USCRTF Watershed Partnership Initiative

Priority Ecosystem Indicators

Watershed Working Group Metrics Subcommittee

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Contents

Acronyms

Atlantic and Gulf Rapid Reef Assessment (AGGRA)
Best Management Practices (BMPs)
Clean Water Act (CWA)
Coefficient of Variation (CV)
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Confidence Interval (CI)
Crustose Coralline Algae (CCA)
Dissolved Oxygen (DO)
Global Positioning System (GPS)
National Coastal Condition Assessment (NCCA)
National Coral Reef Monitoring Program (NCRMP)
National Oceanic and Atmospheric Administration (NOAA)
National Pollution Discharge Elimination System (NPDES)
Nephelometric Turbidity Unit (NTU)
Particulate Organic Nitrogen (PON)
Polychlorinated Biphenyls (PCBs)
Polycyclic Aromatic Hydrocarbons (PAHs)
Stationary Point Count (SPC)
Total Dissolved Nitrogen (TDN)
Total Dissolved Phosphorus (TDP)
Total Maximum Daily Load (TMDL)
Total Nitrogen (TN)
Total Phosphorus (TP)
U.S. Army Corps of Engineers (USACE)
U.S. Environmental Protection Agency (EPA)
U.S. Geological Survey (USGS)
U.S. Virgin Islands (USVI)
U.S. Coral Reef Task Force (USCRTF)
Water Quality Standards (WQS)
Watershed Partnership Initiative (WPI)

Executive Summary

The Watershed Partnership Initiative (WPI) of the U.S. Coral Reef Task Force (USCRTF) selected three watersheds as priority sites where local and federal agency resources are addressing land-based sources of pollution in watersheds located upstream of priority coral reef areas. Specific language to evaluate the programmatic, ecological and social/community engagement success of the partnerships was included in Resolution 28.1 which codified the WPI. Specifically, the resolution states that in support of the WPI, the USCRTF will, "Evaluate the success of this partnership to ensure that the resources contributed are being applied effectively and are having the intended impact on watershed management, water quality issues impacting coral reef ecosystems, and building an informed and engaged community." The purpose of this document is to provide coastal managers, coral reef managers, and watershed coordinators faced with modest budgets and technical expertise with a suite of recommended ecological indicators and measurements to include in their watershed-specific monitoring plans that will help determine the efficacy and evaluate the success of management efforts to reduce land-based sources of pollution. With these metrics, the USCRTF intends to support the collection of ecological data from the watersheds and in the adjacent coastal waters to document any physical, chemical, or biological changes due to management actions or interventions taken to reduce known stressors in the watershed.

The recommended indicators were identified by the USCRTF Watershed Working Group Metrics Subcommittee to assess important ecological aspects of a coral reef community, water quality, and sediment quality. These indicators include: benthic cover, coral recruitment, coral colony size structure, coral taxonomic richness, herbivorous fish biomass, sediment constituent accumulation (% carbonate vs. % terrigenous), sediment toxicity, total Nitrogen, total Phosphorous, chlorophyll *a*, dissolved Oxygen, and turbidity. Watershed management efforts should include before/during/after monitoring of the relevant metrics from this list, as appropriate to their local stressors and management questions. Where possible, the methods for collecting data for these metrics are the same as national scale monitoring conducted through National Oceanic and Atmospheric Administration's (NOAA) National Coral Reef Monitoring Program (NCRMP) or the U.S. Environmental Protection Agency's (EPA) National Coastal Condition Assessment (NCCA) so that it will be possible to track status and trends of the indicators and to make comparisons of relative progress at and among sites. Because each of the WPI sites already has some level of monitoring taking place and the context for each site is different, this document will only provide a set of priority measurements for inclusion in each of these localized monitoring programs based on common stressors – sediment, nutrients, and contaminants – that exist across the three WPI sites. For this reason, resource managers and coordinators for the priority watersheds should discuss best practices for data collection of these indicators in their watershed and adjacent reef areas with the NOAA NCRMP and EPA NCCA leads, and with state/territory agencies for their jurisdiction to ensure that the data will answer the desired questions and/or be compatible for comparisons from the local to jurisdictional scale and allow for progress to be documented locally against larger scale changes. These indicators can also be established as state/territory water quality criteria under the Clean Water Act (CWA). (*See Appendix A for how the CWA can be exercised for improving the state of watersheds in support of protecting coastal reefs using ecological integrity principles, biocriteria, and application of biocriteria to coral reef management programs*).

Introduction and Purpose

The US Coral Reef Task Force (USCRTF) established the Watershed Partnership Initiative (WPI) in 2009 to focus local and federal agency resources in specific geographic areas to address land-based sources of pollution in watersheds located upstream of priority coral reef areas. In 2012, Resolution 28.1 was passed by the USCRTF and included language to evaluate the success of the partnerships across three areas: programmatic, ecological, and social/community engagement. Specifically, the resolution states that in support of the WPI, the USCRTF will, “Evaluate the success of this partnership to ensure that the resources contributed are being applied effectively and are having the intended impact on watershed management, water quality issues impacting coral reef ecosystems, and building an informed and engaged community.”

In 2013, the USCRTF Watershed Working Group Metrics Subcommittee was formed and tasked with developing an evaluative approach to the WPI and to provide recommended indicators for implementation in monitoring programs developed for the WPI priority sites: Guánica, Puerto Rico; West Maui, Hawaii; and Faga’alu, American Samoa. This document provides coastal managers, coral reef managers and watershed coordinators faced with modest budgets and technical expertise with a suite of recommended measurements and indicators to include in their watershed-specific monitoring plans that will help determine the efficacy and evaluate the success of management efforts to reduce land-based sources of pollution. With these metrics, the USCRTF intends to support coordinated efforts by federal, state and local managers to collect ecological data from the watersheds and in the adjacent coastal waters to document any physical, chemical, or biological changes due to management actions or interventions taken to reduce known stressors in the watershed. These recommendations are not intended to take the place of a complete monitoring plan or an ecological characterization system, rather, the metrics identified in Sections 1 - 3 are intended to supplement existing monitoring plans and standardize the plans across the WPI sites to assess changes in water quality and coral reef ecosystems in response to management actions and advance learning and information exchange. Each site has particular circumstances and priority stressors that may call for a different suite of recommended measurements, and guidance to assist with selection of them can be found in Section 4.

Although in the simplest approach it would be possible to measure only water quality metrics directly related to discharge from the watersheds, it was felt necessary to have some level of corresponding data from the reefs in order for resource managers in the jurisdictions to have some indication as to whether their suite of strategies was having any degree of success in relation to the overall condition of adjacent coastal coral reef resources. Through a collaborative process, priority measurements and indicators were identified by the USCRTF Watershed Working Group Metrics Subcommittee to assess important aspects of a coral reef community, water quality, and sediment quality – all factors that should be considered when evaluating the success of efforts completed to reduce land-based sources of pollution from watersheds to adjacent coral reef areas. Essentially, these measurements and indicators will help to answer the following questions:

- Have the key threats to coral reefs in the watershed been identified? What are the sources of these threats? Are the loads of these threats known?

- What are the baseline values for key ecological metrics? In response to management actions, are positive changes in key metrics being observed for the coral community, sediment quantity/quality, and water quality?

Theory of Change

In order to evaluate success it is important to first define it. For the WPI, success – or the ultimate goal – is to improve the condition and health of coral reef communities in the vicinity of the priority watershed sites. To achieve this success, the WPI envisions reducing the land-based sources of pollution (i.e. excessive sediment or nutrient inputs which act as stressors to coral reefs) through investments and management interventions at these sites to allow for naturally resilient coral reef communities to rebound. Therefore, in order to achieve success the WPI partnerships must first reduce key stressors in the watersheds (measured using process indicators) before any expected improvements in coral reef communities may be seen (measured using outcome indicators). This Theory of Change describes a conceptual framework used to focus on what is needed for success. Figure 1.

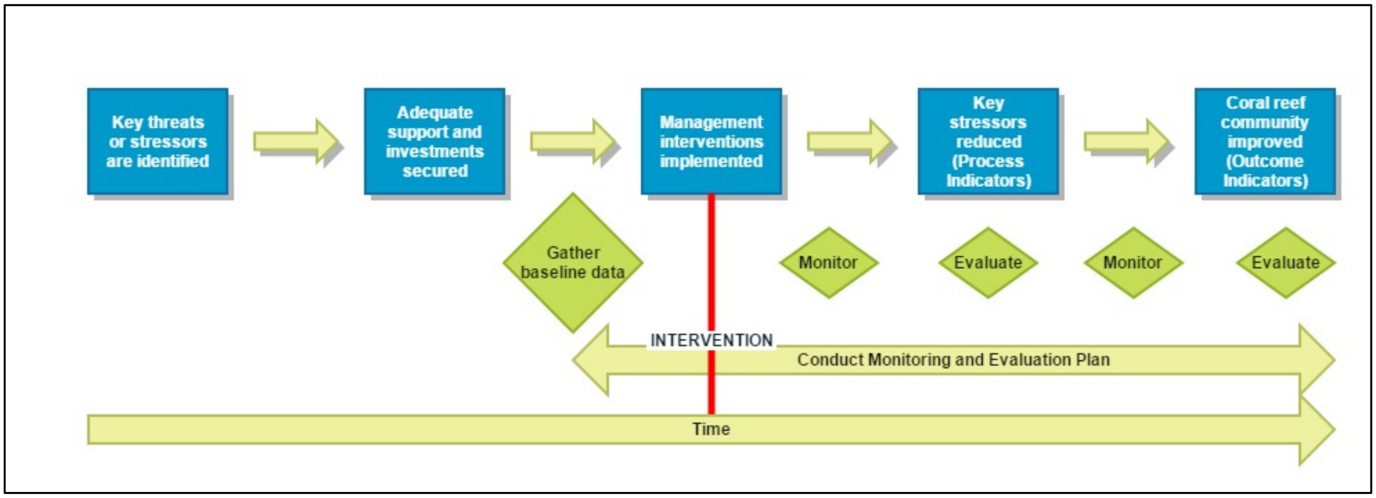

Figure 1. Diagram of Theory of Change for the USCRTF Watershed Partnership Initiative

However, there are important caveats to this theory of change that must be acknowledged. The statement above assumes that there are not any other significant threats affecting the coral reefs in these priority sites and that threshold values for nutrient and/or sediment stress to coral reefs are known. Also, additional stress is likely occurring from climate change, fishing pressure, and physical contact (e.g., ship grounding, fishing gear, etc.) at these priority sites which creates a multiple stressor situation where distinct cause and effect relationships can be difficult to determine conclusively. Given that stressors other than watershed-mediated, land-based sources of pollution and sediment are also at play on all the coral reefs involved, the relationships between the ecological and water quality metrics proposed in this document and the management actions taken in the watershed will inevitably be correlative. There has been very limited research that connects management actions taken in watersheds to downstream impacts in coral reef areas. A recent global review concluded that, "examples of watershed management demonstrating the halting or reversing of coral reef decline are not readily available" (Kroon et al. 2014).

However, the importance of managing land-based stressors in coral watersheds is illustrated by a few recent studies that show increased resilience to climate change impacts and disease when sediment and nutrient levels are reduced. A recent study by Vega-Thurber et al. (2013) from the Florida Keys, and past studies by Wooldridge and Done (2009) have documented the importance of reducing nutrients and bacteria (Sutherland et al. 2011) from nearshore coastal waters to reduce the prevalence of coral diseases and bleaching. Wooldridge (2009) demonstrated the importance of reducing nutrients and resulting chlorophyll *a* in helping reefs withstand higher sea surface temperatures (SSTs) occurring with climate change. The Vega-Thurber study illustrated that an increased input of nutrients to coral reef systems created conditions where much higher rates of coral bleaching took place, but once the nutrients were removed from the system, the coral recovered. Lastly, using a 30 year data set Stender et al (2014) documented an increase in coral cover in 2012 after management actions were implemented to reduce sedimentation in Pelekane Bay following dramatic declines of the coral community between 1977-1996 due to suboptimal land management practices in the watershed. These studies provide evidence for reducing nutrients to help reefs withstand higher SSTs and provide the basis for on-going efforts to control both sediment sources and nutrient inputs to improve management of coral reef resources. Based on these studies, best available science, and known relationships between nutrient and sediment stress on coral reefs, members of the metrics subcommittee identified a core set of process and outcome indicators specifically for evaluating the success of mitigation actions implemented to reduce land-based sources of pollution in the priority watersheds of the WPI and to document resulting long-term outcomes in the coral reef communities downstream (Table 1).

Definitions of key concepts:

A **measure** is a value that is quantified against a standard. Example: 5 cm is a measure, where cm is a standard unit and 5 is the number of these standard units.

An **indicator** is a unit of information measured over time that documents changes in a specific condition. A quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement or to reflect changes connected to an intervention.

- A **process indicator** describes the important processes that contribute to the achievement of outcomes, but do not guarantee the achievement of outcomes.
- An **outcome indicator** measures how well the WPI's initiatives are accomplishing their intended goal. The outcome indicators compare the result of an intervention to the baseline beforehand.
- A **metric** is an indicator that demonstrates a reliable and consistent association with human disturbance. Metrics have been field tested along a human disturbance gradient, from a known source of disturbance (e.g., a port or discharge). (Jackson 2000)

Table 1. Recommended process and outcome indicators of coral reef communities, sediment quality and water quality for the WPI of the USCRTF.

Indicator	Type of Indicator	Unit of Measurement	Preferred Method
Coral Community Indicators			
Benthic Cover	Outcome	Percentage of biotic and abiotic elements occupying the benthos in a defined area	NOAA NCRMP*
Coral Recruitment	Outcome	Density of juvenile (<5cm) corals (number per m^2)	NOAA NCRMP
Coral Colony Size Structure	Outcome	Coral colony size frequency distribution for all coral species in a defined area	NOAA NCRMP
Coral Taxonomic Richness	Outcome	Number of species occurring in a defined area	NOAA NCRMP
Herbivorous Fish Biomass	Outcome/Process	Total weight of herbivorous fish in per unit area (g/m^2) derived from estimates of individual fish lengths	NOAA NCRMP
Sediment Quality Indicators			
Sediment Constituent Accumulation	Process	% by mass by grain size; % weight of organic carbon, carbonate, and terrigenous sediment of a sediment sample	Barber, 2002
Sediment Toxicity Testing	Process	% Survival or successful fertilization of test organisms;	EPA NCCA†
Water Quality Indicators			
Total Nitrogen	Process	Concentration (mg/L)	EPA NCCA
Total Phosphorus	Process	Concentration (mg/L)	EPA NCCA
Chlorophyll *a*	Process	Concentration (µg/L)	EPA NCCA
Dissolved Oxygen	Process	Concentration (mg/L)	EPA NCCA
Turbidity	Process	NTU	EPA Method 180.1; USGS^

*NOAA National Coral Reef Monitoring Program. (NOAA, 2014)

† EPA National Coastal Condition Assessment -- Note: if being used for reporting or enforcement purposes under the CWA, EPA must approve the method as part of the State/Territory Water Quality Standards (WQS) or as an EPA national standard

^ U.S. Geological Survey (USGS) National Field Manual for the Collection of Water-Quality Data

It is relevant to note that the recent, multiyear effort of the interagency working groups of the National Climate Assessment developed priority indicators for climate change, intended to be adopted for consistent use nationally (Kenney 2014). They selected chlorophyll a as a primary indicator for Oceans and Coastal waters, consistent with our recommendations. Their recommended climate indicators also include measures related to ocean acidification and thermal stress which have significant impacts to corals. Although these additional climate indicators may not be sensitive to watershed activities, they can be useful to include for national comparisons.

Ecological Measurements and Derived Indicators

Water bodies conducive to coral reef health exhibit ecological integrity, representing a natural or undisturbed state (Karr and Dudley 1981; Stoddard et al. 2006). Ecological integrity is a combination of three components: chemical integrity, physical integrity and biological integrity. When one or more of these components is degraded, the health of the waterbody and associated biological communities will be adversely affected.

The ecological measurements in this document are recommended for long-term monitoring programs in the priority watersheds to assess the condition of biological resources and water quality stressors. These measurements and indicators are intended to be useful for assessing changes over time, as management practices and pollution controls are implemented in the priority watersheds and adjacent reefs. Additionally, by using the same measurements and methods across the sites it will be possible to track status and trends of the indicators and to make comparisons of relative progress among sites. Many of the prioritized indicators are included in national monitoring programs conducted by NOAA and EPA and recommended by the National Climate Assessment, so by collecting data for indicators using comparable methods one can see how a specific site, such as a WPI site, compares to the jurisdiction as a whole.

Because each of the WPI sites already has some level of monitoring taking place and the context for each site is different, this document will only provide a set of priority measurements for inclusion in each of these localized monitoring programs based on common stressors – sediment, nutrients, and contaminants (e.g. metals, hydrocarbons, herbicides, insecticides) – that exist across the three WPI sites.

Additionally, differences in capacity, survey resources, and local context across the WPI sites and among the various watersheds where these indicators will be gathered make it important that the agency or research staff implementing these monitoring programs have considerable flexibility in the implementation of these surveys, including finer points of methods and survey design. In order to increase clarity about intended survey outcomes and goals, it is highly desirable that written survey plans include: the questions the survey is designed to answer, explicit definitions of the survey domain (e.g. target habitats, depth ranges, and spatial extent), Global Positioning System (GPS) coordinates for sample sites, and expected data quality (best given as Coefficient of Variation = Standard Error/mean of target indicators).

Section 1: Priority Coral Community Indicators

Through the prioritization of the indicators by the USCRTF Metrics Subcommittee, a subset of indicators related to coral reef community condition was identified as particularly relevant in the context of watershed work in coral reef environments. These indicators are: benthic cover, coral taxonomic richness, coral recruitment, coral colony size structure (coral demographics), and herbivorous fish biomass.

There are many coral reef monitoring methods in place across the U.S. coral reef jurisdictions (Brown et al. 2004; Miller et al. 2007; Brandt et al. 2009; Brown et al. 2011; Santavy et al. 2012) that are implemented in specific geographic locations to help answer questions posed by local management authorities. However, the NOAA NCRMP is currently collecting data on all of these indicators at the jurisdictional scale across all seven of the jurisdictions, and the metrics subcommittee recommends that these indicators also be collected at the site scale using the NCRMP methods so that the site vs. jurisdictional scale measurements are comparable.

NCRMP is a broad spatial snapshot for reef condition (i.e. fish species composition/density/size, benthic cover, and coral density/size/condition) to provide context for local-scale studies of tropical reef ecosystems (NOAA 2014). Data collection will occur at stratified random sites where the sampling domain for each region (e.g. Puerto Rico, US Virgin Islands (USVI), Flower Garden Banks, Florida, Main Hawaiian Islands, Northwestern Hawaiian Islands, American Samoa, Pacific Remote Island Areas, Guam, and the Commonwealth of the Northern Mariana Islands) is partitioned by depth, habitat type, reef zone, sub-regional location (e.g. Upper/Middle/Lower Keys, or by island within each region) and management zone (e.g. MPA, no-take area, etc.). NCRMP is intended to supplement local monitoring efforts by providing jurisdictional scale data on reef fishes and the benthos. Methodological differences exist between the Pacific and Atlantic/Caribbean due to logistical considerations for data collection; however these monitoring approaches were developed to be consistent within a jurisdiction and comparable across regions. The following NCRMP protocols cover the data collection methods for the priority coral community indicators for the WPI:

- Line Point-Intercept (LPI) Survey Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary. NOAA 2015a. (*See Appendix B*).
- Rapid Ecological Assessment Methods: Benthic Monitoring. (Main Hawaiian Islands, Northwestern Hawaiian Islands, American Samoa, Pacific Remote Island Areas, Guam, and the Commonwealth of the Northern Mariana Islands). NOAA 2015b. (*See Appendix C*).
- Coral Demographics Survey Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary. NOAA 2015c. (*See Appendix D*).
- Rapid Ecological Assessment Methods: Fish Surveys. (Main Hawaiian Islands, Northwestern Hawaiian Islands, American Samoa, Pacific Remote Island Areas, Guam, and the Commonwealth of the Northern Mariana Islands). NOAA 2015b. (*See Appendix E*).
- Belt Transect Fish Survey Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary. NOAA 2015d. (*See Appendix F*).

NCRMP methodologies should be incorporated into state and territorial bioassessment and coral monitoring programs and would provide much of the information needed to assess biological integrity. The sampling frame would need to be intensified to provide the data coverage needed for CWA reporting at the jurisdictional scale. The jurisdictions would also need to revise their water quality standards to incorporate coral reef biocriteria. (*See Appendix G for additional calculated indicators using data collected using NCRMP methods*).

Benthic Cover

Definition: A calculated measure of relative abundance of benthic cover of ecologically important types of sessile organisms and plants (live coral, macroalgae, turf algae, crustose coralline algae, sponges, etc.) and abiotic features (sand, sediment, pavement, etc.).

Figure 2. NOAA NCRMP divers collecting benthic cover and coral demographics data along a transect. Credit: NOAA.

Rationale: Percent cover of various benthic animals and plants, as well as rock and rubble, is easy to measure and understand (Hill and Wilkinson 2004). In space-limited environments, such as coral reefs, understanding the benthic assemblage and relative 2D coverage of each component provides valuable information about the system. Among these components is coral cover, which represents the reef-building stony (Scleractinian) coral species that are responsible for the three-dimensional structure that provides critical habitat to many reef-dwelling organisms.

Benthic cover data are derived from counts (occurrences) of biotic and abiotic elements occupying the benthos, and each element is tallied and recorded to a predetermined level of taxonomic or functional resolution (NOAA 2014). Typically, the type of substrate (e.g., pavement, dead coral skeletons, rubble, sand) is also recorded. Many coral reefs have a small percentage of cover by scleractinian corals; therefore other components such as algae (turfs, fleshy macroalgae, and crustose coralline algae) as well as other invertebrates (gorgonians and sponges) are fundamental to characterizing benthic communities and habitat. Where the total percent of live coral is very low (generally ≤ 10%), increased sampling effort is needed to detect changes in abundance or composition of the community (NOAA 2014).

Changes in benthic cover reflect the integrated effects of demographic processes (e.g., recruitment, growth, mortality), environmental regimes, and disturbances that characterize each reef system (Rogers et al. 1994; Jokiel et al. 2005; Gove et al. 2013). The documented phase shift from coral-dominated to algal-dominated systems in some coral reef areas represents a change in the ecosystem due to changes in important reef processes such as herbivory intensity and nutrient availability. Increased abundance of macroalgae due to decreased herbivory or increased nutrient input can compete with corals for space, interfere with recruitment and reduce coral survival (Done 1992; Hughes et al. 1999; Lirman 2001; McCook et al. 2001; McManus and Polsenburg 2004; Box and Mumby 2007; Mumby 2009; Bruno et al. 2009; Chadwick and Morrow 2011). Not all algal increases are detrimental and increased coverage of crustose coralline algae, which is a favored substrate for coral settlement (Heyward and Negri 1999; Harrington et al. 2004; Birell et al. 2008), may indicate adequate herbivory and opportunity for recruitment of larval corals. Additionally, information on the coverage of sponges, gorgonians, anthozoans, and other sessile invertebrates are captured along with any abiotic features observed within the transect such as sand, rubble, pavement, etc.

Coral cover and macroalgal cover are components of monitoring programs including the Atlantic and Gulf Rapid Reef Assessment (AGGRA) protocol, the NOAA NCRMP, and the Great Barrier Reef Marine Park Authority's inshore coral reef monitoring program. Coral and macroalgae cover have been identified as key indicators for resilience (McClanahan et al. 2012), water quality gradients (Cooper at al. 2009), and are recommended by Jackson et al. (2014) as a part of a simplified coral reef monitoring plan to provide critical information for managers.

Method: The NCRMP working group recommended coral point-based methods, co-located with fish survey sites, as the preferred approach to derive estimates of percent benthic cover. In the Atlantic/Caribbean, a LPI method will be used for benthic cover, which involves tallying the benthic elements that fall under specified intervals along transects of predetermined length (e.g., Smith et al. 2011). In the Pacific, benthic cover is derived from point counts on sequential photoquadrat images of the benthos acquired along paired transects. *See Appendix B and Appendix C.*

Coral Recruitment and Colony Size Structure (Coral Demographics)

Definition: Coral demographic information includes species composition, density, size, abundance and overall species diversity. Coral recruitment is typically measured by the abundance of juvenile corals less than 5cm in diameter observed per unit area. Community demographics are characterized by information on colony size-frequency and density.

Rationale: Information on coral cover or coral mortality over the long-term is not sufficient to determine whether a reef is healthy. A healthy reef must have young recruits, and monitoring bottom up ecological processes such as coral recruitment is important to identify coral reef areas that function as a source or sink of larvae. This information can determine recovery potential of a reef after disturbance. Coral recruitment has been identified by several recent studies to be an important indicator for resilience (McClanahan et al. 2012), recovery (Jackson et al. 2014), and water quality conditions on coral reefs (Cooper et al. 2009).

The density and size-frequency distribution of corals provides valuable insights into the demography and space utilization of the selected species in the context of their geographical and environmental range

(NOAA 2014). For example, the relative proportion of small and large colonies in a particular species reflects effective juvenile recruitment and colony longevity, while the most frequent colony size indicates the relative impact of total and partial mortality (Bak and Meesters 1998), as well as physical forcing factors (Gove et al. 2013). Size-frequency has been used to assess the impacts of bleaching, predation and tropical cyclones (Done and Potts 1992; Mumby 1999; Brandt 2009), and may be particularly useful for assessing success of juvenile corals. Size-frequency distributions should change in predictable ways as reefs degrade (Bak and Meesters 1999), and populations in marginal habitats tend to have lower abundance and consequently larger coefficients of variation (Vermeij and Bak 2000). Species size-frequency distribution characteristics can be quantified mathematically (skewness, mode, coefficient of variation, etc.), allowing detection of change over time and comparison of different populations, provided sampling effort generates robust distributions.

Method: The NCRMP working group recommended that coral size-frequency and colony density be derived from *in situ* coral demographic surveys along belt transects that systematically assess a predetermined and replicable reef area (e.g., Fisher et al. 2007; Smith et al. 2011; Santavy et al. 2012; NOAA 2014). This data can be analyzed for coral recruitment information.

See Appendix C. *This method collects data on the following: Adult coral colony (≥5 cm) size (maximum diameter and perpendicular diameter), condition (bleaching, disease) and abundance, crustose coralline and Alcyonarian disease, Alcyonarian presence, Juvenile coral colony (<5 cm) size and abundance, and benthic cover*.

See Appendix D. *This method only identifies juvenile corals (<4 cm) to the lowest taxonomic resolution, but does not gather size and abundance data below 4 cm. For colonies greater than 4 cm, data is collected for colony size and condition, including: coral colony size measurements (maximum diameter, perpendicular diameter, and height), old mortality, recent mortality, and bleaching*.

Coral Taxonomic (Species) Richness

Figure 3. Coral reef at French Frigate Shoals, Hawaii. Credit: NOAA photo by Susie Holst.

Definition: The number of species within a defined area. For coral reef surveys, the number of coral species within a defined area at the site of interest.

Rationale: Higher biodiversity generally indicates better ecosystem health in that it represents a more intact ecological community including sensitive species. For coral reefs, structural variety is made by stony corals that build the three-dimensional habitat, and the greater the number of species present will provide a greater amount of structural complexity and functional redundancy due to the various growth morphologies employed by corals. Reduced coral species richness makes reefs more susceptible to natural and anthropogenic disturbances, and can thus reduce a reef's resilience (McClanahan et al. 2012). Studies have indicated coral taxonomic richness as a key indicator of water quality (Fabricius et al. 2005; De'ath and Fabricius 2008; Cooper et al. 2009). Coral taxonomic richness can provide useful information about an ecosystem response to chronic and acute stressors either through mortality of established coral colonies or reduced settlement success of juvenile corals. Fisher et al. (2008 and 2014) have documented increases in coral taxa richness with increased distance from a zone of human disturbance suggesting this indicator responds along a disturbance gradient.

Method: Species richness data can be gathered using methods employed to collect coral demographic data. *See Appendix C and Appendix D.*

Herbivorous Fish Biomass

Definition: A calculated measure for biomass is based on using data collected on fish species, size, and abundance using accepted length – weight relationships. (Froese and Pauly, 2014). Herbivorous fish information can be separated from non-herbivorous fish data, then grouped into functional categories including: browsers, grazers/detritivores, larger excavators/bioeroders, and scrapers/small excavators. Biomass (g/m^2) of these functional categories as well as overall herbivore biomass can be calculated per site (Green and Bellwood, 2009).

Rationale: Herbivory is an important ecological process on coral reefs. In the space-limited environment of reefs, herbivory helps to control the growth of algae and thus helps corals to effectively compete for space. Particularly in nutrient rich waters, macro-algal growth can outcompete and impede coral growth and recruitment if there is not adequate herbivory. Studies in both the Caribbean and the Pacific have made the linkage between functional groups of herbivorous reef fishes and benthic community assemblages (Ogden and Lobel 1978; Lewis and Wainwright 1985; Heenan and Williams 2013; Jackson et.al 2014). Specifically, macroalgal and turf algal cover decreased with increasing biomass of grazers/detritivores, and cover of crustose coralline algae -- the preferred settlement substrate for coral larvae – increased. Furthermore, hard coral cover increased with the biomass of large excavators/bio-eroders, such as large-bodied parrotfishes. Consequently, herbivory tends to shift algal assemblages into states that are much more conducive for coral (e.g., more crustose coralline algae (CCA), less macroalgae, less turf).

NCRMP fish surveys gather data on the number and size of reef fishes within sample units at the lowest feasible taxonomic resolution (typically species level) (NOAA 2014). This abundance data can be converted to a range of diversity indicators, including species richness per sample unit, as well as calculated diversity and evenness measures. Similarly, assuming the dimensions of survey units are known, information on size and numbers allows for the calculation of density and biomass per taxon or functional group, with biomass estimated using species-specific length-to-weight conversion parameters available from a range of published and Web-based sources (e.g., Kulbicki et al. 2005; Froese and Pauly 2014; FishBase 2014).

Figure 4. Fish survey data collection (top left); *Chlorurus microrhinos*, blunt head parrotfish (bottom left); *Acanthuris guttatus*, whitespotted surgeonfish, and *Chlorurus frontialis*, Pacific slope head parrotfish (right). Credit: NOAA photos by Kevin Lino and Paula Ayotte.

Method: In the U.S. Virgin Islands and Puerto Rico, belt transects are conducted. In the Pacific and in Florida, stationary point count (SPC) fish survey methods (Bohnsack and Bannerot 1986; Ault et al. 2006; Smith et al. 2006; Brandt et al. 2009; Richards et al. 2011; Williams et al. 2011) are used. Both diver-based survey methods provide the abundance, size, and species of reef fishes. For fish abundance and size, the NCRMP working group, using an estimated number of 30-50 replicates per reporting unit, set a minimum Co-efficient of Variation (CV) of 20% (i.e., 95% Confidence Interval (CI) of 40%) for biomass of four groupings: 'all herbivorous fishes,' 'all piscivorous fishes,' 'all reef fishes combined,' and parrotfishes. That level of data quality will scale up to lower CV values as data is pooled up at higher levels and replication increased, for example CVs of ≤ 10% are expected at the jurisdictional level. *See Appendix E and Appendix F.*

Section 2: Priority Indicators of Sediment Quality

Terrigenous sediment run-off and deposition on coral reefs can significantly impact coral health by blocking light and inhibiting photosynthesis, directly smothering and abrading coral, triggering increases in macro algae, reducing coral growth and calcification rates, impeding recruitment by covering substrate and reducing fecundity, causing bleaching due to turbidity, necrosis due to smothering, and exposing corals and other benthic organisms to chemical pollutants (Acevedo et al. 1989; Fabricius, 2005; Piniak and Storlazzi, 2008; Rachello-Dolmen et al. 2007; Torres et al. 2002; Perez et al. 2014). Through the prioritization of the indicators by the USCRTF Metrics Subcommittee, a subset of indicators related to sediment condition were identified as particularly relevant in the context of watershed work in coral reef environments. These indicators are: sediment constituent accumulation and sediment toxicity.

Sediment Constituent Accumulation

Definition: A calculated measure of sediment origin (carbonate from coral reef ecosystem, or terrigenous) using sediment collected from the seabed by hand or dedicated devices. Usually presented as a percentage by mass for a sample or specific grain size fraction of a sample.

Rationale: Within the U.S. coral reef jurisdictions significant changes in the drainage basins due to agriculture, deforestation, feral grazing, fires, road building, and urbanization have altered the character and volume of land-based pollution released to adjacent coral reef ecosystems (Fabricius, 2005). There is compelling evidence that the sources of land-based pollution have increased globally as a result of human-induced changes to watersheds (Wilkinson, 2008). Of the many land-based pollutants, sediment is commonly acknowledged to be one of the primary causes of coral reef ecosystem degradation (Rogers 1990; Field et al. 2008). The combination of suspended, re-suspended, and deposited sediment act to limit growth, feeding patterns, photosynthesis, recruitment, and survivorship of corals (Fabricius, 2005). Measuring sediment loads leaving watersheds is difficult in coral reef areas due to episodic high rainfall events in the tropics, extreme weather (hurricanes/typhoons), highly erodible soils, and in some cases steep slopes abutting the coastal zone. These conditions make sediment inputs highly variable and require intensive effort over long periods of time to characterize average sediment loading. Sediment constituent accumulation provides a proxy for such measurements by analyzing the sediment moving through coral reef areas for percent terrigenous versus percent carbonate sediment. Over time, measuring sediment constituent accumulation can provide evidence for changes in sediment delivery to, and removal from, the system.

Coral reefs have developed over the past few hundred million years and they incorporate and/or export carbonate detritus generated due to bioerosion, storms, and other natural processes; thus there is naturally-occurring carbonate sediment in coral reef systems. One stressor that can negatively impact coral reef ecosystems is an elevated level of terrestrially derived sediment, due to erosion in watersheds or along the coastline (Acevedo et al. 1989; Rogers 1990; Torres et al. 2002; Fabricius 2005). Studies show that fine-grained sediment, and especially darker fine-grained sediment such as silts and clays derived from the erosion of lateritic soils that typify the tropics where coral reefs are found, reduces light needed by corals and other photosynthetic organisms in coral reef ecosystems than lighter and larger carbonate sand-size material (Fabricius 2005; Weber et al. 2006; Hernandez et al. 2009; Storlazzi et al. 2015). This indicator, therefore, requires the measurement of not only the sediment grain size, but also the constituents of the sediment. Successful watershed restoration efforts should result in a decrease in the ratio of terrigenous to carbonate material in the system and generally an increase in overall grain size.

Sediment can be collected from the seabed using sampling devices from ships (e.g., Van Veen samplers) or by hand using short cores on SCUBA. However, these methods only measure the net sediment accumulation on the seafloor and do not control for time of deposition (e.g., when was the sediment deposited). A new method to collect net sediment accumulation in coral reef environments with precise age control uses "sed pods" (Figure 5), which are described in Field et al. (2012). Sed pods mimic coral surfaces and allow for accurate measurements of net accumulation (deposition-erosion) over the period of deployment. Sed pods, however, only measure net accumulation and thus will not provide information on the flux of sediment through the system. Total sediment flux is important because it can block light, desorb nutrients and/or contaminants, and temporarily settle on corals and thus cause stress. A useful tool to capture sediment fluxing through a coral reef ecosystem is a sediment trap, which provides a semi-quantitative measure of sediment being transported through the reef. As described by Storlazzi et al. (2011), however, sediment traps can easily be misused and the data incorrectly interpreted but a number of protocols exist to accurately collect and interpret the data from these devices.

Method: See Appendix H for Sediment Constituent Accumulation method.

Figure 5. SedPod deployed at Kawaihae, Big Island, HI. Credit: USGS.

Sediment Toxicity Testing

Definition: Standardized tests that measure the lethal and sublethal effects of contaminants in sediment on specific test organisms.

Rationale: Sediment provides habitat for many estuarine and marine organisms. In the aquatic environment, most anthropogenic chemicals and waste materials including pesticides, herbicides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and metals such as lead, mercury, and arsenic eventually accumulate in sediment. Contaminated sediment can pose an immediate threat to benthic organisms (e.g., stony corals, octocorals, lobsters, crabs, etc.) (Edinger et al. 1998; Burke and Maidens 2004; Fabricius 2005) and resuspended sediment can potentially exert adverse effects on both pelagic and benthic systems (EPA 1994 and 2012b).

Contaminant sources that may impact coral reefs include industrial and municipal wastewater dischargers, polluted runoff from urban, resort, and agricultural areas, and submarine groundwater discharges containing sewage and other contaminants.

Toxicity tests are commonly conducted as a measure of the bioavailability of toxic chemicals to biota in an environment. Chemical analyses alone are insufficient to determine whether contaminants pose a threat to biota. Sediment and porewater toxicity tests are extremely sensitive to a broad range of contaminants in marine environments and provide ecologically relevant data on toxicity to sensitive marine life.

Methods: For EPA's sediment amphipod test, surficial sediment is collected from the station. EPA bases sediment toxicity on 10-day static tests conducted using the Atlantic coast estuarine sediment-burrowing amphipod *Leptocheirus plumulosus.* This organism is considered a proxy for other sensitive marine organisms. After 10 days of exposure, the surviving amphipods will be counted and results expressed as test treatment survival compared to control survival (EPA 2009b and 2012b).

USGS and NOAA have developed and applied pore water toxicity tests using tropical sea urchin fertilization and embryo development to assess lethal and sublethal effects of sediment contamination (Carr and Nipper 2003, Carr et.al. 2006). This test has not been calibrated against EPA's sediment amphipod method, but has the advantage of using sensitive life stages of a topical marine organism for the sediment bioassays.

See Appendix K for sediment toxicity methods.

Section 3: Priority Indicators of Water Quality

Water quality indicators are particularly relevant in the context of watershed work in coral reef environments. Chemical and physical data provide direct information about stressors to aquatic life and human health. Many plants and animals have preferences or requirements regarding water temperature, salinity, dissolved oxygen concentrations, and water clarity. Excess nutrients can cause eutrophication leading to algal blooms and low oxygen conditions, and in the worst case scenario, phase shifts from stony coral dominated reefs to a system dominated by fleshy algae (Hughes 1994; Hughes et al. 2003; Pandolfi et al. 2003; Bellwood et al. 2004; Work et al. 2008; Bruno et al. 2009). Chemical contaminants may cause lethal or sublethal toxic impacts to marine organisms. Monitoring physical and chemical water parameters may therefore indicate important changes in the environmental condition.

Chemical and physical pollutants are regulated under the CWA. See Appendix A for additional information on the CWA. Water quality monitoring programs in the priority watersheds should be designed to allow comparison of local water quality conditions with Water Quality Criteria. States and territories adopt Water Quality Criteria as rules – these are narratives or numeric threshold values for physical and chemical measurements that are protective of human health and aquatic life. These values are critical to linking water quality problems with control programs under the Clean Water Act (e.g. total maximum daily load (TMDL), National Pollution Discharge Elimination System (NPDES) discharge permits). The EPA WQS Repository is available at: http://water.epa.gov/scitech/swguidance/standards/wqslibrary/index.cfm

The USCRTF Metrics Subcommittee selected a subset of indicators related to water quality as priority indicators to be collected in coral reef ecosystems located near the priority watershed sites and in the watershed at the site of planned management actions, as appropriate. These are: nutrients (i.e., total nitrogen and total phosphorous), dissolved oxygen, chlorophyll *a,* and turbidity.

EPA and jurisdictions are conducting a series of surveys of the nation's streams and rivers, lakes and reservoirs, coastal waters, and wetlands. These National Aquatic Resource Surveys (NARS) use randomized probability-based sampling designs, core indicators, and consistent monitoring methods and lab protocols to provide statistically defensible assessments of water quality at the national scale. The National Coastal Condition Assessment (NCCA) is the NARS survey of coastal waters, including estuaries, bays, sounds, coastal wetlands, coral reefs, intertidal zones, mangrove and kelp forests, seagrass meadows, and coastal ocean and upwelling areas (EPA 2009a). NCCA collects data on a suite of indicators at the national and regional scales, and the metrics subcommittee recommends that a subset of these indicators (total nitrogen, total phosphorous, dissolved oxygen, chlorophyll a, and turbidity) also be collected at the site-scale using the NCCA methods so that the site-scale measurements can be compared with national and regional assessments. However in some cases the state/territory water quality criteria may not use the same measurement or method as NCCA. In this situation the USCRTF Metrics Subcommittee recommends that comparability studies be conducted to ensure that the state/territory method will meet the NCCA standard. If the methods are not comparable, the USCRTF Metrics Subcommittee recommends that both the state/territory method and the NCCA method be used.

Total Nitrogen

Definition: A measure of the concentration of all organic and inorganic, dissolved and particulate forms of nitrogen found in a sample.

Rationale: Nitrogen is an essential nutrient for plants and animals. In coastal waters, nitrogen is commonly a limiting nutrient, because plant growth stops when nitrogen is depleted (Thomas 1970; Ryther and Dunstan 1971; Oviatt et al. 1995; Elser et al. 2000). High nitrogen levels negatively affect corals, including increases in disease prevalence and severity, and coral bleaching (Fabricius 2005; Vega-Thurber et al. 2014; Weidenmann et al. 2013), increased prevalence of macroalgae (Lapointe et al. 1987; Lapointe 1989; Littler et al. 1991; McGlathery et al. 1992; Delgado and Lapointe 1994; Fabricius 2005), and reduced coral calcification (Muscatine et al. 1998; Shantz et al. 2014). Several studies have shown that nitrogen inhibits calcification more strongly in mounding morphologies and Poritids than in branching morphologies or Acroporids (Li et al. 2008; van Woesik et al. 2012). This is particularly important in regions predominated by Poritids or mounding species (e.g., the Caribbean), since these reefs may be more vulnerable to the negative effects of excess nutrients than reefs in regions that have more Acroporids and branching corals (Shantz and Burkepile 2013).

Nitrogen is a potential stressor in the priority watersheds and therefore a priority indicator. Sources of nitrogen include: wastewater treatment plant discharges, runoff from fertilized lawns and croplands, cesspools and failing septic systems, runoff from animal manure and storage areas, and industrial discharges that contain corrosion inhibitors.

There are three forms of nitrogen that are commonly measured in water bodies: ammonia, nitrates and nitrites. Although the optimum nitrogen concentration and threshold levels specific to U.S. coral reefs are not known, many states and territories have adopted numeric water quality criteria for nitrogen. These water quality criteria serve as regulatory thresholds for CWA programs. Federal and state regulatory agencies now recommend using Total Nitrogen concentrations (TN) as the best measure of year-round availability of nitrogen nutrients (EPA 2001). TN is calculated as the sum of total dissolved nitrogen (TDN) and particulate organic nitrogen (PON). This is equivalent to the sum of all organic and inorganic, dissolved and particulate forms of nitrogen. However, some state and territory water quality criteria may use different nitrogen forms as indicators and we recommend that site monitoring report both the nitrogen forms that are consistent with the state/territory criteria and the NCCA indicator (TN).

Method: *See Appendix L for Method for Water Chemistry: Total Nitrogen, Total Phosphorous, and Chlorophyll a.*

Total Phosphorus

Definition: A measure of the concentration of all the forms of phosphorus, dissolved or particulate, that are found in a sample.

Rationale: Phosphorus, like nitrogen, can be a limiting nutrient for algae in coral reef systems (LaPointe 1997) and can lead to eutrophication, algal blooms, and reduced oxygen. Phosphorus enrichment also enhances calcification in corals but may compromise skeletal integrity (Shantz and Burkepile 2013). The resulting increased porosity make corals more susceptible to boring organisms and breakage (Caroselli et al. 2011; Shantz and Burkepile 2013). Excess phosphorus also promotes the growth of organisms that predate on corals (Birkeland 1982; Fabricius 2005), or compete with coral (e.g., fleshy macroalgae) (Lapointe et al. 1987, 1992, 1993; Littler et al. 1991). Optimal and threshold phosphorus concentrations specific to U.S. coral reefs are not known, but many states and territories have adopted water quality criteria for phosphorus and these serve as regulatory triggers for the CWA.

Recent federal and state guidelines recommend using total phosphorus (TP) as the best measure of year-round availability of phosphorus nutrients (EPA 2001). TP concentrations are calculated as the sum of total dissolved phosphorus (TDP) and particulate organic phosphorus. However, some state and territory WQSs may use different phosphorus forms as water quality criteria and we recommend that site monitoring report both the nitrogen forms that are consistent with the state/territory criteria and the NCCA indicator (TP).

Method: *See Appendix L for Method for Water Chemistry: Total Nitrogen, Total Phosphorous, and Chlorophyll a.*

Chlorophyll *a*

Definition: Chlorophyll *a* is the main green photosynthetic pigment found in all plants including phytoplanktonic algae and a proxy for planktonic primary producers.

Rationale: The concentration of chlorophyll *a* in coral reef waters is an indicator of the abundance and biomass of phytoplankton, which are the direct or indirect source of food for most marine animals. Phytoplankton communities can vary significantly over space and time - spatial differences are often observed along a general land-ocean gradient (Otero 2003; Otero and Carbery 2005) and temporal differences are observed with greater concentrations in summer than winter. Chlorophyll *a* is also an indicator of nutrient condition. Phytoplankton and other marine plants readily take up nitrogen and phosphorus in surface waters such that nutrient concentrations in the water column may be low, but chlorophyll *a* may be elevated.

Low chlorophyll *a* levels suggest good water condition. However, it is the long-term persistence of elevated levels that is a problem so chlorophyll *a* should be monitored at least monthly to quantify seasonal changes in phytoplankton biomass (Steven et al. 1998).

Method: *See Appendix L for Method for Water Chemistry: Total Nitrogen, Total Phosphorous, and Chlorophyll a.*

Dissolved Oxygen

Definition: A measure of the concentration of oxygen dissolved in the water.

Rationale: Dissolved Oxygen (DO) is an important parameter in assessing water quality because of its influence on the organisms living within a body of water. Wastewater and naturally occurring organic matter contain oxygen-demanding substances that, when decomposing, consume dissolved oxygen. Often, low dissolved oxygen conditions occur as a result of large algal blooms, where bacteria use oxygen as they degrade the algal biomass. Bottom oxygen concentrations are often lowest at dawn because respiration, but not photosynthesis, occurs at night.

Low concentrations of DO can adversely impact coral reefs in several ways. Corals can tolerate reduced oxygen concentrations until reaching a threshold (determined by a combination of exposure time and concentration); exceeding this threshold has a negative effect on coral metabolism (Lesser 1997*;* Finelli et al. 2006; Mass et al*.* 2010), and leads to rapid loss of coral tissue and mortality (Haas et al. 2014). Fossil records suggest that reduced DO concentrations contributed to the prehistoric mass extinction events of Scleractinia (Van de Schootbrugge et al. 2007). Hobbs and McDonald 2010 reported that a fish kill at the Cocos (Keeling) Islands, Indian Ocean during a period of elevated sea temperatures probably occurred because the fish were unable to obtain the additional oxygen required for metabolism at higher temperatures.

States and territories have adopted numeric criteria for DO that serve as regulatory thresholds for CWA programs and are intended to be protective of marine ecosystems.

Method: DO is measured using a calibrated multi-parameter water quality meter (or sonde). Measurements are taken at set depths on both the downcast and upcast to produce a complete hydrographic profile. *See Appendix M for methods for Dissolved Oxygen*.

Turbidity

Figure 6. Aerial photo of West Maui, HI. Credit: NOAA/USGS.

Definition: Turbidity is a measure of the scattering and/or absorption of light due to undissolved suspended matter in solution (ISO 1999).

Rationale: Turbidity in coastal waterways can result from the input/influence of sediment caused by erosion. Watersheds with extensive erosion problems tend to contain large areas that have been cleared of native vegetation, support intensive agriculture, or have unstable stream channels. Other causes of turbidity in coastal waters include: dissolved organic matter from sewage treatment plants, runoff from poorly managed construction sites and agricultural lands, shoreline erosion, re-suspension of previously deposited sediments, dredging, phytoplankton blooms, and humic substances.

High turbidity has a number of detrimental effects on coral reef ecosystems: reduced photosynthesis, coral cover, and diversity (Loya 1976; Roy and Smith 1971; Piniak and Storlazzi, 2008;

Storlazzi et al., 2015), bleaching (Rogers 1990) and reduced coral growth (Dodge and Vaisnys 1977). Nelson et al (2016) recently constructed a “stoplight model” showing different levels of sediment stress and the resulting affect to coral colonies. Their findings also indicate that sub-lethal stress levels can ultimately lead to mortality in a multi-stressor system.

Many states and territories have adopted water quality criteria for turbidity and these are used as protective thresholds for CWA programs.

Method: Turbidity is most often measured with a turbidity meter, and is reported in units called a Nephelometric Turbidity Unit (NTU). As light bounces off the suspended particles, the photodetector can measure the scattered light, which is a function of the number of particles and the particle size. *See Appendix N for Turbidity method*.

Section 4: Recommended Metrics for Overarching Threats

In Sections 1-3, recommended indicators for measuring changes in coral communities, sediment quality, and water quality have been described. This section presents guidance on how watershed coordinators/managers and coastal resource managers can decide which of the indicators they should implement in their watersheds. Each place will have its own context that will determine which indicators should be monitored over time. Factors such as the amount of resources available, capacity for monitoring efforts, and knowledge about the stressors and any interventions that may be occurring to manage them are only a few of the considerations that should be taken into account when selecting parameters to be monitored. The USCRTF Metrics Subcommittee understands managers must deal with or weigh many considerations to effectively manage their watersheds and may need assistance with making these decisions. To support the managers/ coordinators for the WPI sites, and in other coral reef watersheds, in selecting appropriate indicators to help them evaluate the success of management interventions, the USCRTF Metrics Subcommittee has developed a set of decision trees to walk through a logical approach to managing and monitoring three overarching stressors – sediment, nutrient, and contaminants (Figures 7-9).

These decision trees are intended to provide guidance for selecting which of the indicators from Sections 1-3 should be implemented based on a series of questions focused around each stressor. Within each decision tree, additional direction is given to provide guidance, promote actions, and build partnerships where appropriate. As noted previously, this document is not meant to be a substitute for a monitoring plan for any watershed, rather a tool to help select which parameters should be included in that plan based on the context within a given watershed and allow for comparisons with other watersheds where similar interventions have been employed.

Additional resources describing various different types of management interventions and best management practices (BMPs) can be found here:
http://www.coris.noaa.gov/activities/projects/watershed/ and http://www.bmpdatabase.org/.

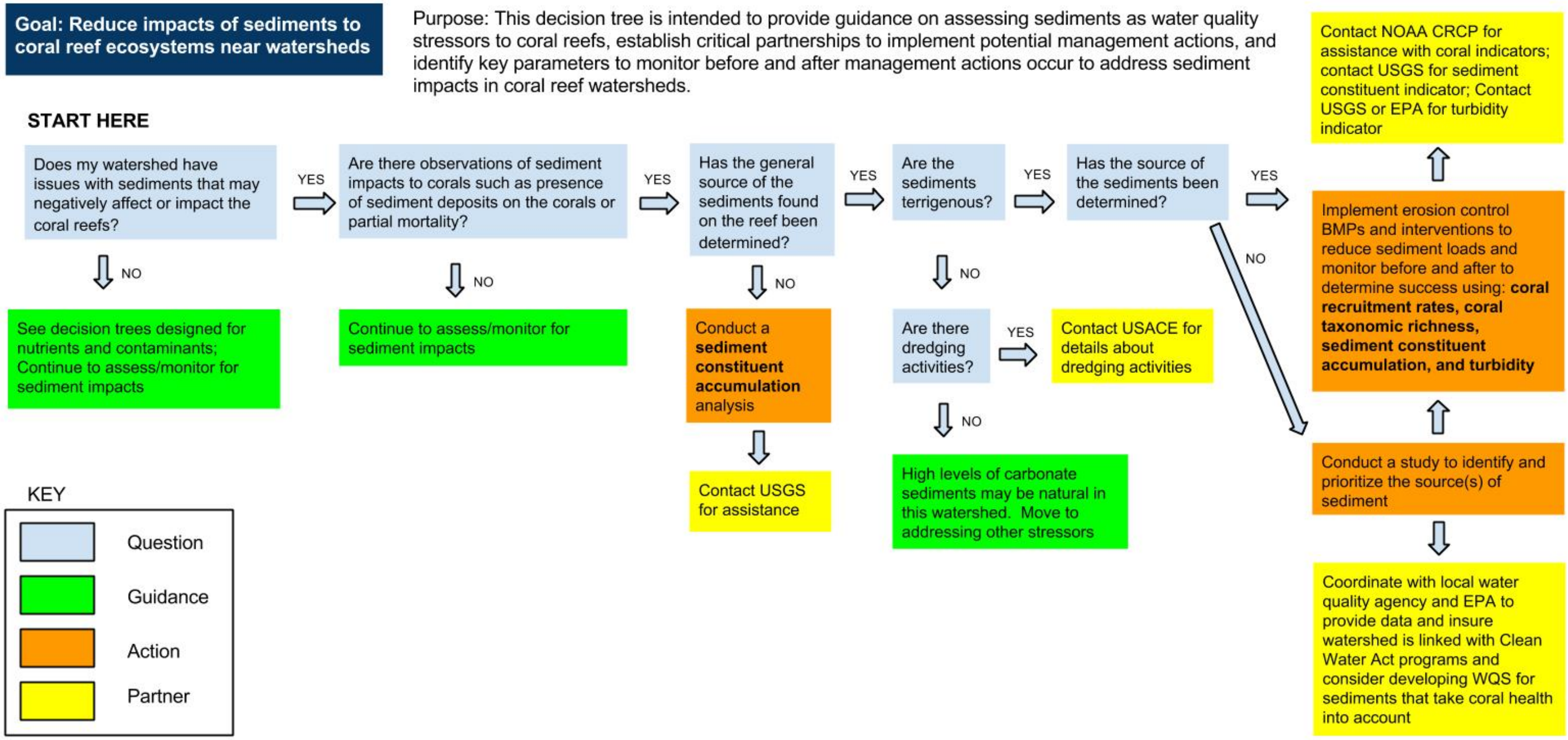

Figure 7. Decision tree for watersheds with sediment impacts. For additional information, bolded indicators can be found in Sections 1-3 of this document.

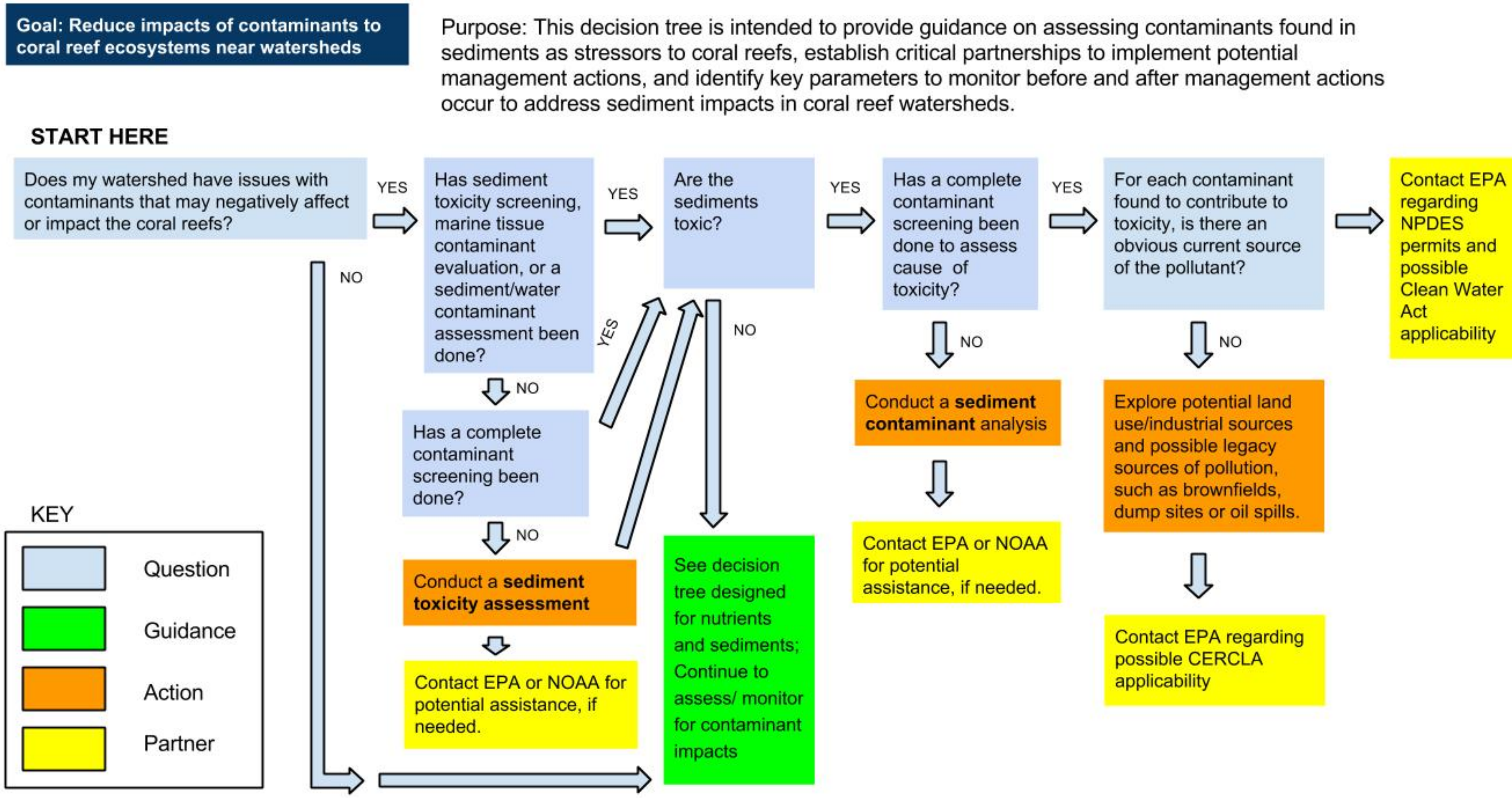

Figure 8. Decision tree for watersheds with contaminant issues in surface sediment.

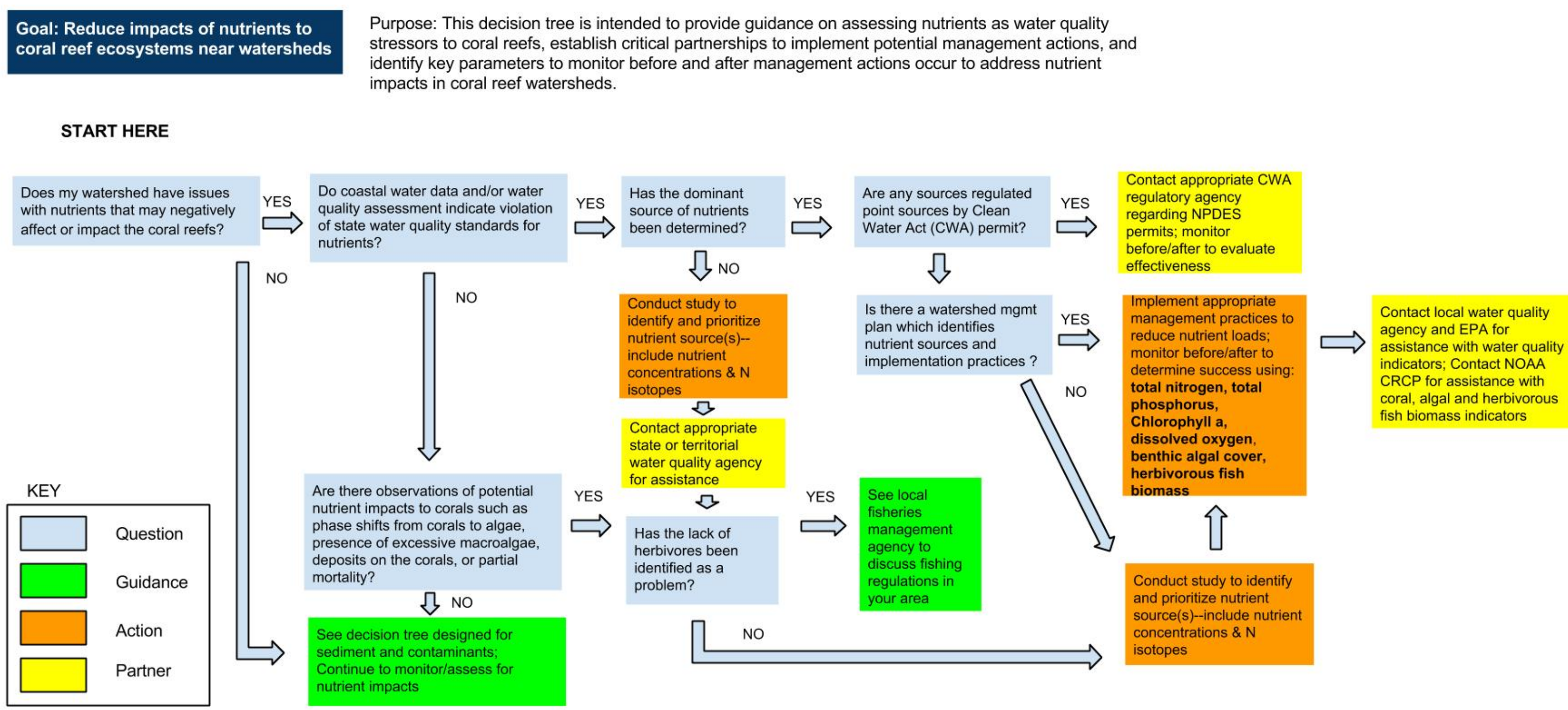

Figure 9. Decision tree for watersheds with nutrient impacts. For additional information, bolded indicators can be found in Sections 1-3 of this document.

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Appendices

Appendix A - Ecological Integrity and the Clean Water Act

Healthy waterbodies exhibit ecological integrity, representing a natural or undisturbed state. Ecological integrity is a combination of three components: chemical integrity, physical integrity, and biological integrity. When one or more of these components is degraded, the health of the waterbody will be affected and, in most cases, the aquatic life living there will reflect the degradation. The identification of water quality degradation requires appropriate monitoring tools to help us detect and characterize the cause and source of chemical, physical and biological impairment.

The Clean Water Act (CWA) is a powerful legal instrument for protecting water resources, including the biological inhabitants of coral reefs. The CWA objective is to restore and maintain the chemical, physical and biological integrity of water resources. The CWA requires states/territories to adopt water quality criteria into their water quality standards. Biocriteria are benchmark, guideline or threshold values that describe the expected (or desired) biological integrity of a waterbody. Biological criteria are adopted into state, tribal, or territorial water quality standards to describe expected condition for aquatic life in waters with a designated aquatic life use. As with any water quality standard, when biological condition does not meet the criterion, the waterbody is listed as impaired. The list of impaired waterbodies is used to prioritize CWA actions and programs (Bradley et al. 2010).

Table A-1. Biocriteria and Other CWA Programs (source: Bradley et al. 2010).

Program	Title	Description	Biocriteria Use(s)
104(b)(3)	Wetlands Program Development Grants	Authorizes grants to states[1], and local governments to conduct projects that promote the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution. Coral reefs, mangroves, and seagrasses are considered special aquatic sites and wetlands under CWA 404, and Section 104(b)(3) grants can directly fund monitoring and assessment of coral reefs and development of biocriteria for coral reefs.	• Providing a threshold against which to measure detrimental effects on biological communities. • EPA Region 9 has awarded Wetlands Program Development Grants to support coral reef biocriteria development for Hawaii and CNMI.
106	Grants for Pollution Control	Authorizes federal grants to states[1] to support the	• In 2009, EPA R10 explicitly mentioned the application of

Program	Title	Description	Biocriteria Use(s)
	Programs	development and operation of state programs implementing the CWA.	biological monitoring and biocriteria that lead to improved TMDLs in their Request for Initial Proposals.
205(j) and 604(b)	Water Quality Management Planning	Authorizes grants to states[1] and funding for sub state agencies for water quality planning.	• To develop water quality criteria, including biocriteria.
301(h)	Effluent Limitations	Waiver to defer secondary treatment if discharge does not adversely affect biological communities.	• Providing a threshold against which to measure detrimental effects on biological communities.
312	Marine Sanitation Devices	No discharge zones.	• To identify appropriate locations for no-discharge zones. • To identify locations with outstanding biological integrity that would benefit from a no-discharge zone status. • To establish thresholds to gauge the effectiveness of no-discharge zones.
319	Nonpoint Source Program (NPS)	Every 5 years, states update their NPS management plans, which outline NPS pollution problems, including categories of NPS pollution and measures used to reduce that pollution.	• Assessing impacts of NPS pollution. • Determining effectiveness of NPS controls. • Site-specific assessment of BMPs for NPS.
320	National Estuary Program (NEP)	Authorizes grants to states[1] for development of NEP management plans and implementation projects.	• To establish thresholds for biological integrity as part of the management plan.
401	State Water Quality Certification	Requires that before issuing a license or permit that may result in any discharge to waters of the United States, a federal agency must obtain from the state in which the proposed project is located, a certification that the discharge is consistent with the CWA, including attainment of applicable state ambient water quality standards.	• Providing a threshold against which to measure dredge/fill impacts on biological communities. • Identify acceptable sites for disposal of dredge and fill material.
402	National	The CWA makes it illegal to	• Determining condition of a

Program	Title	Description	Biocriteria Use(s)
	Pollutant Discharge Elimination System (NPDES)	discharge pollutants from a point source to the waters of the United States. Point sources must obtain a discharge permit from the proper authority (usually a state, sometimes EPA, a tribe, or a territory). The permits set the limit on the amounts of various pollutants that a given source can discharge in a given time.	waterbody prior to issuance of a permit. • Providing a threshold against which to measure discharger impacts on biological communities. • Evaluating effectiveness of implemented controls. • Helping to verify that NPDES permit limits are resulting in achievement of state water quality standard.
403	Ocean Discharge Program	Establishes special requirements for point source permits for discharges into all three ocean regions defined in the CWA (e.g., the territorial sea, the contiguous zone and the ocean)	• Providing a threshold against which to measure discharger impacts on biological communities.

Table A-2. CWA and Existing Coral Reef Management Programs (modified from Bradley et al. 2010).

Management Area	Description	Application of Biocriteria
Marine Protected Areas (MPAs)	Selecting MPA Sites	• To identify waterbodies that have outstanding biological condition and require protection
	Managing MPAs	• To establish thresholds against which to measure effectiveness of MPAs
	Effectively manage the waters between MPAs	• With establishment of designated uses, to protect those uses (i.e., connectivity)
Managing Fisheries	Eliminate open-access fisheries in coral reef ecosystems and establish sustainable fisheries regulations	• To establish levels (e.g., taxa richness, abundance) expected to sustain reef fisheries • Degradation can trigger changes in fishery practices and regulations
	Restricting the species being selected (e.g., coral reef herbivores, including parrotfish)	• To establish expected or desired levels of individual species (e.g., abundance, biomass) • Degradation can trigger changes in fishery practices and regulations
Managing Tourism	Mooring Buoys	• To identify locations with outstanding biological condition that would benefit from the protection of mooring buoys
	Permits – diving, fishing, boating	• With establishment of designated uses, to protect those uses

Management Area	Description	Application of Biocriteria
Watershed Management	Regulating activities in the watershed	• To support setting goals for watershed and regional planning • To prioritize watershed goals and actions • To develop management plans • To establish thresholds against which to measure effectiveness of permits or other management actions
Coastal Zone Management	Regulating Coastal Development	• To support setting goals for watershed and regional planning • To prioritize watershed goals and actions • To develop management plans
	Maintain connectivity between coral reefs and associated habitats such as mangroves, sea grass beds, and lagoons	• All nearshore environments are protected by the CWA • Coral reefs, mangroves, sea grass beds, and lagoons can be specifically protected when they are identified in water quality standards
Damage Assessment and Restoration	Restoring coral reefs or seagrass meadows damaged by boats and anchors	• To establish thresholds against which to measure effectiveness of restoration efforts.
Managing Endangered Species (Endangered Species Act)	Protecting rare, threatened and endangered species	• To establish expected or desired levels of individual species (e.g., abundance, biomass). • To establish thresholds against which to measure effectiveness of legal protection.
National Environmental Policy Act (NEPA) of 1969	Environmental Impact Statements	• To identify where site-specific criteria modifications may be needed to effectively protect a waterbody. • To assess the overall ecological effects of regulatory actions.

Reference:

Bradley P, Fore L, Fisher W, and Davis W. 2010. Coral Reef Biological Criteria: Using the Clean Water Act to Protect a National Treasure. EPA-600-R-054 07-2010.

Appendix B - Line Point-Intercept (LPI) Survey Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary

(Source: NOAA 2015a)

Goal of LPI Surveys

The goal of these surveys is to provide a quantification of percent cover of biotic and abiotic benthic components, using the LPI method in a stratified random sampling design in hardbottom and coral reef habitats in the U.S. Caribbean (U.S. Virgin Islands and Puerto Rico) and Flower Garden Banks National Marine Sanctuary (FGBNMS). Surveys are concurrent with and along the same transect as fish surveys.

Abbreviated Survey Protocol (for full protocol see NOAA 2015a)

The LPI diver collects the following information:

a. **LPI data** – 100 points, at 20cm intervals, starting at the 20cm mark and ending at the 20m mark along the transect tape. Coral is identified to species. Bare substratum is categorized as uncolonized hardbottom, soft, or rubble. Macroalgae, turf algae, crustose coralline algae, seagrass, gorgonians, sponges, and other sessile invertebrates are categorized.

b. **Macroinvertebrate counts** – Spiny lobster (*Panulirus argus*), queen conch (*Lobatus gigas*) and long-spined sea urchin (*Diadema antillarum*) are enumerated in the 25m x 2m area of the belt transect AFTER completing the LPI survey, concurrently with the presence/absence component when the LPI diver is swimming from meter marker 25 (i.e., the end of the transect tape) to meter marker 0 (i.e., the beginning of the transect tape).

c. **Presence/absence Endangered Species Act (ESA)-listed corals** – The presence/absence of seven (7) ESA-listed scleractinian coral species in the 25m x 2m belt transect area are recorded AFTER completing the LPI survey and concurrently with the macro-invertebrate (i.e., lobster, conch, urchin) counts when the LPI diver is swimming from meter marker 25 (i.e., the end of the transect tape) to meter marker 0 (i.e., the beginning of the transect tape).

d. **Photographs** – Underwater photographs of the general survey area, including the transect seascape, as well as interesting features and species identification questions.

Appendix C - Rapid Ecological Assessment Methods: Benthic Monitoring. (Main Hawaiian Islands, Northwestern Hawaiian Islands, American Samoa, Pacific Remote Island Areas, Guam, and the Commonwealth of the Northern Mariana Islands)

(Source: NOAA 2015b)

Line-point-intercept (LPI) for Benthic Cover (2008-Present)

The current line-point-intercept (LPI) method identifies hard corals, octocorals, macroalgae, crustose coralline algae, turf algae, cyanobacteria, and sessile macroinvertebrates to the highest possible taxonomic resolution and records, along with sand cover, at 20-cm intervals along two 25-m transect lines set in a single file row (and separated by a 5-m intertransect space). These surveys generate 125 points per transect (250 points per site) that are used to determine percentage of cover of benthic organisms and sand at each Rapid Ecological Assessment (REA) site (prior to 2008, this method was implemented at 50-cm intervals along the two transects). In concert with LPI surveys, photographs are taken to record the benthos at intervals of 2 m and 5 m along the same two transect lines with a high-resolution digital camera mounted on a pole. This work generates 32 photographs per site that are later analyzed by benthic specialists at NOAA Coral Reef Ecosystem Division (CRED), using the computer program Coral Point Count with Excel extensions (CPCe), to determine the benthic composition at the genus, functional or morphological group level for each REA site (similar photographs of the benthos taken at REA sites surveyed by the fish team also will be analyzed).

Belt Transect for Coral Demographics and Condition (2007-Present)

The REA belt transect method provides information on coral demographics and condition. The coral divers gather data along five evenly spaced segments (each 2.5 x 1 m; 0-2.5 m; 5.0-7.5 m; 10-12.5 m; 15-17.5 m; 20-22.5 m) along each of the same two 25-m transect lines implemented in the LPI survey. This strategy was designed to maximize time for capturing spatial heterogeneity per transect. Within each 2.5-m2 transect section, all coral colonies whose center falls within 0.5 m on either side of each transect line are identified and 2 planar measurements recorded (maximum diameter and the diameter perpendicular to the maximum diameter). For each coral colony identified the extent of mortality is estimated, dedicating special attention to any evidence of disease. Percentage of colony affected as well as lesion severity and levels of coral predation were also recorded.

Field characterization of coral diseases focuses on provision of a general description of lesions instead of attempts to establish a subjective interpretation of causality. Lesions are classified into general, unambiguous categories, including but not limited to: bleaching, acute tissue loss or white syndrome, subacute tissue loss, skeletal growth anomalies, pigmentation responses, discolorations other than bleaching, algal infections, cyanobacterial infections, fungal infections, other unidentified diseases and syndromes, and predation by crown-of-thorns seastars (*Acanthaster planci*), fish, and snails (primarily from the genus *Drupella*). Divers also make an effort to assess the incidence of coralline algal diseases with the following scheme: coralline lethal orange disease, coralline fungal disease, coralline lethal disease, and coralline ring disease.

Benthic Composition and Coral Demographics (2013-present)

Surveys at each site are conducted within two, 18 meter belt transects. Adult coral colonies (≥ 5 cm) are surveyed within four (1.0 × 2.5 m) segments in the following manner: 0–2.5 m (segment 1); 5.0–7.5m (segment 3); 10–12.5 m (segment 5); and 15 – 17.5 m (segment 7). All colonies whose center falls within 0.5 m on either side of each transect line are identified to lowest taxonomic level possible (species or genus), measured for size (maximum diameter to nearest cm), and morphology was noted. In addition, partial mortality and condition of each colony is assessed. Partial mortality is estimated as percent of the colony in terms of old dead and recent dead and the cause of recent mortality is identified if possible. The condition of each colony including disease and bleaching is also noted along with the extent (percent of colony affected) and level of severity (range from moderate to acute).

Juvenile coral colonies (< 5 cm) are surveyed within three (1.0 × 1.0 m) segments along the same two transects: 0–1.0 m (segment 1); 5.0–6.0 m (segment 3); and 10.0–11.0 m (segment 5). Juvenile colonies are distinguished in the field by a distinct tissue and skeletal boundary (not a fragment of larger colony). Each juvenile colony is identified to lowest taxonomic level (genus or species) and measured for size by recording both the maximum and perpendicular diameter to the nearest 2 mm.

Still photographs are collected to record the benthic community composition at predetermined points along the same 2 transect lines with a high-resolution digital camera mounted on a pole. Photographs were taken every 1 m from the 1 m to the 15 m mark. This work generates 30 photographs per site, which are later analyzed by CRED staff and partners using the computer program Coral Point Count with Excel extensions (CPCe) or CoralNet. This analysis is the basis for estimating benthic cover and composition at each site (benthic habitat photographs at sites surveyed by the fish team are also analyzed).

Appendix D - Coral Demographics Survey Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary

(Source: NOAA 2015c)

Goal of Coral Demographics Surveys

The goal of the coral demographic surveys is to collect and report information on species composition, density, size, abundance, and specific parameters of condition (% live vs. dead, bleaching, disease) of non-juvenile scleractinian corals (> 4 cm maximum diameter), and of overall species diversity (all corals) using 10m x 1m belt transects in a stratified random sampling design in hardbottom and coral reef habitats in the U.S. Caribbean and FGBNMS.

Abbreviated Survey Protocol (for full protocol see NOAA 2015c)

The Demographic diver collects the following information:

1) Percent cover of hardbottom: the percent hardbottom cover within the belt transect will be recorded.

2) Species/colony information: identification and additional colony information of all visible scleractinian corals in belt transect will be recorded.

    a. **Coral colony size measurements** - Measure entire coral (skeleton + live tissue) on a planar dimension to three (3) exact dimensions (cm).

    - Measurements made to the nearest whole centimeter (cm).
    - Do not bin, estimate, or aggregate measurements. For example, measurements of length, width, and height of a colony might be 5cm x 3cm x 2cm, respectively.

        1. Maximum diameter – Measure the maximum diameter (cm) of identifiable skeletal unit.
            i. Measure location where diameter of skeletal unit is widest
            ii. Measure skeletal unit, not just the live tissue
        2. Maximum perpendicular diameter width – Measure the perpendicular diameter of skeletal unit at its' greatest width. Maximum diameter length is to be greater than perpendicular diameter width.
        3. Height – Measure the height (cm) of the skeletal unit.
            i. Height is measured from the base of the skeletal unit perpendicular to plane of growth.
                - If colony is growing on a slope, measure perpendicular to the slope
                - Measure linearly (i.e., do not drape tape across the colony)
                - If the colony has an encrusting morphology, the height of the colony should still be measured to the nearest 1.0cm.

b. **Coral condition measurements** – For each measured coral, the total colony area (3D) is assessed for mortality, bleaching and disease. NOTE: these measurements are not collected for juvenile colonies.

- Estimate the percent dead skeletal cover (partial mortality estimate for each colony) based on skeletal structure. Skeletal structure = (old or recent) mortality + live tissue.
- Consider how species and morphology influence normal tissue location (e.g., not on columnar colonies such as *Eusmilia fastigiata* and *Orbicella annularis*).

1. Mortality – Estimates of old and recent mortality are collected. Only include corals that have living tissue present, i.e., total mortality (% old + % recent) is less than 100. If total mortality is 100%, do not record the colony.

   i. Old mortality (%) – Estimate the old mortality as a percentage of the total colony size (NOT as a percentage of total mortality).

   ii. Recent Mortality (%) - Estimate the recent mortality as a percentage of the total colony size (NOT as a percentage of total mortality).

   - Recent mortality is defined as exposed white bare skeleton that does not have bleached tissue present and is not colonized by algae or other organisms.
   - A theoretical colony with an encrusting morphology with dimensions of 10cm x 10cm with one-quarter of the colony recently dead would be scored as 25% recent mortality.

2. Bleaching (T/P/N) – Note if any coral bleaching is present or absent.

   i. Total bleaching (T): bright-white bleaching over the entire colony1

   - Bleaching is defined as bright white tissue.
   - Other conditions such as various shades of paling or disease are not included.

   ii. Partial bleaching (P): bright-white bleaching over a part of the colony

   iii. No bleaching (N): no bleaching present. Use this code to indicate no bleaching. Do not leave this item blank.

   - If a colony is exhibiting any apparent "discoloration" of tissue, unless it is partially or completely white, this condition should be scored as "No bleaching".

3. Coral Disease (P/A) – Note if any coral disease is present or absent.

   i. Present (P): Any form of coral disease is noticeable on the colony.

   ii. Absent (A): No disease is evident.

Appendix E - Rapid Ecological Assessment Methods: Fish Surveys (Main Hawaiian Islands, Northwestern Hawaiian Islands, American Samoa, Pacific Remote Island Areas, Guam, and the Commonwealth of the Northern Mariana Islands)

(Source: NOAA 2015b)

The fish team uses several complementary, noninvasive, underwater surveys to enumerate the diverse components of diurnally active shallow-water reef fish assemblages. For diver surveys, we use two types: 1) Rapid Ecological Assessments (REA), which are comprehensive, small-scale, site-specific surveys that record the number, size, and species of fishes present at a survey site on a reef and are conducted with a new stationary point count (nSPC) method and 2) towed-diver surveys (TDS), which are designed to quantify relatively large-bodied (>50 cm total length, TL), wide-ranging fishes over a broad spatial scale. Each of these two survey types is replicated at locations within or among the various habitat types present around each island or bank. TL is estimated to the nearest centimeter for all quantified fishes, allowing for generation of biomass densities and size distributions by taxa.

New Stationary Point Count (nSPC) Method (2007-Present)

For the current CRED nSPC method, pairs of divers record the number, size, and species of all fishes observed within visually estimated cylinders 15 m in diameter. At the start of a survey dive, a pair of divers first lay down a 30-m transect line along a predetermined depth contour, and then the two divers move to the 7.5- and 22.5-m marks on that line; these marks serve as the centers of two adjacent nSPC cylinders. During the first 5 min of a survey, the divers create a list of the fish species observed in or passing through their cylinder. After the first 5 min, divers systematically proceed down their species lists, counting and estimating the size (TL) of each fish present to the nearest centimeter. Species seen after the 5 min or outside of the survey area are recorded as present.

Towed-diver survey method (2000-Present)

A pair of scuba divers is towed about 1 m above the reef roughly 60 m behind a small boat at a constant speed of about 1.5 kn. One diver quantifies fish populations, and the other diver quantifies the benthos. Each diver maneuvers their own towboard. Towboards are connected to the small boat by a bridle and towline and outfitted with various survey equipment, including a video camera on the fish towboard. The fish diver records the number, size, and species of all large fishes (>50 cm TL) observed within a belt that is 10 m wide and centered on the diver. Observations and species tallies are recorded on preprinted data sheets attached to each towboard. The digital video camera on the fish towboard faces forward and takes a permanent record of fishes encountered in a standard field of view.

A towed survey is typically 50 min long and covers about 2 km of habitat. Each survey is divided into 5-min segments, with data recorded separately per segment to allow for georeferencing of observations within the ~200 m covered during each segment. Throughout a survey, the latitude and longitude of its survey track are recorded at 5-s intervals on the small boat with a global positioning system (GPS).

Following a survey, diver tracks are generated using this GPS data and a layback algorithm to account for position of the diver relative to the small boat.

Appendix F - Belt Transect Fish Survey Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary

(Source: NOAA 2015d)

Goal of Fish Surveys

The goal of the fish community surveys is to collect and report information on species composition, density, size, abundance, and derived metrics (e.g., species richness, diversity) using a 25m x 4m belt transect in a stratified random sampling design in hardbottom and coral reef habitats in the U.S. Caribbean (U.S. Virgin Islands and Puerto Rico) and FGBNMS.

General Task Description

The diver collecting fish information is the lead diver for the dive team. The diver will lay the initial transect for fish surveys which also serves as the transect for the line point-intercept (LPI) and coral demographic surveys.

Abbreviated Survey Protocol (for full protocol see NOAA 2015d)

The Fish diver collects the following information:

a. Fish census – taxa presence and abundance along 25m transect and 2m width on either side of the tape.
    - The Fish diver searches thoroughly for fish in the 25m x 4m survey area.
    - On-site, the Fish diver will make no attempt to avoid structural features within a habitat, such as a sand patch or an anchor, as these features affect fish communities and are "real" features of the habitats.
    - The habitat should not be altered in any manner by lifting or moving structure.
    - The Fish diver should record fish seen in holes, under ledges and in the water column.
    - To identify, enumerate, or locate new individuals, divers may move off the centerline of the transect as long as s/he stays within the 4m transect width and does not look beyond the 4m width or back along area already covered.
    - The diver is allowed to look forward toward the end of the transect for the distance remaining (i.e., if the diver is at meter 15, s/he can look 10 meters distant, but if s/he is at meter 23, s/he can only look 2 meters ahead).
    - The transect will take 15 minutes regardless of habitat type or number of animals present. This standardizes the samples collected to allow for comparisons and allows more mobile animals the opportunity to swim through the transect.

b. Topographic complexity information – The Fish diver will also collect topographic relief information. (see Topographic Complexity Survey Protocol for the U.S. Caribbean and Flower Garden Banks National Marine Sanctuary (NOAA 2015e).)

Appendix G – Derived Indicators from NCRMP Data

Table G-1. Potential stony coral indicators that can be derived from NCRMP data.

Indicator	Description
Abundance	number of colonies
Density	number of colonies per m2 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)
Total surface area (TSA)	total 3D colony surface area (m2) including both living and dead portions
3D total coral cover (3DTC)	TSA per m2 sea floor (m2/m2)
Average colony surface area (CSA)	TSA per number of colonies (m2)
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
Percent live tissue (% LT)	proportion of live coral tissue on each colony
Live surface area (LSA)	live 3D surface area (m2) = TSA*(% LT)
3D live coral cover (3DLC)	LSA per m2 sea floor (m2/m2)
% LSA	Comparative index of live and total surface area [(LSA/TSA) *100]

Table G-2. Potential fish indicators that can be derived from NCRMP data.

Indicator	Description
Species richness (total or mean)	# of fish species at site
Density (total or mean)	# fish /area=relative abundance
Length size (mean or frequency)	Fork length, total length, body length
Biomass (total or mean)	Total weight of all individuals, estimated wet weight
Shannon diversity index (H)	Index of richness & abundance
Pielou evenness index (J)	Index of biodiversity
Abundance (total or mean)	Total # individuals
Frequency of occurrence	Proportion of sampled sites that a given species is present
Biomass, herbivores	Using standard length-weight relationships biomass of various portions of a fish assemblage can be determined
Percentage of population by family (e.g., Acanthuridae, Scaridae, Chaetodontidae)	Specific family-level information expressed in terms of percent of total fish assemblage

Table G-3. Potential indicators that can be derived from NCRMP LPI data.

Indicator	Description
Density (total or mean)	# macro-invertebrate organisms /area=relative abundance
Density (total or mean)	# ESA listed or candidate species /area=relative abundance
% Cover (2D) of different benthic constituents	% of each - sessile organisms and plants (live coral, macroalgae, turf algae, crustose coralline algae, sponges, etc.) and abiotic features (sand, sediment, pavement, etc.).
% Live coral cover (2D)	% of coral colony having living coral tissue
Rugosity	Rugosity (topographic complexity)

Appendix H - Sediment Constituent Accumulation Method

Processing of the sediment generally falls into three parts: (1) Measuring weights, (2) Determining grain sizes, and (3) Constituent analysis; see Barber (2002) for an example of these methods. When measuring the weight of a sample, this is usually done as a dry weight; drying can be done in an oven at a temperature of 30°C for 48 hours. Grain size can be determined, usually as a percentage of the total dry sample weight, via a range of methods, from running the sediment through simple mesh sieves (either wet or dry) up to x-ray or laser diffraction particle size analyzers. Constituent analyses are usually done on some size fractions of the sediment sample; a typical example is conducting analyses on the sand-sized (2.000-0.063 mm), silt-sized (0.063-0.004 mm), and clay-sized (<0.004 mm) fractions. First, the sediment is sieved into these fractions and each fraction is weighed. The carbonate portion of each grain-size fraction is then removed, either by bathing them in an acid (e.g., perchloric) or burning them off in an oven at high (950°C) temperature. By removing all of the carbonate, one is just left with the non-carbonate or terrigenous material, which is then re-weighed to determine percentage of terrigenous by mass; the percentage carbonate is simply the difference between the overall fraction mass and the mass of the terrigenous material remaining in the fraction after removing the carbonate material. Ratios of terrigenous to carbonate material by mass for the different size fractions then can be computed.

Appendix I – Derived Indicators from NCCA Data

Table I-1. Potential Water Quality Indicators that Can Be Derived from NCCA data.

Indicator	Description
Total Nitrogen*	The combination of all organic and inorganic, and dissolved and particulate forms of nitrogen nutrients
Total Phosphorus*	The sum of total dissolved phosphorus (TDP) and particulate organic phosphorus
Chlorophyll *a**	The individual pigment generally measured as an indicator of phytoplankton productivity which serves as a proxy for water column nutrient condition
Dissolved Oxygen*	Oxygen that is dissolved in water and therefore available for plants (phytoplankton), corals, fish, and other animals to use.
Temperature	A comparative objective measure of hot and cold
pH	A measure of the hydrogen ion concentration of a water sample and as such is a measure of the acidity of a water sample
Salinity	A measurement of the amount of salts dissolved in water
Light attenuation	The gradual loss in intensity of sunlight through the water column
Water column transparency	Measurement of how far you can see through the water

* Recommended indicators for all watersheds.

Appendix J - A Note about Water Quality Monitoring

Water quality samples should be collected using the methods described in *National Coastal Condition Assessment Field Operations Manual (EPA-841-R-09-003*), with the exception of the water sample for Total Nitrogen and Total Phosphorus (See Appendix L). NCCA uses dissolved inorganic nitrogen -DIN and dissolved inorganic phosphorus-DIP. For the purposes of the coral reef surveys, the sampling sequence is to:

- Verify site as correct location to obtain samples (whole crew);
- Conduct *in situ* instrumental measurements of dissolved oxygen (and additional site-specific measurements - temperature, salinity, turbidity, pH)
- If light attenuation has been selected as an additional site-specific measurement, take measurements with Photosynthetically Active Radiation (PAR) meter;
- Collect water for chlorophyll-*a;*
- Filter chlorophyll-*a* samples;
- Collect water for nutrients sample;
- Preserve and prepare all samples for shipment;
- Review field forms;
- Report sampling event; and
- Ship time-sensitive samples.

Appendix K – Sediment Toxicity Method

There are multiple bioassays for assessing toxicity of marine sediments. We recommend EPA's amphipod sediment toxicity method used for NCCA and determining suitability for ocean disposal, and USGS's pore water urchin test based on fertilization and embryo development.

For CWA applications, EPA recommends the sediment toxicity test employing *Leptocheirus plumulosus*. Soft sediment can be collected within 37 m of the station. If no sediment is found, crews can expand the area to within 100 m. Collect adequate surficial sediment from a minimum of three Van Veen or Ponar grabs to produce a composite sample of approximately 4 L. The acceptability criteria for each grab can be found in the NCCA Field Operations Manual (*EPA-841-R-09-003*).

The sample must be held on wet ice until transport to the laboratory where it will be refrigerated at 4^{o} C (sample is not to be frozen) to await further processing and initiation of testing as specified in NCCA Laboratory Methods Manual for respective tests. Sediment toxicity tests (SEDTOX) with *Leptocheirus plumulosus,* an Atlantic coast estuarine sediment-burrowing amphipod species are conducted for 10 d in 1 L glass chambers containing 175 mL of sediment and 800 mL of overlying seawater. Exposure is static (*i.e*., water is not renewed), and the animals are not fed over the 10 d exposure period. Sediment tests include control sediment (sometimes called a negative control). The endpoint in the toxicity test is survival. Procedures are described for use with sediments with pore water salinity ranging from > 0‰ to fully marine. Complete guidelines are provided in the NCCA Laboratory Methods Manual (EPA 841-R-09-002).

Note: Before being authorized to conduct SEDTOX tests, a laboratory should provide documentation of their technical capabilities by demonstrating that they have both the facilities and personnel to meet the challenges to successfully conduct static toxicity tests for the durations specified (i.e., 10-day exposures for amphipods). Guidance is provided in the NCCA Quality Assurance Project Plan (EPA 841-R-09-004).

USGS provides information about a pore water bioassay using fertilization and embryo development of a tropical sea urchin to assess sediment toxicity. This test has the advantage of using sensitive life stages of a tropical marine organism. Methods are described in Carr and Nipper (2003) and Carr et.al. (2006).

Appendix L - Method for Water Chemistry: Total Nitrogen, Total Phosphorous, and Chlorophyll *a*

For Clean Water Act applications and to make comparisons against National Coastal Condition Assessment data collected by EPA:

Water samples will be collected at the site at a depth of 0.5 m and 0.5 m above the seabed (additional sampling throughout the water column as needed). Collect the water samples with either a pumped system or a water sampling bottle such as a Niskin, Van Dorn, or Kemmerer bottle and transferred to a rinsed 250 mL amber Nalgene bottle.

Chlorophyll *a* and dissolved nutrients samples will be obtained by filtering up to 2 L of site water (or sufficient volume to produce a visible green residue on the filter) through the 47 mm GFF; the volume of sample water filtered must be recorded on the field data form and on the label on the centrifuge tube in which the filter is stored. Water for the chlorophyll-*a* sample will be transferred to a separate 2 L amber Nalgene bottle.

After filtration, retain the filter with filtered material for the analyses of chlorophyll *a*; keep the filter frozen in a tin foil covered centrifuge tube; and ship to the laboratory on wet ice.

The dissolved nutrient sample will be collected by pouring approximately 200 ml of the filtrate into a clean 250 ml Nalgene bottle. The sample will be capped and stored in darkness on ice in a closed cooler until it is shipped to the laboratory.

Detailed procedures for sample collection and processing are described in the Field Operations Manual, Section 5.3 (EPA, 2010A).

Appendix M - Method for Dissolved Oxygen (DO)

Measure dissolved oxygen (DO) using a calibrated multi-parameter water quality meter (or sonde). Calibrate the DO meter in the field against an atmospheric standard (ambient air saturated with water) prior to launching the boat for each sampling event.

Take the measurements at the following depths: 0.1 m below the surface, 0.5 meters below the surface, every 1 meter from depths of 1.0 to 10.0 meters, and every 5 meters thereafter if the site is greater than 10 m. Take the last measurement at 0.5 m from the bottom. Be sure the site depth is accurately measured and recorded before taking the DO measurements. Take care to avoid the probes contacting bottom sediment, as the instruments are delicate.

Repeat the full sets of measurements at each of the same depth intervals as the probe is retrieved. The hydrographic profile will include a full set of measurements on both the downcast (lowering the probe through the water column), and the upcast (as the probe is brought back to the surface). The downcast and upcast measurements will be taken at the same depths.

Note: additional *in situ* water quality measurements can be made at the same time (e.g., pH, temperature, and salinity) by attaching additional specialized probes to the sonde.

Detailed procedures for sample collection and processing are described in the Field Operations Manual, Section 5.1 (EPA *EPA-841-R-09-003*).

Appendix N – Turbidity Method

The method is based upon a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. The higher the intensity of scattered light, the higher the turbidity. Readings, in Nepholometric Turbidity Units (NTUs), are made in a nephelometer designed according to specifications given in Sections 6.1 and 6.2. A primary standard suspension is used to calibrate the instrument. A secondary standard suspension is used as a daily calibration check and is monitored periodically for deterioration using one of the primary standards.

There are many methods available to measure turbidity, however we recommend:

For application against Clean Water Act (CWA) Water Quality Criteria, use the EPA approved method described in EPA, 1993: *Method 180.1 Determination of Turbidity by Nephelometry.*

For non CWA specific applications use USGS approved method as described in USGS 2005: Turbidity. *In* National Field Manual for the Collection of Water-Quality Data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, section 6.7.

Measure turbidity using a calibrated multi-parameter water quality meter (or sonde). Calibrate the turbidity sensor in the lab against a standard prior to launching the boat for each sampling event.

Take the measurements at the following depths: 0.1 m below the surface, 0.5 meters below the surface, every 1 meter from depths of 1.0 to 10.0 meters, and every 5 meters thereafter if the site is greater than 10 m. Take the last measurement at 0.5 m from the bottom. Be sure the site depth is accurately measured and recorded before taking the turbidity measurements. Take care to avoid the sensor contacting bottom sediment, as the instruments are delicate.

Note: additional *in situ* water quality measurements can be made at the same time (e.g., pH, temperature, and salinity) by attaching additional specialized probes to the sonde.