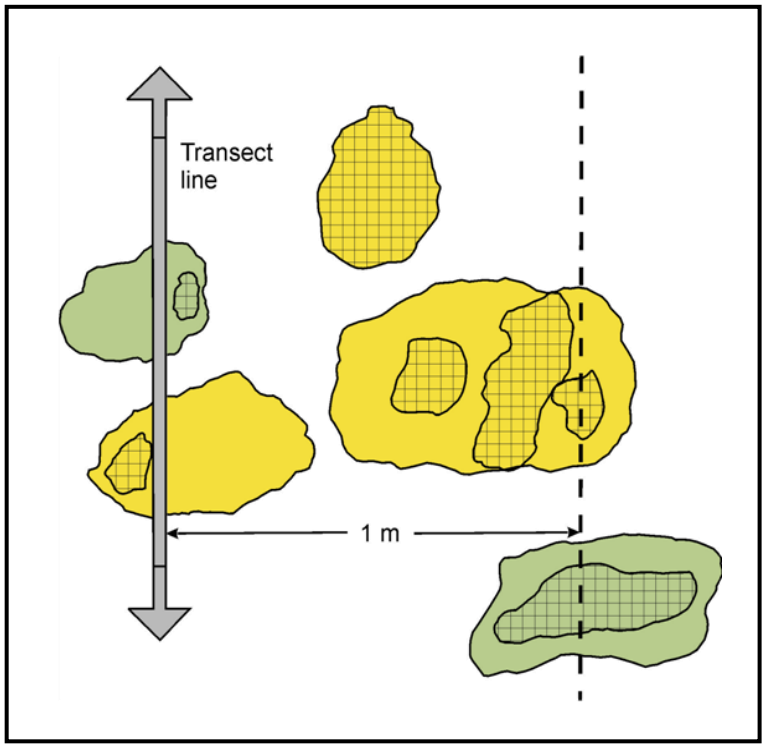


Figure 3-8: All coral colonies ≤1 m in diameter are included in transect if ≥50% of colony is contained within 1 m transect (yellow). If <50% of colony is in transect, the colony is excluded (green). Checkered portions denote coral tissue, clear colored portion denotes dead coral and exposed skeleton.

c. Data for colony size and tissue estimates are collected from the entire colony, not merely from the portion that is contained within the transect perimeter or only from the top (aerial view) of the colony.
d. Large colonies (> 1 m in diameter) that span the transect perimeter are counted and measured even if the majority of the colony lies outside the transect perimeter (Figure 3-9). If they do not span the transect perimeter, they are not counted.
e. Colonies within the transect perimeter with no tissue, but with visible calices to indicate recent mortality are counted and measured. If identification to genus is not possible from the calices, the taxon is reported as “unknown” (Figure 3-10).

6. Post Survey: The survey is completed at the 25-meter mark of the tape and the depth is recorded again. If stony corals are the last to be assessed, the surveyor detaches the transect tape from the seafloor, rolls up the transect line, retrieves all equipment and returns to the surface. After the dive, all data sheets are verified for accuracy, completeness and legibility and any questionable records reconciled by the surveyor. Data sheets are rinsed with freshwater and dried.

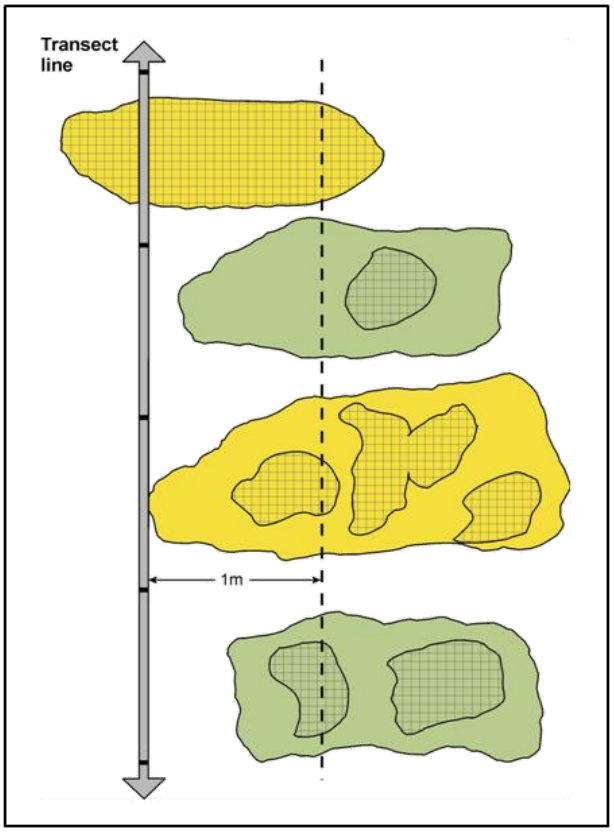


Figure 3-9: All coral colonies > 1 m in diameter are included in transect if the colony spans the entire 1 m width of the transect (yellow), otherwise it is excluded (green). Checkered portions denote coral tissue, clear colored portion denotes dead coral and exposed skeleton.

Figure 3-10: Intact coral skeletons with no tissue are included in the assessment if the colony can be identified to species or genus by calices or skeletal morphology.

Table 3-2: Stony corals included in Western Atlantic and Caribbean assessments (Humann and DeLoach 2002) with the three letter identification code and the morphological conversion factor for calculating 3-D surface area.

Genus and Species	ID Code	Conversion Factor
Acropora cervicornis	Acer	4
Acropora palmata	Apal	4
Acropora prolifera	Apro	4
Agaricia agaricites	Aaga	1
Agaricia fragilis	Afra	1
Agaricia humilis	Ahum	1
Agaricia lamarcki	Alam	1
Agaricia tenuifolia	Aten	3
Cladocora arbuscula	Carb	2
Colpophyllia natans	Cnat	2
Dendrogyra cylindrus	Dcyl	3
Dichocoenia stokesii	Dsto	2
Diploria clivosa	Dcli	2
Diploria labyrinthiformis	Dlab	2
Diploria strigosa	Dstr	2
Eusmilia fastigiata	Efas	3
Favia fragum	Ffra	2
Leptoseris cucullata	Lcuc	1
Isophyllastrea rigida	Irig	2
Isophyllia sinuosa	Isin	2
Madracis decactis	Mdec	3
Madracis formosa	Mfor	3
Madracis mirabilis	Mmir	3
Madracis pharensis	Mpha	1
Manicina areolata	Mare	2
Meandrina meandrites	Mmea	2
Millepora complanata	Mcom	3
Montastraea annularis	Mann	3
Montastraea cavernosa	Mcav	2
Montastraea faveolata	Mfav	2
Montastraea franksi	Mfra	2
Mussa angulosa	Mang	2
Mycetophyllia aliciae	Mali	1
Mycetophyllia danaana	Mdan	1
Mycetophyllia ferox	Mfer	1
Mycetophyllia lamarckiana	Mlam	1
Oculina varicosa	Ovar	3
Porites astreoides	Past	2
Porites colonensis	Pcol	1
Porites divaricata	Pdiv	3
Porites furcata	Pfur	3
Porites porites	Ppor	3
Siderastrea siderea	Ssid	2
Solenastrea bournoni	Sbou	2
Solenastrea hyades	Shya	3
Stephanocoenia intersepta	Sint	2

3.5 How are data managed?

Surveyors must review data sheets for legibility, completeness and correct use of standardized codes for species and disease. A checklist for data sheet actions is provided in Figure B-7. Any photographs taken to verify taxonomic description should be examined and appropriate changes made and initialed on the original data sheet. Data are delivered to the data recorder who transcribes from the underwater data sheets into an electronic spreadsheet for archiving and data analysis. After the data have been electronically entered, they are verified for accuracy and validated simultaneously by the surveyor and recorder. When complete, both the recorder and surveyor sign and date the data sheets, which are scanned and archived.

3.6 How are indicators calculated?

All data are summarized, and procedures are applied to identify outliers, errors, and inconsistencies to be considered prior to data analyses. These procedures can include summary statistics, box plots, and stem and leaf plots. The three core measurements taken in the survey (species, size, and percent tissue area) allow calculation of several indicators reflecting aspects of community composition as well as physical status and biological condition of the colonies. They were first proposed in Fisher (2007) and have been used in subsequent studies.

<u>Community Composition</u>

*Abundanc*e: number of colonies
Density: number of colonies per m^2 sea floor
Relative species abundance: abundance of a selected species per total abundance
Species (taxa) richness: number of species occurring in a reef or region
Species frequency of occurrence: proportion of sites where a species is present
Species diversity: index of taxa richness and relative abundance
Community composition: relative abundance of species with discretionary biological, physical or regulatory attributes (e.g., tolerance, branching, protected status)

<u>Physical Status</u>

Total surface area (TSA): total 3D colony surface area (m^2) including both living and dead portions
3D total coral cover (3DTC): TSA per m^2 sea floor (m^2/m^2)
Average colony surface area (CSA): TSA per total abundance (m^2)
Population structure: size distribution of colony abundance or other attribute for single species
Community structure: size distribution of colony abundance or other attribute for all coral species

<u>Biological Condition</u>

Percent live tissue (% LT): proportion of live coral tissue on each colony
Live surface area (LSA): live 3D surface area (m^2) = TSA*(% LT)
3D live coral cover (3DLC): LSA per m^2 sea floor (m^2/m^2)
% LSA: comparative index of live and total surface area [(LSA/TSA) *100]

The concept of measuring an organism's surface area is not new (Dahl 1973; Szmant-Froelich 1985; Roberts and Ormond 1987; Babcock 1991; Alcala and Vogt 1997; Bak and Meesters

1998), but it has not been widely applied in coral reef studies because of the relative convenience of measuring 2D projected colony surface area (live coral cover). Yet there are several possible approaches to estimate the true surface area of coral colonies. Some studies have used the surface area of geometric surrogates to estimate colony surface area from size classes or measurements of field colony dimensions (Alcala and Vogt 1997; Bak and Meesters 1998; Fisher *et al.* 2007, 2008). Others have used photographic approaches, using computer software to convert multiple 2D photographic images into 3D colony surface area estimates (Bythell *et al.* 2001; Cocito *et al.* 2003; Courtney *et al.* 2007).

The simplest method is to assign a surface index value (Dahl 1973) to a circular footprint based on colony morphology. A circular colony footprint is assumed because colony growth is usually radial. The surface area of a circular footprint is πr^2 (r = radius) and the surface area of a hemispherical colony is $2\pi r^2$ so the surface index for a hemispherical colony is 2. As colony morphology becomes increasingly complex the surface index increases. To accommodate some of the irregularities in colony formation, "r" is measured as the average of colony height and half the maximum colony diameter. In general, surface indices were rated 1 for flattened species morphology, 2 for hemispherical, 3 for lobed and domed morphologies and 4 for branched colonies (Table 3-2 for Caribbean species). Currently, this coarse but simple method is recommended for estimating 3D surface area of stony corals.

More accurate regression equations have been developed to estimate 3D surface area for nine species of Caribbean stony corals (Table 3-3). The equations are derived from log-linear regression models from colony measurements and photographic reconstructions of coral colonies (Courtney *et al.* 2007). Several of the estimations require three colony measurements instead of the two routinely taken. The percent difference of the regression estimates from the photographic reconstruction (actual) are relatively small, less than 10%, for the hemispherical, spherical, and low mounding colony morphologies (unpublished data, Fisher). More complex morphologies, such as branching or other irregular shapes, do not have accurate regression equations for estimating surface area; therefore none is recommended. EPA currently uses the morphological surrogate approach (Table 3-2) to estimate 3D colony surface area.

Table 3-3: Regression equations for estimating 3D surface area for nine coral species. Percent difference is calculated from the actual measured surface area using a photographic reconstruction method. h=maximum colony height, d=maximum colony diameter (Courtney *et al*. 2007)

Species	Equation	% Difference from Actual	Shape
Colpophyllia natans	2π(h+ d/2)	5%	hemisphere
Dichocoenia stokesii	0.904 log(h)+1.165 log(d/2)+0.610	10%	sphere
Diploria labyrinthiformis	0.904 log(h)+1.165 log(d/2)+0.610	5%	sphere
Siderastrea siderea	0.904 log(h)+1.165 log(d/2)+0.610	5%	flattened dome
Stephanocoenia intersepta	0.904 log(h)+1.165 log(d/2)+0.610	5%	sphere
Porites astreoides	0.846 log(h)+0.723 log(d/2)+0.510 log(h+[d/2])+0.656	5%	low mound
Meandrina meandrites	0.904 log(h)+1.165 log(d/2)+0.610	6%	low mound
Porites porites	0.846 log(h)+0.723 log(d/2)+0.510 log(h+[d/2])+0.656	12%	branching
Acropora palmata	0.846 log(h)+0.723 log(d/2)+0.510 log(h+[d/2])+0.656	21%	branching

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4.0 Marine Gorgonian Assessment

4.1 What is measured?

Figure 4-1: Marine gorgonian assessments allow evaluation of ecosystem services such as habitat for fish, marine pharmaceuticals and aesthetic qualities.

Marine gorgonian (Octocorallia) surveys document the size and morphology of each colony to estimate the surface area contribution to reef habitat. Height and maximum diameter are measured for each gorgonian classified by colony morphology (not taxonomy). The dimensions are converted to 3D colony surface area using a formula derived for each morphological type. Additional data collection can include taxonomic identification and reporting of adverse health conditions (e.g., bleaching, disease, predation). Data provide estimates of gorgonian abundance, density, surface area and, if included in the protocol, physical condition and taxa richness.

4.2 Why is it measured?

Marine gorgonians provide many important ecosystem services (Figure 4-1). The rich biochemical diversity of gorgonians provides bioprospecting opportunities for new marine chemicals and pharmaceuticals (Fenical 1996). Cnidaria have contributed over 10% of the marine biochemicals isolated with pharmaceutical potential (Hunt and Vincent 2006). Marine gorgonians are also partially responsible for tourism and recreational opportunities; in particular, large colorful colonies attract snorkelers and divers, while the fish that use them as habitat attract recreational fishers.

Marine gorgonians supply biogenic habitat for reef fish and other invertebrates (Gratwicke and Speight 2005). Gorgonians can serve as a nursery for fish and invertebrates, which may be especially important when stony coral habitat is in decline (Wolff *et al.* 1999; Kuffner *et al.* 2007). Although gorgonians are prominent reef inhabitants, they are often excluded from monitoring programs. This is partially because they are not widely recognized for their important functional contributions to reef environments, and partially because taxonomic distinctions can be difficult. In this approach, classification is based on morphology, categorized by predetermined shapes, which can be easier to apply than taxonomy. Size of the colony, combined with its morphological shape can be used to estimate the contribution to 3D reef habitat (Santavy *et al.* in review). If taxonomic expertise is available, both taxonomic and morphological classification schemes can be used to provide additional information.

4.3 What do we need?

4.3.1 Surveyor skills

The surveyor must be able to discern gorgonians from stony corals, sponges, tunicates, hydrozoans, zooanthids, bryozoans and other marine organisms and classify gorgonians into morphological groups as described below. If taxonomic classification and adverse biological conditions are included, the surveyor must be able to distinguish species (or at least genera) and signs of adverse conditions. Condition information can be acquired with little additional training, whereas taxonomic training requires a greater time investment. Reporting of taxonomic and adverse colony health is facilitated with an underwater camera to record questionable taxa or conditions for comparison with existing literature.

4.3.2 Equipment

- Gorgonian Survey Data Sheet (Figure B-3) or combined Gorgonian and Sponge Survey Data Sheet (Figure B-4) printed on underwater paper
- Gorgonian morphological codes (Table 4-1)
- Underwater slate with clipboard
- Underwater pencils or pens[13] with surgical tubing or rubber bands to attach to slate
- Flexible fiberglass metric measuring tape on reel at least 30 m in length
- 0.5 m or 1 m linear measuring instrument marked in 5 cm increments (e.g., PVC tube)
- 1 m^2 (1m x 1m) or 0.5 m^2 (70.7cm x 70.7cm) quadrat (PVC tubing)
- Optional: automatic underwater digital camera
- Optional: 30 m lead line with 30 tie wraps

Routinely, a single diver surveys both gorgonians and sponges and uses a single data sheet that accommodates data for both groups (Figure B-4). Depending on the goals of the study, it is possible to survey only gorgonians, in which case the surveyor would use the Gorgonian Survey Data Sheet (Figure B-3). If any other survey is conducted, the tape will already be in place. If not, the measuring tape is deployed from the reel and can be attached to the substrate with a small diameter bungee cord and snap clip on the end of the tape. The bungee cord is wrapped around an object on the substrate and clipped back on itself to secure the tape in place. If the transect will be used for other types of surveys (e.g., stony coral, sponge) and there is a significant current, it is recommended that the tape be weighted with a thin lead line to reduce movement. An underwater camera is beneficial to record uncertain gorgonians that can be used later to clarify unknown or questionable identifications with existing literature.

[13] Recycled wood pencils will disintegrate. Always bring multiple pencils or pens.

4.3.3 Morphological classification scheme

Gorgonian colonies (subclass Octocorallia, Order Gorgonacea) are classified into general morphologies using descriptive terms that denote the shape and proportions of a colony without regard for taxonomic affiliation (Santavy *et al.* in review). Basic categories include: sea fans, sea rods, sea whips, sea plumes and encrusting forms (see Table 4-1). In general, sea rods, sea whips and sea plumes are distinguished by the differences in branch and branchlet diameters, which affect the surface area of the colony.

Sea fans

Planar sea fans consist of a reticulate structural array occurring on a single plane resembling a flat fan.

Three-dimensional sea fans have multiple fan structures with varied planar arrangements arising from a central stalk thus significantly increasing the structure's surface area.

Sea rods single or branched, rods are usually 15-30 mm in diameter.

Unbranched sea rods are simple, single or multiple upright rod structures arising from a single basal expansion.

Planar sea rods resemble a candelabra (or menorah) with multiple rods occurring in a single plane.

Branched and bushy sea rods are characterized by arborescent (tree-like) forms and bifurcation. Branched colonies are distinguished from bushy colonies by the former having abundant branching arising above the holdfast, usually not forming an obvious main stem.

Sea whips branches are usually 5-15 mm in diameter.

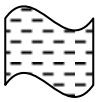
Branched and bushy sea whips are characterized by arborescent forms varying in complexity in number of branches, types of branching and degree of bifurcation. Branched colonies are distinguished from bushy colonies by the former having abundant branching arising above the holdfast, usually not forming an obvious main stem. They can be with or without angular branches in cross section as found in *Pterogorgia.*

Sea plumes branches are usually less than 5 mm in diameter.

Sea plumes have branched morphology that resemble ostrich feathers. They have the smallest diameter of branches and branchlets, the most consistent branch axial diameter and the longest branchlets of all gorgonians.

Encrusting gorgonians have a characteristic crust that spreads over the substrate, with little height. These provide little vertical substrate for habitat.

Table 4-1: Gorgonian morphological shapes with simulated models and *in situ* examples.

Gorgonian Morphology		Simulated Model	*in situ* Example
Sea Fans *(Gorgonia ventalina, Leptogorgia)*	Planar		
(Gorgonia flabellum)	Three-dimensional		
Sea Rods branch and branchlet diameter ≥ 15 - ≤30mm	Unbranched (digitate form, *Briareum*)		
	Branched *(Plexaura)*		
	Bushy *(Eunicea fusca)*		
	Planar *(Eunicea tourneforti)*		
Sea Whips branch & branchlet diameter ≥5 - ≤15mm	Branched *(Pterogorgia)*		
	Bushy *(Pterogorgia guadalupensi)*		
Sea Plumes smallest branch & branchlet diameter usually ≤5mm *(Muriceopsis flavida, Pseudopterogorgia)*			
Encrusting Gorgonians (*Briareum, Erythopodium)*			

4.4 How are data collected?

1. Preparation: Survey information is recorded on the survey data sheet (Figure B-3 or B-4), ensuring each page is numbered consecutively and taking care to enter the date, location and surveyor name prior to entering the water. A weighted marker buoy is set from the surface at the desired sampling location using GPS coordinates. If multiple assessments for other organisms and measurements are to be made, the fish survey should always be done first. If only the gorgonian survey is done, the gorgonian surveyor and buddy enter the water at the site with transect line (30 m tape on reel), quadrat, measuring tool, data sheets, gorgonian morphology codes, slate and pencils (optional camera). The transect location and direction are selected as the best available reef habitat (usually based on stony coral coverage) within 20 m of the buoy weight. The transect tape is securely fastened to the seafloor and extended 25 m in a straight line. (If the gorgonian assessment is preceded by a fish assessment, the transect tape is already set by the fish surveyors). Depths are recorded at the 0 m and 20 m marks.
2. Transect: The quadrat is placed at 0 m, 5 m, 10 m, 15 m and 20 m marks along the 25 m transect tape. If there is insufficient time because there are too many organisms to count in one dive, the quadrat can be placed at only three locations. Alternatively, five smaller quadrats (0.5 m^2) could be used along same five marks. The quadrat is positioned and secured against current and wave action. The quadrat or grid number indicating its position along the transect line is recorded on the data sheet.
3. Procedure: Every gorgonian ≥ 10 cm (in any dimension) that falls within the quadrat is classified as one of ten gorgonian morphologies (Table 4-1). Colony height (greatest distance from substrate) and maximum diameter (parallel to the substrate) are measured to the nearest 5 cm.
4. Optional measurements:
    a. If condition is assessed, notations of bleaching, disease or other abnormality can be noted in the remarks column.
    b. If taxonomy (genus, species) is reported, this can be noted in the remarks column.
    c. If many individuals with the same morphology and approximately the same size occur within the same grid, they can be grouped for recording purposes. The total number of similar gorgonians can be noted as ticks in the remarks column.
    d. If encrusting gorgonians are documented, then maximum diameter and width (dimension orthogonal to the maximum diameter at its midpoint) are measured to the nearest 5 cm increment.
5. Post Survey: The survey is completed at 21 m mark and the depth is again recorded. If gorgonians are the last assemblage to be assessed, the surveyor detaches the transect tape from the seafloor, rolls up the transect line, retrieves all equipment and returns to the surface. After the dive, all data sheets are verified for accuracy, completeness and legibility, and any questionable records reconciled by the surveyor. Data sheets are rinsed with freshwater and dried.

4.5 How are data managed?

Surveyors must review data sheets for legibility, completeness and correct use of standardized codes. Changes are made to the data sheet and should be initialed. A checklist for data sheet actions is in Figure B-7. Any photographs taken to verify taxonomic or morphological description are examined and archived with appropriate file name. Data are delivered to the data recorder who transcribes from the underwater data sheets into electronic format for archiving and data analysis. After the data have been electronically entered, they are verified for accuracy and validated simultaneously by the surveyor and recorder. When complete, both the recorder and the surveyor sign and date the data sheets, which are scanned and archived.

4.6 How are indicators calculated?

All data are summarized and procedures are applied to visualize outliers, errors, and other inconsistencies to be considered prior to data analyses. These procedures can include summary statistics, box plots, and stem and leaf plots. Morphological measurements (height and diameter) are entered into the appropriate regression equation (Table 4-2) to estimate surface area of individual specimens. The regressions were developed from simulated models with measurement errors (Santavy *et al.* in review) (Appendix D). Community ecological attributes such as richness, abundance, density, diversity and cover can be calculated using morphological instead of taxonomic classifications.

Table 4-2: Regression equations to estimate surface area of gorgonians with different morphology. d=maximum diameter, h= height, w=maximum planar width

Gorgonian Morphology	Surface Area Estimations
Sea Fans planar	$SA=0.68h^2+0.66d^2-3.61$
Sea Fans 3D	$SA=0.0113h^3+106d-1190$
Sea Rods planar	$SA=76.4\ d-806$
Sea Rods unbranched	$SA=0.341d^3+11.2h-127$
Sea Rods branched	$SA= 1.46d^2 + 399$
Sea Rods bushy	$SA=0.0288h^3+ 939$
Sea Whips branched	$SA=0.0479h^3+3.37h^2-51.3h+354$
Sea Whips bushy	$SA=0.0672d^3+1610$
Sea Plumes	$SA=4.77h^2-2990$
Encrusting	$SA=dw$

4.7 References

Fenical W. 1996. Marine biodiversity and the medicine cabinet: the status of new drugs from marine organisms. Oceanography 9:23-27.

Gratwicke B and Speight MR. 2005. Effects of habitat complexity on Caribbean marine fish assemblages. Marine Ecology Progress Series 292:301-310.

Hunt B and Vincent ACJ. 2006. Scale and sustainability of marine bioprospecting for pharmaceuticals. Ambios 35:57-64.

Kuffner IB, Brock JC, Grober-Dunsmore R, Bonito VE, Hickey TD and Wright CW. 2007. Relationships between reef fish communities and remotely sensed rugosity measurements in Biscayne National Park, Florida, USA. Environmental Biology of Fish 78:71-82.

Santavy DL, Courtney LA, Fisher WS, Quarles RL and Jordan SJ. (in review, 2012) Estimating the surface area of marine gorgonians and sponges in the field. Hydrobiologia.

Wolff N, Grober-Dunsmore R, Rogers CS and Beets J. 1999. Management implications of fish trap effectiveness in adjacent coral reef and gorgonian habitats. Environmental Biology of Fish 55:81-90.

5.0 Marine Sponge Assessment

5.1 What is measured?

Figure 5-1: Marine sponge assessments allow important ecological and economic services to be evaluated by measuring surface area.

Marine sponge (Porifera) surveys document the size and morphology of each organism to estimate the surface area contribution of sponges to reef habitat. Height and maximum diameter are measured for each sponge classified by colony morphology instead of taxonomy. The dimensions are converted to 3D colony surface area using a formula derived for each morphological type. Additional data collection can include taxonomic identification and reporting of adverse health conditions (e.g., bleaching, disease, predation). Data will provide estimates of sponge abundance, density, surface area and, if included in the protocol, physical condition and taxa richness.

5.2 Why is it measured?

Marine sponges provide many important ecosystem services (Figure 5-1). The diversity of sponges in reef habitats provides bioprospecting opportunities for new marine biochemicals and pharmaceuticals (Fenical 1996). Porifera possess unique biological compounds that have contributed nearly 65% of the marine biochemicals isolated with pharmaceutical potential (Hunt and Vincent 2006). Large and colorful marine sponges attract snorkelers and divers making them partially responsible for tourism and recreational opportunities. The fish that use them as habitat attract recreational fishers. Finally, a small commercial fishery for marine sponges still exists today.

Marine sponges have diverse functional roles that directly influence coral reefs and the survival of many associated organisms. Sponges provide habitat for fish and other invertebrates (Gratwicke and Speight 2005), reinforce reef structure by cementation, contribute to nitrogen and carbon cycling through the metabolic activity of their microbial symbionts, and efficiently filter sediment, algae and small organisms from the water column (Wulff 2006). Although-sponges are one of the most prominent sessile invertebrates on coral reefs, they are often overlooked in monitoring programs. This may be in part because sponge taxonomic classification is confounded by high diversity and morphological plasticity. In this approach, classification is based on morphology rather than taxonomy (Santavy *et al.* in review); however, if taxonomic

expertise is available both classification schemes can be used to provide additional information for assessing biological condition.

5.3 What do we need?

5.3.1 Surveyor skills

The surveyor must be able to discern sponges from stony corals, octocorals, tunicates, hydrozoans, zooanthids, bryozoans and other marine organisms and must be able to classify sponges into morphological groups as described below. Signs of adverse biological conditions can be accomplished with little additional training, whereas taxonomic classification to distinguish species (or at least genera) requires a significant time investment. Taxonomic and adverse health reporting can be facilitated with an underwater camera to record questionable taxa or conditions for comparison with existing literature.

5.3.2 Equipment

- Sponge Survey Data Sheet (Figure B-5) or combined Gorgonian and Sponge Survey Data Sheet (Figure B-4) printed on underwater paper
- Sponge morphological codes
- Underwater slate with clipboard
- Underwater pencils or pens[14] with surgical tubing or rubber bands to attach to slate
- Flexible fiberglass metric measuring tape on reel at least 30 m in length
- 0.5 m measuring tool marked in 5 cm increments (e.g., PVC tube)
- 1 m^2 (1m x 1m) or 0.5 m^2 (70.7 cm x 70.7 cm) quadrat (PVC tubing)
- Optional: automatic underwater camera
- Optional: 30 m lead line with 30 tie wraps

Usually a single diver surveys both gorgonians and sponges, and uses a single data sheet that accommodates data for both groups (Figure B-4). Depending on the goals of the study, it is possible to survey only sponges, in which case the surveyor would use the Sponge Survey Data Sheet (Figure B-5). The metric measuring tape should be on a reel to allow easy deployment and should be clearly marked at 1 m increments. If any other survey is conducted, the tape will already be in place. The tape can be attached to the substrate with a small diameter bungee cord and snap clip on the end of the tape. The bungee cord is wrapped around an object on the substrate and clipped back on itself to secure in place. If the transect will be used for other types of surveys (e.g., coral, sponge), and there is a significant current, it is recommended that the tape be weighted with a thin lead line to reduce movement. The lead line can be attached to the transect line with tie wraps every meter. An underwater camera is beneficial to record uncertain sponges that can be used later to clarify unknown or questionable identifications with existing literature.

5.3.3 Morphological classifications

Marine sponges (class Demospongiae) are classified into ten morphological forms, including barrel, vase, globe, mound, tube, rod, ropey branching, bushy, encrusting, and boring types (Table 5-1). Each group is defined by shape and relative proportions without regard to taxonomic affiliation or surface texture (Santavy *et al.* in review). Although species generally exhibit a particular shape, two individuals of the same species could be classified into two different

[14] Recycled wood pencils will disintegrate. Always bring multiple pencils or pens.

morphological groups. For example, *Cribrochalina vasculum* could be classified as either a barrel or a vase sponge.

Barrel sponges resemble a cylinder with a flat bottom, and can exhibit varying degrees of surface relief and side slope.

Vase sponges are tapered at the base and wider at the top. An individual sponge can have one or multiple vases.

Globe sponges include spherical, hemispherical or elliptical shapes that can vary in height and diameter. The surfaces are mostly convex and have minor irregularities.

Mound sponges are amorphous with an irregular shape, devoid of symmetry or resemblance to a simple geometric figure. They often are described as lobate or having a lumpy surface.

Tube sponges have large hollow cylinders resembling tubes or pipes that can be either singular or multiple; individuals sometimes have 12 or more tubes.

Rod sponges have solid cylinders without large openings. Rods lack branching and are usually single, digitate (finger-like), upright cylinders. Multiple rods can originate from a common base with no branching (stoloniferous).

Bushy sponges resemble large arborescent upright shapes with branching in multiple planes originating from a common stalk or base. They appear similar to bushes or branched forms.

Branching ropey sponges are similar to small rod sponges but appear tangled and intertwined as a rope. This sponge has digitate branching in one or more planes and can have irregular or regular branching, appearing as arborescent (tree-like) or tangled rods in any or multiple planes. The branching forms can be either simple or complex.

Encrusting sponges resemble veneer-like overgrowth with very little colony height. Dimensions of an encrusting sponge are recorded as maximum diameter and width of the colony orthogonal to and at the midpoint of the maximum diameter.

Boring sponges also resemble veneer-like overgrowth and are distinguished from encrusting sponges by penetration of the coral's surface and skeleton. Dimensions of a boring sponge are recorded as maximum diameter and width of the colony orthogonal to and at the midpoint of the maximum diameter.

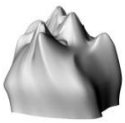
5.4 How are data collected?

1) Preparation: Survey information is recorded on the survey data sheet (Figure B-5 or B-4), ensuring each page is numbered consecutively and taking care to include date, location, and surveyor name prior to entering the water. A weighted marker buoy is set from the surface at the desired sampling location using GPS coordinates. If multiple assessments for other organisms are to be made, the fish survey should always be done first. If only a

sponge survey is done, the sponge surveyor and buddy enter the water at the site with measuring tape on reel, quadrat, measuring tool, data sheets, sponge morphology codes, pencils and slate (optional: camera). The transect location and direction are selected as the best available reef habitat (usually based on stony coral coverage) within 20 m of the buoy weight. The transect tape is securely fastened to the seafloor and extended 25 m in a straight line. (If the sponge assessment is preceded by a fish assessment, the transect tape is already set by the fish surveyors). Depths are recorded at the 0 m and 20 m marks.

2) Transect: The quadrat is placed at 0 m, 5 m, 10 m, 15 m and 20 m along the 25 m transect tape. If there is insufficient time to complete the quadrats because there are too many organisms to count in one dive, the quadrat can be placed at only three locations. Alternatively, five smaller quadrats (0.5 m^2) could be used along same five marks. The quadrat is positioned against current and wave action. The quadrat or grid number indicating its position along the transect line is recorded on the data sheet.
3) Procedure: Every sponge ≥ 10 cm (in any dimension) falling within the quadrat is classified as one of ten sponge morphologies (Table 5-1). If the base of sponge is in the quadrat, it is considered in the transect. Colony height (greatest distance from substrate) and maximum diameter (parallel to the substrate) are recorded to the nearest 5 cm.
4) Optional measurements:
    a. If condition is assessed, notations of bleaching, disease or other abnormality can be noted in the remarks column.
    b. If taxonomy (genus, species) is reported, this can be noted in the remarks column.
    c. If many individuals with the same morphology and approximately the same size class (height x diameter within 5 cm increments) occur within the same grid, they can be grouped for recording purposes. The total number of similar sponges can be noted as ticks in the remarks column.
    d. If encrusting and boring sponges are documented, then maximum diameter and width (dimension orthogonal to the maximum diameter at its midpoint) are measured to the nearest 5 cm increment.
5) Post-Survey: The survey is completed at the 21 m mark and the depth is recorded again. If sponges are the last assemblage to be assessed, the surveyor detaches the transect tape from the seafloor, rolls up the transect line, retrieves all equipment and returns to the surface. After the dive, all data sheets are verified for accuracy, completeness and legibility and any questionable records reconciled by the surveyor. Data sheets are rinsed with freshwater and dried.

Table 5-1: Sponge morphological shapes with simulated models and *in situ* examples.

Sponge Morphology (spp. example)	Simulated Model	*in situ* Example
Barrel (*Xestospongia muta, Verongula reiswigi*)		
Vase (*Callyspongia plicifera, Callyspongia vaginalis*)		
Globe (*Iricinia strobilina, Spheciospongia vesparium*)		
Tube (*Aplysina archeri, Aplysina fistularis*)		
Mound (*Oligoceras hemorrhages, Iricinia felix*)		
Rod (*Aplysina cauliformis, Niphates erecta*)		
Bushy (*Aplysina fulva*)		
Branched Ropey (*Iotrochota birotulata*)		
Encrusting (*Amphimedon compressa, Chrondrilla caribensis*)		
Boring (*all Clionids*)		

5.5 How are data managed?

Surveyors must review data sheets for legibility, completeness and correct use of standardized codes. Changes are made to the data sheet and should be initialed. A checklist for data sheet actions is in Figure B-7. Any photographs taken to verify morphological or taxonomic description should be examined and archived with appropriate file name. Data are delivered to the data recorder who transcribes from the underwater data sheets into electronic format for archiving and data analysis. After the data have been electronically entered, they are verified for accuracy and validated simultaneously by the surveyor and recorder. When complete, both the recorder and the surveyor sign and date the data sheets, which are scanned and archived.

5.6 How are indicators calculated?

All data are summarized, and procedures are applied to visualize outliers, errors, and other inconsistencies to be considered prior to data analyses. These procedures can include summary statistics, box plots, and stem and leaf plots. Morphological measurements (height and diameter dimensions) are entered into the appropriate regression equation (Table 5-2) to estimate surface area of individual specimens. The regressions were developed from simulated models and measurement errors provided in Santavy *et al.* (in review) (Appendix D). For barrel, vase and tube sponge morphologies, surface areas are calculated using both outside and inside surfaces. Community ecological attributes such as richness, density, diversity indices and abundance can be calculated using morphological as well as taxonomic classifications if taxa are recorded.

Table 5-2: Equations to estimate surface area of sponges with different morphology. d=maximum diameter, h=height, w=maximum planar width

Sponge Morphology	Regression Equations
Barrel	$SA=4.31d^2 + 0.827h^2 +108$
Vase	$SA=3.71h^2–161$
Globe	$SA=1.88h^2 +0.0573d^3+83.3$
Mound	$SA=30.0h+18.7d–193$
Tubes	$SA=0.493d^3+109$
Rods	$SA=7.69h+1.83d^3–33.5$
Bushy	$SA=0.462h^2+0.834d^2+19.3$
Ropey Branched	$SA=18.8d+7.97h–132$
Encrusting & Boring	$SA=dw$

5.7 References

Fenical W. 1996. Marine biodiversity and the medicine cabinet: the status of new drugs from marine organisms. Oceanography 9:23-27.

Gratwicke B and Speight MR. 2005. Effects of habitat complexity on Caribbean marine fish assemblages. Marine Ecology Progress Series 292:301-310.

Hunt B and Vincent ACJ. 2006. Scale and sustainability of marine bioprospecting for pharmaceuticals. Ambios 35:57-64.

Santavy DL, Courtney LA, Fisher WS, Quarles RL and Jordan SJ. (in review 2012). Estimating the surface area of marine gorgonians and sponges in the field. Hydrobiologia.

Wulff JL. 2006. Rapid diversity and abundance decline in a Caribbean coral reef sponge community. Biological Conservation 127:167-176.

6.0 Reef Rugosity, Live Coral Cover and Macroinvertebrate Assessments

6.1 What is measured?

Reef rugosity is surveyed to infer topographical complexity of the coral reef surface. A rugosity index is applied as a reef-scale indicator of reef contour or roughness (Figure 6-1). It is determined using a chain-transect method that compares the length of a chain draped along the coral and bottom of a reef to the length of a taut line across the same linear distance.

Figure 6-1: Rugosity is a measure of reef surface complexity.

Linear point intercept (LPI) method is used to estimate the percent planar live coral coverage on the reef. This method uses points along a transect to quantify no coral, live coral, or dead coral coverage lying underneath each point.

Selected macroinvertebrates that contribute to ecological and ecosystem services are enumerated by visual count census. Invertebrates targeted for Caribbean surveys are queen conch (*Strombus gigas*) recorded as adult or juvenile, spiny lobster (*Panilaurus argus*), reef crabs larger than 20 cm, sea urchins and long-spined sea urchins (*Diadema antillarum*).

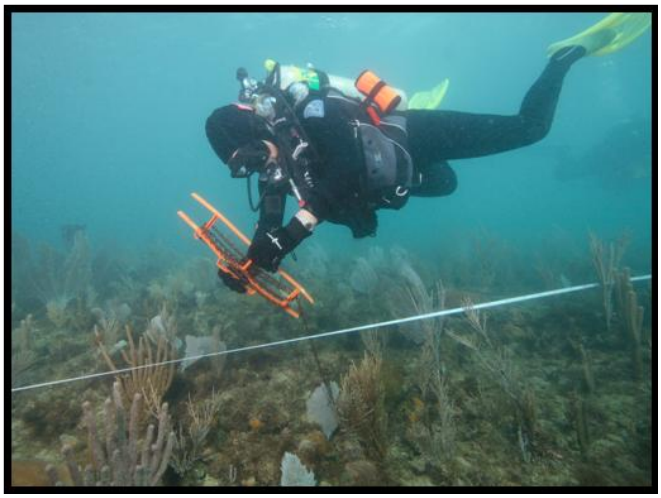
The three assessments are presented together because they are easily completed simultaneously.

6.2 Why is it measured?

Vertical relief and topographical complexity of coral reefs are assessed by measuring rugosity, which is a coarse estimate of reef contour (McCormick 1994; Alvarez-Filip *et al.* 2009) (Figure 6-2). Several studies have applied a rugosity index to estimate physical habitat provided by a reef (McCormick 1994; Rogers *et al.* 1994; Lang 2003). The rugosity index estimates complexity by sampling the two-dimensional (2D) vertical contour of stony corals and non-coral substrate along the draped line. This generates a unitless value that can be used for relative comparisons across stations and reefs. The chain-transect method estimates topography by extrapolation. While rugosity accounts for important vertical dimensions, it is only captured in one horizontal dimension and might not be as useful as 3D estimates of colony size and complexity.

Many past reef assessments have used 2D coral coverage as an indicator of reef condition. In order to compare results from 3D coral cover assessments with other studies, it is recommended that LPI also be assessed (Loya 1978).

Selected commercially and ecologically important macroinvertebrates are documented to indicate their population status on reefs. Queen conch, spiny lobsters and some crabs are harvested for food and consequently have been declining throughout the Caribbean for decades. Queen conch is a threatened and endangered species, protected in Florida, with catch limits enforced in Puerto Rico and United States Virgin Islands. Sea urchins (especially *Diadema antillarum*) have an important herbivory role on reefs and are considered a keystone species. An epizootic in the 1980s decimated *Diadema antillarum* populations throughout the Western Atlantic (Lessios 2005).



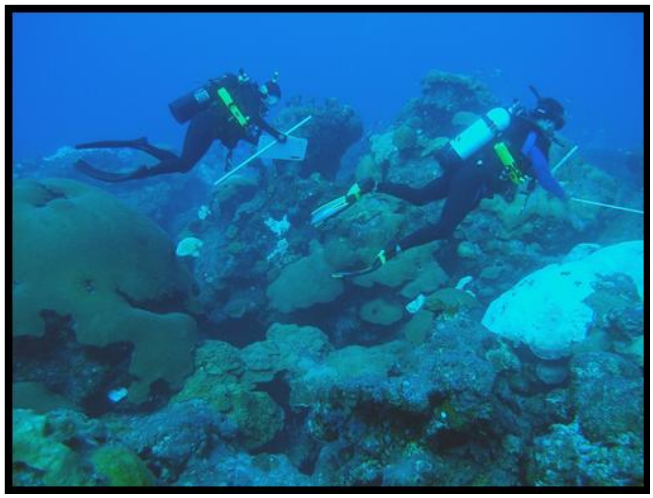


Figure 6-2: Examples of low rugosity (left) and high rugosity (right) reefs.

6.3 What do we need?

6.3.1 Surveyor skills

Only basic skills for underwater work are required for these assessments. For rugosity, a chain is draped over stony corals at several locations and its length measured. For LPI, one characterizes whether coral is present and whether it is alive or dead underneath each meter mark along a 25 m transect. For macroinvertebrates, one must be able to recognize the queen conch (*Strombus gigas*), the spiny lobster *(Panilaurus argus)*, crabs larger than 20 cm, sea urchins and distinguish the long-spined sea urchin *(Diadema antillarum)* (Figure 6-3). The queen conch is recorded by maturity level. An adult conch has a flared lip on the edge of its shell and a juvenile does not (Fig. 6-4).

6.3.2 Equipment

- Rugosity, Biosurvey and LPI Data Sheet on underwater paper (Figure B-6)
- Underwater slate with clipboard
- Several underwater pencils or pens[15] with surgical tubing or rubber bands to attach to slate
- Flexible fiberglass metric measuring tape on reel at least 30 m in length marked 1 m increments

[15] Recycled wood pencils will disintegrate. Always bring multiple pencils or pens.

- Second flexible fiberglass metric measuring tape on reel at least 10 m in length
- 6 m length linked chain or line with pencil weights inserted (to minimize reef damage)

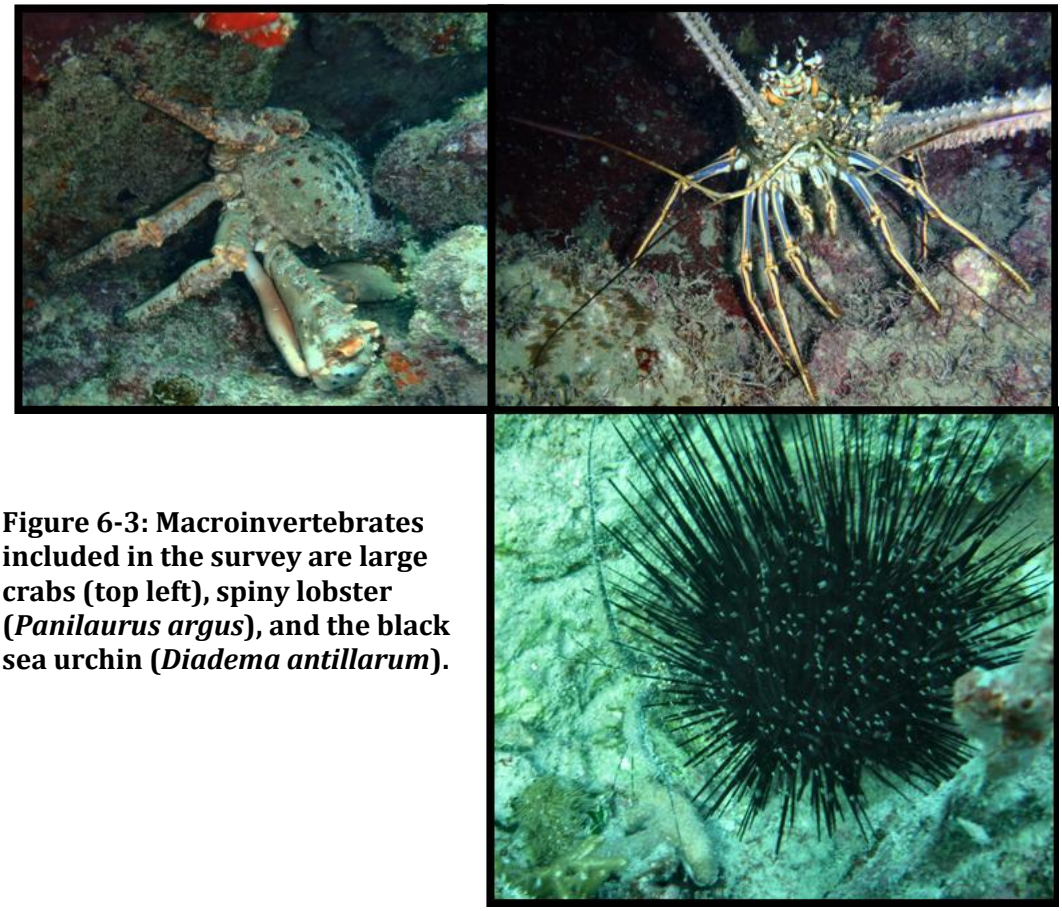


Figure 6-3: Macroinvertebrates included in the survey are large crabs (top left), spiny lobster (*Panilaurus argus*), and the black sea urchin (*Diadema antillarum*).

6.4 How are data collected?

1) Preparation: Survey information is recorded on the Rugosity, Biosurvey and LPI Data Sheet (Figure B-6), ensuring each page is numbered consecutively and taking care to include date, location, and surveyor name prior to entering the water. A weighted marker buoy is set from the surface at the desired sampling location using GPS coordinates. If multiple assessments for other organisms and measurements are to be made, the fish survey should always be done first. Often the fish surveyors can do these surveys after they finish while the other surveyors are assessing corals, gorgonians and sponges. If only this survey is done, the surveyor and buddy diver enter the water at the site with two measuring tape, 6 m linked chain, slate, pencils and data sheets. The best available habitat within 20 m of the buoy weight is selected for the survey. The transect tape is securely fastened to the seafloor and extended 25 m in a straight line. (If the rugosity, LPI and macroinvertebrate surveys are preceded by a fish assessment or other group, the transect tape is already set up.) Depths at the 0 and 20 m mark are recorded.
2. Rugosity: Divers perform five rugosity measurements at the 0, 5, 10, 15 and 20 m marks along the 25 m transect using a separate tape measure, laid parallel but not on top

of the transect tape. The linked chain is placed such that it follows the relief of hardbottom substrate. The chain is placed on top of any hard substrate encountered, but not on top of gorgonians or sponges since only hardbottom rugosity is being measured. To avoid these organisms, place the chain around or along the bottom to avoid placing on branches, but it can drape over the base. An effort should be made to ensure the chain is touching the substrate at all points along transect without doubling back on itself. The second diver can adjust the chain as the surveyor lays it over the substrate to ensure it has the best contact. A surveyor records the linear distance above the 6 m chain draped across the coral colonies in the transect, using another measuring tape. The tape must be pulled taut to determine the linear distance (NOAA CCMA 2008).

3. LPI Survey: Divers evaluate the presence or absence of coral under the 25 m transect tape at every meter mark between 0 m and 25 m, including each end. If coral is present then it is recorded as either live or dead coral.
4. Macroinvertebrate Abundance: Divers count the designated macroinvertebrates within 2 m on either side of the 25 m tape measure (survey area 4 m x 25 m =100 m^2). The survey can be done while deploying the 25 m tape or by the rugosity surveyors on their way back from the end of the 25 m tape. Large crabs, lobsters, sea urchins and conch are visually noted. The surveyors should search the reef surface for relief such as holes, overhangs, or crevices deep within the reef framework for these often contain hidden invertebrates. Record whether the conch is an adult or juvenile based on the shell's lip structure (Figure 6-4).

Figure 6-4: Adult and juvenile forms of queen conch (*Strombus gigas*). The adult has a flared lip that the juvenile form lacks. (Photo credit: <http://www.breef.org/OurMarineResources/Conch/tabid/55/Default.aspx>)

5. Post-Survey: When the survey is completed, the depth is recorded at the 25 m end. If this is the last survey to be completed, all survey gear is retrieved and returned to the surface. The surveyor detaches the transect tape from the seafloor, rolls up the transect line and returns to the surface. After the dive, all data sheets are verified for accuracy, completeness and legibility and any questionable records reconciled by the surveyor. Data sheets are rinsed with freshwater and dried.

6.5 How are data managed?

Surveyors must review data sheets for legibility, completeness and correct use of standardized codes. A checklist for data sheet actions is in Figure B-7. Data are transcribed from the underwater data sheets into electronic format for archiving, data management and data analysis. After the data have been electronically entered, they are verified for accuracy and validated simultaneously by the surveyor and recorder. When complete, both the recorder and the surveyor sign and date the data sheets, which are scanned and archived.

6.6 How are indicators calculated?

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

LPI is recorded as the number of points of each coral class divided by the total number of points evaluated. This results in estimates for planar coverage of coral vs. no coral, and live coral vs. dead coral (exposed skeleton).

Key macroinvertebrates are reported as density to compare their presence across stations. *Strombus gigas* are reported as either adults or juveniles based on the presence of a flared lip.

6.7 References

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National Oceanographic and Atmospheric Administration, Center for Coastal Monitoring and Assessment (NOAA CCMA). 2008. Detailed Methods for Characterization and Monitoring of Coral Reef Ecosystems and Associated Biological Communities. <http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html>.

Rogers C, Garrison G, Grober R, Hillis Z-M and Franke MA. 1994. Coral Reef Monitoring Manual for the Caribbean and Western Atlantic. US Virgin Islands National Park Service.

Appendix A: Other Coral Reef Assessment Programs

Table A-1: Some current coral reef monitoring and assessment programs, including websites.

Program	Acrony	Website	Year		Ocean	Country	Taxa Assessed					
			Begin	End			Corals	Fish	Algae	Sponges	Octocorals	Macro Invertebrate
Atlantic and Gulf Rapid Reef Assessment	AGRRA	www.agrra.org	1998	Present	NW Atlantic	Caribbean nations & US	X	X	X			X
Australian Institute of Marine Science	AIMS	www.aims.gov.au/docs/research/monitoring/reef/latest-surveys.html	1985	Present	Pacific/Coral Sea	Australia	X	X	X	X	X	X
British Virgin Islands Dept. Environ. & Fisheries	BVIDEF	www.bvidef.org/main/	2005	Present	Caribbean Sea	British Virgin Islands	X	X				X
Caribbean Coral Reef Ecosystem Assessment Monitoring Project	CCMA	ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/	2000	Present	Caribbean Sea	US Virgin Islands & Puerto Rico, Florida Keys	X	X	X	X	X	X
Coral Reef Assessment and Monitoring Program	CRAMP	cramp.wcc.hawaii.edu	1998	1999	N Pacific Ocean	Hawaii	X	X	X			
Coral Reef Evaluation and Monitoring Project	CREMP	ocean.floridamarine.org/fknms_wqpp/pages/cremp.html	1996	2007	NW Atlantic	Florida Keys	X					
US Environmental Protection Agency	EPA	www.epa.gov/bioiweb1/pdf/EPA-260-R-06-004StonyCoralsUSVIField Testing_.pdf	2006	2006	Caribbean Sea	US Virgin Islands	X					
International Union for the Conservation of Nature	IUCN	cmsdata.iucn.org/downloads/resilience_assessment_final.pdf	2005	Present	Worldwide	Tropical nations	X	X	X			
Reef Check	RC	www.reefcheck.org	2007	Present	Worldwide	Tropical nations	X	X	X		X	X
Regional Organization for Conservation of Environment of Red Sea & Gulf of Aden	PERSGA	www.persga.org/	2008	2009	Red Sea & Gulf Aden	Middle East Asia	X	X	X	X		X

Appendix B: Survey Data Sheets and Data Check List

Figure B-1: Fish Survey Data Sheet

FISH SURVEY DATA SHEET									
Surveyor				Station			Page	of	
Tender				Date			Depth ft	start	end
		Size (cm)							
	FISH ID	<5	5-10	10-15	15-20	20-25	25-30	30-35	>35
1									
2									
3									
4									
5									
6									
7									
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28									
29									
30									

Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

FISH SURVEY DATA SHEET									
Surveyor				Station			Page	of	
Tender				DATE			Depth ft	start	end
		Size (cm)							
	FISH ID	<5	5-10	10-15	15-20	20-25	25-30	30-35	>35
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
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16									
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24									
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27									
28									
29									
30									

Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

Figure B-2: Stony Coral Survey Data Sheet

STONY CORAL SURVEY DATA SHEET							
Date		Station				Page of	
Surveyor						Depth ft	
	Taxon	% Live Tissue	Height max (cm)	Diameter max (cm)	Disease	Bleach	Clionid
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
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19							
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21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

STONY CORAL SURVEY DATA SHEET							
Date		Station				Page of	
Surveyor						Depth ft	
	Taxon	% Live Tissue	Height max (cm)	Diameter max (cm)	Disease	Bleach	Clionid
31							
32							
33							
34							
35							
36							
37							
38							
39							
40							
41							
42							
43							
44							
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58							
59							
60							

Entered by: _____ Date: _____

QA by: _____ Date: _____

Figure B-3: Gorgonian Survey Data Sheet

GORGONIAN SURVEY DATA SHEET					
Date		Station			Page of
Surveyor					Depth ft
	Grid #	Gorgonian Shape	Height (cm)	Diameter (cm)	Remarks
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
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27					
28					
29					
30					

Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

GORGONIAN SURVEY DATA SHEET					
Date		Station			Page of
Surveyor					Depth ft
	Grid #	Gorgonian Shape	Height (cm)	Diameter (cm)	Remarks
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
44					
42					
43					
44					
45					
46					
47					
48					
49					
50					
51					
55					
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54					
55					
56					
57					
58					
59					
60					

Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

Figure B-4: Gorgonian and Sponge Survey Data Sheet

		GORGONIAN & SPONGE SURVEY DATA SHEET					
Date		Station					Page of
Surveyor							Depth ft
	Grid #	Gor/Spo	Height	Dia max	Morphological Description		
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
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26							
27							
28							
29							
30							

Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

		GORGONIAN & SPONGE SURVEY DATA SHEET					
Date		Station					Page of
Surveyor							Depth ft
	Grid #	Gor/Spo	Height	Dia max	Morphological Description		
31							
32							
33							
34							
35							
36							
37							
38							
39							
40							
41							
42							
43							
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57							
58							
59							
60							

Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

Figure B-5: Sponge Survey Data Sheet

SPONGE SURVEY DATA SHEET					
Date		Station			Page of
Surveyor					Depth ft
	Grid #	Sponge Shape	Height (cm)	Diameter (cm)	Remarks
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
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27					
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29					
30					

Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

SPONGE SURVEY DATA SHEET					
Date		Station			Page of
Surveyor					Depth ft
	Grid #	Sponge Shape	Height (cm)	Diameter (cm)	Remarks
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
44					
42					
43					
44					
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Entered by: _____ **Date:** _____

QA by: _____ **Date:** _____

Figure B-6: Rugosity, BioSurvey and LPI Data Sheet

Rugosity, BioSurvey and LPI Data Sheet

Date:	Station:	Surveyor:	Depth:

Draped Chain = 6 m

Rep #	Linear Distance (tape)	Notes
0 m		
5 m		
10 m		
15 m		
20 m		

Mark (m)	OBS	Mark (m)	OBS	Mark (m)	OBS
0		10		20	
1		11		21	
2		12		22	
3		13		23	
4		14		24	
5		15		25	
6		16			
7		17			
8		18			
9		19			

Observations (OBS):
Live Coral - LC
Dead Coral - DC
No Coral - NC

#Biota within 2m on both sides of line
Queen Conch (flared)
Queen Conch (juv)
Spiny Lobster
Slipper Lobster
Large Crabs
Sea Urchin *Diadema*
Sea Urchin
Other
Notes:

Entered by: _____ Date: _____ QA by: _____ Date: _____

Figure B-7: Check List for Data Sheet Actions

Prior dive:

_____Complete date, location, and surveyor specific information at top of data sheet.

During dive:

_____Accurately report data, using established codes and formating for assessment.

Post dive:

_____Check for completion of date, location, and surveyor specific information.

_____Check for completion and adherence of recorded data to standards in protocols.

_____Research any uncertain taxa information especially those photographed.

_____Wash data sheet in freshwater, hang and allow to dry.

_____Verify data sheet for completeness and accuracy.

_____Deliver data sheet to data recorder.

Appendix C: Fish Species Codes, Biomass Coefficients and Trophic Guild Assignments

Table C-1: Table of fish species found in the tropical Western Atlantic and Caribbean Sea. Both common names and taxonomic classification at the family, genus and species level are presented, which include the four letter species code used to record data. Estimates for biomass are made by employing values for the α and β coef-ficients derived from FishBase (Froese and Pauley 2007). Five trophic guilds for fish were derived from Randall 1967 (as used in Mensa *et al.* 2006 and Caldrow *et al.* 2009). Abbreviations for the trophic guilds are: H= herbivore, MI = mobile invertivore, P = piscavors, SI = sessile invertivore, Z = zooplanktonivore, and D = detritavor.

Species Code	Family	Genus	Species	Common Name	Trophic Guild	α Coef.	β Coef.	Length:Weight Conversion
ABHI	Belonidae	*Ablennes*	*Ablennes hians*	Flat needlefish	P	0.0007	3.13	1
ABSA	Pomacentridae	*Abudefduf*	*Abudefduf saxatilis*	Sergeant major	SI	0.017	3.12	1
ABTA	Pomacentridae	*Abudefduf*	*Abudefduf taurus*	Night sergeant	H	0.017	3.12	1
Acanthemblemaria UNK	Chaenopsidae	*Acanthemblemaria*	*Acanthemblemaria sp.*	Tube Blenny	MI	0.0077	2.962	1
Acanthurus UNK	Acanthuridae	*Acanthurus*	*Acanthurus sp.*	Surgeonfish	H	0.0286	3	1
ACAS	Chaenopsidae	*Acanthemblemaria*	*Acanthemblemaria aspera*	Roughhead blenny	MI	0.0077	2.962	1
ACBA	Acanthuridae	*Acanthurus*	*Acanthurus bahianus*	Ocean surgeonfish	H	0.0191	3.08	1
ACCH	Acanthuridae	*Acanthurus*	*Acanthurus chirurgus*	Doctorfish	H	0.0225	3	1
ACCO	Acanthuridae	*Acanthurus*	*Acanthurus coeruleus*	Blue tang	H	0.0305	3	1
ACDE	Syngnathidae	*Acentronura*	*Acentronura dendritica*	Pipehorse	MI/SI	0.0004	3.0768	1
ACMA	Chaenopsidae	*Acanthemblemaria*	*Acanthemblemaria maria*	Secretary blenny	MI	0.0077	2.962	1
ACPO	Ostraciidae	*Acanthostracion*	*Acanthostracion polygonia*	Honeycomb cowfish	MI/SI	0.0179	3	1
ACQU	Ostraciidae	*Acanthostracion*	*Acanthostracion quadricomis*	Scrawled cowfish	SI	0.0014	3.418	1
ACSP	Chaenopsidae	*Acanthemblemaria*	*Acanthemblemaria spinosa*	Spinyhead blenny	MI	0.0077	2.962	1
AENA	Myliobatidae	*Aetobatus*	*Aetobatus narinari*	Spotted eagle ray	MI	0.0059	3.13	1
ALAF	Serranidae	*Alphestes*	*Alphestes afer*	Mutton hamlet	MI	0.0174	3	1
ALCI	Carangidae	*Alectis*	*Alectis ciliaris*	African pompano	MI/P	0.0412	2.85	0.885
ALSC	Monacanthidae	*Aluterus*	*Aluterus scriptus*	Scrawled filefish	SI/Z	0.0022	3	1
ALVU	Albulidae	*Albula*	*Albula vulpes*	Bonefish	MI	0.0279	2.89	1
AMPI	Cirrhitidae	*Amblycirrhitus*	*Amblycirrhitus pinos*	Redspotted hawkfish	Z	0.0026	3.427	1
ANSU	Haemulidae	*Anisotremus*	*Anisotremus surinamensis*	Black margate	MI	0.0233	3.01	1
ANVI	Haemulidae	*Anisotremus*	*Anisotremus virginicus*	Porkfish	MI	0.0148	3.167	1
APAU	Apogonidae	*Apogon*	*Apogon aurolineatus*	Bridle cardinalfish	Z	0.0157	3.073	1
APBI	Apogonidae	*Apogon*	*Apogon binotatus*	Barred cardinalfish	Z	0.0157	3.073	1
APLA	Apogonidae	*Apogon*	*Apogon lachneri*	Whitestar cardinalfish	Z	0.0157	3.073	1
APMA	Apogonidae	*Apogon*	*Apogon maculatus*	Flamefish	Z	0.0157	3.073	1
Apogon UNK	Apogonidae	*Apogon*	*Apogon sp.*	Cardinalfish	Z	0.0157	3.073	1
APPS	Apogonidae	*Apogon*	*Apogon pseudomaculatus*	Twospot cardinalfish	Z	0.02	2.943	1
APQU	Apogonidae	*Apogon*	*Apogon quadrisquamatus*	Sawcheek cardinalfish	Z	0.0157	3.073	1
APTO	Apogonidae	*Apogon*	*Apogon townsendi*	Belted cardinalfish	Z	0.0157	3.073	1
ARRH	Sparidae	*Archosargus*	*Archosargus rhomboidalis*	Sea bream	H	0.018	3.102	1
ASPU	Apogonidae	*Astrapogon*	*Astrapogon puncticulatus*	Blackfin cardinalfish	MI	0.017	3.077	1
ASST	Apogonidae	*Astrapogon*	*Astrapogon stellatus*	Conchfish	MI	0.017	3.077	1
Atherinomorus UNK	Atherinidae	*Atherinomorus*	*Atherinomorus sp.*	Silverside	Z	0.0079	3.1938	1
AUMA	Aulostomidae	*Aulostomus*	*Aulostomus maculatus*	Trumpetfish	P	0.004	2.866	1
BASO	Gobiidae	*Bathygobius*	*Bathygobious soporator*	Frillfin goby	MI	0.0144	3	1

Species Code	Family	Genus	Species	Common Name	Trophic Guild	α Coef.	β Coef.	Length:Weight Conversion
BAVE	Balistidae	*Balistes*	*Balistes vetula*	Queen triggerfish	MI	0.0864	2.784	1
Belonidae UNK	Belonidae	*UNK*	*UNK*	Needlefish	P	0.0013	3.08	1
BOBO	Gobiidae	*Bollmannia*	*Bollmannia boqueronensis*	White-eye goby	MI/SI	0.0035	3.766	1
BOLU	Bothidae	*Bothus*	*Bothus lunatus*	Peacock flounder	P	0.0098	3.189	1
BOOC	Bothidae	*Bothus*	*Bothus ocellatus*	Eyed flounder	MI/P	0.0098	3.189	1
BOPU	Labridae	*Bodianus*	*Bodianus pulchellus*	Spotfin hogfish	MI	0.0145	3.053	1
BORU	Labridae	*Bodianus*	*Bodianus rufus*	Spanish hogfish	MI	0.0145	3.053	1
Bothus UNK	Bothidae	*Bothus*	*Bothus sp.*	Lefteye Flounder	P	0.0098	3.189	1
CABAJ	Sparidae	*Calamus*	*Calamus bajonado*	Jolthead porgy	MI	0.0672	2.822	1
CABAR	Carangidae	*Caranx*	*Caranx bartholomaei*	Yellow jack	P	0.034	2.84	1
CACA	Sparidae	*Calamus*	*Calamus calamus*	Saucereye porgy	MI/SI	0.0429	2.801	1
CACR	Carangidae	*Caranx*	*Caranx crysos*	Blue runner	P	0.0524	2.69	1
CAHI	Carangidae	*Caranx*	*Caranx hippos*	Crevalle jack	MI/P	0.0518	2.734	1
CAJA	Tetraodontidae	*Canthigaster*	*Canthigaster jamestyleri*	Goldface toby	MI/SI	0.0197	2.9174	1
CALA	Carangidae	*Caranx*	*Caranx latus*	Horse-Eye jack	P	0.021	2.97	1
Calamus UNK	Sparidae	*Calamus*	*Calamus sp.*	Porgy	MI	0.0447	2.8662	1
CALI	Carcharhinidae	*Carcharhinus*	*Carcharhinus limbatus*	Blacktip shark	P	0.0061	3.01	0.828
CALU	Carangidae	*Caranx*	*Caranx lugubris*	Black jack	P	0.0251	2.84	1
CAMA	Monacanthidae	*Cantherhines*	*Cantherhines macrocerus*	America whitespotted filefish	SI	0.0561	2.653	1
CANO	Sparidae	*Calamus*	*Calamus nodosus*	Knobbed porgy	MI	0.0077	3.13	0.926
Canthigaster UNK	Tetraodontidae	*Canthigaster*	*Canthigaster sp.*	Puffer	MI/SI	0.0197	2.9174	1
CAPENNA	Sparidae	*Calamus*	*Calamus penna*	Sheepshead porgy	MI	0.0196	3	1
CAPENNAT	Sparidae	*Calamus*	*Calamus pennatula*	Pluma	MI	0.0178	3.11	1
CAPU	Monacanthidae	*Cantherhines*	*Cantherhines pullus*	Orangespotted filefish	H	0.0683	2.563	1
Caranx UNK	Carangidae	*Caranx*	*Caranx sp.*	Jack	P	0.0224	2.9457	1
CARO	Tetraodontidae	*Canthigaster*	*Canthigaster rostrata*	Sharpnose puffer	MI/SI	0.0197	2.9174	1
CARU	Carangidae	*Caranx*	*Caranx ruber*	Bar jack	P	0.0065	2.748	1
CASU	Balistidae	*Canthidermis*	*Canthidermis sufflamen*	Ocean triggerfish	MI/Z	0.0217	3	1
CEAR	Pomacanthidae	*Centropyge*	*Centropyge argi*	Cherubfish	H	0.0314	2.7995	1
CEAU	Pomacanthidae	*Centropyge*	*Centropyge aurantonotus*	Flameback angelfish	H/SI	0.0314	2.7995	1
CECR	Serranidae	*Cephalopholis*	*Cephalopholis cruentata*	Graysby	P	0.0121	3.082	1
CEFU	Serranidae	*Cephalopholis*	*Cephalopholis fulva*	Coney	MI/P	0.0174	3	1
Chaenopsis UNK	Chaenopsidae	*Chaenopsis*	*Chaenopsis sp.*	Pike blenny	MI	0.0077	2.962	1
CHAN	Diodontidae	*Chilomycterus*	*Chilomycterus antennatus*	Bridled burrfish	MI	0.0236	3.124	1
CHCA	Chaetodontidae	*Chaetodon*	*Chaetodon capistratus*	Foureye butterflyfish	SI	0.047	2.86	1
CHCY	Pomacentridae	*Chromis*	*Chromis cyanea*	Blue chromis	Z	0.0202	2.9595	1
CHFA	Ephippidae	*Chaetodipterus*	*Chaetodipterus faber*	Atlantic spadefish	SI	0.0407	2.25	1
CHIN	Pomacentridae	*Chromis*	*Chromis insolata*	Sunshinefish	Z	0.0202	2.9595	1
CHLI	Chaenopsidae	*Chaenopsis*	*Chaenopsis limbaughi*	Yellowface pikeblenny	MI	0.0077	2.962	1
CHMU	Pomacentridae	*Chromis*	*Chromis multilineata*	Brown chromis	Z	0.0202	2.9595	1

Species Code	Family	Genus	Species	Common Name	Trophic Guild	α Coef.	β Coef.	Length:Weight Conversion
CHOCELLATA	Chaenopsidae	*Chaenopsis*	*Chaenopsis ocellata*	Bluethroat pikeblenny	MI	0.0077	2.962	1
CHOCELLATU	Chaetodontidae	*Chaetodon*	*Chaetodon ocellatus*	Spotfin butterflyfish	SI	0.0318	2.984	1
CHSC	Pomacentridae	*Chromis*	*Chromis scotti*	Purple reeffish	Z	0.0202	2.9595	1
CHSE	Chaetodontidae	*Chaetodon*	*Chaetodon sedentarius*	Reef butterflyfish	MI/SI/D	0.0251	3.076	1
CHST	Chaetodontidae	*Chaetodon*	*Chaetodon striatus*	Banded butterflyfish	SI	0.0222	3.14	1
CLPA	Labridae	*Clepticus*	*Clepticus parrae*	Creole wrasse	Z	0.0135	3.043	1
Clupeidae UNK	Clupeidae	*UNK*	*UNK*	Herring	Z	0.0009	3.62	1
CODI	Gobiidae	*Coryphopterus*	*Coryphopterus dicrus*	Colon goby	MI/H	0.0345	2.68	1
COEI	Gobiidae	*Coryphopterus*	*Coryphopterus eidolon*	Pallid goby	MI/H	0.0345	2.68	1
COEL	Syngnathidae	*Cosmocampus*	*Cosmocampus elucens*	Shortfin pipefish	MI/Z	0.0006	3	1
COGL	Gobiidae	*Coryphopterus*	*Coryphopterus glaucofraenum*	Bridled goby	MI/H	0.0345	2.68	1
COLI	Gobiidae	*Coryphopterus*	*Coryphopterus lipernes*	Peppermint goby	MI/H	0.0345	2.68	1
COPE	Gobiidae	*Coryphopterus*	*Coryphopterus personatus/hyalinus*	Masked/Glass goby	MI/H	0.0345	2.68	1
Coryphopterus UNK	Gobiidae	*Coryphopterus*	*Coryphopterus sp.*	Goby	MI/H	0.0345	2.68	1
COTR	Congridae	*Conger*	*Conger triporiceps*	Manytooth conger	MI/P	0.0002	3.41	1
CRRO	Scaridae	*Cryptotomus*	*Cryptotomus roseus*	Bluelip parrotfish	H	0.0505	3.182	1
CTSA	Gobiidae	*Ctenogobius*	*Ctenogobius saepepallens*	Dash goby	MI/H	0.0345	2.68	1
CTST	Gobiidae	*Ctenogobius*	*Ctenogobius stigmaticus*	Marked goby	MI/H	0.0345	2.68	1
DAAM	Dasyatidae	*Dasyatis*	*Dasyatis americana*	Southern stingray	SI	0.0014	2.672	1
DAVO	Dactylopteridae	*Dactylopterus*	*Dactylopterus volitans*	Flying gurnard	MI	0.0217	2.8	0.936
Decapterus UNK	Carangidae	*Decapterus*	*Decapterus sp.*	Scad	Z	0.0078	3.14	0.905
DEIN	Serranidae	*Dermatolepis*	*Dermatolepis inermis*	Marbeled grouper	P	0.0017	3	1
DEMA	Carangidae	*Decapterus*	*Decapterus macarellus*	Mackerel scad	Z	0.0078	3.14	0.905
DIAR	Sparidae	*Diplodus*	*Diplodus argenteus caudimacula*	Silver porgy	H/MI	0.0205	2.9902	1
DIBI	Serranidae	*Diplectrum*	*Diplectrum bivittatum*	Dwarf sand perch	MI/SI	0.0094	3.1121	1
DIFO	Serranidae	*Diplectrum*	*Diplectrum formosum*	Sand perch	P	0.0114	3.078	1
DIHOLB	Sparidae	*Diplodus*	*Diplodus holbrooki*	Spottail pinfish	H	0.0205	2.9902	1
DIHOLO	Diodontidae	*Diodon*	*Diodon holocanthus*	Balloonfish	MI	0.0219	3	1
DIHY	Diodontidae	*Diodon*	*Diodon hystrix*	Porcupinefish	MI	0.533	2.276	1
DOME	Labridae	*Doratonotus*	*Doratonotus megalepis*	Dwarf wrasse	MI/SI	0.0049	3.51	1
ECCA	Muraenidae	*Echidna*	*Echidna catenata*	Chain moray	MI	0.0012	3	1
ECNA	Echeneidae	*Echeneis*	*Echeneis naucrates*	Sharksucker	Z/D	0.127	2.113	1
ECNE	Echeneidae	*Echeneis*	*Echeneis neucratoides*	Whitefin sharksucker	Z/D	0.127	2.113	1
Elacatinus UNK	Gobiidae	*Elacatinus*	*Elacatinus sp.*	Goby	SI	0.008	3.137	1
ELCH	Gobiidae	*Elacatinus*	*Elacatinus chancei*	Shortstripe goby	SI	0.008	3.137	1
ELDI	Gobiidae	*Elacatinus*	*Elacatinus dilepis*	Orangesided goby	SI	0.008	3.137	1
ELEV	Gobiidae	*Elacatinus*	*Elacatinus evelynae*	Sharknose goby	SI	0.008	3.137	1

Species Code	Family	Genus	Species	Common Name	Trophic Guild	α Coef.	β Coef.	Length:Weight Conversion
ELLO	Gobiidae	*Elacatinus*	*Elacatinus louisae*	Spotlight goby	SI	0.008	3.137	1
ELMU	Gobiidae	*Elacatinus*	*Elacatinus multifasciatus*	Greenbanded goby	SI	0.008	3.137	1
ELOC	Gobiidae	*Elacatinus*	*Elacatinus oceanops*	Neon goby	SI	0.008	3.137	1
ELPR	Gobiidae	*Elacatinus*	*Elacatinus prochilos*	Broadstripe goby	SI	0.008	3.137	1
ELSA	Gobiidae	*Elacatinus*	*Elacatinus saucrum*	Leopard goby	SI	0.008	3.137	1
EMAT	Inermiidae	*Emmelichthyops*	*Emmelichthyops atlanticus*	Bonnetmouth	P/Z	0.0148	3.105	1
Emblemariopsis UNK	Chaenopsidae	*Emblemariopsis*	*Emblemariopsis sp.*	Blenny				
EMPA	Chaenopsidae	*Emblemaria*	*Emblemaria pandionis*	Sailfin blenny	Z	0.0077	2.962	1
Engraulidae UNK	Engraulidae	*UNK*	*UNK*	Anchovies	Z	0.005	3.1355	1
Enneanectes UNK	Tripterygiidae	*Enneanectes*	*Enneanectes sp.*	Triplefin	H/SI/MI	0.0141	3.05	1
ENNI	Muraenidae	*Enchelycore*	*Enchelycore nigricans*	Viper moray	MI/P	0.0017	3	1
EPAD	Serranidae	*Epinephelus*	*Epinephelus adscensionis*	Rock hind	MI	0.0153	3	1
EPGU	Serranidae	*Epinephelus*	*Epinephelus guttatus*	Red hind	MI/P	0.036	2.839	1
EPMO	Serranidae	*Epinephelus*	*Epinephelus morio*	Red grouper	MI	0.0122	3.035	1
EPST	Serranidae	*Epinephelus*	*Epinephelus striatus*	Nassau grouper	P	0.0157	3	1
EQLA	Sciaenidae	*Equetus*	*Equetus lanceolatus*	Jackknife fish	MI	0.0011	3.844	1
EQPU	Sciaenidae	*Equetus*	*Equetus punctatus*	Spotted drum	MI	0.0011	3.844	1
Eucinostomus UNK	Gerreidae	*Eucinostomus*	*Eucinostomus sp.*	Mojarra	MI	0.014	3.25	1
EUGU	Gerreidae	*Eucinostomus*	*Eucinostomus gula*	Silver jenny	MI	0.014	3.25	1
EUJO	Gerreidae	*Eucinostomus*	*Eucinostomus jonesii*	Slender mojarra	MI	0.0923	2.65	1
EUME	Gerreidae	*Eucinostomus*	*Eucinostomus melanopterus*	Flagfin mojarra	MI/Z	0.0128	2.91	0.903
FITA	Fistulariidae	*Fistularia*	*Fistularia tabacaria*	Bluespotted cornetfish	P	0.0053	2.59	0.672
GACU	Carcharhinidae	*Galeocerdo*	*Galeocerdo cuvier*	Tiger shark	P	0.0025	3.26	1
GECI	Gerreidae	*Gerres*	*Gerres cinereus*	Yellowfin mojarra	MI/SI	0.013	2.69	1
GICI	Ginglymostomatidae	*Ginglymostoma*	*Ginglymostoma cirratum*	Nurse shark	MI/P	0.0105	2.892	0.705
GNTH	Gobiidae	*Gnatholepis*	*Gnatholepis thompsoni*	Goldspot goby	H	0.0035	3.766	1
Gobiidae UNK	Gobiidae	*UNK*	*UNK*	Goby	MI/H	0.0345	2.68	1
GOGR	Gobiidae	*Gobiosoma*	*Gobiosoma grosvenori*	Rockcut goby	MI/H	0.0345	2.68	1
GRLO	Grammatidae	*Gramma*	*Gramma loreto*	Fairy basslet	MI/Z	0.0128	3.036	1
GYFU	Muraenidae	*Gymnothorax*	*Gymnothorax funebris*	Green moray	MI/P	0.0041	2.856	1
GYMI	Muraenidae	*Gymnothorax*	*Gymnothorax miliaris*	Goldentail moray	MI/P	0.0011	2.574	1
Gymnothorax UNK	Muraenidae	*Gymnothorax*	*Gymnothorax sp.*	Moray eel	P	0.001	3.158	1
GYMO	Muraenidae	*Gymnothorax*	*Gymnothorax moringa*	Spotted moray	P	0.001	3.158	1
GYVI	Muraenidae	*Gymnothorax*	*Gymnothorax vicinus*	Purplemouth moray	P	0.0043	2.876	1
HAAL	Haemulidae	*Haemulon*	*Haemulon album*	Margate (White)	MI/SI	0.014	3.09	1
HAAU	Haemulidae	*Haemulon*	*Haemulon aurolineatum*	Tomtate	SI/Z	0.011	3.2	1
HABI	Labridae	*Halichoeres*	*Halichoeres bivittatus*	Slippery dick	MI	0.0094	3.15	1
HACAR	Haemulidae	*Haemulon*	*Haemulon carbonarium*	Caesar grunt	MI	0.0404	2.74	1
HACAU	Labridae	*Halichoeres*	*Halichoeres caudalis*	Painted wrasse	MI	0.0052	3.375	1
HACH	Haemulidae	*Haemulon*	*Haemulon chrysargyreum*	Smallmouth grunt	SI/Z	0.0141	3.08	1

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HACY	Labridae	*Halichoeres*	*Halichoeres cyanocephalus*	Yellowcheek wrasse	MI	0.0094	3.15	1
Haemulon UNK	Haemulidae	*Haemulon*	*Haemulon sp.*	Grunt	SI/Z	0.011	3.2	1
HAFL	Haemulidae	*Haemulon*	*Haemulon flavolineatum*	French grunt	MI/SI	0.0207	3	1
HAGA	Labridae	*Halichoeres*	*Halichoeres garnoti*	Yellowhead wrasse	MI	0.0052	3.375	1
Halichoeres UNK	Labridae	*Halichoeres*	*Halichoeres sp.*	Wrasse	MI	0.0126	3.0673	1
HAMACR	Haemulidae	*Haemulon*	*Haemulon macrostomum*	Spanish grunt	MI	0.0176	3.06	1
HAMACU	Labridae	*Halichoeres*	*Halichoeres maculipinna*	Clown wrasse	SI	0.0028	3.693	1
HAME	Haemulidae	*Haemulon*	*Haemulon melanurum*	Cottonwick	MI	0.0557	2.63	1
HAPA	Haemulidae	*Haemulon*	*Haemulon parra*	Sailors choice	MI	0.028	2.89	1
HAPI	Labridae	*Halichoeres*	*Halichoeres pictus*	Rainbow wrasse	MI	0.0052	3.375	1
HAPL	Haemulidae	*Haemulon*	*Haemulon plumierii*	White grunt	MI	0.0259	3	1
HAPO	Labridae	*Halichoeres*	*Halichoeres poeyi*	Blackear wrasse	MI	0.0052	3.375	1
HARA	Labridae	*Halichoeres*	*Halichoeres radiatus*	Puddingwife	MI	0.0131	3.038	1
HASC	Haemulidae	*Haemulon*	*Haemulon sciurus*	Bluestriped grunt	MI	0.0218	3	1
HASP	Labridae	*Halichoeres*	*Halichoeres sp.*	Mardi gras wrasse	MI	0.0126	3.0673	1
HAST	Haemulidae	*Haemulon*	*Haemulon striatum*	Striped grunt	Z	0.0175	3.099	1
HECR	Priacanthidae	*Heteropriacanthus*	*Heteropriacanthus cruentatus*	Glasseye snapper	Z	0.0188	3	1
HELO	Congridae	*Heteroconger*	*Heteroconger halis*	Brown garden eel	Z	0.0006	3.2486	1
Hippocampus UNK	Syngnathidae	*Hippocampus*	*Hippocampus sp.*	Pipefish	MI/SI	0.0015	3	1
HIRE	Syngnathidae	*Hippocampus*	*Hippocampus reidi*	Longsnout seahorse	MI/SI	0.0015	3	1
HOAD	Holocentridae	*Holocentrus*	*Holocentrus adscensionis*	Squirrelfish	MI	0.0208	3	1
HOBE	Pomacanthidae	*Holacanthus*	*Holacanthus bermudensis*	Blue angelfish	SI	0.0319	2.899	1
HOCI	Pomacanthidae	*Holacanthus*	*Holacanthus ciliaris*	Queen angelfish	SI	0.0337	2.9	1
Holacanthus UNK	Pomacanthidae	*Holacanthus*	*Holacanthus sp.*	Angelfish	SI	0.0337	2.9	1
HORU	Holocentridae	*Holocentrus*	*Holocentrus rufus*	Longspine squirrelfish	MI	0.015	3.059	1
HOTR	Pomacanthidae	*Holacanthus*	*Holacanthus tricolor*	Rock beauty	SI	0.0428	2.858	1
HYAB	Serranidae	*Hypoplectrus*	*Hypoplectrus aberrans*	Yellowbelly hamlet	MI	0.009	3.04	1
HYCH	Serranidae	*Hypoplectrus*	*Hypoplectrus chlorurus*	Yellowtail hamlet	MI	0.009	3.04	1
HYGU	Serranidae	*Hypoplectrus*	*Hypoplectrus guttavarius*	Shy hamlet	MI	0.009	3.04	1
HYIN	Serranidae	*Hypoplectrus*	*Hypoplectrus indigo*	Indigo hamlet	MI	0.009	3.04	1
HYNI	Serranidae	*Hypoplectrus*	*Hypoplectrus nigricans*	Black hamlet	MI/P	0.009	3.04	1
Hypoplectrus UNK	Serranidae	*Hypoplectrus*	*Hypoplectrus sp.*	HAMLET	MI	0.009	3.04	1
HYPU	Serranidae	*Hypoplectrus*	*Hypoplectrus puella*	Barred hamlet	MI	0.009	3.04	1
HYUN	Serranidae	*Hypoplectrus*	*Hypoplectrus unicolor*	Butter hamlet	MI/P	0.011	3.182	1
INVI	Inermiidae	*Inermia*	*Inermia vittata*	Boga	Z	0.0078	3.14	0.905
Jenkinsia UNK	Clupeidae	*Jenkinsia*	*Jenkinsia sp.*	Herring	Z	0.0009	3.62	1
KYSE	Kyphosidae	*Kyphosus*	*Kyphosus sectatrix*	Chub (Bermuda/Yellow)	H	0.0174	3.08	1
LABI	Ostraciidae	*Lactophrys*	*Lactophrys bicaudalis*	Spotted trunkfish	MI/SI	0.0294	3	1
Lactophrys UNK	Ostraciidae	*Lactophrys*	*Lactophrys sp.*	Trunkfish	MI/SI	0.0309	3	1
LAFI	Labrisomidae	*Labrisomus*	*Labrisomus filamentosus*	Quillfin blenny	MI	0.0341	2.72	1

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LAMA	Labridae	*Lachnolaimus*	*Lachnolaimus maximus*	Hogfish	MI	0.0104	2.706	1
LANU	Labrisomidae	*Labrisomus*	*Labrisomus nuchipinnis*	Hairy blenny	MI	0.0341	2.72	1
LATRIG	Ostraciidae	*Lactophrys*	*Lactophrys trigonus*	Trunkfish	MI	0.375	2.1	1
LATRIQ	Ostraciidae	*Lactophrys*	*Lactophrys triqueter*	Smooth trunkfish	SI	0.0309	3	1
LIRU	Serranidae	*Liopropoma*	*Liopropoma rubre*	Peppermint basslet	MI	0.0128	3.036	1
LOCY	Gobiidae	*Lophogobius*	*Lophogobius cyprinoides*	Crested goby	H/SI/MI	0.0035	3.766	1
LOMI	Opistognathidae	*Lonchopisthus*	*Lonchopisthus micrognathus*	Swordtail jawfish	Z	0.0119	2.995	1
LUAN	Lutjanidae	*Lutjanus*	*Lutjanus analis*	Mutton snapper	MI	0.0221	2.95	1
LUAP	Lutjanidae	*Lutjanus*	*Lutjanus apodus*	Schoolmaster	MI/P	0.0189	3	1
LUBU	Lutjanidae	*Lutjanus*	*Lutjanus buccanella*	Blackfin snapper	MI/P	0.0747	2.735	1
LUCY	Lutjanidae	*Lutjanus*	*Lutjanus cyanopterus*	Cubera snapper	MI/P	0.0093	2.88	1
LUGR	Lutjanidae	*Lutjanus*	*Lutjanus griseus*	Gray snapper	MI/P	0.0182	2.94	1
LUJO	Lutjanidae	*Lutjanus*	*Lutjanus jocu*	Dog snapper	MI/P	0.0085	3.2	1
LUMA	Lutjanidae	*Lutjanus*	*Lutjanus mahogoni*	Mahogany snapper	MI/P	0.0428	2.719	1
LUSY	Lutjanidae	*Lutjanus*	*Lutjanus synagris*	Lane snapper	MI/P	0.0387	2.844	1
Lutjanus UNK	Lutjanidae	*Lutjanus*	*Lutjanus sp.*	Snapper	MI/P	0.0167	2.9773	1
MAAU	Labrisomidae	*Malacoctenus*	*Malacoctenus aurolineatus*	Goldline blenny	MI/Z	0.0341	2.72	1
MABI	Myliobatidae	*Manta*	*Manta birostris*	Giant manta	P/Z	0.0164	3	1
MABO	Labrisomidae	*Malacoctenus*	*Malacoctenus boehlkei*	Diamond blenny	MI/Z	0.0089	3	1
MAGI	Labrisomidae	*Malacoctenus*	*Malacoctenus gilli*	Dusky blenny	MI/Z	0.0089	3	1
Malacoctenus UNK	Labrisomidae	*Malacoctenus*	*Malacoctenus sp.*	Scaly blenny	MI/Z	0.0195	2.6477	1
MAMA	Labrisomidae	*Malacoctenus*	*Malacoctenus macropus*	Rosy blenny	MI/Z	0.0341	2.72	1
MAPL	Malacanthidae	*Malacanthus*	*Malacanthus plumieri*	Sand tilefish	MI	0.027	2.696	1
MATR	Labrisomidae	*Malacoctenus*	*Malacoctenus triangulatus*	Saddled blenny	MI	0.0089	3	1
MAVE	Labrisomidae	*Malacoctenus*	*Malacoctenus versicolor*	Barfin blenny	MI/Z	0.0089	3	1
MEAT	Megalopidae	*Megalops*	*Megalops atlanticus*	Tarpon	P	0.012	2.984	1
MENI	Balistidae	*Melichthys*	*Melichthys niger*	Black durgon	H/Z	0.0058	3.554	1
MICA	Gobiidae	*Microgobius*	*Microgobius carri*	Seminole goby	Z	0.0079	3	1
MICH	Pomacentridae	*Microspathodon*	*Microspathodon chrysurus*	Yellowtail damselfish	H	0.0239	3.082	1
Microgobius UNK	Gobiidae	*Microgobius*	*Microgobius sp.*	Goby	H	0.0079	3	1
MISI	Gobiidae	*Microgobius*	*Microgobius signatus*	Microgobius signatus	Z	0.0079	3	1
MOCI	Monacanthidae	*Monacanthus*	*Monacanthus ciliatus*	Fringed filefish	H/Z	0.0256	2.7	1
Monacanthus UNK	Monacanthidae	*Monacanthus*	*Monacanthus sp.*	Filefish	H/Z	0.0256	2.7	1
MOTU	Monacanthidae	*Monacanthus*	*Monacanthus tuckeri*	Slender filefish	Z/D	0.0256	2.7	1
MUCE	Mugilidae	*Mugil*	*Mugil cephalus*	Striped mullet	Z/D	0.0148	2.903	0.895
MUMA	Mullidae	*Mulloidichthys*	*Mulloidichthys martinicus*	Yellow goatfish	MI/Z	0.0207	3	1
Muraenidae UNK	Muraenidae	*UNK*	*UNK*	Moray Eel	MI/P	0.001	3.158	1
MYBO	Serranidae	*Mycteroperca*	*Mycteroperca bonaci*	Black grouper	P	0.0069	3.205	1
MYBR	Ophichthidae	*Myrichthys*	*Myrichthys breviceps*	Sharptail eel	MI	0.001	3	1
Mycteroperca UNK	Serranidae	*Mycteroperca*	*Mycteroperca sp.*	Grouper	P	0.0135	3.0418	1

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MYIN	Serranidae	*Mycteroperca*	*Mycteroperca interstitialis*	Yellowmouth grouper	P	0.0188	2.94	0.987
MYJA	Holocentridae	*Myripristis*	*Myripristis jacobus*	Blackbar soldierfish	MI	0.111	2.72	0.926
MYOC	Ophichthidae	*Myrichthys*	*Myrichthys ocellatus*	Goldspotted eel	MI	0.001	3	1
MYPH	Serranidae	*Mycteroperca*	*Mycteroperca phenax*	Scamp	P	0.0144	3	0.978
Myrichthys UNK	Ophichthidae	*Myrichthys*	*Myrichthys sp.*	Snake eel	MI	0.001	3	1
MYTI	Serranidae	*Mycteroperca*	*Mycteroperca tigris*	Tiger grouper	P	0.0094	3.12	0.974
MYVE	Serranidae	*Mycteroperca*	*Mycteroperca venenosa*	Yellowfin grouper	P	0.0069	3.14	1
NELO	Gobiidae	*Nes*	*Nes longus*	Orangespotted goby	MI/SI	0.0035	3.766	1
NEMA	Holocentridae	*Neonifon*	*Neonifon marianus*	Longjaw squirrelfish	MI	0.0185	2.9705	1
OCCH	Lutjanidae	*Ocyurus*	*Ocyurus chrysurus*	Yellowtail snapper	MI/Z	0.0155	3	1
ODDE	Sciaenidae	*Odontoscion*	*Odontoscion dentex*	Reef croaker	Z	0.0105	3.007	1
OGNA	Ogcocephalidae	*Ogcocephalus*	*Ogcocephalus nasutus*	Shortnose batfish	MI	0.0154	3.063	1
OPAU	Opistognathidae	*Opistognathus*	*Opistognathus aurifrons*	Yellowhead jawfish	Z	0.0093	2.99	1
Opistognathus UNK	Opistognathidae	*Opistognathus*	*Opistognathus sp.*	Jawfish	MI/Z	0.0093	2.99	1
OPMACC	Blenniidae	*Ophioblennius*	*Ophioblennius macclurei*	Redlip blenny	H	0.0324	2.379	1
OPMACR	Opistognathidae	*Opistognathus*	*Opistognathus macrognathus*	Banded jawfish	MI	0.0093	2.99	1
OPOP	Ophichthidae	*Ophichthus*	*Ophichthus ophis*	Spotted snake eel	MI/P	0.002	3	1
OPWH	Opistognathidae	*Opistognathus*	*Opistognathus whitehursti*	Dusky jawfish	MI	0.0093	2.99	1
OXST	Gobiidae	*Oxyurichthys*	*Oxyurichthys stigmalophius*	Spotfin goby	MI/SI	0.012	2.9554	1
PAAC	Sciaenidae	*Pareques*	*Pareques acuminatus*	Highhat	MI	0.0087	3.202	1
PABA	Callionymidae	*Paradiplogrammus*	*Paradiplogrammus bairdi*	Lancer dragonet	MI/SI	0.023	3.121	1
PAFU	Serranidae	*Paranthias*	*Paranthias furcifer*	Atlantic creolefish	Z	0.0135	3.043	1
PAMA	Blenniidae	*Parablennius*	*Parablennius marmoreus*	Seaweed blenny	Z	0.0109	3.0249	1
PESC	Pempheridae	*Pempheris*	*Pempheris schomburgkii*	Glassy sweeper	SI/Z	0.0439	2.62	1
POAR	Pomacanthidae	*Pomacanthus*	*Pomacanthus arcuatus*	Gray angelfish	SI	0.0345	2.968	1
Pomacanthus UNK	Pomacanthidae	*Pomacanthus*	*Pomacanthus sp.*	Angelfish	SI	0.0345	2.968	1
POPA	Pomacanthidae	*Pomacanthus*	*Pomacanthus paru*	French angelfish	SI	0.0203	3.126	1
PRAC	Chaetodontidae	*Prognathodes*	*Prognathodes aculeatus*	Longsnout butterflyfish	MI/SI	0.0318	2.984	1
PRAR	Priacanthidae	*Priacanthus*	*Priacanthus arenatus*	Bigeye	MI/Z	0.013	3.039	1
PRHI	Gobiidae	*Priolepis*	*Priolepis hipoliti*	Rusty goby	MI	0.0133	3.041	1
PSMA	Mullidae	*Pseudupeneus*	*Pseudupeneus maculatus*	Spotted goatfish	MI	0.0229	2.958	1
PTHE	Microdesmidae	*Ptereleotris*	*Ptereleotris helenae*	Hovering goby	Z	0.0091	3	1
RERE	Echeneidae	*Remora*	*Remora remora*	Common remora	Z	0.0042	3	0.946
RYBI	Serranidae	*Rypticus*	*Rypticus bistrispinus*	Freckled soapfish	MI/P	0.0128	3.036	1
RYSA	Serranidae	*Rypticus*	*Rypticus saponaceus*	Greater soapfish	MI/P	0.0121	3.082	1
SABU	Holocentridae	*Sargocentron*	*Sargocentron bullisi*	Deepwater squirrelfish	MI	0.0162	3.07	1
SACO	Holocentridae	*Sargocentron*	*Sargocentron coruscus*	Reef squirrelfish	MI	0.0162	3.07	1
SAVE	Holocentridae	*Sargocentron*	*Sargocentron vexillarium*	Dusky squirrelfish	MI	0.0162	3.07	1
Scarus UNK	Scaridae	*Scarus*	*Scarus sp.*	Parrotfish	H	0.0177	3	1
SCCO	Scaridae	*Scarus*	*Scarus coeruleus*	Blue parrotfish	H	0.0124	3.111	0.952

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SCCR	Blenniidae	*Scartella*	*Scartella cristata*	Molly miller	H	0.0028	2.414	1
SCGU	Scaridae	*Scarus*	*Scarus guacamaia*	Rainbow parrotfish	H	0.0352	2.88	1
SCIS	Scaridae	*Scarus*	*Scarus iseri*	Striped parrotfish	H	0.0208	2.92	1
Scorpaena UNK	Scorpaenidae	*Scorpaena*	*Scorpaena sp.*	Scorpionfish	MI/Z	0.0244	2.949	1
SCPL	Scorpaenidae	*Scorpaena*	*Scorpaena plumieri*	Spotted scorpionfish	MI/Z	0.0244	2.949	1
SCRE	Scombridae	*Scomberomorus*	*Scomberomorus regalis*	Cero	P	0.0202	2.8	1
SCTA	Scaridae	*Scarus*	*Scarus taeniopterus*	Princess parrotfish	H	0.0177	3	1
SCVE	Scaridae	*Scarus*	*Scarus vetula*	Queen parrotfish	H	0.0177	3	1
SEBA	Serranidae	*Serranus*	*Serranus baldwini*	Lantern bass	MI	0.0128	3.036	1
SECR	Carangidae	*Selar*	*Selar crumenophthalmus*	Bigeye scad	P/Z	0.0074	3.29	1
SEDU	Carangidae	*Seriola*	*Seriola dumerili*	Greater amberjack	P	0.0324	2.809	1
SEPU	Serranidae	*Serraniculus*	*Serraniculus pumilio*	Pygmy sea bass	MI/SI	0.0128	3.036	1
Serranus UNK	Serranidae	*Serranus*	*Serranus sp.*	Seabass	P/MI/Z	0.0128	3.036	1
SETA	Serranidae	*Serranus*	*Serranus tabacarius*	Tobaccofish	P	0.0128	3.036	1
SETI	Serranidae	*Serranus*	*Serranus tigrinus*	Harlequin bass	MI	0.0145	3.048	1
SETO	Serranidae	*Serranus*	*Serranus tortugarum*	Chalk bass	Z	0.0128	3.036	1
Sparisoma UNK	Scaridae	*Sparisoma*	*Sparisoma sp.*	Parrotfish	H	0.0162	3.0252	1
SPAT	Scaridae	*Sparisoma*	*Sparisoma atomarium*	Greenblotch parrotfish	H	0.0122	3.028	1
SPAU	Scaridae	*Sparisoma*	*Sparisoma aurofrenatum*	Redband parrotfish	H	0.0206	3	1
SPBA	Sphyraenidae	*Sphyraena*	*Sphyraena barracuda*	Great barracuda	P	0.0063	3	1
SPCH	Scaridae	*Sparisoma*	*Sparisoma chrysopterum*	Redtail parrotfish	H	0.0199	3	1
SPPI	Sphyraenidae	*Sphyraena*	*Sphyraena picudilla*	Southern sennet	P	0.067	2.942	1
SPRA	Scaridae	*Sparisoma*	*Sparisoma radians*	Bucktooth parrotfish	H	0.0122	3.028	1
SPRU	Scaridae	*Sparisoma*	*Sparisoma rubripinne*	Yellowtail parrotfish	H	0.0156	3.064	1
SPSP	Tetraodontidae	*Sphoeroides*	*Sphoeroides spengleri*	Bandtail puffer	MI/SI	0.042	2.61	1
SPTE	Tetraodontidae	*Sphoeroides*	*Sphoeroides testudineus*	Checkered puffer	MI/Z	0.0164	3.072	1
SPVI	Scaridae	*Sparisoma*	*Sparisoma viride*	Stoplight parrotfish	H	0.037	2.905	1
STAD	Pomacentridae	*Stegastes*	*Stegastes adustus*	Dusky damselfish	H	0.0379	2.857	1
STDI	Pomacentridae	*Stegastes*	*Stegastes diencaeus*	Longfin damselfish	H	0.0379	2.857	1
STLE	Pomacentridae	*Stegastes*	*Stegastes leucostictus*	Beaugregory	H/Z/SI	0.0303	2.887	1
STPA	Pomacentridae	*Stegastes*	*Stegastes partitus*	Bicolor damselfish	H	0.0182	3.152	1
STPL	Pomacentridae	*Stegastes*	*Stegastes planifrons*	Threespot damselfish	SI/D/H	0.0379	2.857	1
Stromateidae UNK	Stromateidae	*UNK*	*UNK*	Butterfish	MI/P	0.0207	3.105	0.862
STSE	Monacanthidae	*Stephanolepis*	*Stephanolepsis setifer*	Pygmy filefish	H/SI/MI	0.0198	2.9846	1
STVA	Pomacentridae	*Stegastes*	*Stegastes variabilis*	Cocoa damselfish	H/SI	0.0324	2.836	1
Syacium UNK	Paralichthyidae	*Syacium*	*Syacium sp.*	Sand flounder	MI/SI	0.0037	3.274	1
SYDA	Syngnathidae	*Syngnathus*	*Sygnathus dawsoni*	Sygnathus dawsoni	MI/SI	0.003	3.2122	1
SYIN	Synodontidae	*Synodus*	*Synodus intermedius*	Sand diver	P	0.0099	2.999	1
SYSA	Synodontidae	*Synodus*	*Synodus saurus*	Bluestriped lizardfish	P	0.004	3.19	1
THBI	Labridae	*Thalassoma*	*Thalassoma bifasciatum*	Bluehead	MI/Z	0.0101	3.04	1

Species Code	Family	Genus	Species	Common Name	Trophic Guild	α Coef.	β Coef.	Length:Weight Conversion
TRFA	Carangidae	*Trachinotus*	*Trachinotus falcatus*	Permit	MI/P	0.531	2.803	1
TRGO	Carangidae	*Trachinotus*	*Trachinotus goodei*	Palometa	P	0.204	3	0.776
Triglidae UNK	Triglidae	*UNK*	*UNK*	Searobin Family	MI/P	0.0096	3.0538	1
TYCR	Belonidae	*Tylosurus*	*Tylosurus crocodilus*	Houndfish	P	0.0013	3.08	1
XYMA	Labridae	*Xyrichtys*	*Xyrichtys martinicensis*	Rosy razorfish	MI	0.01	3	1
XYNO	Labridae	*Xyrichtys*	*Xyrichtys novacula*	Pearly razorfish	MI	0.048	2.234	1
Xyrichtys UNK	Labridae	*Xyrichtys*	*Xyrichtys sp.*	Razorfish	MI/Z	0.01	3	1
XYSP	Labridae	*Xyrichtys*	*Xyrichtys splendens*	Green razorfish	Z	0.01	3	1

Appendix D: Estimating Surface Area of Gorgonians and Sponges

Estimating the Surface Area of Marine Gorgonians and Sponges in the Field

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Abstract
An approach to estimate the three dimensional surface area (SA) of gorgonians and sponges was developed to assess *in situ* habitat provision. The empirical method for estimating habitat SA contributed by sponges and gorgonians used colony height, diameter and morphology which can be easily obtained during underwater surveys. While developed for shallow-water (<25 m) organisms that occur in the Western Atlantic Ocean, a similar approach might be applicable to other regions and deep-water reefs. Computer-simulated images were developed to represent natural populations of each morphological type. Population characteristics were compiled from field measurements and taxonomic literature. Modeling software was used to determine the SA of each simulated image. Stepwise regression analysis was used to generate models for estimating SA for different morphological types using height and diameter as variables that included linear, quadratic and cubic terms. Regression models and geometric surrogates were compared to known SA for each morphology using covariate analysis. Regression models were more robust than geometric surrogates, exhibiting greater accuracy at range extremes and, explaining over 90% of the variation. Results indicated that regression models fit better than geometric surrogates, particularly for estimates of small and large individuals. The regression models for all morphologies exhibited forecast errors of less than 20%. Application of these methods in combination with estimates for stony corals can be used to estimate biogenic habitat, which is an important ecosystem service of coral reef ecosystems. The approach using regression models to estimate surface area easily documented in field surveys, is relatively rapid, low tech and non-invasive.

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