RESTORE CMAP Report Series: Task 3 and Task 4

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COUNCIL MONITORING AND ASSESSMENT PROGRAM (CMAP)

Common Monitoring Program Attributes and Methodologies for the Gulf of Mexico Region

A joint collaboration between
National Oceanic and Atmospheric Administration and the U.S. Geological Survey

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NOAA National Ocean Service, National Centers for Coastal Ocean Science, Marine Spatial Ecology Division
NOAA National Marine Fisheries Service, Southeast Regional Office

and

USGS Southeast Region
USGS Wetland and Aquatic Research Center
USGS Oklahoma-Texas Water Science Center
USGS Lower Mississippi-Gulf Water Science Center

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RESTORE Council Background

The Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (RESTORE Act Final Rule at 31 C.F.R. Part 34) was signed into law on July 6, 2012. The RESTORE Act calls for a regional approach to restoring the long-term health of the valuable natural ecosystem and economy of the Gulf Coast region. The RESTORE Act dedicates 80 percent of civil and administrative penalties paid under the Clean Water Act, after the date of enactment, by the responsible parties in connection with the Deepwater Horizon oil spill to the Gulf Coast Restoration Trust Fund (Trust Fund) for ecosystem restoration, economic recovery, and tourism promotion in the Gulf Coast region. In addition to creating the Trust Fund, the RESTORE Act established the Gulf Coast Ecosystem Restoration Council (Council). The Council includes the Governors of the states of Alabama, Florida, Louisiana, Mississippi, and Texas, the Secretaries of the U.S. Departments of Agriculture, the Army, Commerce, Homeland Security, and the Interior, and the Administrator of the U.S. Environmental Protection Agency. The Council plays a key role in developing strategies and implementing projects that help ensure the Gulf's natural resources are sustainable and available for future generations. This has included the development of a Comprehensive Plan to restore the ecosystem and the economy of the Gulf Coast region (RESTORE Council, 2016). Approved in 2013 and updated in 2016, the Comprehensive Plan provides a framework to implement a coordinated, Gulf Coast region-wide restoration effort in a way that restores, protects, and revitalizes the Gulf Coast. The Comprehensive Plan identifies five goals for Gulf Coast restoration: Restore and Conserve Habitat, Restore Water Quality, Replenish and Protect Living Coastal and Marine Resources, Enhance Community Resilience, and Restore and Revitalize the Gulf Economy. Under the Council-Selected Restoration Component of the RESTORE Act, the Council develops Funded Priority Lists (FPLs) that describe the projects and programs it will fund. Projects and programs funded through this component must be in furtherance of the goals and objectives of the Council's Comprehensive Plan.

The Initial FPL, finalized in December of 2015, had a strong emphasis on watershed and estuary restoration and foundational cross-Gulf projects. The Council Monitoring and Assessment Program (CMAP) was approved as a Gulf-wide investment in the 2015 Initial FPL, and is administered jointly by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS). Funded activities include the organization of basic, foundational components for a Gulf-wide monitoring network to measure the efficacy of investments in Gulf restoration by the Council. The program, in coordination with the Gulf of Mexico Alliance (GOMA) and through collaboration with the Gulf States, federal and local partners, academia, non-governmental organizations, and business and industry, has leveraged existing resources, capacities, and expertise and built on existing monitoring programs and their data.

Project Team

We would like to thank the project team for their participation and expertise.

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Executive Summary

Under the Resources and Ecosystem Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act of 2012 (RESTORE Act), the Gulf Coast Ecosystem Restoration Council (RESTORE Council or Council) is required to report on the progress of funded projects and programs. Systematic monitoring of restoration at the project-specific and programmatic-levels (i.e., watershed and Gulf of Mexico) enables consistent reporting and gives the public confidence that the restoration investments selected by the RESTORE Council will be evaluated and adaptively managed accordingly. Monitoring information that has been collected at different spatial and temporal scales can be used as the foundation to illustrate progress towards comprehensive ecosystem restoration goals and objectives that promote holistic Gulf of Mexico recovery (see 'RESTORE Council Background' at the beginning of this report for additional Council information).

Federal, state and local agencies, universities, private industry, and non-governmental organizations (NGOs) have conducted and are conducting extensive monitoring activities around the Gulf of Mexico. In addition, each RESTORE Council-funded project will, at a minimum, perform project-specific monitoring. This collection of monitoring activities was inventoried and compiled into a framework of tools and resources by the Council-funded RESTORE Council Monitoring and Assessment Program (CMAP). CMAP was designed and funded to inventory and integrate existing water quality and habitat monitoring and mapping efforts to support discovery and accessibility of existing monitoring data and ensure the collected information is made available to support management decisions. Results of CMAP Inventory queries can be used to identify opportunities for efficiencies and support cross-program review of performance across Gulf of Mexico ecosystem recovery efforts.

The fundamental approach being used to inform the build out of the CMAP Gulf of Mexico water quality monitoring, habitat monitoring, and mapping framework includes:

1. Adopt, or construct as needed, a comprehensive inventory of existing habitat and water quality observation, monitoring, and mapping programs in the Gulf of Mexico (hereafter referred to as the "Inventory"; NOAA and USGS, 2019a);
2. Evaluate the suitability/applicability of each program and its existing and prospective data for use in restoration activities;
3. Develop a process to use the Inventory to conduct gap assessments;
4. Develop a catalog of baseline assessments conducted in the Gulf of Mexico (NOAA and USGS, 2019b); and
5. Develop a searchable monitoring information portal/database to enable access to collected information and products.

Report Overview

This report is a component of a series for the RESTORE Council (NOAA and USGS, 2019a,b; NOAA and USGS, 2020). The objective of this report is to explore the monitoring programs in the Inventory, evaluate levels of programmatic documentation (i.e., "monitoring program elements"), and identify commonly monitored parameters as well as methods through which they are monitored in order to inform monitoring guidance for future RESTORE Council-funded restoration projects.

Chapter 1 provides background information about CMAP and describes the goals and objectives for this report. A wide, disparate array of monitoring and restoration efforts exist throughout the spatially and ecologically diverse Gulf of Mexico region. In order to most effectively utilize the data generated by these efforts, it is important to be aware of the comparability and accessibility of the data. CMAP was developed to compile water quality monitoring, habitat monitoring, and mapping information from across the Gulf of Mexico in the Inventory and identify comparable parameters, methods and programs. The frequency that a parameter is monitored or methodology used across programs provides a general indication of the scientific acceptance of its use.

Chapter 2 describes the methods for identifying core parameters, determining monitoring program elements (i.e., programmatic documentation) needed to assess data comparability between programs, and examining findings relevant to particular restoration approaches. For monitoring programs captured in the Inventory, monitoring protocols were reviewed to identify methods and units of data collection for different parameters. When possible, this information was linked to the habitat type(s) where data was collected. Core parameters were identified by first using the Inventory to determine the most commonly monitored parameters by habitat type, and then assessing the frequency at which those parameters were also recommended in established monitoring guidance documents, such as Deepwater Horizon (DWH) Natural Resource Damage Assessment's (NRDA) Monitoring and Adaptive Management Manual (NRDA Trustees, 2017). Parameters for each habitat type were subsequently assigned to one of four Tiers denoting how commonly measured or recommended they were, with Tier 1 parameters being the most common. In order to evaluate the monitoring programs themselves, eight attributes captured by the Inventory—termed "monitoring program elements" (MPEs)—were used to characterize a program's potential comparability and accessibility. Monitoring or restoration practitioners can use the core parameters and MPEs to quickly identify monitoring programs in the Inventory that could inform future monitoring or restoration practitioners' efforts by filtering for programs that collect the core parameters or MPEs they are interested in. To illustrate this, the programs in the Inventory were linked to two RESTORE Council restoration approaches (*Restore oyster habitat* and *Reduce excess nutrients and other pollutants to watersheds*) using habitat types that would be applicable to those approaches. For example, with each restoration approach, the Inventory can be further curated to obtain a list of monitoring programs operating in the applicable habitat type and measuring at least one Tier 1 parameter, and a record of MPEs within each program. The programs in that list can then be investigated by the user.

Chapter 3 summarizes the results of core parameter identification and program evaluation by highlighting examples using two habitat types (oyster/bivalve bed and water column) and linking the Inventory to two RESTORE Council restoration approaches. Seven Tier 1 parameters were identified for oyster/bivalve bed habitat, all of which would be relevant for tracking the ecological benefits of oyster restoration efforts. For example, the most commonly measured parameter, area of habitat types, is known to be important for developing habitat maps as well as identifying the locations and sizes of oyster reefs. Additional mapping information, such as the type of classification scheme (most oyster mapping programs used local schemes) and data sources (e.g., orthophotography), was also gathered. Parameters relating to animal size or population demographics (e.g., density or size) and environmental quality (e.g., conductance or dissolved oxygen) were also categorized as Tier 1. Seven parameters were categorized as Tier 1 for the water column, all of which were either field parameters (e.g., water temperature or turbidity) or nutrients (e.g., total phosphorous or total nitrogen). All of these parameters are important sources of information related to restoration and management of the water column habitat. Programs operating within habitat types applicable to each restoration approach (oyster/bivalve bed for *Restore oyster habitat* and water column, agriculture, and urban for *Reduce excess nutrients and other pollutants to watersheds*) were selected from the Inventory to identify those most useful for a particular approach. For example, the Apalachicola Bay Oyster Restoration program measured all seven Tier 1 oyster/bivalve bed habitat type parameters and was well-documented with accessible metadata and monitoring protocol information. Thus, such a program could be useful to inform future restoration efforts in similar environs in the Gulf of Mexico by providing historical monitoring information or serve as a model for how other efforts could operate.

Chapter 4 highlights the uses, benefits, and limitations of this information as well as monitoring recommendations for RESTORE Council projects and general guidance for monitoring practitioners. The information gathered in the Inventory and represented in this report presents a first step for determining comparability and standardization by habitat type within the Gulf of Mexico restoration sphere. For example, in the habitat types that align with the restoration objectives identified by NRDA, the core parameters identified in this report match very well, with more than 80% of NRDA core parameters identified as Tier 1 parameters by CMAP. In cases where core parameters were not also recommended by NRDA (e.g., plant/macroalgae survivorship in emergent marsh habitats) the differences could be attributed to the differing goals of these two efforts, with CMAP gathering information on all habitat and water quality monitoring while NRDA is focused on restoration monitoring. This work serves as a starting point for helping Gulf of Mexico restoration and management practitioners to aggregate useful and comparable data or methods to larger spatial or temporal scales. Additionally, in habitats where monitoring or restoration efforts are not as common, this type of information could serve as a foundation to build upon. It could also be used to update existing and develop new guidance documents for Gulf of Mexico habitats. The Inventory, which is a static body of work, is limited by the frequency of updates and the completeness of accessible metadata. For this analysis, parameters and methods were tied to particular habitat types using protocol documentation, and these assignments may not reflect what was originally captured when developing the Inventory's database of programmatic metadata. Resolving these types of discrepancies is recommended as a focus of a future effort. Lastly, consideration of monitoring additional core parameters to those identified in NRDA Trustees (2017) are recommended for five habitat types and it is suggested that monitoring programs further invest in making their metadata web accessible.

1 Introduction

Credit: Michael Lee (USGS)

Background

There are many programs in the Gulf of Mexico that track general trends in environmental conditions to assess and evaluate the effectiveness of restoration, conservation, or management actions. These programs have often been established with specific goals and employ a wide range of methods to meet objectives across temporal and spatial scales. Knowing the types of data being collected by these programs, the methods used, and the accessibility of data and metadata provides opportunities to scale up ecosystem assessments within the Gulf of Mexico. The Deepwater Horizon (DWH) oil spill reminded the environmental community of all the necessary scientific information needed to respond to such a disaster and that this information, if it exists, is often housed in disparate locations across the Gulf of Mexico with many program-specific intricacies, including frequency of sampling and differing methods. These intricacies make it difficult to use, synthesize, or compare the available data, hindering our ability to comprehensively understand the Gulf of Mexico's ecosystem function, health, and baseline condition. Efforts to increase such comparability are needed to provide greater utility for restoration or conservation assessment in the Gulf of Mexico.

Monitoring data are most useful and effective when they are comparable across different temporal and spatial scales. Data comparable across temporal scales allow practitioners to quantify changes to a system over time (e.g., assessing the consequences of a disaster like the DWH oil spill). The Gulf of Mexico is spatially heterogeneous and variations, large or small, can have a significant impact on habitats and the organisms that use them. If the data produced by the many monitoring programs in the Gulf of Mexico were comparable, it would be possible to translate information across local, regional, and/or larger scales (Henle et al., 2010).

While monitoring data that are temporally and spatially comparable are valuable, such data must also be well-documented, discoverable, and easily accessible. Practitioners commonly spend significant amounts of time conducting data discovery only to find that the datasets they have accumulated are not suitable for compilation due to many factors, including incompatible sampling design, inadequate frequency, insufficient scale of station location, or incomplete parameter collections. Often data sets are hard to find, not readily available, or have incomplete metadata. An inherent characteristic of long-term monitoring is the need for consistent data collection over time, which requires rigorous attention to data management and quality assurance. Instituting good data management practices is a critical first step to improving the quality and applicability of data for meeting project objectives as well as broader meta-analysis and macrosystem ecologic research (Sutter et al., 2015).

The Council Monitoring and Assessment Program (CMAP) was developed to identify and compile monitoring program metadata in the Gulf of Mexico and identify comparable parameters, methods, and programs. The foundation of the program, the CMAP inventory (the Inventory), currently houses 544 water quality monitoring, habitat monitoring, and mapping programs operating in the Gulf of Mexico (NOAA and USGS, 2019a) and is accessible online via a searchable webtool (https://restorethegulf.gov/cmap). Conducting metadata discovery for the Inventory uncovered over 100 data portals or webtools providing access to data.

The information collected about inventoried programs can be evaluated to determine parameters that are commonly measured and how they are measured (i.e., methods and units). Assuming that a high frequency of use indicates general acceptance among the scientific community, this information can be used to identify monitoring parameters and data collection methods that are sound and robust. To maximize data comparability, it can also inform a set of guidelines for standard monitoring, including distinguishing parameters that could be considered core and their accompanying methods. The concept of establishing core parameters for habitat and water quality monitoring is not new. Many organizations have formed guidelines and recommendations to help establish and communicate best practices for the Gulf of Mexico (NRDA Trustees, 2017; Thayer et al., 2005).

Core parameters and methods, as defined by CMAP, are those that are commonly included in monitoring programs in the Inventory or suggested by others in guidance documents and may work together as a suite to provide consistent data that can be used to detect and track change within the ecosystem. Collectively, these parameters and methods would: 1) function to identify significant changes in ecosystems so as to trigger and guide the design of future investigations; 2) be suitable for measurement and comparison among a variety of sites and scales; and 3) easily fit into existing monitoring programs (Vaughn et al., 2001). The information compiled in this framework can inform the development of spatially and temporally comprehensive networks for habitat and water quality monitoring that can be used to make scientifically sound decisions regarding the health and viability of the Gulf of Mexico ecosystem. To ensure that the information compiled provides the greatest utility to the restoration and management community in the Gulf of Mexico, the Council Monitoring and Assessment Workgroup (CMAWG), which recommends monitoring and assessment standards that may be applied to RESTORE projects and programs, and the Monitoring Community of Practice (MCoP), a forum to share and receive feedback from monitoring practitioners, were engaged throughout this effort.

Purpose and Scope

The objective of this report is to identify common monitoring parameters, methods, and programmatic documentation efforts. Highlighting common parameters and methods may lead to greater data consistency, comparability, and quality. Additionally, programmatic documentation criteria, such as data accessibility, will give monitoring data users confidence in selecting well-documented and readily available information from the Inventory and reduce the time and effort historically associated with data discovery.

This report describes the process of evaluating water quality and habitat monitoring and mapping programs, their parameters and methods, and how this information can be used to inform restoration or management objectives. The information developed through this effort can also be used as a starting point to identify and assess informational, spatial, and temporal gaps (NOAA and USGS, 2020).

Credit: Sarah Hile (NOAA , CSS)

2 Framework and Process

Credit: Nicholas Enwright (USGS)

Synthesis of Common Inventory Parameters and Methods

CMAP Inventory Background

CMAP compiled an extensive inventory of water quality monitoring, habitat monitoring, and mapping programs in the Gulf of Mexico (NOAA and USGS, 2019a). The Inventory contains descriptive metadata for each program including a list of habitat types the program operated in, parameters it measured, and links to available documentation such as data collection procedures, analytical procedures, and quality assurance protocols. Information for each program was gathered and reviewed internally. Additionally, 61% of Inventory records were verified by a program point of contact (POC).

Protocol Documentation

After the Inventory was developed, protocol information from programs in the Inventory was aggregated and evaluated to determine which parameters and methods were most commonly measured and implemented within specific habitat types (for full procedures see Appendix 1). Depending on the type of parameter (e.g., water quality, habitat, or mapping) examined, there were slight variations in this aggregation and evaluation process.

For each inventoried program (NOAA and USGS, 2019a), available documentation was reviewed to identify and record pertinent parameter collection methods and unit information. Due to the wide variety of methods encountered, similar methods were binned into broader categories. For example, habitat monitoring parameters measured using rulers, calipers, balances, and other mechanical tools were binned as "instrument/tool measurement." For water quality monitoring, electronic instruments such as probes and meters were binned into a "sensor" category. These categories allowed for greater comparability between different monitoring programs. If a method or other information could not be found in the protocols or supporting documents, it was noted as "unavailable."

Additionally, if a state agency's protocol stemmed from a federal source, the federal method was listed. For example, the Florida Department of Environmental Protection (FDEP) water temperature method is the same as the Environmental Protection Agency (EPA) water temperature method; thus, the EPA method was documented.

All parameters were linked to a specific CMAP Inventory habitat type (Table 1). For example, if a program was operating within multiple habitat types (e.g., emergent marsh, barrier island, and submerged aquatic vegetation), program documentation was used to denote which parameters were collected in each habitat type. In some cases, this in-depth examination of protocol documents revealed that a program collected parameters in a habitat type not originally included in its record in the Inventory. In those cases, the habitat type was retained for use in this analysis and will be updated in the Inventory at a later date. If a specific habitat link was not apparent from the protocol documents, parameters were linked to each habitat type noted for that program in the Inventory. Additionally, programs that only performed water quality monitoring were only linked to the water column habitat type, regardless of whether additional habitat types were noted in the Inventory.

Mapping Program Documentation

Mapping programs developed a wide variety of map products. These map products, hereafter referred to as "parameters", included both primary data sources (e.g., digital photography, satellite imagery, backscatter intensity, surficial elevation) and maps derived from primary data sources (e.g., land use/land cover, area of habitat types [AOHT]). To align with the information provided in various monitoring guidance sources (discussed below), only three mapping parameters, AOHT, land use/land cover, and surficial elevation, were included in this analysis.

While the frequency of occurrence was calculated for those parameters, programmatic details and methods were only investigated for programs that produced AOHT and land use/land cover maps. Although AOHT and land use/land cover are separate CMAP parameters, they were lumped together as AOHT during this analysis due to the similarity of these data. Methods were not documented for surficial elevation since collection efforts for this parameter are commonly gathered using existing standards for topographic (e.g., Heidemann, 2018) and bathymetric data collection (e.g., NOAA, 2019).

Table 1. Habitat types where programs in the Council Monitoring and Assessment Program (CMAP) Inventory conduct monitoring activities.

CMAP habitat types	
Agriculture	Mangrove
Artificial reef	Oyster/Bivalve bed
Barrier island	Sargassum/Floating macroalgae
Beach/dune	Submerged aquatic vegetation
Coral reef	Shrub/Grassland
Deep sea benthic communities	Soft bottom
Emergent marsh	Tidal flat
Forest	Urban
Hard bottom	Water column
Karst/Barren	

While surficial elevation is defined as a CMAP mapping parameter, or map product, it is also often used as a data source to derive habitat maps.

The information documented for each program that mapped AOHT included:

1. Map theme (e.g., oyster reef, coral/artificial reef, benthic—SAV, benthic—general, wetlands [non-SAV or oyster reef], beach/dune, land use/land cover, and shoreline position);
2. Classification scheme type (e.g., national standardized scheme, such as Cowardin et al. [1979], or a custom local scheme);
3. Various bins of habitat classes per theme;
4. Temporal information (e.g., mapping frequency, date of earliest map);
5. Data source information (e.g., satellite imagery, orthophotography, in situ data collection);
6. Mapping unit development (e.g., pixel-based, object-based, digitizing);
7. Mapping algorithm type (e.g., photointerpretation, machine learning);
8. Data, metadata, and documentation availability; and
9. Whether the program conducted accuracy assessments and/or change analyses.

To evaluate common parameters (see Evaluation of Common Parameters below), mapping "methods" were defined using data source information (e.g., satellite imagery, orthophotography, in situ data collection). Data source information was preferable to more detailed methodologies, such as mapping units and algorithms, due to decreased variability based on the scale of the map product, budget for mapping, or monitoring objectives. This definition of methodology is also consistent with the level of information commonly used in NRDA Trustees (2017). Due to the number of mapping data sources represented in the Inventory, this information was binned into broader categories (see Appendix 4).

As with habitat monitoring programs, a closer inspection of mapping programs to document methods identified some discrepancies between the Inventory and the summary tables presented in this report. For instance, during Inventory development, some mapping programs that map AOHT may have been linked generally to oyster reef as a habitat type relevant to the program; however, upon closer inspection of associated program documentation and products, a program may be deemed as not producing AOHT maps that are directly relevant to oyster reefs. Additionally, despite using a thorough quality assurance protocol for its development, the Inventory may yet contain some inaccuracies. For example, Sentinel-2 is a satellite sensor that collects data for mapping, but in the Inventory, it was listed as producing AOHT products.

Review of Program Method Determination

After the initial recording of each program's methods, 10% of water quality monitoring programs and 20% of habitat monitoring programs were randomly chosen for a quality assurance review conducted by team members not involved in the original protocol examination. Because only two mapping parameters were included in the analysis, all the corresponding methods information was reviewed by a single independent reviewer.

Evaluation of Common Parameters

After review, the methods, units, and habitat type information for all monitored or mapped parameters were compiled into a dataset. Each record in this dataset contained the following fields:

1. Unique program identifier (PID);
2. Program type (i.e., water quality, habitat, or mapping);
3. Habitat type;
4. Parameter measured;
5. Parameter method; and
6. Units

The upper quartile (top 25th percentile) of a parameter's frequency of occurrence within a habitat type was chosen as a consistent and standardized approach to assess commonality across the 19 CMAP habitat types. For the water column habitat, only programs measuring water quality parameters were included in the frequency calculations. Those in the top quartile were considered the most common and in some cases the break between quartiles was clear while in others the break was small. This approach was chosen as a simple method to evaluate CMAP parameters without making other complicated decision rules for inclusion. This approach was not intended to be an authoritative approach, and could be modified by other users to establish their own techniques for designating common parameters.

Established Monitoring Guidance

After the CMAP parameters and methods were assessed, a compilation of other commonly referenced monitoring guidance documents for Gulf of Mexico habitats, such as NRDA Trustees (2017) and NOAA's 'Science-Based Restoration Monitoring of Coastal Habitats' (Thayer et al., 2005), was developed through communication with subject matter experts and literature review. These documents present recommendations and guidance for identifying core performance parameters for monitoring, mapping, and/or restoration applications that could pertain to various habitat types, including those documented in the Inventory.

A total of 21 guidance documents (Table 2) were compiled, and a crosswalk was performed with results from the parameter and methods analysis from the Inventory. Most guidance documents provided information on multiple habitat types, and most habitat types had at least one document providing monitoring guidance (though numbers ranged from 0–8). Guidance documents outlining monitoring recommendations were a challenge to find for certain habitats. For example, sargassum/floating macroalgae monitoring guidance was not referenced in any of the reviewed documentation, while five habitat types (agriculture, hard bottom, karst/barren, soft bottom, and urban) were addressed by a single guidance document each.

Credit: Michael Lee (USGS)

Table 2. Guidance and recommendation documents with associated CMAP habitat types. SAV = Submerged aquatic vegetation

Guidance document	*Habitat types*	*Source citation*
Natural Resources Damage Assessment (NRDA) Monitoring and Adaptive Management Manual	Barrier island, beach/dune, emergent marsh, oyster/bivalve bed, SAV, water column	NRDA Trustees, 2017
Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico	Emergent marsh, oyster/bivalve bed, SAV	NAS, 2017
Science-Based Restoration Monitoring of Coastal Habitats	Beach/dune, coral reef, emergent marsh, forest, Hard bottom, mangrove, oyster/bivalve bed, soft bottom, SAV, tidal flat, water column	Thayer et al., 2005
2019 Monitoring Community of Practice (MCoP) Workshop	Barrier island, beach/dune, emergent marsh, oyster/bivalve bed	GOMA MCoP, unpublished data
Ecological Resilience Indicators for Five Northern Gulf of Mexico Ecosystems	Coral reef, emergent marsh, mangrove, oyster/bivalve bed, SAV	Goodin et al., 2018
Selecting Indicators to Monitor Outcomes Across Projects and Multiple Restoration Programs in the Gulf of Mexico	Barrier island, beach/dune, coral reef, deep-sea benthic communities, emergent marsh, forest, mangrove, shrub/grassland, SAV, water column	Baldera et al., 2018
Monitoring of Coastal Wetland Elevation and Vegetation Community Dynamics in the South Atlantic Geography	Emergent marsh	Rankin and Boyle, 2016
Strategic Conservation Assessment of Gulf Coast Landscapes	Agriculture, barrier island, beach/dune, emergent marsh, forest, Karst/barren, mangrove, shrub/grassland, tidal flat, Urban	RESTORE Council, 2015
Texas Coast: EcoHealth Metrics Framework Technical Support Document	SAV	Harte Research Institute, 2017
Submerged Aquatic Vegetation Community of Practice	SAV	Handley et al., 2018 (Revised 2020)
Oyster Habitat Restoration Monitoring and Assessment Handbook	Oyster/Bbivalve bed	Baggett et al., 2014
Gulf of Mexico Ecosystem Service Logic Models and Socio-Economic Indicators (GEMS)	Oyster/Bivalve bed	Olander et al., 2020
White Paper on Gulf of Mexico Water-Quality Monitoring: Providing Water-Quality Information to Support Informed Resource Management and Public Knowledge	Water column	GOMA Water Quality Team, 2013
Guidelines and Management Practices for Artificial Reef Siting, Use, Construction, and Anchoring in Southeast Florida	Artificial reef	Lindberg and Seaman, 2011
Atlantic and Gulf Rapid Reef Assessment (AGRRA) Detailed Benthic Protocol	Artificial reef, coral reef	Lang et al., 2010
Artificial Reef Evaluation with Application to Natural Marine Habitats	Artificial reef	Seaman, 2000
NRDA Mesophotic and Deep Benthic Communities Restoration Type	Deep-sea benthic communities	NOAA and NRDA, 2019; NOAA and NRDA, 2020
Review of Deep-Sea Ecology and Monitoring as They Relate to Deep-Sea Oil and Gas Operations	Deep-sea benthic communities	Kropp, 2004
Guidelines for Providing Benthic Habitat Survey Information for Renewable Energy Development on the Atlantic Outer Continental Shelf Pursuant to 30 CFR Part 585	Deep-sea benthic communities	BOEM, 2019
Reef Rehabilitation Manual	Coral reef	Edwards, 2010
Global Coral Reef Monitoring Network (GCRMN) Caribbean Guidelines for Coral Reef Biophysical Monitoring	Coral reef	GCRMN, 2016

Each guidance document was examined to determine recommended monitoring parameters for habitat types. Across the array of guidance documents, some placed recommended parameters into categories based on goals or efforts while others simply listed which parameters they recommended for a particular habitat type. For example, NRDA categorized parameters as either “core” or “objective-specific” wherein core parameters were those used consistently across projects in order to facilitate the aggregation of project monitoring results and the evaluation of restoration progress for each Restoration Type (NRDA Trustees, 2016, Appendix 5.E.4 of PDARP/PEIS; NRDA Trustees, 2017). Objective-specific performance monitoring parameters, however, were those that were only applicable to projects with a particular restoration objective. Other guidance documents used “core” and “supplemental” as designations. For CMAP purposes, the designations of “core” and “supplemental” were used in this analysis, thus parameters labeled as “objective-specific” were included as supplemental. In the absence of this distinction, all recommended parameters were considered core. Most guidance documents did not provide detailed information on methods or units, but this information was recorded when available. Instances of overlap between methods identified in guidance documents and methods found in the protocol documents from the Inventory were noted.

Determining Core CMAP Parameters

A decision tree (DT) framework (Figure 1) was developed to establish an evaluation process for CMAP parameters in conjunction with established core and supplemental parameters identified in the guidance documents. The project team and the CMAWG identified the importance for consistency between NRDA and RESTORE monitoring guidance to facilitate opportunities for data aggregation and evaluation of holistic ecosystem restoration. Therefore, a primary criteria in the DT was established to build off of recommendations in NRDA Trustees (2017). This DT was applied to categorize each parameter into one of four groupings: Tier 1 (T1); Tier 2 (T2); Tier 3 (T3); or Tier 4 (T4). This process was repeated for each parameter within each habitat type.

For each habitat type, the top quartile designations from the Inventory were used as the starting point for the DT. The next step in the DT accounted for a parameter’s presence in NRDA Trustees (2017), and, if present, the parameter’s designation as either core or supplemental. In cases where the parameter was listed as supplemental, the number of additional guidance documents that the parameter was noted in was used to determine the appropriate tier designation (i.e., T1–T4). Since only five habitat types were directly addressed in NRDA Trustees (2017; i.e., barrier island, beach/dune,

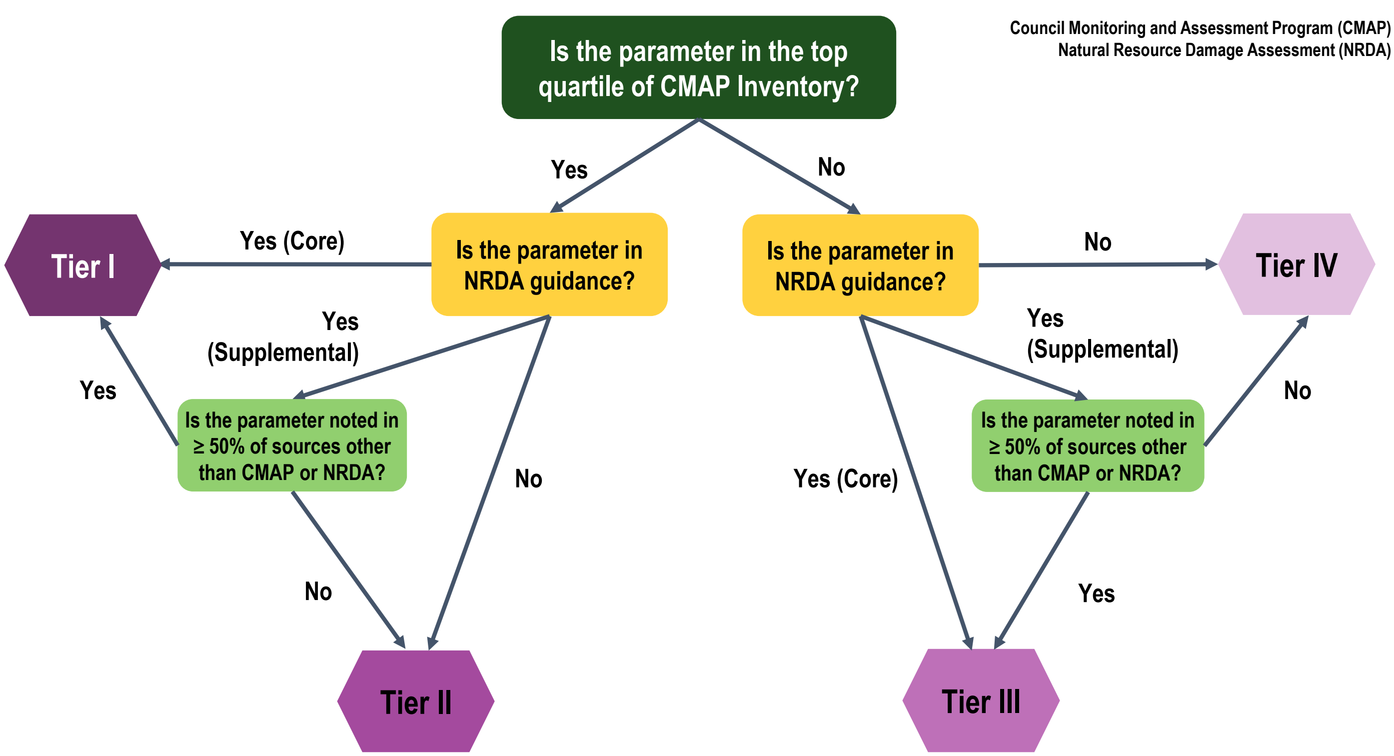


Figure 1. Decision Tree used by the Council Monitoring and Assessment Program (CMAP) to assign labels to each parameter measured in the habitats included in the National Resource Damage Assessment (NRDA) Monitoring and Adaptive Management Manual (NRDA Trustees, 2017).

emergent marsh, oyster/bivalve bed, and submerged aquatic vegetation), an alternate DT framework was used for non-NRDA habitat types (Figure 2). Although water column was not a specific habitat type detailed in NRDA (2017), some water column guidance was obtained from the other habitat types listed and the NRDA decision tree was used in the assignment of tiers. For all non-NRDA habitat types, only the quartile designations from the Inventory and the number of additional guidance documents were used to determine which tier designation the parameter was assigned. For an example of a parameter categorization using the DT, see Figure 3.

Parameters assigned a T1 designation were commonly monitored in the Inventory or recommended by other guidance sources; this included a designation of core or supplemental by NRDA for relevant habitat types. T2 parameters were also common in the Inventory, but were either designated supplemental or not considered by NRDA and were not frequently recommended by other guidance sources.

Although not commonly found in the Inventory, T3 parameters were considered core or supplemental if NRDA or other guidance documents supported that designation. Lastly, T4 parameters were generally not commonly monitored by CMAP programs nor recommended as core by other guidance sources; however, in some cases these parameters were identified by NRDA as supplemental.

To summarize this information, tables were developed that display the parameters (organized by Tier), methods, and units for each habitat type. Each table also details the number of inventoried programs that measured each parameter as well as the number of programs with respective methods for each parameter documented within a protocol. Since the sargassum/floating macroalgae habitat type was not covered by any of the guidance documents, only the summary information from the Inventory is presented and no tier assignments were made.

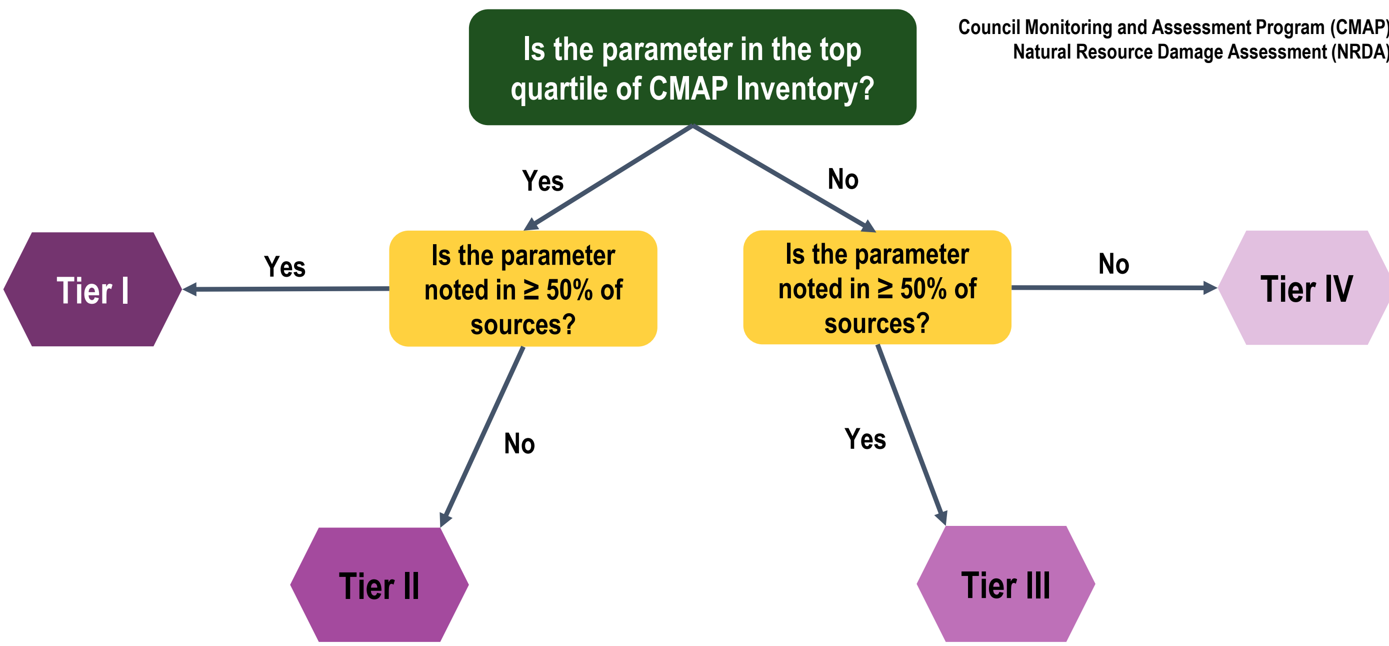


Figure 2. Decision tree used by the CMAP to assign labels to each parameter measured in habitat types not found in the NRDA Monitoring and Adaptive Management Manual (NRDA Trustees, 2017).

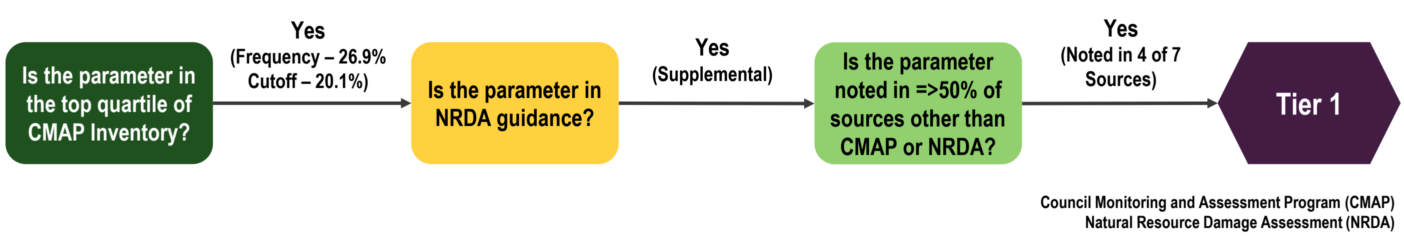


Figure 3. Example categorization of the submerged habitat-building animals (SHBA) — settlement/recruitment parameter for the oyster/bivalve bed habitat type through the decision tree (NRDA Trustees, 2017).

Evaluation of Inventoried Programs

Monitoring program elements

A subset of descriptive programmatic-level information contained within the Inventory was identified and termed monitoring program elements (MPEs). These MPEs include eight binary elements which indicate the level of comparability and accessibility of a program:

1. Does the program have a POC?
2. Are data accessible (web accessible or sent upon request)?
3. Are data available in a machine-readable format?
4. Are the data collected under this program/project documented with metadata (any format)?
5. Does the program have documented quality assurance protocols (applied during collection and analyses) for the majority of parameters?
6. Does the program have documented collection procedures for the majority of parameters?
7. Does the program have documented analytical procedures for the majority of parameters?
8. For Water Quality Monitoring programs in the Inventory, Are data units clearly defined and labeled?

It is important to point out that some programs may have materials for MPEs 5–7, but these materials were either not web-accessible or provided during a POC engagement process, which had a response rate of 61% (NOAA and USGS, 2019a). Thus, if materials were not accessible, the program would be marked as not having those MPEs. An MPE percentage was calculated for each program in the Inventory; a higher percentage indicates a higher number of MPEs which are accessible (i.e., with an answer of "Yes"). Accessible MPE's were identified from available online information or through conversation with a program's POC. This value, along with other variables of interest, can be used to evaluate inventoried programs. While each of these elements may not be of equal importance for all practitioners, CMAP considered this suite of attributes to collectively characterize the degree of a program's documentation and data availability. Thus, the higher the percentage, the greater the confidence that quality program information is available. This in turn makes it possible to assess whether data may be compatible with other datasets.

Application of Evaluations

In order to illustrate how the information contained within the Inventory could be used to inform future monitoring and/or restoration efforts, CMAP habitat types were paired with one or more applicable restoration approaches identified by the RESTORE Council in the 2019 Planning Framework (RESTORE Council, 2019; Table 3). With this linkage, monitoring programs can be identified and evaluated using the parameter and MPE criteria process to highlight those programs that may support restoration activities.

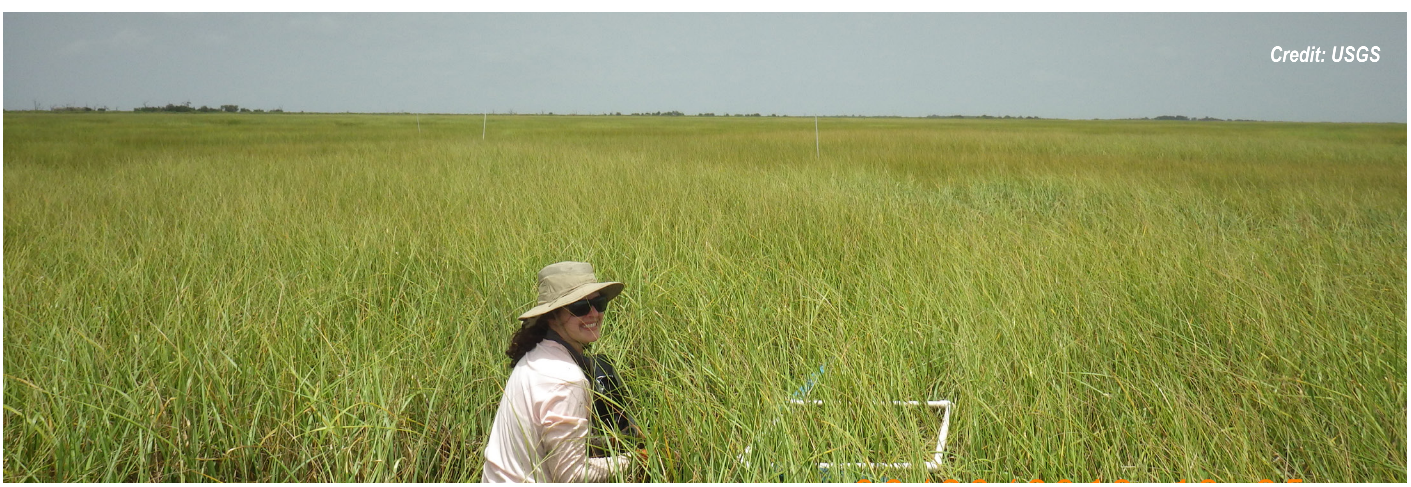
Credit: Sachin Shah (USGS)


Credit: Brian Petri (USGS)

Table 3. Habitat types that were identified as components for RESTORE Council Restoration Approaches. Refer to Glossary for habitat type definitions.

	RESTORE Council Restoration Approaches[1]				
Habitat type	*Create, restore, and enhance coastal wetlands, islands, shorelines, and headlands*	*Protect and conserve coastal, estuarine, and riparian habitats*	*Restore hydrology and natural processes*	*Reduce excess nutrients and other pollutants to watersheds*	*Restore oyster habitat*
Emergent marsh	X	X			
Beach/Dune	X	X			
Barrier island	X	X			
Oyster/Bivalve bed					X
Submerged aquatic vegetation (SAV)		X			
Water column			X	X	
Agriculture		X		X	
Coral reef		X			
Forest	X	X			
Hard bottom		X	X		
Mangrove	X	X			
Sargassum/Floating macroalgae		X			
Shrub/Grassland		X			
Soft bottom		X	X		
Tidal flat	X	X			
Urban		X		X	

[1] *RESTORE Council Restoration Approaches see the 2019 Planning Framework (RESTORE Council, 2019).*

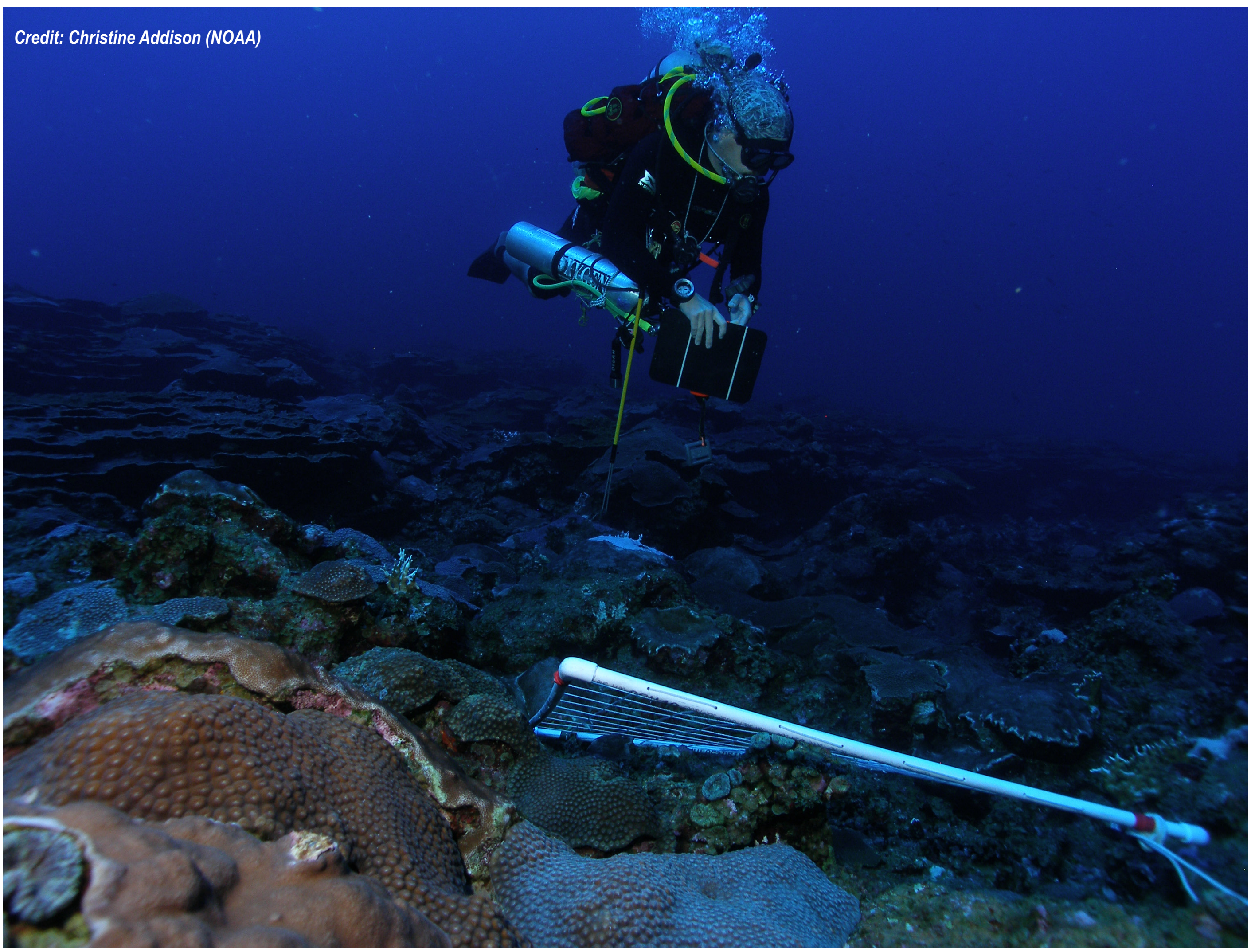


Framework and Process

A conceptual framework was developed to aid in the identification of inventoried programs that may inform the planning, implementation, and evaluation of future RESTORE Council-funded projects (Figure 4). This framework outlines a process in which a practitioner may approach a query of the Inventory using three key filters: 1) habitat types linked to a relevant restoration approach (Table 3); 2) habitat-specific T1 parameters (presented in Chapter 3 and Appendix 3); and 3) MPEs. The product of this query is a compilation of known monitoring and/or mapping efforts that are well-documented and measure core parameters within a habitat, or habitats, linked to a restoration approach. The identification of these programs is a foundational step in further investigating past and current protocols, procedures, data standards, baseline conditions, and, ultimately, potential measures of restoration success.

The following chapter details outputs from this framework by providing examples of two RESTORE Council Restoration Approaches (*Restore oyster habitat* and *Reduce excess nutrients and other pollutants to watersheds*) and the monitoring programs that were identified as most relevant to support or inform those restoration approaches. While these two restoration approaches are highlighted, the process would be the same for the others.

The *Restore oyster habitat* approach was linked solely to the CMAP oyster/bivalve bed habitat type (Table 3). The Inventory was queried to identify all programs that monitored T1 parameters within that habitat type. The restoration approach *Reduce excess nutrients and other pollutants to watersheds* was linked to three CMAP habitat types: water column, agriculture, and urban. Programs that monitored T1 parameters in at least one of the three habitat types were identified. The next chapter further explores the ways in which T1 parameters and MPEs could be used in tandem to inform restoration and monitoring efforts.


Credit: Christine Addison (NOAA)

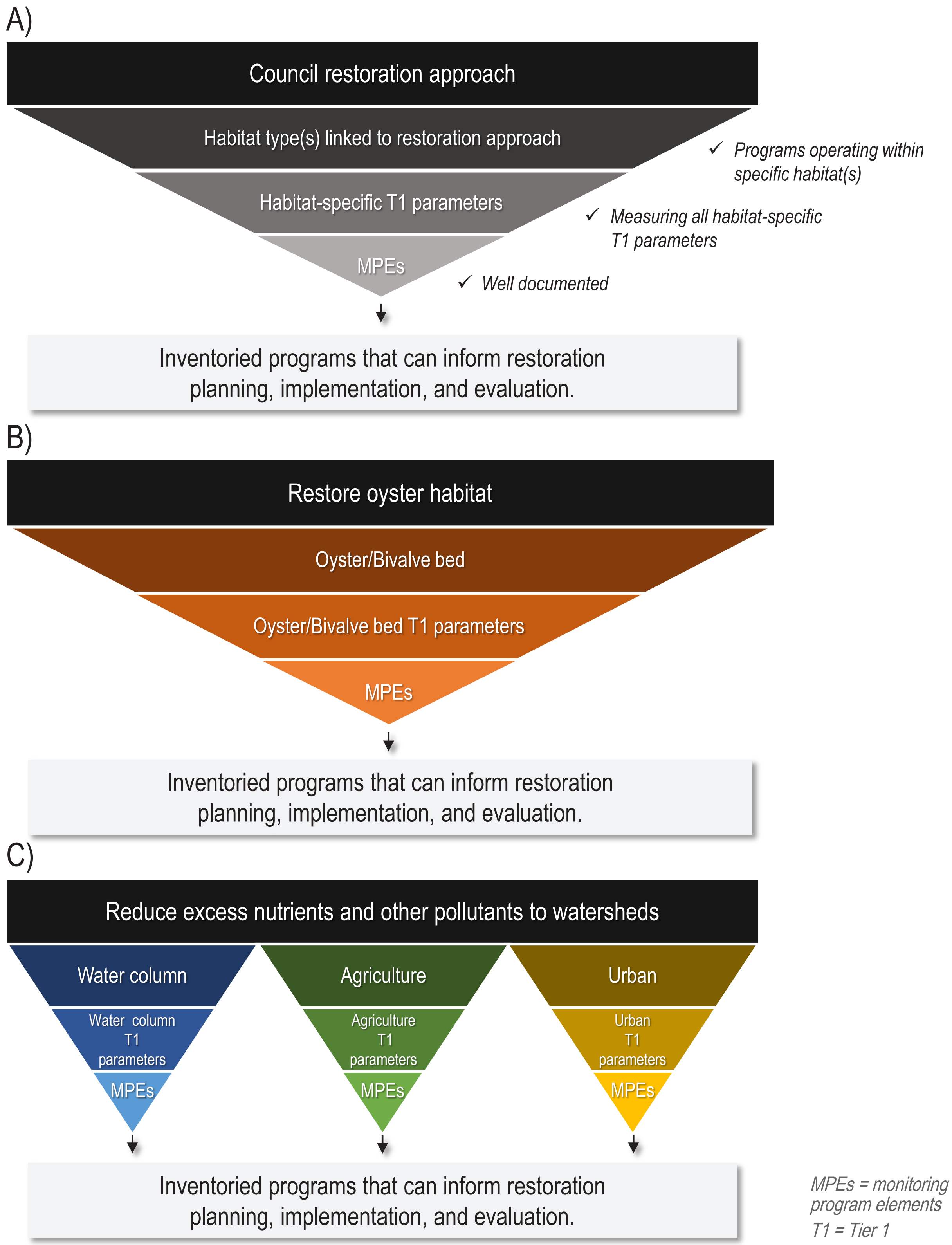


Figure 4. A) General framework of how each program was evaluated to inform RESTORE Council Restoration Approaches. B) Framework of how each program was evaluated to inform the RESTORE Council Restoration Approach *Restore oyster habitat*. C) Framework of how each program was evaluated to inform the RESTORE Council Restoration Approach *Reduce excess nutrients and other pollutants to watersheds*.

Practitioners can utilize the CMAP webtool (https://restorethegulf.gov/cmap) and data package (NOAA NCCOS, 2020) to query the Inventory and its derivatives to identify programs that may inform potential restoration or monitoring activities in the Gulf of Mexico. Once a user identifies relevant habitat types or programs, associated programmatic metadata could be explored more fully. Also, the MPEs can be used as a reference to evaluate whether that program information would be useful. In this chapter, two habitat types (oyster/bivalve bed and water column) were chosen to illustrate the kinds of information users can obtain from the Inventory, and two examples focusing on the RESTORE Council's restoration approaches (*Restore oyster habitat* and *Reduce excess nutrients and other pollutants to watersheds*) are presented to detail how that information can inform restoration or monitoring activities.

Core Parameters of Select Habitat Types

Oyster/Bivalve Bed Core Parameters

A total of 67 programs that measured parameters in the oyster/bivalve bed habitat were identified, and the number of programs that measured each parameter (Figure 5) ranged from 1 program (n = 1.5%; stage) to 37 programs (n = 55.2%; AOHT). The top quartile cutoff for this habitat type was 14 programs (n = 20.9%; turbidity) and included twelve parameters measured by 14–37 programs.

The DT process was applied to the parameters in the top quartile from Figure 5. Of the 12 common Inventory parameters, four were listed by NRDA Trustees (2017) as core (AOHT, size, density, and mortality) and were denoted as T1 parameters (Table 4). Five of the T1 Inventory parameters were identified by NRDA (2017) as supplemental (water temperature, conductance, settlement/recruitment, dissolved oxygen, and turbidity). Only three of those (conductance, settlement/recruitment, and dissolved oxygen) were also identified in at least 50% of the seven additional guidance documents and therefore were categorized as T1. The remaining Inventory parameters were categorized as either T2 (n = 4), T3 (n = 2), or T4 (n = 33). For the full list of parameters, refer to Appendix 3.

Each of the T1 parameters listed in Table 4 are applicable to both monitoring and restoration of oyster/bivalve bed habitats. For example, in order to effectively monitor oyster reefs, resource managers must know the location and extent of oyster reefs. For restoration purposes, habitat maps denoting suitable substrate are important for determining where restoration efforts may be successful. AOHT was the most common T1 parameter (n = 37; 55.2%). The programs in the Inventory and additional guidance documents noted a variety of methods used to map AOHT ranging from seismic/sub-bottom profiles and ancillary data (each used by a single program) to in situ data collection and orthophotography (each used by 16 programs).

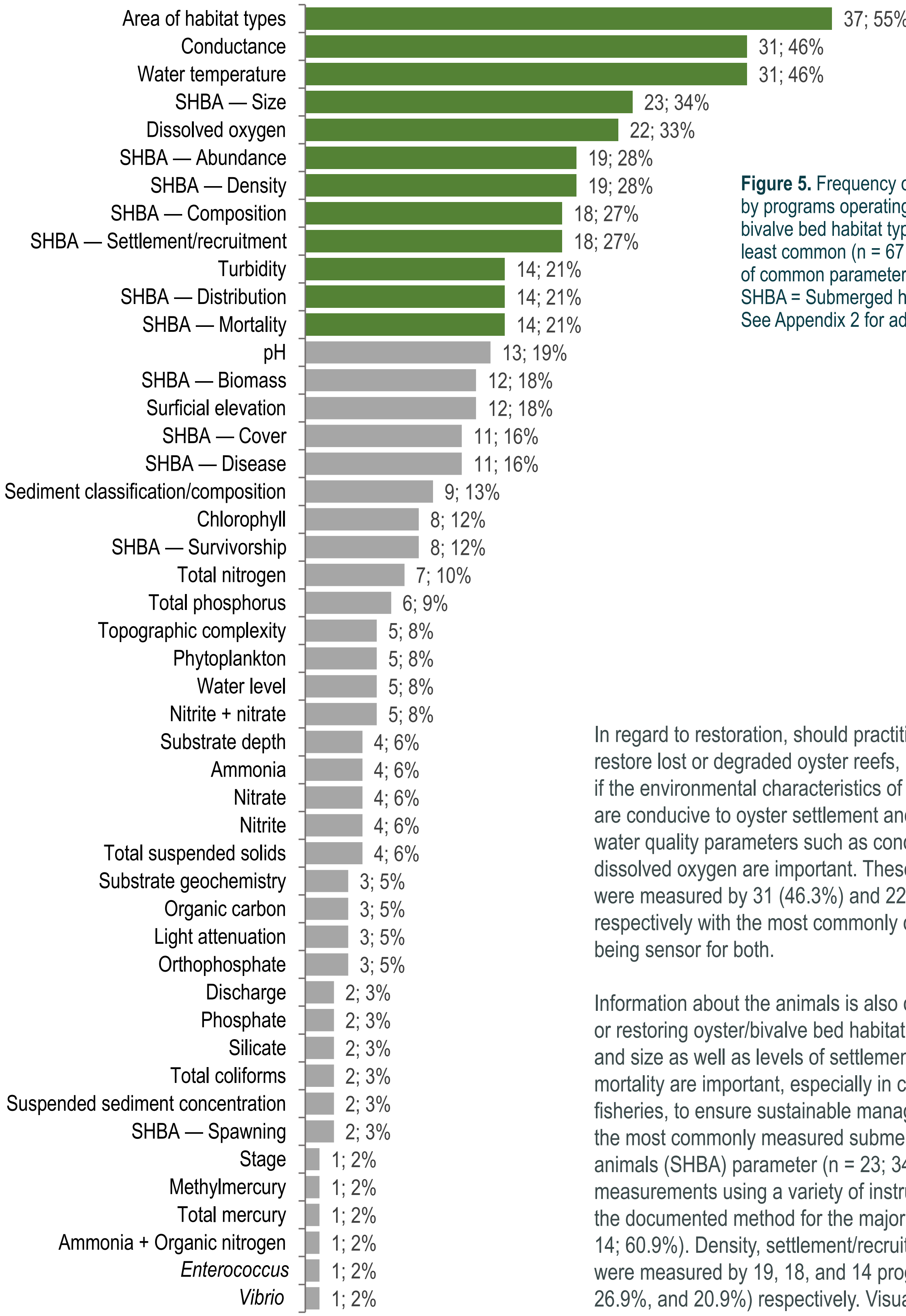


Figure 5. Frequency of parameters monitored by programs operating within the CMAP oyster/bivalve bed habitat type in order from most to least common (n = 67 programs). Top quartile of common parameters is highlighted in green. SHBA = Submerged habitat-building animals. See Appendix 2 for additional habitat types.

In regard to restoration, should practitioners seek to restore lost or degraded oyster reefs, it is critical to know if the environmental characteristics of restoration sites are conducive to oyster settlement and growth. Thus, water quality parameters such as conductance and dissolved oxygen are important. These two parameters were measured by 31 (46.3%) and 22 (32.8%) programs respectively with the most commonly documented method being sensor for both.

Information about the animals is also crucial to monitoring or restoring oyster/bivalve bed habitat. Oyster density and size as well as levels of settlement/recruitment or mortality are important, especially in cases of commercial fisheries, to ensure sustainable management. Size was the most commonly measured submerged habitat-building animals (SHBA) parameter (n = 23; 34.3%) with direct measurements using a variety of instruments or tools being the documented method for the majority of programs (n = 14; 60.9%). Density, settlement/recruitment, and mortality were measured by 19, 18, and 14 programs (28.4%, 26.9%, and 20.9%) respectively. Visual observations were the most commonly documented method for each of those parameters.

Table 4. Oyster/Bivalve bed Tier 1 parameters, methodologies, and units identified within the Inventory and additional guidance documents. Cells that are highlighted in green include methodologies that overlap between those documented in protocol documents obtained through Inventory construction and at least one additional guidance document. See CMAP data package (NOAA NCCOS, 2020) for other habitat types. SHBA = Submerged habitat-building animals. Descriptions of methods and units can be found in the Glossary.

Parameter group	Parameter	# programs measuring parameter	Method	Unit	# programs documenting method
Mapping	Area of habitat types (AOHT)	37	In situ data collection	km^2; m^2	16
			Orthophotography	km^2; m^2	16
			Satellite imagery	km^2; m^2	5
			Sonar	m^2	4
			Other imagery	m^2	1
			Unmanned aerial systems (UAS)	-	2
			Surficial elevation	-	7
			Seismic/subbottom profiles	-	1
			Ancillary data	-	1
Field parameters	Conductance	31	Sensor	mS/cm; ppt; psu; µmhos/cm; µS/cm	7
			Refractometer	ppt; µS/cm	2
			SM 2520	ppt; µS/cm	5
			EPA 120.1	ppt; µS/cm	5
SHBA	Size	23	Instrument/tool measurement	cm; in; mm	14
			GPS	cm; m	1
			Water displacement	L/m^2	1
			Level/rod	m	1
			Survey equipment	cm; m	0
			Sonar	cm; m	0
Field parameters	Dissolved oxygen	22	Sensor	mg/L; ppm	6
			EPA 360.1	mg/L	4
			Titration-based drop count	-	0
SHBA	Density	19	Visual observation	# individuals/m^2; # live individuals/ft^2; # live or dead/m^2; % live of mean; # seed (spat/seed/sack)/acre; # seed (spat/seed/sack)/m^2	13
SHBA	Settlement/ Recruitment	18	Visual observation	# individuals/m^2; # seed (spat/seed/sack)/m^2	9
			Spat monitoring array	# seed (spat/seed/sack)/shell/month	1
			Settlement tile	-	1
			Plankton tow	-	0
			Instrument/tool measurement	-	0
SHBA	Mortality	14	Visual observation	# live or dead/m^2; %	11
			Instrument/tool measurement	mm	1

Every T1 parameter, except for mortality, had at least one method that was implemented by a program and identified by a guidance document (e.g., sensor for both conductance and dissolved oxygen). Generally, these T1 parameters were the most commonly documented parameters and the associated methods tended to be more generalized (e.g., instrument/tool measurement for size). Interestingly, state or federal protocols such as SM 2520 or EPA 120.1 (conductance) were not noted in guidance documents (SM, Standard Methods). Since these kinds of protocols were only noted for water quality parameters, this could reflect guidance documents choosing to focus more on the instrumentation used to measure specific parameters rather than a state protocol. Additionally, many of the guidance documents covered habitats and ecosystems that cross jurisdictional boundaries and focused on instrumentation rather than a specific state or federal protocol.

Three of the seven T1 parameters included at least one method unique to one of the additional guidance documents (i.e., survey equipment for size) that were not documented by any of the programs in the Inventory.

A total of 14 programs mapped oyster reefs and provided accessible methods or protocols. Table 5 summarizes the detailed information compiled for oyster reef mapping programs. Of these programs 79% used a custom, local classification scheme, such as Florida Land Use, Cover, and Forms Classification System (FLUCCS), as opposed to a national standardized scheme. This may be due to the fact that these programs are predominantly local monitoring efforts. A majority of programs (57%) noted the presence of oyster/bivalve reef, but did not provide any additional classification details. However, some programs did include information on oyster condition, reef structure, and tidal zonation.

Oyster mapping programs used a wide variety of data sources, but in situ data collection (e.g., GPS data) and orthophotography were the most common methods found in the Inventory (79%). In situ data may include field data collected for the purpose of ground-truthing habitat maps. Programs generally employed similar methods to create maps. Most programs (86%) used photointerpretation of orthophotography to identify oyster reef locations. To create map features, 79% of programs delineated oyster reef boundaries through digitizing.

The summary tables for the remaining map themes (coral/artificial reef, benthic—SAV, benthic—general, wetlands [non-SAV or oyster reef], beach/dune, land use/land cover, and shoreline position) are in Appendix 4. See Appendix 4 for more detailed explanations of the bins used in these mapping theme summary tables.

Credit: Nicholas Enwright (USGS)

Credit: NOAA

Table 5. Summary of methods and techniques used by programs mapping the oyster reef habitat (n = 14). See Appendix 4 for additional madp themes.

Classification standard	***% of programs***	***Definition***
Custom local scheme	79%	Classification scheme tailored to the habitats and land cover of a particular state, region, or locality, or customized for a certain program or project. Examples include Laswell et al. (1990) and the Everglades Vegetation Classification System.
National standardized scheme	14%	Widely used classification schemes that can be applied to large regions or the entire United States. Examples include Anderson et al. (1976), Cowardin et al. (1979), and Comer et al. (2003).

Classification details	***% of programs***	***Definition***
Oyster reef	57%	Includes the presence of oyster reefs, bars, or beds.
Oyster reef with condition	14%	Includes the presence of oyster habitats with details on condition or health.
Oyster reef with structure	14%	Includes the presence of oyster habitat with details on structural characteristics (e.g., cultched water bottom).
Oyster reef with zonation	14%	Includes the presence of oyster habitat with details on tidal zonation (i.e., subtidal or intertidal).

Data sources	***% of programs***	***Definition***
Ancillary data	7%	See Glossary for definitions.
In situ data collection	79%	
Orthophotography	79%	
Other imagery	7%	
Satellite imagery	14%	
Seismic/subbottom profiles	7%	
Sonar	21%	
Surficial elevation	29%	
UAS	7%	

Mapping unit development	***% of programs***	***Definition***
Pixel-based	7%	Method of map development in which each pixel is classified individually.
Digitizing	79%	Method of converting an image into vector data (i.e., polygons or lines) that involves manual development of linework using photointerpretation.

Mapping algorithm	***% of programs***	***Definition***
Machine learning	7%	Method that utilizes either supervised or unsupervised nonparametric classification algorithms.
Photointerpretation	86%	Manual method of classification or editing in which a trained user visually identifies classes in a remotely sensed image using feature appearance, context, and/or expert opinion.

Other information	***% of programs***	***Definition***
Accuracy assessment	43%	Programs that assess the accuracy of area of habitat type maps.
Change analyses	64%	Programs that analyze change between area of habitat type maps.
Data accessible	50%	Programs with web-accessible data.
Metadata accessible	36%	Programs have metadata that are available on the web.

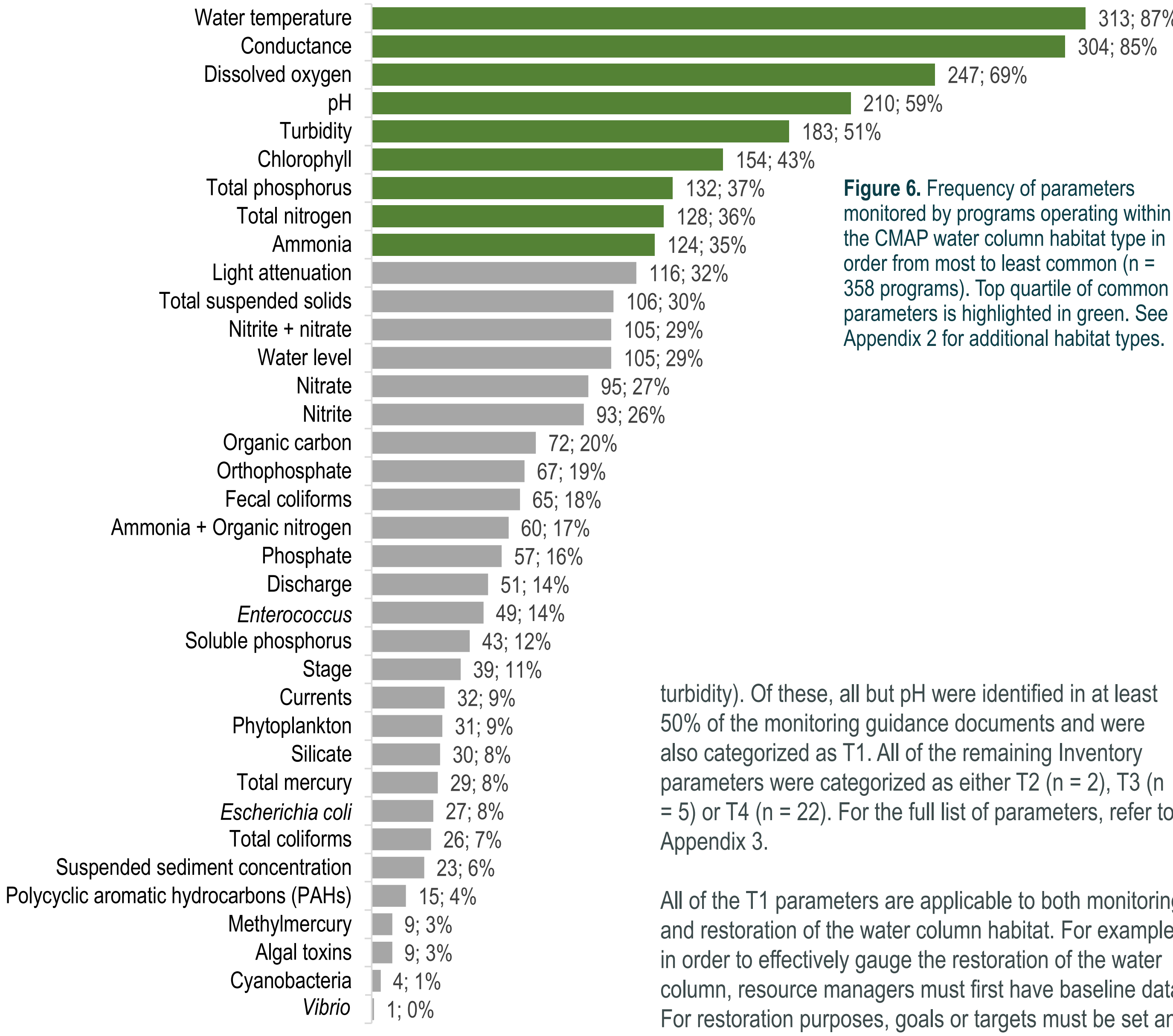


Figure 6. Frequency of parameters monitored by programs operating within the CMAP water column habitat type in order from most to least common (n = 358 programs). Top quartile of common parameters is highlighted in green. See Appendix 2 for additional habitat types.

Water Column Core Parameters

A total of 358 programs that measured parameters in the water column habitat were identified. The number of programs that measured each parameter (Figure 6) ranged from 1 program (n = 0.3%; *Vibrio*) to 313 programs (n = 87.4%; water temperature). The top quartile cutoff for this habitat type was 33.0% and included parameters measured by 124–313 programs.

Of the 10 most common Inventory parameters, three were listed by NRDA Trustees (2017) as core (total phosphorus, total nitrogen, and ammonia) and, thus, were denoted as T1 parameters (Table 6). Five of the parameters were identified by NRDA Trustees (2017) as supplemental (water temperature, conductance, dissolved oxygen, pH, and turbidity). Of these, all but pH were identified in at least 50% of the monitoring guidance documents and were also categorized as T1. All of the remaining Inventory parameters were categorized as either T2 (n = 2), T3 (n = 5) or T4 (n = 22). For the full list of parameters, refer to Appendix 3.

All of the T1 parameters are applicable to both monitoring and restoration of the water column habitat. For example, in order to effectively gauge the restoration of the water column, resource managers must first have baseline data. For restoration purposes, goals or targets must be set and then monitored to make sure that the goals are met and conditions maintained.

Field parameters are the most commonly measured parameters in the Inventory with four of the T1 parameters being field parameters (water temperature, conductance, dissolved oxygen, and turbidity). The high collection frequency of those parameters by programs across the Gulf (i.e., 183–313 programs) offers a wealth of baseline information for restoration or monitoring practitioners. The programs in the Inventory and guidance documents noted a variety of methods used to measure field parameters ranging from the use of sensors to methods defined by the EPA and SM. Sensors were the most commonly listed method for collecting water temperature (n = 96; 30.7%), conductance (n = 93; 30.6%), and dissolved oxygen (n = 78; 31.6%).

Table 6. Water column Tier 1 parameters, methodologies, and units identified within the Inventory and additional guidance documents. Highlighted methodology cells in green indicate methodologies that overlap between those documented in protocol documents obtained through Inventory construction and at least one additional guidance document. See CMAP data package (NOAA NCCOS, 2020) for other habitat types. Descriptions of methods and units can be found in in the Glossary.

Parameter group	Parameter	# programs measuring parameter	Method	Unit	# programs documenting method
Field parameters	Water temperature	313	Sensor	C; F	96
			EPA 170.1	C	51
			USGS TWRI 9	C	5
			SM 2550	C	1
Field parameters	Conductance	304	Sensor	mS/cm; ppt; psu; µmhos/cm; µS/cm	93
			EPA 120.1	ppt; psu; µmhos/cm; µS/cm	52
			SM 2520	ppt; µS/cm	44
			SM 2510	ppt; µmhos/cm; µS/cm	9
			Refractometer	ppt; psu	7
			USGS TWRI 9	µS/cm	5
			EPA 120.6	µS/cm	3
			EPA 120.7	µS/cm	1
Field parameters	Dissolved oxygen	247	Sensor	mg/L; %; ppm; ppt	78
			EPA 360.1	mg/L	52
			Winkler titration	mg/L; ppm	6
			Test kit	mg/L; ppm	4
			EPA 360.2	%	1
Field parameters	Turbidity	183	EPA 180.1	NTU	47
			Sensor	NTU	22
			SM 2130	NTU	15
			Turbidimeter	NTU	8
			Test kit	NTU	2
			USGS I-3860-85	NTU	2
Nutrients	Total phosphorus	132	EPA 365.1	mg/L; µg/L	52
			EPA 365.4	mg/L	17
			SM 4500 P	mg/L; µg/L	13
Nutrients	Total nitrogen	128	EPA 351.2	mg/L	33
			EPA 353.2	mg/L	30
			Auto analyzer	mg/L; µg/L	9
			SM 4500 N	mg/L	8
			EPA 351.1	mg/L	6
			Spectrophotometer	mg/L; µg/L	5
			EPA	mg/L	3
			USGS OFR 00-170	mg/L	2
			USGS OFR 93-125	mg/L	2
			USGS I-3556-77	mg/L	1
Nutrients	Ammonia	124	EPA 350.1	mg/L	49
			Auto analyzer	mg/L; µmol/L	10
			SM 4500 NH3	mg/L	9
			USGS OFR 93-125	mg/L	3

Additionally, some T1 parameters (total phosphorus, total nitrogen, and ammonia) are related to biological and nutrient loads in the water column with at least 34% of programs measuring one or more of these parameters. These parameters could be extremely useful for monitoring or restoration practitioners seeking to address eutrophication or when excess nutrients in the water column lead to excessive biological growth. The most commonly documented methods for these parameters were EPA protocols such as EPA 365.1 for total phosphorus (n = 52; 39.4%).

Every T1 parameter, except turbidity and ammonia, had at least one method that was implemented by an inventoried program and noted within a guidance document (e.g., SM 4500 P for total phosphorus). Sensor, a generalized term that includes multiple instrument types (see Glossary), was the most commonly documented method in the Inventory for those parameters. As stated earlier, a few guidance documents specifically noted federal or state protocols as recommended methods for these parameters. There were a few exceptions in the water column habitat. Both total phosphorus and total nitrogen had a single method (SM 4500 P and SM 4500 N, respectively) that was listed for programs in the Inventory as well as one of the guidance documents (Thayer et al., 2005). Interestingly, EPA protocols were prevalent in the water quality protocols from the Inventory with many of the state protocols being based on EPA methods. The development of consistent monitoring protocols, such as EPA water quality methods, can promote consistency across programs, maximizing data comparability.

Evaluation of Inventoried Programs

Below we highlight the restoration approach examples demontrating how practitioners can use the CMAP Inventory, T1 parameters, parameter/methods analyses, and MPEs to inform their restoration or monitoring efforts in the Gulf of Mexico. Since the tables below are very large and could not fit on a single page, subsets of the programs are presented here (for table legibility). The full tables are available for users through the CMAP data package on the NOAA project page (NOAA NCCOS, 2020).

Table 7 identifies programs measuring T1 parameters and associated MPE percentages which have been linked to the *Restore oyster habitat* restoration approach. Only one program (Apalachicola Bay Oyster Restoration) measured all seven T1 parameters and had complete documentation (an MPE percentage of 100%). If, for example, an oyster reef restoration effort was proposed for the Big Bend area of Florida, the Apalachicola Bay Oyster Restoration program could be useful in the planning and implementation of restoration efforts. Since the Apalachicola Bay Oyster Restoration program was well-documented, restoration practitioners could potentially access protocols or data collected during its lifespan through the Inventory web link or by contacting the POC listed in the Inventory. This is also a local program with a goal aimed at identifying which restoration strategies are best suited for Apalachicola Bay's oyster fishery, but the lessons learned from those efforts could very well be applicable to other areas in the Gulf of Mexico.

Table 7. Subset of programs in the Inventory linked to the *Restore oyster habitat* restoration approach with summaries of the T1 parameters measured and monitoring program element (MPE) presence percentages (e.g., a program with an MPE of 88% addressed 7 of the 8 MPEs). (•) indicates that a program collects that T1 parameter. Green shading indicates a program collects all of the T1 parameters and has 100% of the MPEs. Yellow shading indicates a program collects all of the T1 parameters but does not have 100% of the MPEs. SHBA= submerged habitat-building animals.

Program name	*Area of habitat type*	*Conductance*	*Dissolved oxygen*	*SHBA—Density*	*SHBA—Size*	*SHBA—Mortality*	*SHBA—Settlement/Recruitment*	*Total T1 parameters*	*MPE %*
Apalachicola Bay Oyster Restoration	•	•	•	•	•	•	•	7	100%
Louisiana Annual Oyster Stock Assessment and Sampling	•	•	•	•	•	•	•	7	88%
Louisiana Oyster Program Sampling	•	•	•	•	•	•	•	7	88%
Naples Bay Oyster Habitat Restoration and Monitoring	•	•	•	•	•	•	•	7	88%
Oyster Population Monitoring for Fisheries Management		•	•	•	•	•	•	6	100%
Alabama Oyster Cultch Restoration		•	•	•	•	•	•	6	75%
Alabama Swift Tract Living Shoreline	•	•	•	•	•	•		6	75%
Charlotte Harbor Oyster Habitat Restoration Program	•	•	•	•	•		•	6	75%
Florida Cat Point Living Shoreline Project	•	•	•	•	•		•	6	25%
University of Florida Lone Cabbage Reef Oyster Restoration Project		•		•	•	•	•	5	88%

A total of 67 programs operated in oyster/bivalve bed habitats and were linked to this restoration approach. Ten programs (14.9%) did not measure any of the T1 parameters while 57 programs (85.1%) measured at least one of the T1 parameters. Fourteen programs (24.6%) were completely documented. Depending on the kind of information a restoration or monitoring practitioner may need, programs that did not monitor all of the T1 parameters or all of the MPEs may be useful. For example, three programs (Apalachicola Bay Oyster Restoration, Louisiana Oyster Program Sampling, and Naples Bay Oyster Habitat Restoration and Monitoring) measured all T1 parameters, had moderate documentation (an MPE percentage of 88%), and did not provide accessible metadata. If a restoration or monitoring practitioner is only interested in the kinds of data collected and whether those data are accessible and protocols documented, these programs may be excellent examples to investigate further. Interestingly, accessible metadata was the most commonly missing MPE (30 programs; 52.6%) for programs that measured at least one T1 parameter linked to the *Restore oyster habitat* restoration approach, while the presence of a POC was the least commonly missing MPE. A practitioner interested in a program's metadata, if not available through the Inventory, could potentially seek this information directly from the program POC.

Additionally, linking habitat types to RESTORE Council restoration approaches (Table 3) and CMAP habitat type integration could be a helpful resource to quickly identify common parameters or methods. Time spent searching the literature or program websites could be more effectively directed to the Inventory, where monitoring practitioners could more efficiently determine which parameters or methods would be most useful for their efforts or most comparable across the Gulf of Mexico. For example, all of the programs that measured all seven T1 parameters (Apalachicola Bay Oyster Restoration, Louisiana Oyster Program Sampling, Louisiana Annual Oyster Stock Assessment and Sampling, and Naples Bay Oyster Habitat Restoration and Monitoring) used visual observation methods to measure oyster density. Visual observation was also the most commonly documented method for density in oyster/bivalve bed habitats. Thus, for an oyster monitoring effort that is getting started, visual observations may be the preferred choice to measure oyster density from a comparability perspective.

Tables 8, 9, and 10 identify the programs which have been linked to the *Reduce excess nutrients and other pollutants to watersheds* restoration approach. Unlike the oyster example, this restoration approach is linked to three habitat types. A total of 381 programs were assessed that operated in at least one of the three relevant habitat types: water column (n = 358; Table 8), agriculture (n = 29; Table 9), and urban (n = 30; Table 10). Sixty-two (17.3%) programs measured all seven T1 water column parameters and 17 (27.4%) of those had complete documentation. Three (10%) of the 29 programs that operated in the agriculture habitat measured both agriculture T1 parameters; two of those programs (66.7%) had complete documentation. Of the 30 programs that collected data in urban areas, about half (14; 47%) measured more than one urban T1 parameter and seven (50%) of those programs had complete documentation.

Credit: Michael Lee (USGS)

Table 8. Subset of programs in the Inventory that operated in the water column habitat and are associated with the *Reduce excess nutrients and other pollutants to watersheds* restoration approach with summaries of the Tier 1 (T1) parameters measured and monitoring program element (MPE) presence percentages (e.g., a program with a MPE of 88% addressed 7 of the 8 MPEs). (•) indicates that a program collects that T1 parameter. Green shading indicates that a program collects all of the T1 parameters and has 100% of the MPEs. Yellow shading indicates that a program collects all of the T1 parameters but does not have 100% of the MPEs.

Program name	Conductance	Dissolved oxygen	Turbidity	Water temperature	Ammonia	Total nitrogen	Total phosphorus	Total T1 parameters	MPE %
National Ecological Observatory Network (NEON)	•	•	•	•	•	•	•	7	100%
National Wetland Condition Assessment	•	•	•	•	•	•	•	7	100%
Sarasota County Surface Water Quality and Habitat Monitoring	•	•	•	•	•	•	•	7	100%
City of Fort Myers National Pollutant Discharge Elimination System (NPDES) Outfall Monitoring	•	•	•	•	•	•	•	7	75%
Mississippi Statewide Assessment (Total Maximum Daily Load) Program	•	•	•	•	•	•	•	7	38%
Florida LAKEWATCH Program	•			•		•	•	4	100%
Hypoxia in the Northern Gulf of Mexico	•	•	•	•				4	88%
Alabama Water Watch (AWW)		•	•	•				3	88%
Ecosystem Impacts of Oil and Gas Inputs to the Gulf (ECOGIG)	•	•		•				3	13%
National Data Buoy Center (NDBC) C-MAN and Moored Buoys Program	•			•				2	100%

Table 9. Subset of programs in the Inventory that operated in the agriculture habitat and are associated with the *Reduce excess nutrients and other pollutants to watersheds* restoration approach with summaries of the Tier 1 (T1) parameters measured and monitoring program element (MPE) presence percentages (e.g., a program with a MPE of 88% addressed 7 of the 8 MPEs). (•) indicates that a program collects that T1 parameter. Green shading indicates that a program collects all of the T1 parameters and has 100% of the MPEs. Yellow shading indicates that a program collects all of the T1 parameters but does not have 100% of the MPEs.

Program name	Area of habitat type	Plant/Macroalgae—Composition	Total T1 parameters	MPE %
Ecological Mapping Systems of Texas (EMS-T)	•	•	2	100%
National Ecological Observatory Network (NEON)	•	•	2	100%
Horse Creek Stewardship Program	•	•	2	88%
Coastal-Change Analysis Program (C-CAP)	•		1	100%
Coastal Mapping Program	•		1	100%
Cropland Data Layer (CDL)	•		1	100%
National Land Cover Database (NLCD)	•		1	100%
National Wetland Condition Assessment		•	1	100%
Sarasota County Surface Water Quality and Habitat Monitoring	•		1	100%
Surface-Water Flow Through the Seminole Tribal Lands within the Greater Everglades	•		1	100%

Table 10. Subset of programs in the Inventory that operated in the urban habitat and are associated with the *Reduce excess nutrients and other pollutants to watersheds* restoration approach with summaries of the Tier 1 (T1) parameters measured and monitoring program element (MPE) presence percentages (e.g., a program with a MPE of 88% addressed 7 of the 8 MPEs). (•) indicates that a program collects that T1 parameter. Green shading indicates that a program collects all of the T1 parameters and has 100% of the MPEs. Yellow shading indicates that a program collects all of the T1 parameters but does not have 100% of the MPEs.

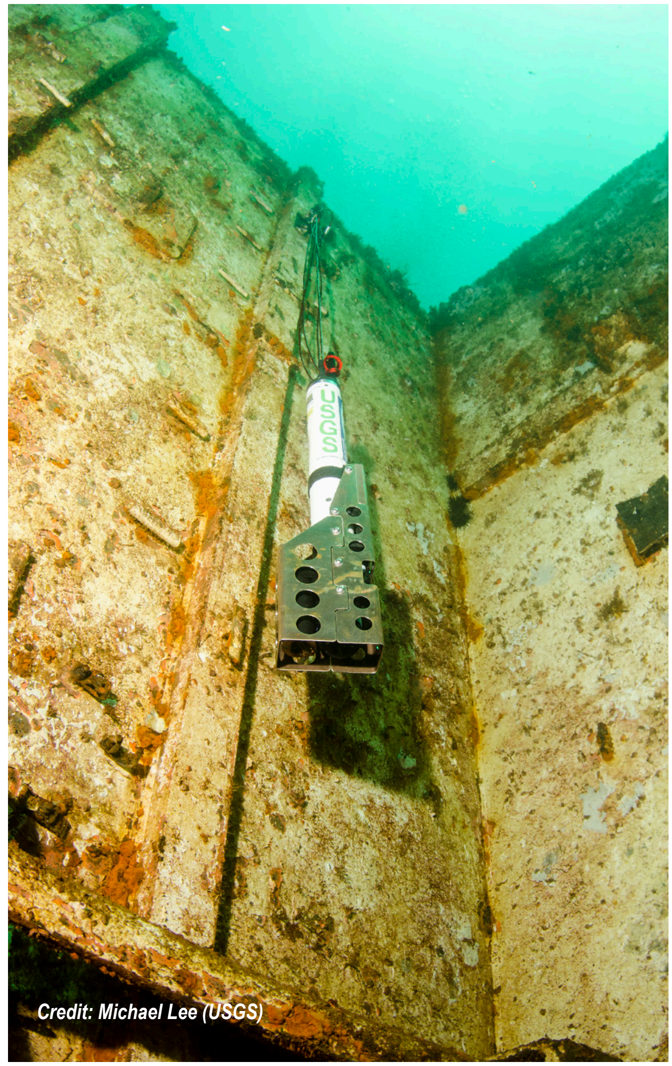
Program name	Area of habitat type	Total T1 parameters	MPE %
Barrier Island Comprehensive Monitoring (BICM) Program	•	1	100%
Coastal-Change Analysis Program (C-CAP)	•	1	100%
Coastal Mapping Program	•	1	100%
Ecological Mapping Systems of Texas (EMS-T)	•	1	100%
National Land Cover Database (NLCD)	•	1	100%
Sarasota County Surface Water Quality and Habitat Monitoring	•	1	100%
Surface-Water Flow Through the Seminole Tribal Lands within the Greater Everglades	•	1	100%
Forest Inventory and Analysis (FIA) Program	•	1	86%
Mississippi Division of Marine Resources (MDMR) Shoreline Erosion in Port Areas	•	1	86%
National Gap Analysis Project	•	1	86%


Credit: Nicholas Enwright (USGS)

While no single program collected all the T1 parameters across all three habitat types, there were two (National Ecological Observatory Network and Sarasota County Surface Water Quality and Habitat Monitoring) that collected all but one. The National Ecological Observatory Network program measured all of the T1 water column and agriculture parameters, but not the single urban T1 parameter. Sarasota County Surface Water Quality and Habitat Monitoring, however, collected all the T1 parameters except plant/macroalgae—composition in the agriculture habitat type. A third program (National Wetland Condition Assessment) measured all but two T1 parameters (AOHT for both agriculture and urban habitats). All three of these programs had complete documentation, so much like the Apalachicola Bay Oyster Restoration program, they could be very useful for restoration or monitoring practitioners or city officials looking to reduce nutrient or pollutant inputs into watersheds.

Even though only a few programs measured T1 parameters across all three habitats, not every T1 parameter may be useful in the context of this restoration approach. Since the restoration approach focuses primarily on nutrient and pollutant inputs into watersheds, parameters like conductance, dissolved oxygen, and water temperature may not be as important as the nutrient parameters associated with the water column habitat for those seeking to reduce nutrient and pollutant inputs. If this is the case for a user, then a total of 79 programs operating in the water column habitat measure all three nutrient parameters and 19 of those had complete documentation.

Additionally, in the absence of direct water quality measurements, parameters like plant/macroalgae—composition in the agriculture habitat type and AOHT in both agriculture and urban contexts may provide clues for restoration practitioners to investigate. Because different crops have different fertilizer or pesticide needs, knowing the plant composition of agricultural areas may reveal the types of nutrient or pollutant inputs making their way from fields into the watersheds. Thus, programs like the Texas Stream Team or Ecological Mapping Systems of Texas, which did not measure ammonia, total nitrogen, or total phosphorus in the water column but did measure plant composition in agricultural settings, could provide points of contact or data for restoration practitioners to investigate. Knowing where agricultural and urban areas are and how large they are (e.g., data provided by the Cropland Data Layer Program) could also be important for determining where nutrients or pollutants are most likely to enter the environment. Ten programs mapped agricultural and urban areas, and most of them had complete documentation (n = 6; 60%).



Credit: Michael Lee (USGS)

Similar to the *Restore oyster habitat* restoration approach, the most commonly missing MPE in the *Reduce excess nutrients and other pollutants to watersheds* restoration approach was accessible metadata. More than half of programs measuring at least one T1 parameter across all three habitat types did not have accessible metadata (n = 184; 52.9%). Additionally, the presence of a POC was the least commonly missing MPE for this restoration approach. Thus, restoration practitioners may need to use the POC information to locate needed information when metadata is unavailable or potentially incomplete.

4 Uses, Benefits, Limitations, and Future Recommendations

Credit: USGS

General Conclusions

The parameter and methods analysis in this report builds on previous efforts, such as the NRDA Trustees (2017), which laid a valuable foundation on which to base the analysis. Many of the subject matter experts that participated in the development of the NRDA Trustees (2017) guidance also participated on the CMAWG. The ability to utilize and incorporate input and recommendations from the CMAWG, and then iterate the results through the MCoP to get feedback from the practitioner's perspective, has provided and will continue to provide buy-in and utility of the guidance.

In order for the results to be broadly applicable to the restoration, conservation, and resource management communities across the Gulf of Mexico, our analysis of parameters and methods was conducted by habitat type. Programs in the Inventory monitor parameters associated with habitat structure and functions, as well as parameters that can have indirect influences on those habitats. Understanding what parameters are being collected and the methods employed, regardless of the intent or objective of the specific monitoring program, informs how comparable and consistent data are across the Gulf of Mexico.

Consistency is important when trying to implement restoration at an ecosystem scale, as required in RESTORE's Comprehensive Plan Update (RESTORE Council, 2016), Planning Framework (RESTORE Council, 2019), and NRDA's Programmatic Damage Assessment and Restoration Plan (NRDA Trustees, 2016). The similarity in goals between RESTORE and DWH NRDA, and approaches used to achieve those goals, made it important to try to align monitoring parameter and method recommendations between the two programs. We were able to align core and supplemental parameters from NRDA Trustees (2017) with five habitat types in our analysis by incorporating a priority criteria in our decision tree.

In comparing the commonly measured parameters documented by CMAP to those core performance monitoring parameters highlighted by NRDA Trustees (2017), we found considerable agreement in habitats across the Gulf of Mexico. Overall, 81% of core parameters identified by NRDA were classified as T1 parameters by CMAP. For example, five parameters were considered core for emergent marsh (i.e., plant composition, % cover of vegetation, plant survivorship, mapped area of marsh, and surficial elevation) under NRDA Trustees (2017). All ranked in the top quartile in the CMAP analysis except for plant survivorship (plant/macroalgae—survivorship, Appendix 2). This parameter was identified as core in NRDA Trustees (2017) only if a project incorporates vegetation planting. Knowing that the CMAP Inventory includes both restoration and resource monitoring programs, it was not surprising to see plant/macroalgae—survivorship ranked in the third quartile with only 10 inventoried programs measuring that parameter. Three other parameters were in the top quartile within the CMAP Inventory (sediment composition, conductance/salinity, and vertical accretion). These three parameters, and many others, were identified as supplemental for NRDA.

Core monitoring parameters identified by NRDA and CMAP for SAV included AOHT, vegetation species composition, and percent cover. For the SAV habitat, plant survivorship was identified as core by NRDA when vegetation was planted as a component of a project, and CMAP identified it as T3. CMAP identified many environmental condition field parameters as T1 including temperature, conductance/salinity, dissolved oxygen, turbidity/light attenuation, and pH, whereas NRDA identified only a few of them as supplemental.

When comparing oyster parameters, NRDA identified oyster demography (i.e., density, size and mortality) to be important, which was supported by the findings from this analysis. However, CMAP also identified water temperature, conductance/salinity, and dissolved oxygen as T1 parameters, as over 30% of the programs monitoring within an oyster habitat measured these parameters. NRDA identified water temperature and salinity as supplemental. NRDA also suggested two parameters (surficial elevation and reef volume) that were either classified as T3 (surficial elevation) or not in the Inventory at all. These parameters not only describe the resource but are also informative to project construction metrics (i.e., was the project designed to specifications). This demonstrates the difference between restoration monitoring under NRDA and resource monitoring that is more commonly represented in the Inventory.

Beaches and barrier islands had the same core parameters (area, shoreline position, and elevation) identified by NRDA. Under CMAP, shoreline position is actually captured under mapping–AOHT. CMAP identified those three parameters as core as well as accretion and plant/macroalgae—composition for both habitats. Additionally, beaches also included plant/macroalage—percent cover and sediment classification/composition as core. NRDA only included vegetation as a performance monitoring parameter if it was tied to a project-specific objective.

Although there was significant agreement between CMAP and NRDA in the identification of core parameters for the five habitat types described above, CMAP typically identified additional core parameters beyond those in the NRDA guidance. The parameters identified primarily address environmental conditions such as water quality which are important explanatory parameters critical in understanding the structural response of habitats. CMAP also identified additional parameters that get at habitat function, such as vertical accretion. Marshes vertically accrete to build elevation in response to sea level rise and subsidence, and this parameter is important to inform coastal marsh and barrier island habitat sustainability and vulnerability.

Uses and Benefits

Many restoration and resource management activities are targeted for specific habitats. Evaluating and identifying core parameters and methods at the habitat level provides information that can be aggregated spatially and temporally within a single habitat or across multiple habitats. The habitat level of aggregation is particularly useful because restoration techniques and approaches applied in different habitats (e.g., sediment placement in a salt marsh versus a freshwater marsh) commonly have different objectives associated with them. Identifying common parameters across adjacent habitats can support a more ecosystem-based monitoring approach and allow evaluations of restoration efforts that may have cumulative impacts across multiple habitat types. In addition to implementing restoration projects, the RESTORE Council is supporting the development of similar programs across the Gulf states, such as water quality improvement programs. The core parameters and methods identified by this effort could inform a programmatic monitoring approach to water quality that could cross political boundaries and contribute to a more consistent suite of core parameters measured and data available across the Gulf states.

Credit: Nicholas Enwright (USGS)


Credit: Samuel Rendon (USGS)

Data availability and documentation level are the main characteristics needed to gauge data comparability. In several MCoP workshops, practitioners noted that data comparability is of utmost concern and that data discovery can often be a lengthy and tedious process that sometimes winds up fruitless. Core parameters and MPEs identified by CMAP should improve practitioners' efficiency in the data discovery process and allow for more targeted queries of the data type and quality desired. In documenting the programs conducting monitoring efforts within the 20 habitat types selected, we found a number of habitats that have limited information available. Identifying commonly measured parameters and methods in poorly known habitats such as sargassum/floating macroalgae and karst/barren provides a useful starting point for establishing monitoring guidelines and best practices.

The CMAP products could be used as source materials when developing or updating monitoring and adaptive management plans or other monitoring program guidance documents. The RESTORE Council requires that projects and programs develop an Observational Data Plan (ODP; RESTORE Council, 2018) and the ODP should identify "quantitative metrics and parameters by which the project or program will be assessed" and "ensures that data are collected properly for data comparison and compatibility." The identification of most frequently collected parameters by habitat type and restoration approach, most common monitoring methods, most common monitoring units, and level of program documentation (e.g., MPEs) from this effort can be used to support ODP development.

Limitations and Recommendations

All parameters were linked to a specific CMAP Inventory habitat type in our analyses. Because the Inventory contains programmatic-level descriptive metadata, rather than site and/or parameter-specific information, habitat type classifications were not fully apparent from the metadata, and the CMAP team determined the classifications from available protocol documents. Inconsistencies in how habitat types were documented may prohibit a user from replicating our approach by solely using the Inventory. Programs where there were uncertainties in our classification of habitat can be revisited during future updates to the Inventory.

Our analysis of the Inventory found a wide variety of documented methods that were very similar in approach. We binned the similar methods into categories such as "sensor" and "visual observation" to facilitate the evaluation of common methodologies. Although appropriate as an initial evaluation, users will need to examine the variability in measurement approaches (i.e., accuracy and precision) within a binned category to determine appropriateness for data aggregation and analysis.

In this report, parameters were evaluated by both frequency of occurrence in the Inventory and appearance in guidance documents, but inventoried programs and guidance documents may view parameters through different lenses and may not be fully comparable for setting restoration monitoring guidelines. Several key guidance documents, such as NRDA Trustess (2017), are restoration-focused and prioritize monitoring specific performance measures to answer a restoration question or trigger an adaptive management mechanism. The Inventory, however, included both restoration-focused monitoring programs as well as general monitoring programs that are not tied to a restoration question or effort. We found this approach to be a strength rather than a limitation as both restoration actions and management actions overlap on the geographic landscape and commonly have similar or synergistic objectives that are being monitored. This can facilitate the evaluation of common parameters at larger than project scales that meet multiple objectives. This difference in monitoring objectives could explain why some common restoration-focused parameters are not labeled as T1 in this effort.

It is important that users weigh the results to their specific needs since the parameter quartile approach may under- or over-estimate the gauging of commonality. Our approach in using a consistent decision rule was not intended to limit the selection of any parameter/method that may be relevant to a specific need. A user may therefore choose a 2nd quartile parameter that meets their objectives while also finding strong consistency with other programs in the Inventory.

This report outlined how we used NRDA Trustees (2017) and other restoration monitoring guidance documents to identify core parameters and methods. Based on our results, the following T1 parameters for the five habitat types identified below are recommended for consideration as additional core parameters to those identified in NRDA Trustees (2017):

Emergent marsh
- Conductance/salinity
- Vertical accretion
- Sediment classification/composition

Submerged aquatic vegetation
- Water temperature
- Conductance/salinity
- Dissolved oxygen
- Density
- Turbidity
- Sediment classification/composition
- Light attenuation
- pH

Oyster/Bivalve bed
- Settlement/recruitment
- Conductance/salinity
- Dissolved oxygen

Barrier island
- Vertical accretion
- Plant species composition

Beach/dune
- Vertical accretion
- Plant species composition
- Plant percent cover
- Sediment classification/composition

The report also identified that accessible metadata was commonly missing from monitoring programs in the Inventory and we recommend monitoring programs invest in making metadata web accessible. Comprehensive evaluations of metadata are now enhanced through the use of machines that can find and use data, and guidance has been developed to enhance data mining and advance discovery using FAIR (Findability, Accessibility, Interoperability, and Reuse) guiding principles (Wilkinson et al., 2016). Utilizing these principles in the future could further advance discovery, processing, and re-use of data on the web.

This report and the recommendations herein were developed as supporting materials for the ODP to help applicants identify “consistent local or regional monitoring efforts, methods, or standards”, and “potentially complementary datasets.” The ODP guidance identifies that “applicants will be expected to adopt, utilize, and reference applicable standard monitoring protocols (e.g., those used by appropriate Gulf of Mexico resource agencies), and leverage ongoing monitoring efforts, as appropriate, to facilitate cross-program assessment of project performance within Gulf of Mexico ecosystem recovery efforts (i.e., NRDA and NFWF programs).” The CMAWG may use the report to make recommendations to the Council on specific content that should be added to the ODP guidance. This report and the other published CMAP documents (NOAA and USGS, 2019a; NOAA and USGS, 2019b; NOAA and USGS, 2020) and web-visualization tool (https://restorethegulf.gov/cmap/) should advance the discovery and use of monitoring information that may provide a better understanding of the effects of our restoration and management actions on our diverse Gulf of Mexico habitats.


Credit: Nicholas Enwright (USGS)

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CMAP Glossary

UNITS

List of units used throughout this report, including Appendices.

Unit	Definition
C	degree Celsius
cells/mL	cells per milliliter
cfs	cubic feet per second
cfu/100 mL	colony forming units per 100 milliliters
cm	centimeter
cm/s	centimeters per second
F	degree Fahrenheit
ft	foot
g/m^2	grams per square meter
in	inch
km	kilometer
km^2	square kilometer
kpar	diffuse attenuation coefficient of photosynthetic available radiation
L/m^2	liters per square meter
lux	luminous flux per unit area
m	meter
m^2	square meter
mean % oysters/size class	mean percentage of oysters per size class
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter
mm	millimeter
mpn/100 mL	most probable number of organisms per 100 milliliters
m/s	meters per second
m^3/s	cubic meters per second
mS/cm	millisiemens per centimeter
ng/g	nanograms per gram
ng/L	nanograms per liter
NTU	nephelometric turbidity unit
# individuals/m^2	number of individuals per square meter
# individuals/size class	number of individuals per size class
# live individuals/ft^2	number of live individuals per square foot
# live or dead/m^2	number of live/dead per square meter
# seed (spat/seed/sack)/acre	number of spat/seed/sack per acre
# seed (spat/seed/sack)/m^2	number of spat/seed/sack per square meter
# seed (spat/seed/sack)/shell/month	number of spat/seed/sack per shell per month
%	percent
% live of mean	percent live of mean
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
psu	practical salinity unit
Standard Unit	Standard Unit (SU) for measuring pH
µE/s/m^2	microeinsteins per second per square meter
µg/g	micrograms per gram
µg/kg	micrograms per kilogram
µg/L	microgram per liter
µmhos/cm	micromhos per centimeter
µmol/L	micromole per liter
µS/cm	microsiemens per centimeter

TERMS

Habitat Types

Habitat types monitored/mapped/observed within the program extent.

Agriculture: Land areas used for the cultivation or breeding of animals and plants to provide food, fiber, medicinal plants and other products to sustain and enhance life.

Artificial reef: An underwater structure built by humans to promote marine life.

Barrier island: A long broad sandy island lying parallel to the mainland that is built up by the action of waves, currents, and winds and that protects the shore from the effects of the ocean.

Beach/Dune: The area above a mean low water mark extending across the backside of the associated sand ridges, which may, or may not be vegetated.

Coral reef: Ecosystems held together by structures formed by the growth and deposition of calcium carbonate by coral.

Deep sea benthic communities: The assemblage of organisms that live in and above the sediments forming the deep ocean floor, including corals, worms, clams, crabs, lobsters, sponges, and microorganisms.

Emergent marsh: An area of low-lying wetland dominated by erect, rooted, herbaceous plant species rather than woody plant species.

Forest: A large area dominated by trees and can include upland (dry) and riverine forests and swamps.

Hard bottom: Nearshore/offshore areas dominated by a hard substrate.

Karst/Barren: Includes barren rock outcrops (exposures of rock, either natural or due to mining or construction), and karst formations (caves and sinkholes). Sinkholes may be barren, grass- or water-filled, or forested.

Mangrove: Coastal wetlands dominated by mangrove species.

Oyster/Bivalve bed: Large aggregations of aquatic mollusks that have a compressed body enclosed within a hinged shell; can occur in either fresh or marine environments.

Sargassum/Floating macroalgae: Genera of large brown algae that float in island-like masses.

Shrub/Grassland: Non-saline, grass-dominated sections of the coastal plain, generally associated with the occurrence of heavy clay soils.

Submerged aquatic vegetation (SAV): Benthic macroalgae and aquatic plants that grow to the surface of the water but do not emerge from it. Submerged aquatic vegetation are submerged monocotyledonous plants with narrow grass-like leaves often occurring in dense underwater meadows. Benthic macroalgae are large aquatic photosynthetic organisms attached to the benthos and often occurring in dense beds. Both of these habitats can occur in both freshwater and saltwater.

Soft bottom: Nearshore/offshore areas dominated by a soft substrate.

Tidal flat: Nonvegetated coastal wetlands within the intertidal zone, usually characterized by mud deposited by tides.

Urban: Land areas used primarily for human settlement, often with large population sizes and infrastructure built on the environment.

Water column: Conceptual column of water that extends from the water's surface to porewater amongst sediment grains and groundwater.

Habitat Monitoring Parameters and Methods

Parameters that provide information on the condition and/or state of habitats for broad categories such as corals, oysters, plants, sediment, and other physical characteristics of the environment. Methods listed under parameters are select examples and not a complete list.

Abiotic: The non-living chemical and physical aspects of the environment that affect living organisms and the functioning of ecosystems. Within the CMAP application, abiotic is a general habitat monitoring parameter that includes substrate metrics and coastal processes parameter groups.

Abundance: A measure of the number of individuals of a species that exist within a community. Within the CMAP application, abundance is a habitat monitoring parameter subgroup within the general parameters associated with submerged habitat-building animals and plants/macroalgae.

List of example measurement methods:

Benthic grab and sieve: Instrumentation used to collect sediment and/or organisms living on or below the surface of the benthos. The sediment and/or organisms can then be sifted through and examined.

Calculation/extrapolation: Includes larger scale abundance, survivorship, substrate texture class, colony surface area, density, and biomass calculations and estimates based on observations in quadrats or measures of diameter at breast height, or sediment/soil samples; calculations of bulk density; estimates of subsidence/vertical accretion of shorelines; estimates of primary productivity based on biomass measures; can include inverse distance-weighted methods of spatial interpolation for distribution.

Instrument/Tool measurement: An overarching term used to encompass several tools used to collect habitat monitoring information. This can include balances/scales, calipers, chain and tape, clinometers/extendable rods, densiometers, diameter tape, depth gauges, measuring sticks/tape, and rangefinders. These tools and instruments are used to collect a wide variety of information such as bulk density and moisture content of soil/sediment samples, biomass, plant/animal size, canopy cover, vertical relief of oyster or coral reefs, and substrate depth.

Photo/Video imagery: An overarching term used to encompass any measurement or observation made via photographic or video imagery at scales ranging from aerial surveys to repetitive photo sites. This may include any of the following: species or community composition of benthic or terrestrial ecosystems, observed instances of disease, coral bleaching, habitat distribution, habitat cover, density, size of organisms, records of survivorship, mortality, and characterized elevation.

Point intercept method: Method used to characterize species and community composition and structure as well as vegetation cover at specific intervals along a transect.

RTK GPS: Real-time kinematic global positioning system (RTK GPS) is an instrument that uses satellite-based positioning systems to characterize height and position (e.g., x, y, z). This instrument is used for many aspects of habitat monitoring, but a few examples include creating marsh shoreline profiles and/or surveying oyster reefs.

Satellite imagery: Multispectral imagery that is collected from satellite sensors (e.g., Landsat, Sentinel-2).

Sonar: Sound navigation and ranging (sonar) includes remote sensing instruments that use a sound transmitting and receiving system to characterize subaqueous settings. This category includes instruments used to estimate water depth and map the seafloor (e.g., single beam echosounder [SBES] and multibeam echosounder [MBES]), as well as those used to search for and detect objects on the seafloor (e.g., side-scan sonar) or characterize the sediment (e.g., sub-bottom profilers).

Visual observation: An overarching term used to encompass any estimates or observations made visually. This can involve field counts of organisms; estimates of cover; observations of soil/sediment type, and species composition, and density; notations of mortality; survivorship; disease/bleaching; and settlement/recruitment of target organisms in a wide array of habitat types.

Biomass: The total mass of organisms in a given area or volume. Within the CMAP application. biomass is a habitat monitoring parameter subgroup within the general parameters associated with submerged habitat-building animals and plants/macroalgae. Biomass includes any measures of biomass (i.e., above ground plant biomass, wet/dry biomass, oyster biomass).

Methods:

Calculation/Extrapolation (see Abundance)

Instrument/Tool measurement (see Abundance)

Leaf litter trap: Instrument used to collect leaf litter that falls from tree canopies for use in determining litterfall rates and biomass.

Photo/video imagery (see Abundance)

Root ingrowth core: Method of determining belowground biomass by placing a mesh bag of root free soil in the root zone. The bag is removed after a period of time and the root growth inside can be quantified.

Shear vane test: Instrument used to measure the shear strength of soil as a proxy for below-ground biomass. The shear vane is inserted into the soil and the amount of torque required to shear the soil is recorded.

Visual observation (see Abundance)

Bleaching: Process whereby coral colonies or sea anemones lose their color, either due to the loss of pigments by microscopic algae (zooxanthellae) living in symbiosis with their host organisms (polyps/anemones) or because the zooxanthellae have been expelled. Within the CMAP application, bleaching is a parameter subgroup within the general parameter submerged habitat-building animals.

Methods:

Photo/Video imagery (see Abundance)

Visual observation (see Abundance)

Canopy extent/structure: The organization or spatial arrangement of a plant canopy. Within the CMAP application, canopy extent/structure is a parameter subgroup contained in the plants/macroalgae general parameter.

Methods:

Instrument/Tool measurement (see Abundance)

Photo/Video imagery (see Abundance)

Relative transparency diagram: Method wherein forest canopy is examined by assessing the transmission of light through the foliage of individual trees. Branches that support foliage are identified, and the amount of light passing through the crown is estimated.

Satellite imagery (see Abundance)

Visual observation (see Abundance)

Coastal processes: Physical processes influencing the coastal zone. Within the CMAP application, coastal processes is a parameter group within the abiotic general parameter and includes vertical accretion and subsidence subgroups.

Composition: The makeup or contribution of all the groups of organisms living together in the same area. Within the CMAP application, composition is a parameter subgroup of the submerged habitat-building animals and plants/macroalgae general parameters. Composition includes species and community composition.

Methods:

Benthic grab/sieve (see Abundance)

Photo/Video imagery (see Abundance)

Point intercept method (see Abundance)

Satellite imagery (see Abundance)

Visual observation (see Abundance)

Cover: A measure of the amount of area covered by organisms or substrate types within a given extent. Within the CMAP application, cover is a parameter subgroup of the submerged habitat-building animals and plants/macroalgae general parameters. Cover includes percent cover, acreage, and/or basal area measurements.

Methods:

Benthic grab/sieve (see Abundance)

UAS: Unmanned aerial systems (UAS) include an unmanned aerial vehicle (UAV), as well as the ground control, camera system, and other required systems associated with the UAV.

GPS: Global positioning system (GPS) is an instrument that uses satellite-based positioning systems to characterize height and position (e.g., x, y, z). This instrument can be used to characterize shoreline and/or reef height, area, and/or elevation as well as seagrass beds. This includes differential GPS measurements.

Laser line-scan technology: Instrument used to characterize the seafloor using a solid-state laser and a rotating mirror to produce images that can then be constructed into mosaics for analysis. The resulting images can be analyzed for faunal cluster presence and area of habitat or colony clusters.

Photo/Video imagery (see Abundance)

Point intercept method (see Abundance)

Poling: Method wherein the bottom substrate is probed with a wooden or metal pole to determine bottom or substrate type and/or depth and note presence of oyster shell or cultch.

Satellite imagery (see Abundance)

Sonar (see Abundance)

Visual observation (see Abundance)

Density: The number of organisms per unit area. Within the CMAP application, density is a parameter subgroup of the submerged habitat-building animals and plants/macroalgae general parameters and includes all instances of density.

Methods:

Calculation/extrapolation (see Abundance)

Photo/video imagery (see Abundance)

Satellite imagery (see Abundance)

Visual observation (see Abundance)

Disease: Any condition that results in the disorder of a structure or function in a living organism that is not due to any external injury. Within the CMAP application, disease is a parameter subgroup contained under the submerged habitat-building animals general parameter. Examples of disease include dermo disease (oysters) and black band disease (corals).

Methods:

Paraffin histology method: Method of examining tissue or cells, including for presence of disease or infection, under a microscope after embedding the material in paraffin wax and mounting it on a microscope slide. In CMAP, this methodology is used by programs monitoring oyster tissue for *Haplosporidium nelsoni* infection.

Photo/Video imagery (see Abundance)

Polymerase chain reaction (PCR) amplification: Method of copying DNA molecules within a sample allowing for amplification of a small amount of DNA for analysis. In

CMAP, this methodology is used by programs monitoring oysters for *Haplosporidium nelsoni* infection.

Ray's fluid thioglycollate method: Method used to characterize oyster infection prevalence and intensity by *Perkinsus marinus* wherein gill and mantle tissue samples are treated with Ray's fluid thioglycollate media, antibiotics, and antifungals before being examined for *P. marinus* hypnospores.

Visual observation (see Abundance)

Distribution: Measures of how organisms are spread out over a given area. Within the CMAP application, distribution is a parameter subgroup contained under the submerged habitat-building animals and plants/macroalgae general parameters.

Methods:

Calculation/Extrapolation (see Abundance)

GPS (see Cover)

Instrument/tool measurement (see Abundance)

Laser line-scan technology (see Cover)

Photo/Video imagery (see Abundance)

Point-pattern analysis: Method used to characterize spatial patterns over time and at different scales (i.e., the clumping, randomness, or dispersed distribution of stem-mapped trees).

Remote sensing: Method that uses remotely collected data (e.g., aerial photography, video, satellite imagery) to characterize habitats.

Sonar (see Abundance)

Visual observation (see Abundance)

Ecological metrics: Parameters or measures of how biological communities are structured or composed in a particular area (both animal and plant communities). Within the CMAP application, ecological metrics is a parameter group contained under the submerged habitat-building animals and plants/macroalgae general parameters. Ecological metrics includes composition, species abundance, percent cover, density, biomass parameter subgroups.

Growth: A measure of how quickly an organism grows during a given time frame. Within the CMAP application, growth is a parameter subgroup contained under the plants/macroalgae general parameter.

Methods:

Instrument/tool measurement (see Abundance)

Photo/video imagery (see Abundance)

Visual observation (see Abundance)

Larval transport: A measure of the distance larval organisms are transported from natal populations to settlement sites. Within the CMAP application, larval transport is a parameter subgroup contained under the submerged habitat-building animals general parameter.

Methods:

Sediment trap: Instrument deployed to collect settling particles, including larvae suspended in the water column. The captured particles and/or larvae are preserved in situ in collection bottles in 10% dimethylsulfoxide (DMSO) until retrieval to the surface for storage and examination.

Litterfall: Dead plant material that has fallen to the ground. Within the CMAP application, litterfall is a parameter subgroup contained within the plants/macroalgae general parameter.

Methods:

Leaf litter trap (see Biomass)

Visual observation (see Abundance)

Mortality: A measure of how many organisms die over a given time frame. Within the CMAP application, mortality is a parameter subgroup contained under the submerged habitat-building animals and plants/macroalgae general parameters. Mortality includes all measures related to mortality (i.e., mortality rate, percent recent mortality, percent dead shell, and percent dead cover).

Methods:

Instrument/Tool measurement (see Abundance)

Photo/Video imagery (see Abundance)

Visual observation (see Abundance)

Physiology/Health: Parameters or measures detailing animal physiology or health information (i.e., presence of coral disease or bleaching). Within the CMAP application, physiology/health is a parameter group within the submerged habitat-building animals general parameter. Physiology/health includes disease, size, bleaching, and growth parameter subgroups. Physiology alone is also a parameter group within the plants/macroalgae general parameter and includes size, growth, canopy extent/structure, and litterfall.

Plants/Macroalgae: Terrestrial or submerged plants and macroalgal species within the environment that act as biological habitat and/or food sources for animal and other plant species. Within the CMAP application, plants/macroalgae is a general parameter and includes ecological metrics, physiology, and population dynamics parameter groups.

Population dynamics: Study of how and why populations change in size and structure over time (for animal and plant populations). Within the CMAP application, population dynamics is a parameter group contained under the submerged habitat-building animals and plants/macroalgae general parameters. Population dynamics groups includes settlement/recruitment, survivorship, larval transport, spawning, mortality, reproductive effort, and primary production.

Primary production: The synthesis of organic compounds from atmospheric or aqueous carbon dioxide, primarily through photosynthesis. It can also occur through chemosynthesis via oxidation or reduction of inorganic chemical compounds. Within the CMAP application, primary production is a parameter subgroup contained under the plants/macroalgae general parameter.

Methods:

Calculation/Extrapolation (see Abundance)

Instrument/Tool measurement (see Abundance)

Geochemical techniques: Term encompassing several methodologies documented aimed at characterizing net primary productivity and photosynthesis in seagrass beds including but not limited to alkalinity anomaly techniques, carbonate system equations, calcium measurements, and air-sea CO_2 flux measurements.

Reproductive effort: The proportion of the total energy budget of an organism devoted to reproductive processes. Within the CMAP application, reproductive effort is a parameter subgroup contained under the plants/macroalgae general parameter. Reproductive effort includes mast/seed production, flowering, fruiting, and/or seedling production.

Methods:

Leaf litter trap (see Biomass)

Visual observation (see Abundance)

Sediment classification/composition: Measures of physical characteristics of sediment used for classification. Within the CMAP application, sediment classification is a parameter subgroup contained under the abiotic general parameter. Sediment classification includes bulk density, grain size, texture, moisture levels, soil type, and the makeup of the substrate in a given area (i.e., % bedrock, % silt, etc.).

Methods:

Calculation/Extrapolation (see Abundance)

Dielectric constant measuring device: Instrument used to measure moisture content in soil.

Elemental analysis: Term encompassing several methodologies aimed at characterizing or measuring the concentrations of various components of soil/sediment samples (i.e., organic pollutants, hydrocarbons, metals, organic matter, nutrients, and/or mercury).

Folk settling method: Method used to determine grain size from a sediment sample. This method involves preparing a dispersed, homogeneous suspension of the fine fraction, dilution with a dispersant solution (usually 0.5% sodium hexametaphosphate) to 1000 ml, and allowing the particles to settle in a graduated cylinder. As the settling of sediment particles continues according to Stoke's Law, samples are either withdrawn (pipette) or measurements made (hydrometer) of the suspension at preset time intervals.

Gamma-ray attenuation: Method used to determine bulk density of a sediment sample that involves passing a gamma beam through a sediment core and measuring the scattering that occurs.

Instrument/Tool measurement (see Abundance)

Laser analysis: Method of determining the soil particle size distribution via laser diffraction.

Particle size distribution analysis: Method used to characterize a soil/sediment sample involving sieving and describing the proportion of differently sized particles (i.e., clay, sand, silt).

Photo/Video imagery (see Abundance)

Pipette analysis: Method of determining grain size by withdrawing volumes of a sediment sample from a suspension column after stirring. The aliquots are removed at predetermined times and depths to sample specific grain sizes. The aliquots are then dried and weighed.

Probing rod: Method wherein the bottom substrate is probed with a fiberglass rod to determine bottom or substrate type and/or depth

Remote sensing (see Distribution)

Sediment logging: A suite of techniques used to describe physical (e.g., stratigraphy) and chemical properties of sediment cores such as gamma ray attenuation or magnetic susceptibility. For CMAP purposes, this term is used in relation to grain size analysis.

Sieve analysis: Method of using sieves to determine grain sizes of sediment samples by drying the samples in an oven and then passing the sample through sieves of varying sizes.

Sonar (see Abundance)

Sounding rod: Instrument used to determine sediment particle size when bottom substrate is not visible.

Visual and/or tactile observation: An overarching term used to encompass any technique to describe soil/sediment type and/or grain size either visually or tactilely. Additionally, observations of soil/sediment subsidence, depth, and/or oxidation can be made.

Wolman pebble count: Method used to determine grain size of a soil/sediment sample by measuring the sizes of 100 random particles via gravelometer.

Settlement/Recruitment: For animals, settlement refers to the number of individuals that settle from the water column onto appropriate substrate. Recruitment is a measure of how many individuals (animal or plant/macroalgae) are added to a population. Within the CMAP application, settlement/recruitment is a parameter subgroup contained under the submerged habitat-building animals and plants/macroalgae general parameters.

Methods:

Instrument/Tool measurement (see Abundance)

Photo/Video imagery (see Abundance)

Plankton tow: Method of collecting larvae or other organisms in the water column wherein a plankton net is towed horizontally in the water column with the current. Can be used, specifically, to determine the concentration of oyster larvae in the water column near an oyster reef.

Settlement tile: Instruments deployed in situ to allow recruitment of coral or oyster spat among other organisms. The tiles can be retrieved and counts of target organisms can be made to determine settlement rates.

Spat monitoring array: Instrument used to monitor oyster spat recruitment that is are deployed in situ to allow spat to recruit onto settlement media and is are then retrieved for examination.

Visual observation (see Abundance)

Size: Measures of animal or plant/macroalgae size. Within the CMAP application, size is a parameter subgroup of the submerged habitat-building animals and plants/macroalgae general parameters. Size includes animal/plant height, animal/plant weight, animal diameter, diameter at breast height (DBH).

Methods:

Calculation/Extrapolation (see Abundance)

GPS (see Cover)

Instrument/Tool measurement (see Abundance)

Level/rod: Instrument used to measure elevation along a transect in a variety of habitats. A stadia or leveling rod is carried along a transect starting at USGS markers with known elevations and pausing along the transect at each elevation change for readings.

Photo/Video imagery (see Abundance)

Remote sensing (see Distribution)

Sonar (see Abundance)

Survey equipment: Instrumentation used to determine reef height during oyster reef surveys. This can include level and rod or transit pole and self-leveling laser.

Visual observation (see Abundance)

Water displacement: Method used to determine an animal's size by submerging the organism in a container filled with water and then measuring the displaced water volume.

Spawning: The release of sperm, eggs, or planula into the water column by sessile aquatic organisms. Within the CMAP application, spawning is a parameter subgroup contained under the submerged habitat-building animals general parameter.

Methods:

Visual observation (see Abundance)

Submerged habitat-building animals: Animals such as corals, bivalves, sponges, or tube worms that create structure on the benthos. Within the CMAP application, submerged habitat-building animals (SHBA) is a general parameter. SHBA includes the physiology/health, population dynamics, and ecological metrics parameter groups.

Subsidence: The gradual caving in or sinking of an area of land. Within the CMAP application, subsidence is a parameter subgroup contained under the abiotic general parameter.

Methods:

Calculation/Extrapolation (see Abundance)

Chalk block dissolution: A proxy measurement of erosion rate wherein chalk blocks dissolution rates are measured in situ (i.e., in seagrass beds).

GPS (see Cover)

GPS/Total station: Instruments used to establish benchmark elevations for rod surface elevation table benchmarks to determine wetland elevation.

Level/rod (see Size)

Photo/video imagery (see Abundance)

RTK GPS (see Abundance)

SET: Instruments used to determine land elevation. Surface Elevation Tables (SETs) are constructed from in situ benchmarks that horizontal leveling arms are attached to which pins can be raised or lowered to the surface of the sediment.

Settlement plate: Steel plates installed to allow the measurement of changes in sediment accretion on top of the plate over time.

Total plot/station: Instrument used to perform topographic surveys along transects that can allow for characterization of vertical accretion and/or subsidence.

Visual and/or tactile observation (see Sediment classification/composition)

Substrate depth: A measure of how deep the substrate in a given area is. Within the CMAP application, substrate depth is a parameter subgroup contained under the abiotic general parameter.

Methods:

Elemental analysis (see Sediment classification/composition)

Instrument/Tool measurement (see Abundance)

Open-ended sampler: Instrument used to sample soil/sediment and allows for recording of substrate depth. Involves the insertion of a corer to retrieve the sample.

Sonar (see Abundance)

Visual and/or tactile observation (see Sediment classification/composition)

Substrate geochemistry: Measures related to the chemical composition of the sediment in a given area. Within the CMAP application, substrate geochemistry is a parameter subgroup contained under the abiotic general parameter. Substrate geochemistry includes nutrient concentrations, redox potential, metal concentration, organic pollutants, and organic content.

Methods:

Elemental analysis (see Sediment classification/composition)

Isotopes/Stable isotope analysis: Method of analysis used to characterize sedimentation rate and substrate geochemistry (i.e., to reconstruct temperature records from carbonate rock or to determine the origination point of samples).

Loss on ignition: Method used to determine the organic matter of soil samples by measuring the change in weight after combustion.

Magnetometer: Instrument used to measure magnetic susceptibility of a sediment/soil sample in order to determine the concentration of iron.

Sensor (see Sensor from Water Quality)

Sieve analysis (see Sediment classification/composition)

Visual and/or tactile observation (see Sediment classification/composition)

Substrate metrics: Parameters used to describe or classify the substrate in a given area. Within the CMAP application, substrate metrics is a parameter group contained under the abiotic general parameter. Substrate metrics include substrate geochemistry, substrate composition, topographic complexity, sediment classification, and substrate depth.

Survivorship: A measure of the number or proportion of individuals surviving to each life stage for a given species or group. Within the CMAP application, survivorship is a parameter subgroup contained under the submerged habitat-building animals and plants/macroalgae general parameters.

Methods:

Calculation/Extrapolation (see Abundance)

Photo/Video imagery (see Abundance)

Visual observation (see Abundance)

Topographic complexity: Measures of the diversity and arrangement of three-dimensional structural elements on the benthos. Within the CMAP application, topographic complexity is a parameter subgroup contained under the abiotic general parameter. Topographic complexity includes rugosity and vertical relief.

Methods:

Chain and tape method: Used to measure topographic complexity on coral reefs.

Dive computer: Instrument used by scuba divers to monitor depth and bottom time, which allows divers to plan dives in relation to safety stops and decompression needs. The depth information recorded by the computer can also be used to gather topographic or profile information on natural and/or artificial reefs.

GIS: Software used for mapping and geospatial analysis. In the context of CMAP, geographic information systems (GIS) are used to calculate topographic complexity.

GPS (see Cover)

Instrument/tool measurement (see Abundance)

Level/rod (see Size)

Lidar: Light detecting and ranging (lidar) is a method of measuring bathymetric, topographic, or shoreline profile data using optical remote sensing technology.

Orthophotography: High-resolution aerial or satellite imagery that has been orthorectified (i.e., corrected for distortions). Any source that specifically mentions using orthophotos or orthorectified imagery is included in this category.

Photo/Video imagery (see Abundance)

RTK GPS (see Abundance)

Satellite imagery (see Abundance)

Sonar (see Abundance)

Total plot/station (see Subsidence)

Vertical accretion: A measure of the accumulation of sediment over time. Within the CMAP application, vertical accretion is a parameter subgroup contained under the abiotic general parameter.

Methods:

Ancillary data (see Area of Habitat Types)

Calculation/Extrapolation (see Abundance)

Dated Horizon: Method of measuring vertical accretion of sediments.

Elemental analysis (see Sediment classification/composition)

GPS (see Cover)

GPS/Total station (see Subsidence)

Isotopes/Stable isotope analysis (see Substrate geochemistry)

LIDAR (see Topographic complexity)

Orthophotography (see Topographic complexity)

Photo/Video imagery (see Abundance)

RTK GPS (see Abundance)

Surface elevation table (*SET):* Instruments used to determine land elevation. SETs are constructed from in situ benchmarks that horizontal leveling arms are attached to which pins can be raised or lowered to the surface of the sediment. This can also include rod surface elevation tables (RSET), level/rod, and feldspar methodologies/instruments.

Settlement plate (see Subsidence)

Total plot/station (see Subsidence)

Mapping Parameters and Methods

Parameters that provide information on the condition or state of water quality or habitat through remotely sensed measurements (e.g., light detection and ranging (lidar), sound navigation and ranging (sonar, satellite, aerial imagery). Methods listed under parameters are select examples and not a complete list.

Area of habitat types: The areal coverage of particular habitat types.

Methods:

Ancillary data: Refers to a pre-existing data source used to help collect or analyze a mapping parameter. This category includes everything from large national datasets (e.g., USGS National Hydrography Dataset, National Land Cover Database, soil datasets) to local and regional maps or datasets.

In situ data collection: Refers to any data collected directly in the field, including both elevation and non-elevation data. This category includes field data collected for the purpose of validating remotely sensed data (e.g., ground-truthing). Commonly listed data sources include RTK GPS, GPS data, and vegetation percent cover.

Orthophotography (see Topographic complexity)

Other imagery: Includes a variety of imagery sources that are not commonly represented in monitoring programs and do not fit into an existing data source category. Examples include oblique imagery (i.e., non-orthorectified imagery) and hyperspectral imagery. This category also encompasses imagery sources that are described in too little detail to be grouped elsewhere (e.g., “imagery” or “photo/video imagery”).

Satellite imagery (see Abundance)

Seismic/subbottom profiles: Includes any data source that uses sound vibrations to map patterns of rock formations below the surface of the Earth (seismic), or identifies and measures various marine sediment layers that exist below the sediment/water interface (subbottom profiles). This category also includes imagery of the sediment-water interface (i.e., sediment profile imagery).

Sonar (see Abundance)

Surficial elevation: Includes measurements of bathymetric, topographic, or shoreline profile data. This category also includes topographic and topobathy metric lidar data.

UAS (see Cover)

Surficial elevation: Measurements of bathymetric, topographic, or shoreline profile data.

Methods: Methods for surficial elevation were not investigated since these remotely sensed data are typically collected using existing data collection standards. For more information, please refer to existing standards documents for lidar data collection from the USGS (e.g., https://pubs.usgs.gov/tm/11b4) and the American Society for Photogrammetry and Remote Sensing (e.g., https://www.asprs.org/a/society/committees/standards/Combined_Procurement_Guidelines.pdf), and bathymetric data collection from NOAA (e.g., https://nauticalcharts.noaa.gov/publications/docs/standards-and-requirements/specs/hssd-2017.pdf)

Water Quality Monitoring Parameters and Methods

Parameters or a suite of parameters that are used to monitor water quality within a particular body of water. Methods listed under parameters are select examples and not a complete list.

Algal toxins: A toxin produced by aquatic microorganisms mainly true algae, dinoflagellates, and cyanobacteria. Algal toxins can be produced in large quantities during algal bloom events and can pose a serious environmental threat. Within the CMAP application, the algal toxins parameter includes brevetoxins, microcystins, and domoic acid and is a detail parameter of the general parameter group, harmful algal bloom indicators.

Methods:

Cylindrospermopsin immunoassay: Target specific immunosorbent assay for algal toxin, cylindrospermopsin

EPA 8321 B: Environmental Protection Agency (EPA) Method Solvent-Extractable Nonvolatile Compounds by High-Performance Liquid Chromatography/Thermospray/ Mass Spectrometry (HPLC/TS/MS) or Ultraviolet (UV) Detection

Immunosorbent assay (*ELISA) ADDA kits:* Enzyme-linked immunosorbent assay kit for detection of proteins and antigens from algal toxins

Sedgewick-Rafter counting chamber: Transparent slide for counting the exact number of algal toxins in a set volume of fluid

USGS OGRL 5400: USGS Organic Geochemistry Research Laboratory (OGRL) method for harmful algal blooms

Ammonia: A common form of nitrogen (N) that exists in aquatic environments that can cause toxic effects on aquatic life. Ammonia (NH_3) is naturally produced through decomposition of organic matter, nitrogen fixation, as waste products from organisms, and other processes. This parameter includes data expressed as either ion mass (milligram/liter mg/l as ammonium [NH_4]) or as nitrogen mass per unit volume (mg/l as N), and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered–filtered). Within the CMAP application, ammonia is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer: General term for laboratory instrumentation that is automated such as continuous flow analysis and flow injection analyzers

EPA 350.1: Environmental Protection Agency (EPA) Method Determination of Ammonia Nitrogen by Semi-Automated Colorimetry

SM 4500 NH3: Standard Methods for the Examination of Water and Wastewater Nitrogen (Ammonia)

USGS OFR 93-125: USGS Open-File Report Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory; determination of inorganic and organic constituents in water and fluvial sediments

Ammonia + organic nitrogen: Total concentration of ammonia and organic nitrogen. In water chemistry, this summation is often used to express the amount of unoxidized nitrogen. This sum, when expressed as nitrogen mass per unit volume, ([NH_3-N] + [NH_4^+-N] + [Organic nitrogen as N]), is often referred to as the total Kjeldahl nitrogen (TKN). This parameter includes data expressed as either compound mass or as nitrogen mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, ammonia + organic nitrogen is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer (see Ammonia)

EPA 351.2: Environmental Protection Agency (EPA) Method Determination of Total Kjeldahl Nitrogen by Semi-Automated Colorimetry

EPA 350.1 (see Ammonia)

SM 4500 NH3 (see Ammonia)

USGS OFR 00-170: USGS Open-File Report Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory — Determination of ammonium plus organic nitrogen by a Kjeldahl digestion method and an automated photometric finish that includes digest cleanup by gas diffusion

Aquatic primary producers: The organisms responsible for primary production of organic matter. These form the basis of the food chain. Within the CMAP application, aquatic primary producers is a general parameter group which consists of the detail parameters chlorophyll and phytoplankton.

Brevetoxins: A suite of cyclic polyether compounds produced naturally by certain species of dinoflagellates. Brevetoxins are commonly associated with "red tide" algal blooms and can cause large scale fish kills. In addition, large concentrations may accumulate in shellfish, posing significant health risk when consumed by humans or wildlife. Within the CMAP application, brevetoxins are included in the detail parameter, algal toxins.

Chlorophyll: A green pigment that allows plants and algae to photosynthesize and can be used as a measure of the amount of algae or phytoplankton growing or the trophic condition of a waterbody. Within the CMAP application, chlorophyll is a detail parameter of the general parameter group, aquatic primary producers, and includes all types of chlorophyll (i.e., a, b, c, etc.). Since phytoplankton produce chlorophyll and contain chlorophyll within their cells, phytoplankton and chlorophyll are very closely related terms, differing often only by methodology. Chlorophyll data, analyzed by various methods, are generally expressed as a mass of chlorophyll per unit volume, where phytoplankton data may be expressed by total biomass, biovolume, cell count, or diversity.

Methods:

Fluorometer: A instrument used to measure the fluorescence of chlorophyll

SM 10200 H: Standard Methods for the Examination of Water and Wastewater Spectrophotometric Determination of Chlorophyll

EPA 445.0: Environmental Protection Agency (EPA) Method In Vitro Determination of Chlorophyll a and Pheophytin a in Marine and Freshwater Algae by Fluorescence

EPA 446.0: Environmental Protection Agency (EPA) Method In Vitro Determination of Chlorophylls a, b, $c_1 + c_2$ and Pheopigments in Marine and Freshwater Algae by Visible Spectrophotometry

Sensor: Sensor is a generalized term used to describe one or more of the following: datasonde, conductivity, temperature, and depth (CTD), depth sounder, probe, meter, electrode, pH meter, and quantum sensor where applicable. Sensor is also used to describe specific agency methods if the process could be captured by noting a sensor being used. Some agency specific methods have been generalized to the term sensor to show compatibility among program methods.

SM 10300 C: Standard Methods for the Examination of Water and Wastewater Periphyton

Spectrophotometer: An analytical instrument that uses the UV and visible regions to measures the wavelength of a compound

Conductance: Conductance is one of the most useful and commonly measured water quality parameters. In addition to being the basis of most salinity and total dissolved solids calculations, conductivity is an early indicator of change in a water system. Most bodies of water maintain a fairly constant conductivity that can be used as a baseline of comparison to future measurements. Within the CMAP application, salinity is included in the detailed parameter of conductance.

Methods:

EPA 120: Environmental Protection Agency (EPA) Method Conductance (Specific Conductance, µmhos at 25ºC) by Conductivity Meter

Refractometer: A laboratory or field instrument used to check salinity by measuring the refractive index

Sensor (see Chlorophyll)

SM 2510: Standard Methods for the Examination of Water and Wastewater Conductivity

SM 2520: Standard Methods for the Examination of Water and Wastewater Salinity

USGS TWRI 9: A USGS published series of manuals titled the Techniques of Water-Resources Investigations Book 9 Handbooks for Water-Resources Investigations

***Cryptosporidium*:** A small parasite present in fecal material with pathogenic effects in humans. Within the CMAP application, *Cryptosporidium* is a detail parameter included in the general parameter group, pathogens.

Currents: The rate of movement in the water. Within the CMAP application, currents is a detailed parameter of the general parameter group, field parameters.

Methods:

Current meter: An instrument used to measure flow velocity in feet or meters per second

USGS TWRI 3: A USGS published series of manuals titled the Techniques of Water-Resources Investigations Book 3 Applications of Hydraulics

Cyanobacteria: A phylum of bacteria that obtain their energy through photosynthesis, and are the only photosynthetic prokaryotes able to produce oxygen. Cyanobacteria (which are prokaryotes) used to be called "blue-green algae". They have been renamed 'cyanobacteria' in order to avoid the term "algae", which in modern usage is restricted to eukaryotes. These bacteria can form dense mats and produce cyanotoxins, such as microcystin and domoic acid, that can be health hazards to humans and wildlife during harmful algal blooms. Cyanobacteria data, analyzed by various methods, are generally expressed as a mass cyanobacteria per unit volume, where phytoplankton data may be expressed by total biomass, biovolume, cell count, or diversity. Within the CMAP application, cyanobacteria is a detail parameter of the general parameter group, harmful algal bloom indicators.

Discharge: Rate of fluid flow passing a given point at a given moment in time. Within the CMAP application, discharge is a detailed parameter of the general parameter group, freshwater inflow.

Methods:

Calculated: Term used to note that the discharge rate was the result of a calculation

Flowmeter: An instrument used to measure discharge by measuring the rate of flow past the flowmeter sensors

USGS TWRI 3 (see Currents)

Dissolved oxygen: The amount of gaseous oxygen dissolved in water. Dissolved oxygen may be expressed as a concentration or as a percent saturation. Low dissolved oxygen is related to an excess of nutrients which can lead to excessive growth of vegetation. Within the CMAP application, dissolved oxygen is a detail parameter of the general parameter group, field parameters.

Methods:

EPA 360.1: Environmental Protection Agency (EPA) Method Dissolved Oxygen by Membrane Electrode

EPA 360.2: Environmental Protection Agency (EPA) Method Dissolved Oxygen by Modified Winkler, Full-Bottle Technique

Sensor (see Chlorophyll)

Test kit: General term for a quick result monitoring kit used to measure reactive dissolved oxygen. This test kit is typically a titration kit.

Winkler titration: Procedure that uses titration to neutralize an acidic sample solution that has reacted with oxygen in order measure the amount of dissolved oxygen in a fixed water sample

Domoic acid: A neurotoxin that causes amnesic shellfish poisoning (ASP). It is produced by algae and accumulates in shellfish, sardines, and anchovies. When higher trophic level predators ingest the contaminated animals, poisoning may result. Exposure to this compound affects the brain, causing seizures, and possibly death. Within the CMAP application, domoic acid is included in the detail parameter, algal toxins.

Enterococcus: A large bacterial genus present in human and animal feces and used as an indicator of fecal pollution of water bodies. *Enterococcus* are highly tolerant in the environment of temperature, pH and salinity. Within the CMAP application, *Enterococcus* is a detail parameter included in the general parameter group, pathogens.

Methods:

Enterolert: A laboratory procedure that uses a nutrient indicator to determine quantitative enterococci in 24 hours

EPA 1600: Environmental Protection Agency (EPA) Method *Enterococci* in Water by Membrane Filtration Using membrane-*Enterococcus* Indoxyl-B-D-Glusoside Agar (mEI)

ADEM 2064: Alabama Department of Environmental Management Water Quality Assessment and Listing Methodology Bacteriological Sample Collection

USGS TWRI 9 (see Conductance)

SM 9230 D: Standard Methods for the Examination of Water and Wastewater Fecal *Enterococcus/Streptococcus* Groups Fluorogenic Substrate *Enterococcus* Test

Escherichia coli: A large and diverse group of bacteria found in the environment, foods, and intestines and feces of people and animals and used as an indicator of fecal pollution of water bodies. Within the CMAP application, *Escherichia coli* is a detail parameter included in the general parameter group, pathogens.

Methods:

Coliscan Easygel: A patented medium and procedure approved by the EPA for determination of *Escherichia coli* and other coliforms in a water sample

SM 9223 B: Standard Methods for the Examination of Water and Wastewater Enzyme Substrate Coliform Test *Escherichia coli*

EPA 1603: Environmental Protection Agency (EPA) Method *Escherichia coli* (*E. coli*) in Water by Membrane Filtration Using Modified membrane-Thermotolerant *Escherichia coli* Agar (Modified mTEC)

USGS TWRI 9 (see Conductance)

Fecal coliforms: A subset of total coliforms, fecal coliforms are distinguished by their tolerance for warmer temperatures. The fecal coliform group includes *Escherichia coli*. The fecal coliform parameter is used as a broad indicator of environmental contamination by human or animal waste. Within the CMAP application, fecal coliforms is a detail parameter included in the general parameter group, pathogens.

Methods:

Colilert: A patented medium and procedure approved by the EPA for determination of *Escherichia coli* and other coliforms in a water sample within 24 hours

Coliscan Easygel (see *Escherichia coli*)

SM 9221 E: Standard Methods for the Examination of Water and Wastewater Multiple-Tube Fermentation Technique, Fecal Coliform Procedure

SM 9222 D: Standard Methods for the Examination of Water and Wastewater Membrane Filter Technique for Members of the Coliform Group Thermotolerant (Fecal) Coliform Membrane Filter Procedure

Field parameters: Parameters that are typically collected through observation or instrumentation at a sampling site. Within the CMAP application, this general parameter group consists of the detail parameters: water temperature, conductance, dissolved oxygen, pH, turbidity, light attenuation, currents, and water level.

Freshwater Inflow: Freshwater inflow is the freshwater that flows into an estuary.

***Giardia*:** A protozoan parasite present in human and animal wastes that has pathogenic effects in both children and adults. Within the CMAP application, giardia is a detail parameter included in the general parameter group, pathogens.

Harmful algal bloom (HAB) indicators: An algal bloom is a rapid increase or accumulation in the population of algae in freshwater or marine water systems, and is recognized by the discoloration in the water from their pigments. Cyanobacteria were mistaken for algae in the past, so cyanobacterial blooms are sometimes also called algal blooms. Blooms that can injure animals or the ecology are called harmful algal blooms (HAB) and can lead to fish die-offs, cities cutting off water to residents, or states having to close fisheries. Within the CMAP application, harmful algal bloom indicators is a general parameter group which consists of the detail parameters, cyanobacteria and algal toxins.

Light attenuation: Light attenuation refers to field methods which evaluate the penetration of ambient sunlight below the water surface. Light attenuation includes methods such as Secchi disk and photosynthetic active radiation (PAR). Within the CMAP application, light attenuation is a detail parameter of the general parameter group, field parameters.

Methods:

Photometer: An instrument used for measuring the electromagnetic radiation by converting light into an electrical current

Secchi: A passive measurement of the penetration of sunlight below the surface of a body of water. Secchi disk measurements are used to evaluate the photic zone of a body of water

Transmissometer: An instrument used for measuring the extinction coefficient of water by sending a laser through the aquatic medium

Mercury: A bioaccumulative environmental toxicant that has negative effects on humans and wildlife even at low concentrations. Within the CMAP application, mercury is a general parameter that includes the detail parameters, methylmercury and total mercury.

Methylmercury: An organic form of mercury that acts as a bioaccumulative environmental toxicant. Methylmercury accumulates in fish tissue that is transferred to humans upon consumption. Within the CMAP application, methylmercury is a detail parameter of the general parameter group mercury.

Methods:

EPA 1631: Environmental Protection Agency (EPA) Method Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry

Test kit: General term for a quick result monitoring kit used to measure reactive methylmercury

USGS OFR 01-445: USGS Open-File Report Determination of Methyl Mercury by Aqueous Phase Ethylation, Followed by Gas Chromatographic Separation with Cold Vapor Atomic Fluorescence Detection

Microcystin: A class of toxins produced by freshwater cyanobacteria. Microcystins can be produced in large quantities during algal bloom events and can pose a serious environmental threat. Within the CMAP application, microcystins are included in the detail parameter, algal toxins.

Nitrate: Nitrogen in its fully oxidized form (NO_3), which is readily assimilated by plants and algae through photosynthetic processes. Excess nitrate in water can cause health problems in infants and contribute to eutrophication in water bodies. This parameter includes data expressed as either nitrate mass per unit volume or as nitrogen mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, nitrate is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer (see Ammonia)

EPA 300.0: Environmental Protection Agency (EPA) Method Determination of Inorganic Anions by Ion Chromatography

EPA 300.6: Environmental Protection Agency (EPA) Method Chloride, Orthophosphate, Nitrate, and Sulfate in Wet Deposition by Chemically Suppressed Ion Chromatography

EPA 353.2: Environmental Protection Agency (EPA) Method Determination of Nitrate-Nitrite Nitrogen by Automated Colorimetry

Sensor (see Chlorophyll)

SM 4110 B: Standard Methods for the Examination of Water and Wastewater Determination of Anions by Ion Chromatography, Ion Chromatography with Chemical Suppression of Eluent Conductivity

SM 4500 NO3: Standard Methods for the Examination of Water and Wastewater Nitrate in Water by Colorimetry and Cadmium Reduction

Spectrophotometer (see Chlorophyll)

Test kit: General term for a quick result monitoring kit used to measure reactive nitrate

USGS TM 5-B8: USGS Techniques and Methods Colorimetric Determination of Nitrate Plus Nitrite in Water by Enzymatic Reduction, Automated Discrete Analyzer Methods

Nitrite: Nitrogen in an intermediate form of oxidation (NO_2). Nitrite is further oxidized to nitrate through biological oxidation (nitrification). This parameter includes data expressed as either nitrite mass per unit volume or as nitrogen mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, nitrite is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer (see Ammonia)

EPA 300.0 (see Nitrate)

EPA 300.6 (see Nitrate)

EPA 353.2 (see Nitrate)

SM 4110 B (see Nitrate)

SM 4500 NO2: Standard Methods for the Examination of Water and Wastewater Nitrogen (Nitrite)

Spectrophotometer (see Chlorophyll)

USGS TM 5-B8 (see Nitrate)

Nitrite + nitrate: A measure of the combined concentrations of nitrite and nitrate. In water chemistry, this summation is often used to express the amount of inorganic nitrogen available for biological uptake. This parameter includes data expressed as either ion mass per unit volume or as nitrogen mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, nitrite + nitrate is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer (see Ammonia)

EPA 300.0 (see Nitrate)

EPA 300.6 (see Nitrate)

EPA 353.2 (see Nitrate)

SM 4110: Standard Methods for the Examination of Water and Wastewater Determination of Anions by Ion Chromatography

SM 4500 NO3 (see Nitrate)

USGS TM 5-B8 (see Nitrate)

Nitrogen: An essential nutrient for plant and animal growth and nourishment. Overabundance in water can cause a number of adverse health and ecological effects. Nitrogen assumes many forms: organic nitrogen, which includes proteins and amino acids, inorganic nitrogen, which includes nitrate (NO_3), and nitrite (NO_2), ammonia (NH_3), and ammonium (NH_4^+). Within the CMAP application, nitrogen is a detail parameter of the general parameter group, nutrients. Note that concentration data of nitrogen is commonly expressed in one of two forms, the mass of the ion or compound per unit volume, or by the mass of the nitrogen per unit volume. For example, a nitrate result may be reported mg/l NO_3 or mg/l NO_3 as N. (The difference between these two results will be a conversion factor accounting for the mass of oxygen.) Both of these conventions are included in the CMAP application.

Nutrients: Molecules that are essential for the growth and nourishment of organisms within the environment. Within the CMAP application, nutrients are a general parameter group that consists of the detail parameters: total nitrogen, nitrite, nitrate, nitrite + nitrate, ammonia, ammonia + organic nitrogen, total phosphorus, soluble phosphorus, phosphate, orthophosphate, and silicate.

Organic carbon: Within the CMAP application, organic carbon is a detail parameter of the general parameter group, carbon. The organic carbon parameter includes total organic carbon and dissolved organic carbon.

Methods:

Analyzer: General term for laboratory instrumentation machine used to measure organic carbon

EPA 415.1: Environmental Protection Agency (EPA) Method Organic Carbon, Total (Combustion or Oxidation)

EPA 415.2: Environmental Protection Agency (EPA) Method Organic Carbon, Total (Low Level) (UV Promoted, Persulfate Oxidation)

SM 5310: Standard Methods for the Examination of Water and Wastewater Total Organic Carbon

SW 9060: Environmental Protection Agency (EPA) Test Methods for Evaluating Solid Waste Total Organic Carbon

Organic nitrogen: Nitrogen that exists in compounds such as proteins or amino acids that have been produced through metabolic processes. Organic nitrogen is in an unoxidized form that cannot be readily consumed by most plants and animals. Within the CMAP application, this parameter includes data expressed as either compound mass per unit volume or as nitrogen mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, organic nitrogen is a detail parameter of the general parameter group, nutrients.

Orthophosphate: A term used to describe the phosphate molecule alone without any associated chemical species (PO_4^{3-}) Orthophosphate is readily consumable by the biological community and is usually the limiting factor of biological growth. This parameter includes data expressed as either PO_4^{3-} mass per unit volume or as phosphorus mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, orthophosphate is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer (see Ammonia)

EPA 365.1: Environmental Protection Agency (EPA) Method Determination of Phosphorus by Semi-Automated Colorimetry

EPA 365.2: Environmental Protection Agency (EPA) Method Determination of Phosphorus, All Forms (Colorimetric, Ascorbic Acid, Single Reagent)

SM 4500 P: Standard Methods for the Examination of Water and Wastewater Phosphorus

Test kit: General term for a quick result monitoring kit used to measure reactive orthophosphate

USGS I-2604-77: USGS Test Method Orthophosphate, water, filtered, calculated

USGS I-4601-85: USGS Test Method Phosphorus, Orthophosphate, Colorimetric, Phosphomolybdate, Automated-Segmented Flow

USGS I-4650-03: USGS Test Method Evaluation of Alkaline Persulfate Digestion as an Alternative to Kjeldahl Digestion for Determination of Total and Dissolved Nitrogen and Phosphorus in Water

Pathogen: Disease causing bacteria, virus, or protozoan that can contaminate water resources making it unsafe for humans. Within the CMAP application, the general parameter pathogen consists of the detail parameters: *Escherichia coli, Enterococcus*, fecal coliforms, total coliforms, *Giardia*, *Cryptosporidium*, and *Vibrio*.

pH: The negative logarithm of the hydrogen ion concentration of a solution that is used as a measure of the acidity or alkalinity of a liquid. Within the CMAP application, pH is a detail parameter of the general parameter group, field parameters.

Methods:

EPA 150.1: Environmental Protection Agency (EPA) Method Determination of pH by Electrometric Method

EPA 150.6: Environmental Protection Agency (EPA) Method pH of Wet Deposition by Electrometric Determination

Sensor: (see Chlorophyll)

SM 4500 H+B: Standard Methods for the Examination of Water and Wastewater pH Value in Water by Potentiometry Using a Standard Hydrogen Electrode

Test kit: General term for a quick result monitoring kit used to measure pH. The pH is typically measured with testing strips or testing drops

Phosphate: A phosphorus-containing anion that is often a limiting nutrient in an environment (especially freshwater environments) and is widely used in fertilizers and detergents. This parameter includes data expressed as either ion mass per unit volume or as phosphorus mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, phosphate is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer (see Ammonia)

EPA 365.1 (see Orthophosphate)

SM 4500 P (see Orthophosphate)

Photosynthetic active radiation (PAR): A passive measurement of the photosynthetically active range of sunlight. In water quality applications PAR can be used to delineate the photic zone of a body of water. Within the CMAP application, PAR is included in the detail parameter light attenuation of the general parameter group, field parameters.

Phytoplankton: The term phytoplankton encompasses all photoautotrophic microorganisms in aquatic food webs. Phytoplankton serve as the base of the aquatic food web, providing an essential ecological function for all aquatic life. Phytoplankton are a diverse group, incorporating protistan eukaryotes and both eubacterial and archaebacterial prokaryotes. Note that phytoplankton and chlorophyll are very closely related terms, differing only by methodology. Chlorophyll results, analyzed by various methods, are generally expressed as a mass of chlorophyll per unit volume, where phytoplankton results may be expressed by total biomass, cell count, or diversity. Within the CMAP application, phytoplankton is a detail parameter of the general parameter group, aquatic primary producers.

Methods:

Flow cytometer: Analytical procedure used to determine different species of phytoplankton by distinguishing the fluorescence of each species

High performance liquid chromatography: Analytical procedure used to determine the composition and biomass of phytoplankton by analyzing phytoplankton pigments

Sedgewick-Rafter counting chamber (see Algal toxins)

Polycyclic aromatic hydrocarbons (PAHs): PAHs are a large family of compounds including anthracene, phenanthrene, tetracene, chrysene, and others that occur naturally in coal, crude oil, and gasoline. Within the CMAP application, PAHs are a detail parameter of the general parameter group, carbon.

Methods:

Gas chromatography/Mass spectrometry (*GC/MS):* An analytical procedure that combines gas chromatography with mass spectrometry to determine the different types of PAHs within a sample

USGS WRIR 03-4318: USGS Water-Resources Investigation Report Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory — Determination of Polycyclic Aromatic Hydrocarbon Compounds in Sediment by Gas Chromatography/Mass Spectrometry

Salinity: A measure of the amount of salts dissolved in a body of water. Within the CMAP application, salinity is included in the conductance detailed parameter of the field parameters general group.

Sediment: Solid particulate material suspended, transported and deposited by wind or water. In aquatic environments evaluation of sediment quantity, size distribution, suspension, transport and deposition are important components of both the hydrology and ecology of the environment. Within the CMAP application, the general parameter sediment includes quantification of suspension, transport, deposition and size distribution. Suspended sediment concentration (SSC) and total suspended solids (TSS) are additionally included as detail parameters due to their common usage. The distinction between these two parameters is maintained due to differences in methodology that produce results of limited comparability.

Silicate: Silicate, or silicic acid (H_4SiO_4), is an important nutrient in the ocean and estuaries. Unlike the other major nutrients such as phosphate, nitrate, or ammonium, which are needed by almost all marine plankton, silicate is an essential chemical requirement for very specific biota, including diatoms, radiolaria, silicoflagellates, and siliceous sponges. These organisms extract dissolved silicate from open surface waters for the buildup of their particulate silica (SiO_2), or opaline, skeletal structures. This parameter includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, silicate is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer (see Ammonia)

EPA 366.0: Environmental Protection Agency (EPA) Method Determination of Dissolved Silicate in Estuarine and Coastal Waters by Gas Segmented Continuous Flow Colorimetric Analysis

EPA 370.1: Environmental Protection Agency (EPA) Method Silica, Dissolved (Colorimetric)

SM 4500 Si: Standard Methods for the Examination of Water and Wastewater Silica

Soluble phosphorus: Hydrated phosphate ions that are dissolved in water through weathering or in the production of fertilizers that plants can use. This parameter includes data expressed as either ion mass per unit volume or as phosphorus mass per unit volume. Within the CMAP application, soluble phosphorus is a detail parameter of the general parameter group, nutrients.

Methods:

ADEM 2062: Alabama Department of Environmental Management Water Quality Assessment and Listing Methodology Dissolved Reactive Phosphorus (DRP) Collection and Field Processing

Auto analyzer (see Ammonia)

EPA 365.1 (see Orthophosphate)

Stage: The height of the water surface above an established datum plane, such as in a river above a predetermined point that may or may not be near the channel floor. Within the CMAP application, stage is a detail parameter of the general parameter group, freshwater inflow.

Methods:

Sensor (see Chlorophyll)

USGS TWRI 3 (see Currents)

USGS WRIR 01-4044: USGS Water-Resources Investigation Report Standards for the Analysis and Processing of Surface-Water Data and Information Using Electronic Methods

Suspended sediment concentration (SSC): A measure of how much sediment is suspended and transported in a body of water. Within the CMAP application, the detail parameter suspended sediment concentration (SSC) is included in the general parameter group, sediment.

Methods:

USGS TM 5-C1: USGS Techniques of Water-Resources Investigations Laboratory Theory and Methods for Sediment Analysis

Total coliforms: A large group of bacteria that generally originate in the intestines of warm-blooded animals. This group includes *Citrobacter*, *Enterobacter*, *Hafnia*, *Klebsiella,* and *Escherichia* genera. The total coliform parameter is used as a broad indicator of environmental contamination by human or animal waste. Within the CMAP application, total coliforms is a detail parameter included in the general parameter group, pathogens.

Methods:

Coliscan Easygel (see Escherichia coli)

SM 9222 B: Standard Methods for the Examination of Water and Wastewater Membrane Filter Technique for Members of the Coliform Group Standard Total Coliform Membrane Filter Procedure

USGS TWRI 9 (see Conductance)

Total mercury: A measure of the concentration of mercury compounds, organic and inorganic, in an environment or the tissues of an organism. Within the CMAP application, total mercury is a detail parameter of the general parameter group, mercury.

Methods:

EPA 245.1: Environmental Protection Agency (EPA) Method Determination of Mercury in Water by Cold Vapor Atomic Absorption Spectrometry

EPA 245.2: Environmental Protection Agency (*EPA*) *Method Determination of Mercury* (Automated Cold Vapor Technique) by Atomic Absorption

EPA 245.6: Environmental Protection Agency (EPA) Method Determination of Mercury in Tissues by Cold Vapor Atomic Absorption Spectrometry

EPA 245.7: Environmental Protection Agency (EPA) Method Determination of Mercury in Water by Cold Vapor Atomic Fluorescence Spectrometry

EPA 1631 (see Methylmercury)

EPA 7473: Environmental Protection Agency (EPA) Method Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrometry

Test kit: General term for a quick result monitoring kit used to measure reactive mercury

USGS WRIR 01-4132: USGS Water-Resources Investigation Report Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory — Determination of Organic Plus Inorganic Mercury in Filtered and Unfiltered Natural Water with Cold Vapor-Atomic Fluorescence Spectrometry

Total nitrogen: The sum of organic nitrogen, nitrate (NO_3), and nitrite (NO_2), ammonia (NH_3), and ammonium (NH_4^+). Excess nitrogen in aquatic environments can result in eutrophication, algal blooms, and low levels of dissolved oxygen. This parameter includes data expressed as either compound mass per unit volume or as nitrogen mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, total nitrogen is a detail parameter of the general parameter group, nutrients.

Methods:

Auto analyzer (see Ammonia)

EPA 351.1: Environmental Protection Agency (EPA) Method Total Kjeldahl Nitrogen (Colorimetric, Automated Phenate) by Autoanalyzer

EPA 351.2 (see Ammonia + organic nitrogen)

EPA 353.2 (see Nitrate)

SM 4500 N: Standard Methods for the Examination of Water and Wastewater Nitrogen

Spectrophotometer (see Chlorophyll)

USGS I-3556-77: USGS Test Method Total Nitrogen, water, unfiltered, calculated

USGS OFR 00-170 (see Ammonia + organic nitrogen)

USGS OFR 93-125 (see Ammonia)

Total organic carbon: The amount of carbon found in organic compounds that can be used as an indicator of water quality. Within the CMAP application, total organic carbon is included in the organic carbon detailed parameter of the carbon general parameter group.

Total phosphorus: A measure of the sum of all phosphorus compounds. This parameter includes data expressed as either compound mass per unit volume or as phosphorus mass per unit volume, and includes the fractional results, dissolved (filtered), total (unfiltered), or suspended (unfiltered - filtered). Within the CMAP application, total phosphorus is a detail parameter of the general parameter group, nutrients.

Methods:

EPA 365.1 (see Orthophosphate)

EPA 365.4: Environmental Protection Agency (EPA) Method Total Phosphorus (Colorimetric, Automated, Block Digester AA II)

SM 4500 P (see Orthophosphate)

Total suspended solids (TSS): The dry weight of solids suspended in water that can be trapped by a filter. This can include silt, decaying plant/animal matter, sewage, industrial waste, etc. Within the CMAP application, total suspended sediment (TSS) is a detail parameter of the general parameter group, sediment.

Methods:

EPA 160.2: Environmental Protection Agency (EPA) Method Residue, Non-Filterable (Gravimetric, Dried at 103-105ºC)

SM 2540 D: Standard Methods for the Examination of Water and Wastewater Total Suspended Solids Dried at 103-105ºC

USGS TWRI B5-A1: A USGS published series of manuals titled the Techniques of Water-Resources Investigations Book 5 Water Analysis, A1 Methods for determination of inorganic substances in water and fluvial sediments

Turbidity: A measure of relative clarity of a liquid. Turbidity is measured by illuminating the water with a light source of specific wavelength, the sensor measures the scatter of light, giving a light attenuation measurement that is independent of ambient light. Due to the specificity of the instrument's light source and sensor, turbidity measurement from different models of turbidity sensors can vary significantly. Within the CMAP application, turbidity is a detail parameter of the general parameter group, field parameters, and the term turbidity includes all unit variations of turbidity measurements.

Methods:

EPA 180.1: Environmental Protection Agency (EPA) Method Determination of Turbidity by Nephelometry

Sensor (see Chlorophyll)

SM 2130: Standard Methods for the Examination of Water and Wastewater Turbidity by Nephelometric Method

Test kit: General term for a quick result monitoring kit used to measure turbidity

Turbidimeter: An instrument that measures the surface area of suspended particles to determine the clarity of a sample

USGS I-3860-85: USGS Test Method Turbidity, Nephelometric

***Vibrio*:** Bacterial genus found in warm coastal waters that can cause human illness when raw/undercooked shellfish is contaminated or if an open wound is exposed to brackish/salt water. Within the CMAP application, *Vibrio* is a detail parameter included in the general parameter group, pathogens.

Methods:

Gene probe: Also known as a DNA probe. This instrument uses a specific nucleotide sequence to determine *Vibrio* in a sample

qPCR: Quantitative polymerase chain reaction (qPCR) is a laboratory method that measures the amplification of Vibrio targeted DNA molecules to determine quantitative levels

Water level: The height reached by the water in a reservoir, river, etc.

Methods:

Measuring stick: A simple method of using a marked stick or rod to determine water level

Sensor (see Chlorophyll)

USGS TWRI 3 (see Currents)

Weighted line: Field method of using a properly distance marked rope or lead line weighted at the end to determine water depth

Water temperature: A measure of water temperature. Water temperature can include temperature measures taken at the surface and throughout the water column. Within the CMAP application, water temperature is a detail parameter of the general parameter group, field parameters.

Methods:

EPA 170.1: Environmental Protection Agency (EPA) Method Temperature by Thermometer

Sensor (see Chlorophyll)

SM 2550: Standard Methods for the Examination of Water and Wastewater Temperature

USGS TWRI 9 (see Conductance)

Appendix 1: Procedures

Introduction

This document outlines the process of synthesizing common monitoring parameter and method information from program protocols, assessing recommended monitoring or restoration guidance documents, determining core parameters, and evaluating monitoring programs contained in the CMAP monitoring program Inventory (the Inventory; NOAA and USGS, 2019). Each component of this document is presented in a separate section.

Section 1 – Synthesis of Common Parameters and Methods

This section details how common parameters, methods, and units were extracted from protocol documentation and organized by habitat type.

Section 2 – Assessment of Monitoring or Restoration Guidance Documents

This section details how guidance documents were evaluated and parameter/method/unit information from them was collected.

Section 3 – Determining Core CMAP Parameters

This section details how a decision tree was used to categorize parameters into tiers for each habitat type. Additionally, this section also illustrates how core parameter tables were constructed to summarize parameter/method/unit information collected in the previous sections.

Section 4 – Evaluation of Inventory Programs

This section details how organizing the Inventory programs by habitat type and displaying how many of the Tier I parameters and Monitoring Program Elements (MPEs) each measures can be useful for restoration or monitoring practitioners to inform their efforts.

Synthesis of Common Parameters and Methods

During the completion of the Inventory, monitoring protocol documents were obtained either through correspondence with program points of contact or via the Internet. Each of these protocol documents were reviewed to identify and record parameter collection methods and units for each CMAP parameter measured by a program. Protocols were examined for each parameter related to each monitoring type (i.e., habitat, water quality, and mapping) separately before being joined together in a single spreadsheet. The main process (detailed below) was similar for habitat and water quality monitoring; however, mapping information, had a separate process that is listed after the habitat and water quality monitoring section.

Habitat and Water Quality Protocol Review

1. Protocols collected during the Inventory development were collated in program folders on a shared drive. In some cases, protocols are used by multiple programs and this is reflected in the program folder name (e.g., CMAP_POC_Protocol_PID_24_271to277).
2. If a program did not have a program folder, then the program's Inventory record (specifically the protocol fields) was checked to ensure that links to online protocols were not present. If no links or documents were present for a program, then the program was noted as "Unavailable" for all relevant method/unit fields.
3. For programs with protocol documents, the protocols were read and/or searched via keywords to determine what methods were used to measure the relevant CMAP parameters. If unit information is available, then this was recorded as well.
4. In some cases, similar methods were able to be aggregated into more generalized bins (e.g., rulers, calipers, balances and other tools used to measure animal or plant size can be grouped under "instrument/tool measurement").
5. In cases where a parameter is measured by multiple methods or recorded with multiple units, each unique parameter/method/unit combination was recorded in a separate row (thus, there was no need to include lists of field entries).
6. There were a few places where protocol review differed between habitat and water quality monitoring programs. These are detailed below.
   a. ***Habitat Monitoring***
      i. When recording method and unit information for a parameter, sampling area type, sampling area size, nestedness, and habitat type was denoted. *Nestedness indicated if the sampling area was located within a larger sampling area (e.g., a subplot within a larger sampling plot).
      ii. Similar to the above bullet, each unique combination of habitat type/sampling area type/sampling area size/nestedness for a parameter

was recorded in a separate line.

iii. In cases where specific habitat type/parameter combination information was not available, all applicable habitat types from the program's Inventory record were included.

iv. When information was not available, the field was noted as "Unavailable."

b. ***Water Quality Monitoring***

i. In cases where state agency protocols stem from federal sources, the federal method was used.

ii. When information is not available, the field was noted as "Unavailable."

Mapping Protocol Review

The Inventory contains mapping programs that collect source data products (e.g., satellite imagery, orthophotography, sonar, lidar) and/or produce maps from source data (e.g., habitat data, land use land cover data, shoreline position data). The objective of this effort for mapping programs was to document the methodologies used by programs that develop products for the CMAP Area of habitat types parameter, which included one or more of the following: (1) habitat data; (2) land use land cover data; and (3) shoreline position data.

Documented assumptions

- Programs that contained the mapping program type were extracted from the Inventory.
- Selected programs that develop products for the CMAP Area of habitat types parameter, which included one or more of the following: (1) habitat data; (2) land use land cover data; and (3) shoreline position data. In other words, methodology was not documented for programs that only collect source data (e.g., satellite imagery, orthophotography, sonar, lidar).
- The assessment was limited to programs that included map products listed in Table A1.1.

Standard Operating Procedure (SOP)

This section includes steps used for documenting a program. A semicolon was used to separate lists/general comments in free text fields. For sections other than internal fields, no fields were left as blank. If something was not applicable then "NA" was used. If the program methodology varied over time, then the most recent methodology was documented.

Initial content check:

- Check whether the program meets the documented assumptions. If not, click the checkbox for "Source data only." Add any relevant comments to the "Processing comments" field.
- If the program does not just produce source data then check to see whether the program produces any of our targeted map products (Table A1.1). For example, it's possible that a habitat monitoring program was checked as mapping, but does not actually produce maps. If you do not see any map products then check "No target map products." Add any relevant comments to the "Processing comments" field.

Temporal information:

- The mapping frequency was entered. If the frequency varies by theme (i.e., shoreline position, beach/dune, etc.) then the frequency was formatted as a semicolon-separated list (e.g., shoreline position: 5 years; beach/dune: 6 years)
- Enter the earliest map. If the earliest map varied by theme (i.e., shoreline position, beach/dune, etc.) then the earliest map was formatted as a semicolon-separated list (e.g., shoreline position: 1888; beach/dune: 1998).

Data accessibility:

- "Yes", "no" or "unsure" were used to indicate if any of the mapping data was generally accessible (i.e., downloadable geographic information system files).
- "Yes", "no" or "unsure" were used to indicate if any of the mapping metadata was generally accessible (i.e., downloadable metadata files).

Documentation:

- The metadata standard was indicated by using a dropdown (e.g., Federal Geographic Data Committee [FGDC], International Organization for Standardization [ISO], other). The "other" standard was used for custom metadata (e.g., programs that only create data dictionary type documents). If multiple standards (except something

Table A1.1. List of map product types analyzed for determining common mapping methodologies and program characteristics.

General category	*Detailed categories*
Benthic	Coral Oyster SAV General bottom characterization
Emergent and forested wetlands	NA
Beach/Dune	NA
Shoreline position	NA
Land use/land cover	NA

and other) were used then field was changed to a semicolon-separated list.

- "Yes", "no, "unsure", or "NA" was used to indicate if the program had documentation on data collection procedures. "NA" was used for programs that did not have any data collection activities.
- "Yes", "no" or "unsure" was used to indicate if the program had documentation on analytical procedures.
- "Yes", "no" or "unsure" was used to indicate if the program had documentation on data QA procedures.

Thematic information:

- The classification scheme used was noted. Common schemes included: 1) Anderson land use/land cover (Anderson et al., 1976); 2) Cowardin (Cowardin et al., 1979); 3) Coastal and Marine Ecological Classification Standard (CMECS); or 4) custom (e.g., National Estuarine Research Reserve System's (NERRS) Comprehensive Habitat and Land Use Classification System, BICM detailed habitat classification scheme). If more than one scheme was used, then the schemes were listed using a semicolon.
- All of the relevant classes were added to each map product type as a semicolon-separated list.

Source data information:

- The source data was documented and if more than three sources were used, then the additional sources were captured in the "Additional source data" field as a semicolon-separated list.
- Types of in situ data that were collected were noted (e.g., vegetation surveys, ground truthing, etc.).

Map development:

- Indicated if the map development was pixel-based (i.e., each pixel was classified individually), object-based (i.e., object-based image analysis; pixels were grouped into objects and then classified), or based on digitizing (i.e., manually developing linework for a map using photointerpretation).

Mapping algorithm/method:

- Binary fields were used to indicate what map algorithm or method was used. If machine learning was used, then the specific algorithm(s) were also listed. A general comments field was used to capture general details on the map algorithm or method. For a list of algorithms/methods that were searched for with definitions, see the Glossary.

Feature representation:

- The final model type of the final product(s) was noted as either pixel-based or vector-based. If pixel-based, then the spatial resolution of final products was noted in meters.

Miscellaneous:

- "Yes", "no" or "unsure" was used to indicate whether the program conducts accuracy assessments (or validation) for mapping products.
- "Yes", "no" or "unsure" was used to indicate whether the program conducts change analyses for mapping products.
- "Yes", "no" or "unsure" was used to indicate whether the methodology used by the program has varied over time.

Protocol Review Compilation

1. The PID, Program Type; Parameter, Habitat Type, Method, and Unit information was collected for each of the three monitoring type datasets and collated into a unified spreadsheet.
2. Pivot tables were used to create tables that listed the total counts and frequencies of occurrence (as percentages) of each parameter measured within every CMAP habitat type.
3. These tables were used to calculate quartiles for the frequencies of occurrence for each habitat type using the built-in "QUARTILE" function of Google Sheets.
4. Pivot tables in Google Sheets, were used to create tables that listed the counts of each method/unit combination for each CMAP habitat type.

Assessment of Monitoring or Restoration Guidance Documents

1. Monitoring or restoration guidance documents were located in a shared folder.
2. A guidance document was read and parameters that were suggested in the document were noted along with accompanying methods/units.
3. The parameter and method information was identified within each applicable habitat type for that guidance document.
4. It was noted if the guidance document distinguished between "core" and "supplemental" parameters. In cases where such designations are not made, then all parameters were considered "core."

Determining Core CMAP Parameters

Using the decision tree, take each parameter through the steps. This was done for every habitat type.

1. The first step was related to the top quartile of the Inventory.
   a. If the parameter was in the top quartile, then "yes" was noted.
   b. If the parameter was not in the top quartile, then "no" was noted.
2. For habitat types (emergent marsh, barrier island, beach/dune, submerged aquatic vegetation, oyster/bivalve bed, and water column) addressed by the DWH NRDA's Monitoring and Adaptive Management (MAM) Manual (NRDA Trustees, 2017), the next step was related to whether the parameter was included in the MAM Manual.
   a. When the parameter was included in the top quartile:
      i. If the parameter was noted as "core" by NRDA, then it was categorized as Tier I (T1)
      ii. If the parameter was not included in the MAM Manual, then it was categorized as Tier II (T2)
      iii. If the parameter was noted as "supplemental" by NRDA, then the third step was employed.
   b. When the parameter was not included in the top quartile:
      i. If the parameter was noted as "core" by NRDA, then it was categorized as Tier III (T3)
      ii. If the parameter was not included in the MAM Manual, then it was categorized as Tier IV (T4)
      iii. If the parameter was noted as "supplemental" by NRDA, then the third step was employed.
3. The third step was related to the additional non-NRDA guidance documents.
   a. When the parameter was included in the top quartile:
      i. If the parameter was noted in at least 50% of the additional guidance documents for that habitat type, then it was categorized as Tier I (T1
      ii. If the parameter was not noted in at least 50% of the additional guidance documents for that habitat, then it was categorized as Tier II (T2)
   b. When the parameter was not included in the top quartile:
      i. If the parameter was noted in at least 50% of the additional guidance documents for that habitat type, the it was categorized as Tier III (T3)
      ii. If the parameter was not noted in at least 50% of the additional guidance documents for that habitat, then it was categorized as Tier IV (T4)
4. For habitat types not addressed in the NRDA MAM Manual, the second step and third step above was not employed.
   a. When the parameter was included in the top quartile:
      i. If the parameter was noted in at least 50% of the additional guidance documents for that habitat type, then it was categorized as Tier I (T1)
      ii. If the parameter was not noted in at least 50% of the additional guidance documents for that habitat, then it was categorized as Tier II (T2)
   b. When the parameter was not included in the top quartile:
      i. If the parameter was noted in at least 50% of the additional guidance documents for that habitat type, then it was categorized as Tier III (T3)
      ii. If the parameter was not noted in at least 50% of the additional guidance documents for that habitat, then it was categorized as Tier IV (T4)

Core Parameter Tables

1. For each habitat type, parameters collected were organized into a table by tier (Table A1.2)
2. Columns were included for method and unit information as well as the number of programs measuring each parameter and the number of programs with a particular method documented in their protocols.
3. In addition to organizing the parameters by tiers, parameters were ordered within each tier by the "Number of Programs With Parameter" column.
4. Rows were highlighted in the methods/units cells where the method appeared in both CMAP-obtained protocols and at least one additional guidance document.
5. When a method was found in a guidance document that was not already documented from the Inventory, a 0 was included next to that method in the "Number of Times Documented in Protocols" column.

Evaluation of Inventoried Programs

1. For each habitat type, a new tab was created in a spreadsheet that included every program in the Inventory.

Table A1.2. Example of selected parameters from a core parameter table for oyster/bivalve bed habitat. Highlighted cells are CMAP methods that overlap with other sources

Parameter group	*Parameter*	*# of programs with parameter*	*Method*	*Unit*	*# of times documented in protocols*	*Tier*
Mapping	Area of habitat types	37	In situ data collection	km^2; m^2	16	Tier 1
			Orthophotography	km^2; m^2	16	
			Satellite imagery	km^2; m^2	5	
			Sonar	m^2	4	
			Other imagery	m^2	1	
			Unmanned aerial systems (UAS)	-	2	
			Surficial elevation	-	7	
			Seismic/subbottom profiles	-	1	
			Ancillary data	-	1	
Field parameters	Conductance	31	Sensor	mS/cm; ppt; psu; µmhos/cm; µS/cm	7	Tier 1
			Refractometer	ppt; µS/cm	2	
			SM 2520	ppt; µS/cm	5	
			EPA 120.1	ppt; µS/cm	5	
SHBA	Size	23	Instrument/tool measurement	cm; in; mm	14	Tier 1
			GPS	cm; m	1	
			Water displacement	L/m^2	1	
			Level/rod	m	1	
			Survey equipment	cm; m	0	
			Sonar	cm; m	0	

2. A column was added that indicated which of the Inventory programs operate within the focal habitat (i.e. oyster/bivalve bed). This field was populated using the spreadsheet containing the concatenated method/unit information for each program.
3. Columns were added for each T1 parameter and were calculated to note which programs collect that parameter.
4. Columns were added for the eight Inventory fields identified as Monitoring Program Elements (MPEs). Programs were noted which programs have those elements.
    a. ***Monitoring Program Elements included the following:***
        i. Does the program have a point of contact?
        ii. Are data accessible (web accessible or send upon request)?
        iii. Are data available in a machine-readable format?
        iv. Are the data collected under this program/project documented with metadata (i.e., any format)?
        v. Does the program have documented quality assurance protocols (i.e., collection and analyses) for the majority of parameters?
        vi. Does the program have documented collection procedures for the majority of parameters?
        vii. Does the program have documented analytical procedures for the majority of parameters?
        viii. Are data units clearly defined and labeled (only documented for Water Quality Monitoring programs in the Inventory)?
5. Columns were added that indicated the total number of T1 parameters a program measures and the total number of MPEs it had.
6. CMAP habitat types—and therefore, programs operating within those habitats—were linked to the RESTORE Council's Restoration Approaches based on Table A1.3 below.
7. Resulting compilation tables can be utilized by users of the webtool to identify useful programs for their own restoration or monitoring efforts.

References

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Table A1.3. Crosswalk between the Gulf Coast Ecosystem Restoration Council (RESTORE Council) Restoration Approaches and CMAP habitat types.

	RESTORE Council Restoration Approaches[1]				
Habitat type	Create, Restore, and Enhance Coastal Wetlands, Islands, Shorelines, and Headlands	Protect and Conserve Coastal, Estuarine, and Riparian Habitats	Restore Hydrology and Natural Processes	Reduce Excess Nutrients and Other Pollutants to Watersheds	Restore Oyster Habitat
Emergent marsh	X	X			
Beach/dune	X	X			
Barrier island	X	X			
Oyster/Bivalve bed					X
Submerged aquatic vegetation (SAV)		X			
Water column			X	X	
Agriculture		X		X	
Coral reef		X			
Forest	X	X			
Hard bottom		X	X		
Mangrove	X	X			
Sargassum/Floating macroalgae		X			
Shrub/Grassland		X			
Soft bottom		X	X		
Tidal flat	X	X			
Urban		X		X	

[1] *RESTORE Council Restoration Approaches see the 2019 Planning Framework (RESTORE Council, 2019).*

Appendix 2: Frequency of parameters monitored within each habitat type

The figures below show the frequency of parameters monitored by programs operating within each CMAP habitat type. Parameters are ordered from most to least common, and the top quartile of common parameters are highlighted in blue. See Figures 5 and 6 in the report for the oyster/bivalve bed and water column habitat type figures.

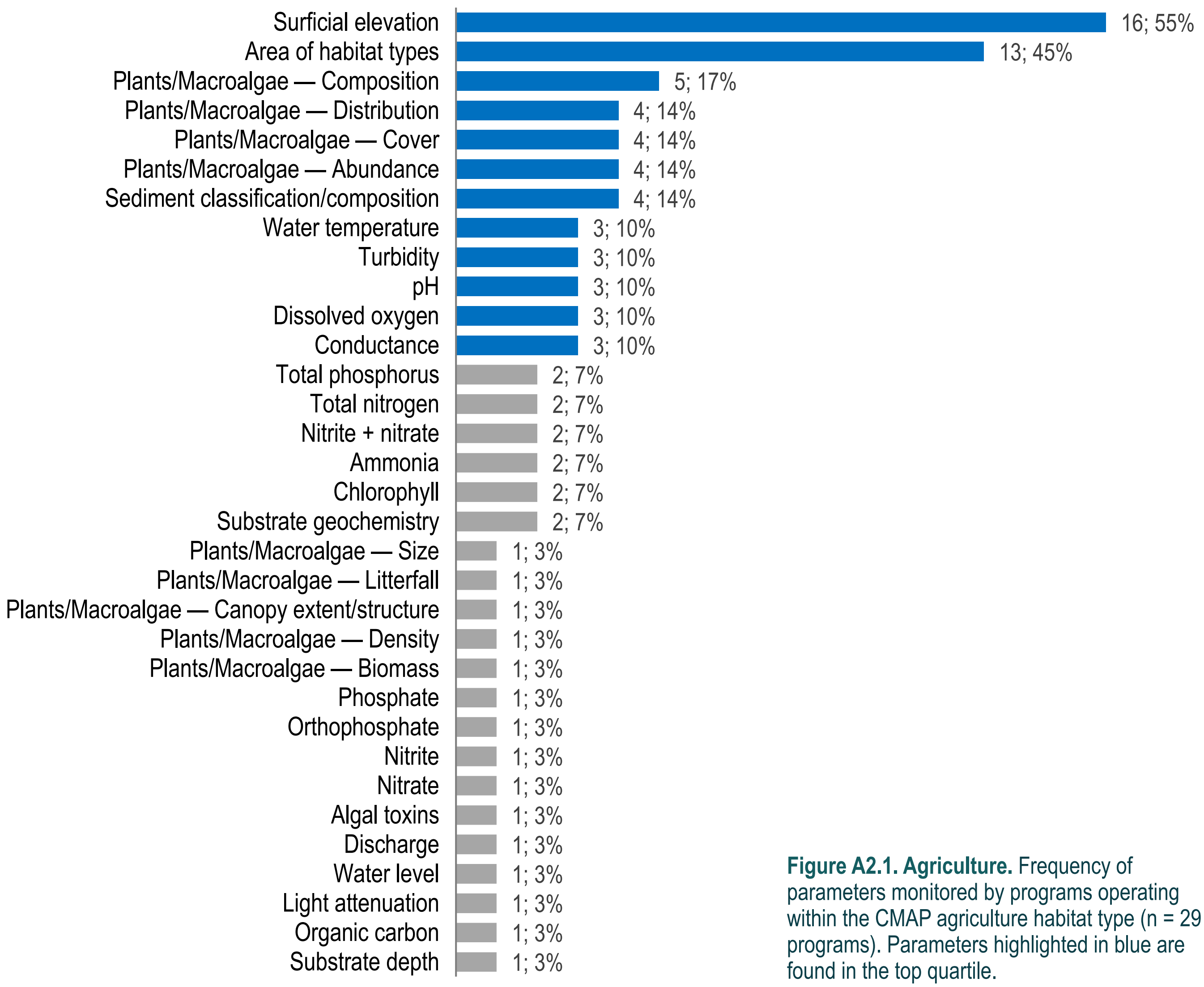


Figure A2.1. Agriculture. Frequency of parameters monitored by programs operating within the CMAP agriculture habitat type (n = 29 programs). Parameters highlighted in blue are found in the top quartile.

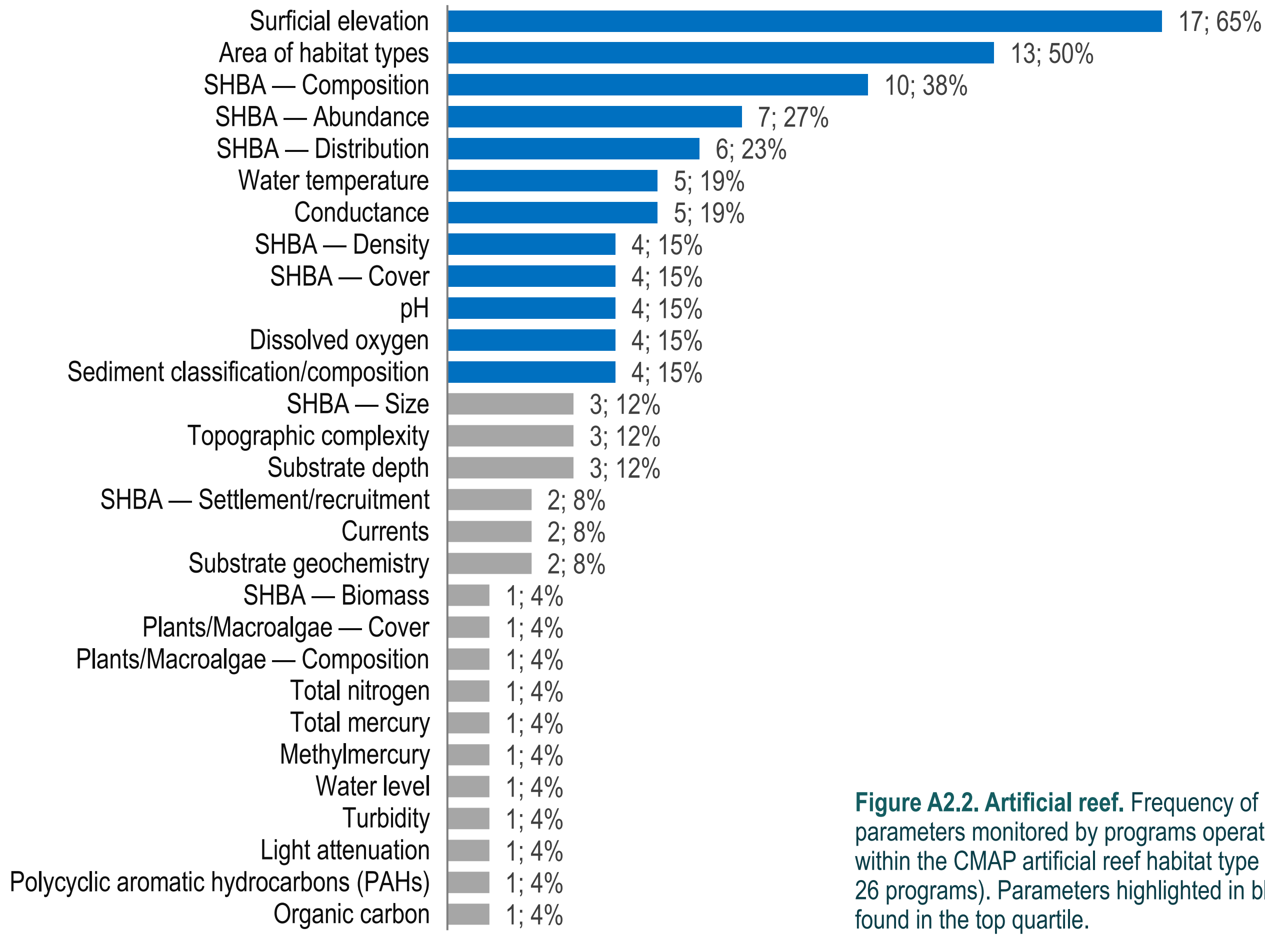


Figure A2.2. Artificial reef. Frequency of parameters monitored by programs operating within the CMAP artificial reef habitat type (n = 26 programs). Parameters highlighted in blue are found in the top quartile.

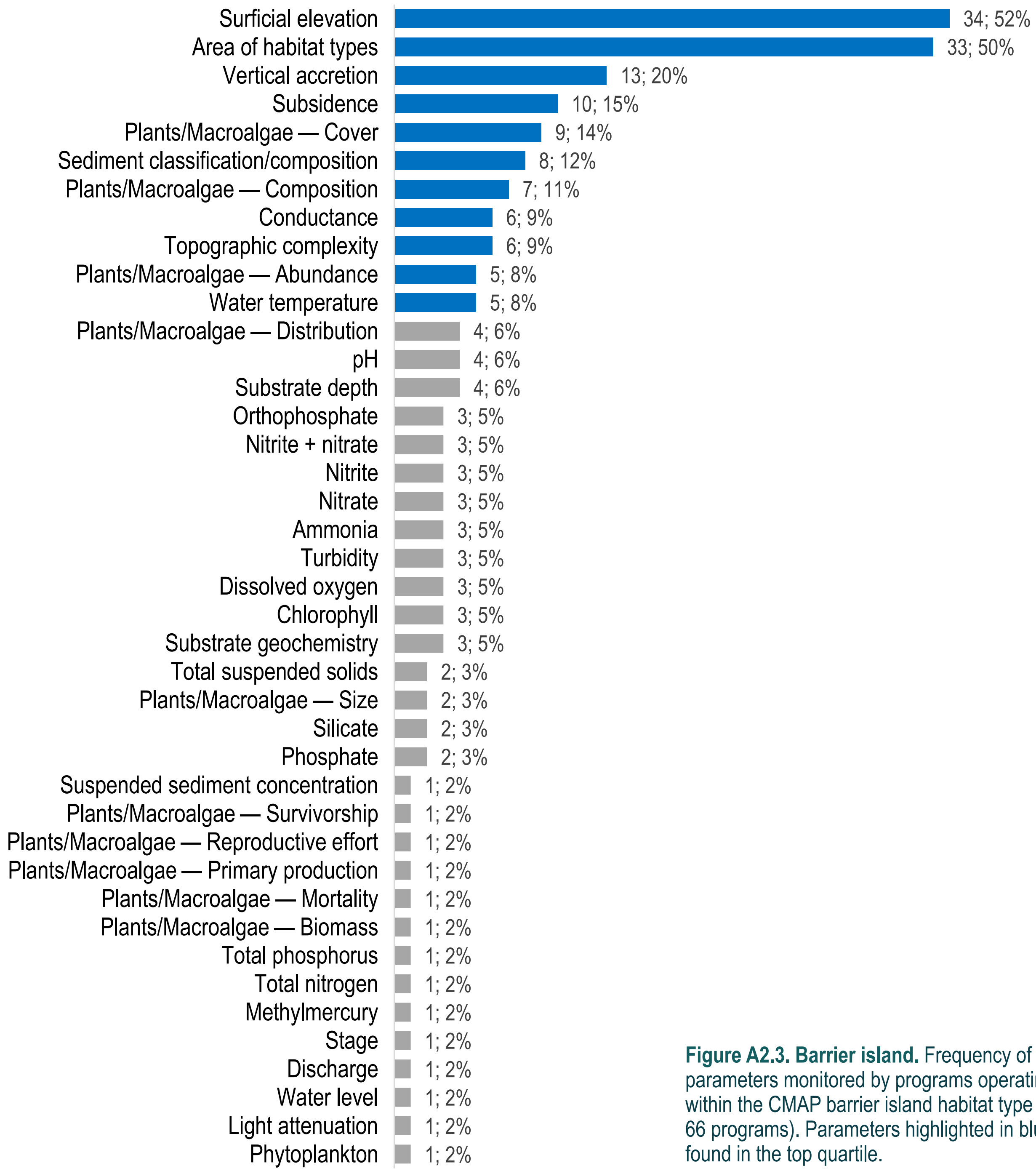


Figure A2.3. Barrier island. Frequency of parameters monitored by programs operating within the CMAP barrier island habitat type (n = 66 programs). Parameters highlighted in blue are found in the top quartile.

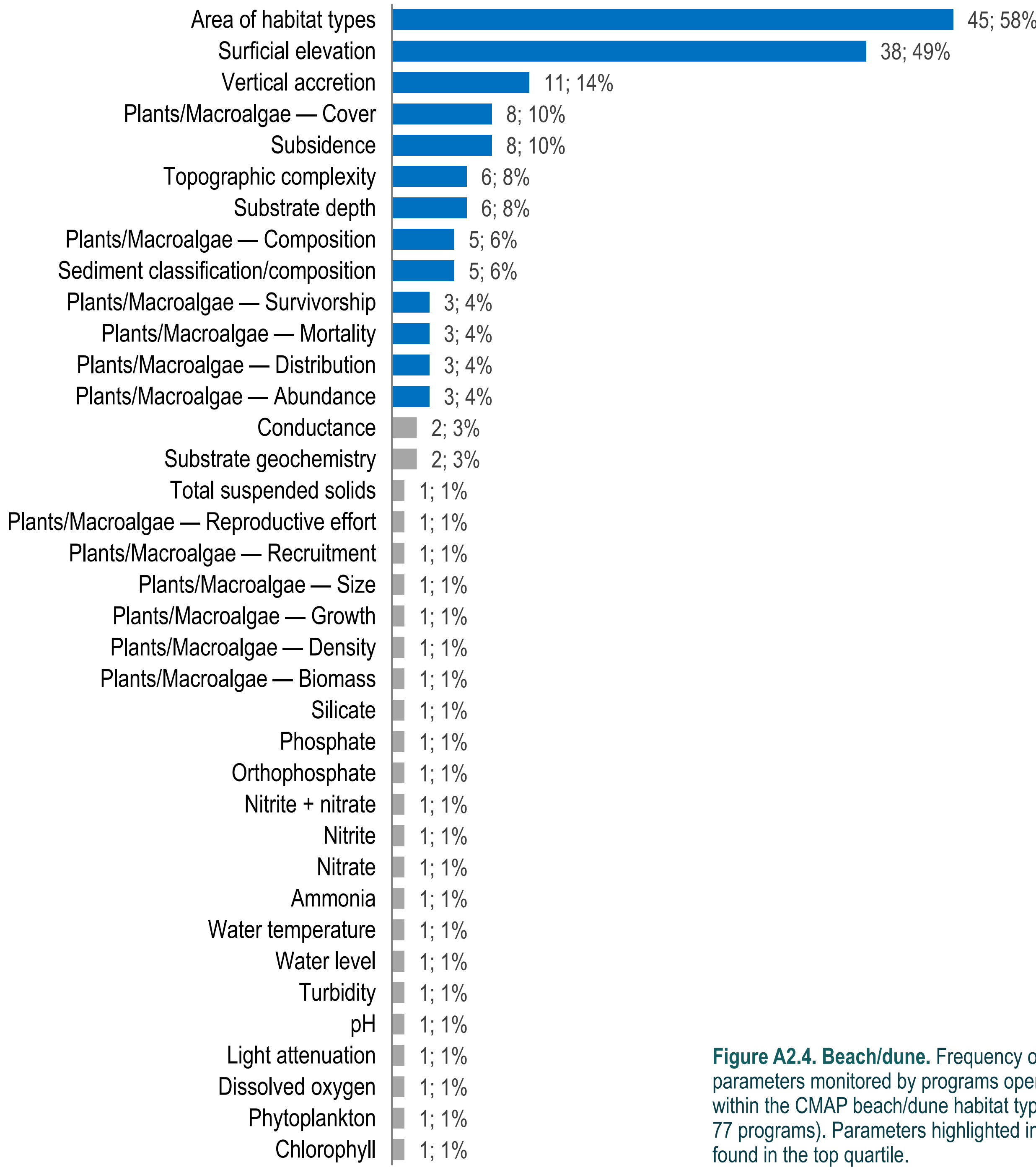


Figure A2.4. Beach/dune. Frequency of parameters monitored by programs operating within the CMAP beach/dune habitat type (n = 77 programs). Parameters highlighted in blue are found in the top quartile.

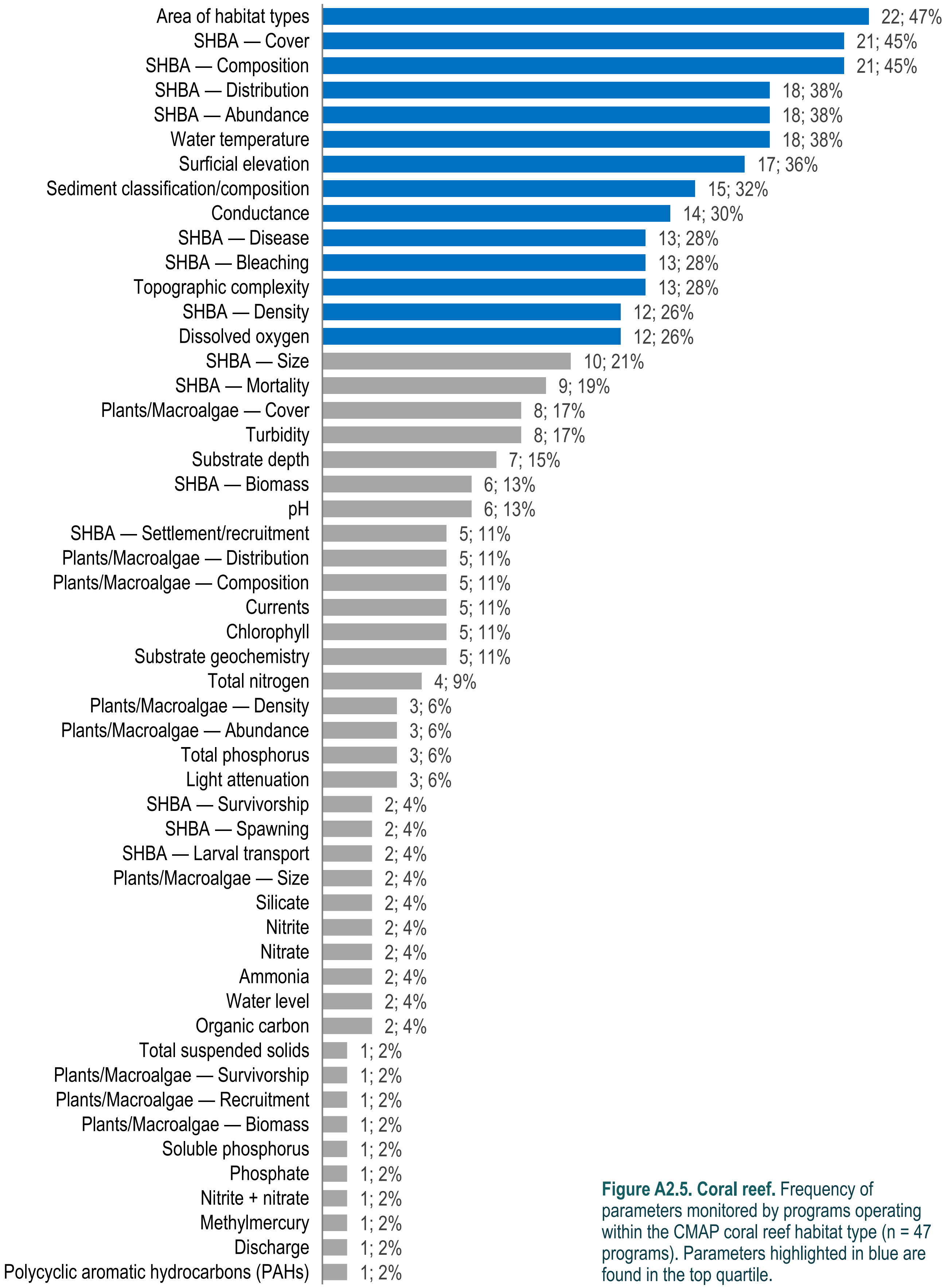


Figure A2.5. Coral reef. Frequency of parameters monitored by programs operating within the CMAP coral reef habitat type (n = 47 programs). Parameters highlighted in blue are found in the top quartile.

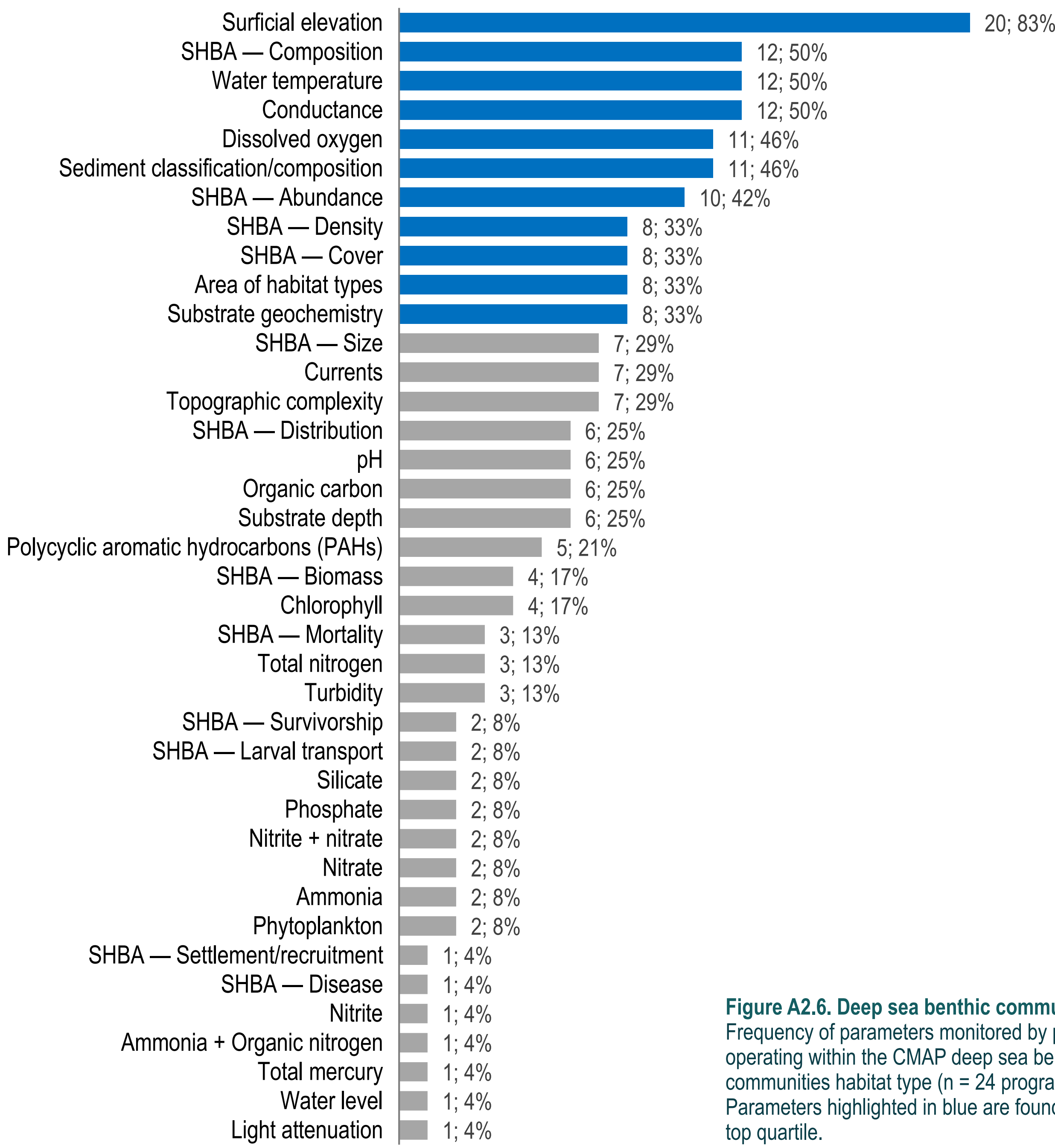


Figure A2.6. Deep sea benthic communities. Frequency of parameters monitored by programs operating within the CMAP deep sea benthic communities habitat type (n = 24 programs). Parameters highlighted in blue are found in the top quartile.

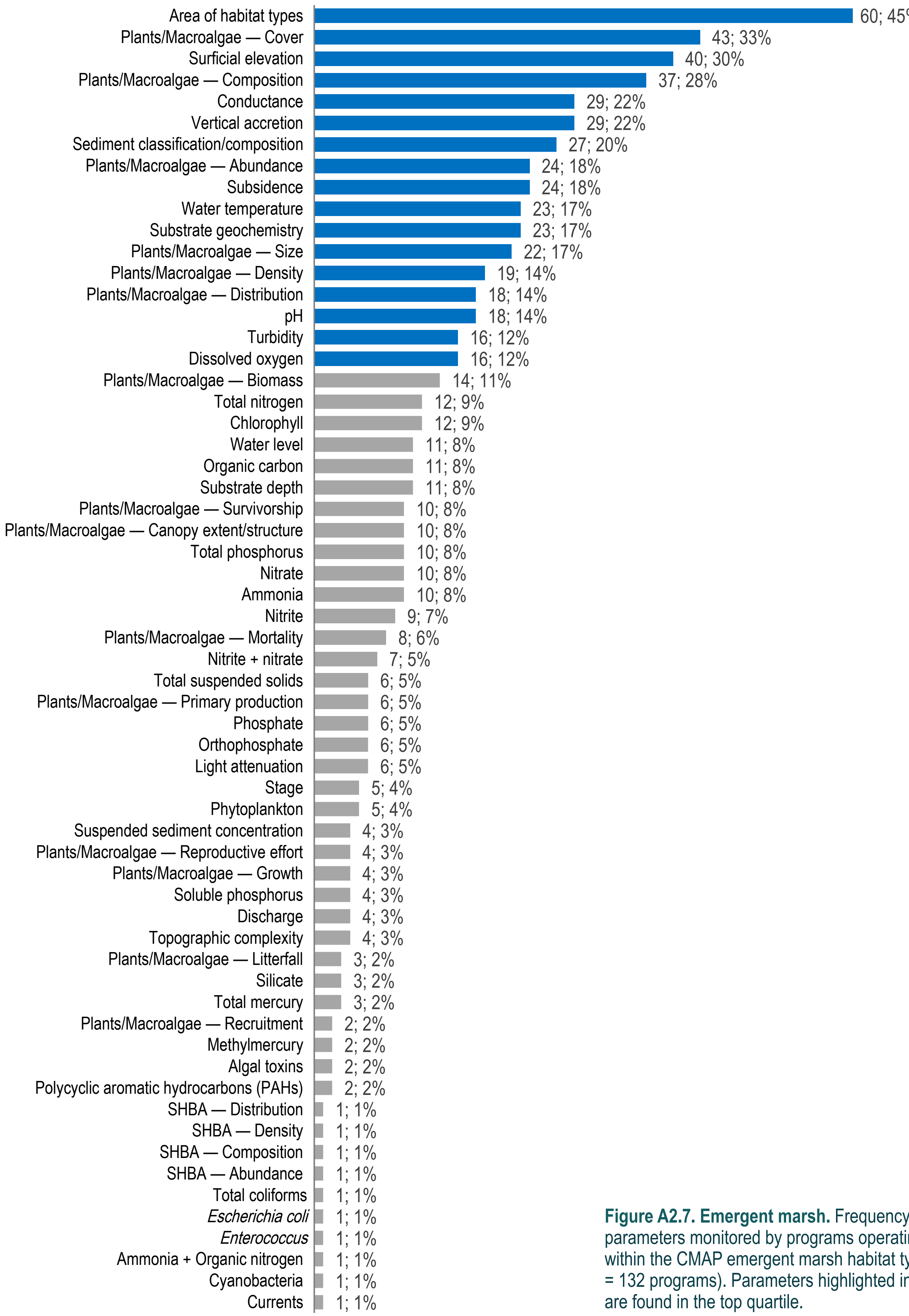
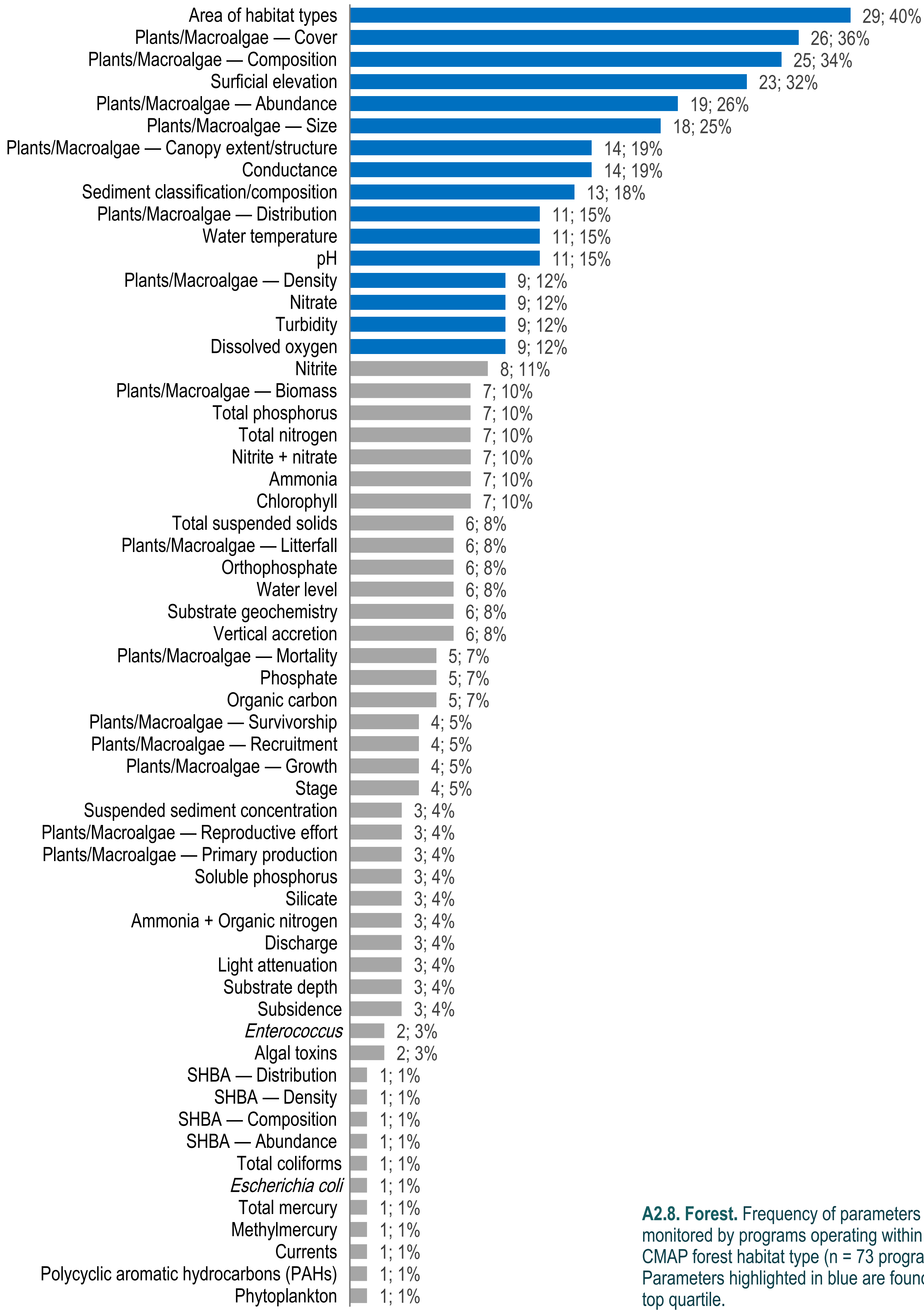
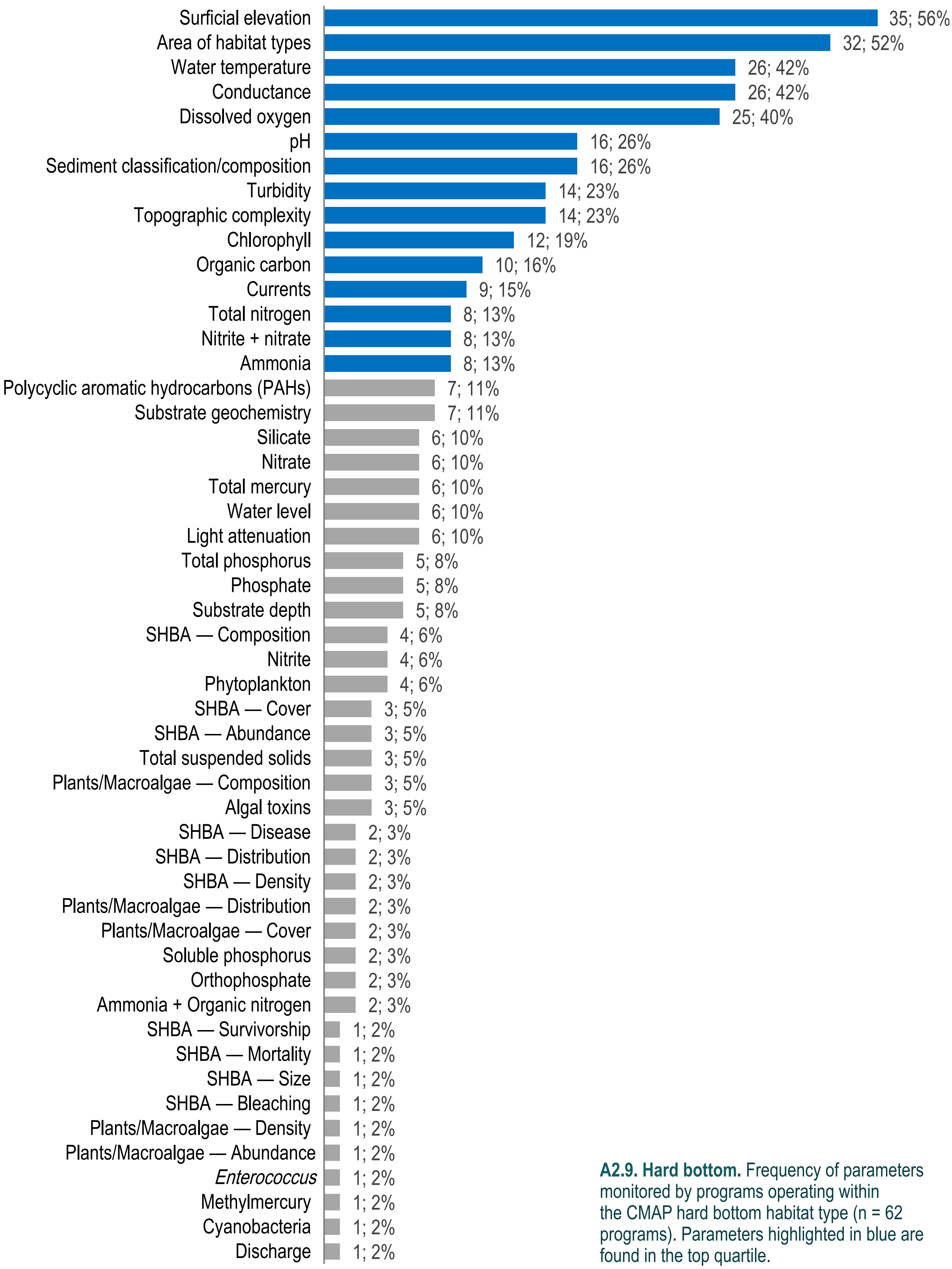


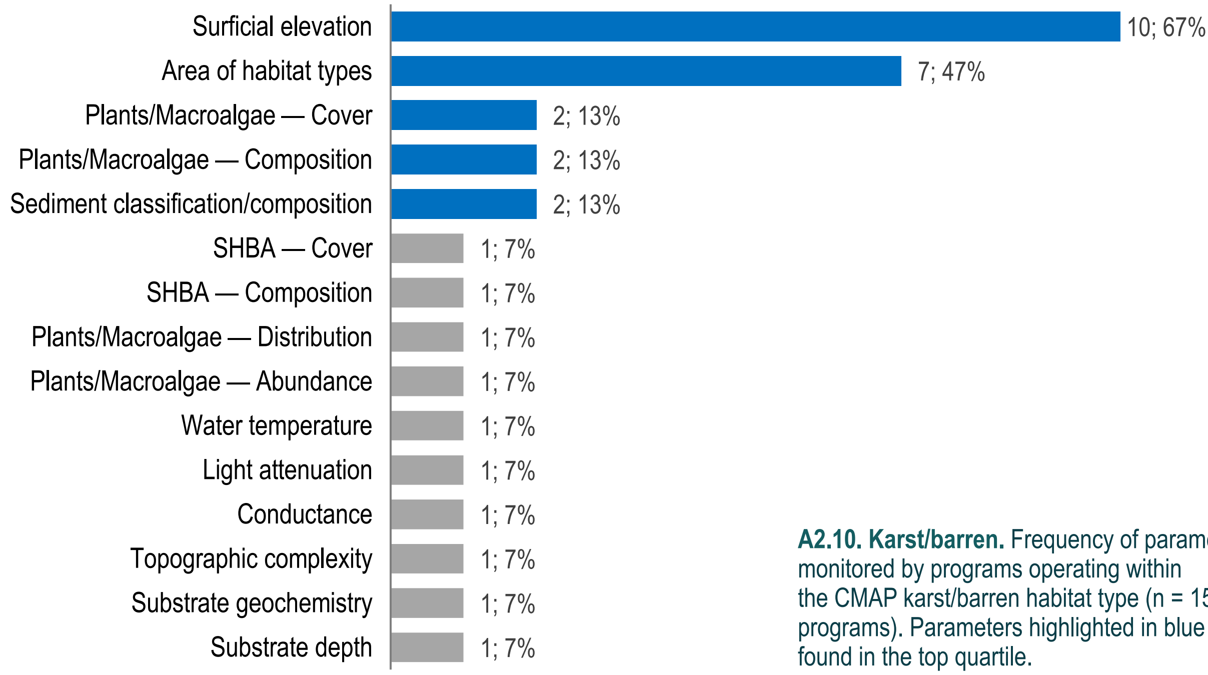
Figure A2.7. Emergent marsh. Frequency of parameters monitored by programs operating within the CMAP emergent marsh habitat type (n = 132 programs). Parameters highlighted in blue are found in the top quartile.



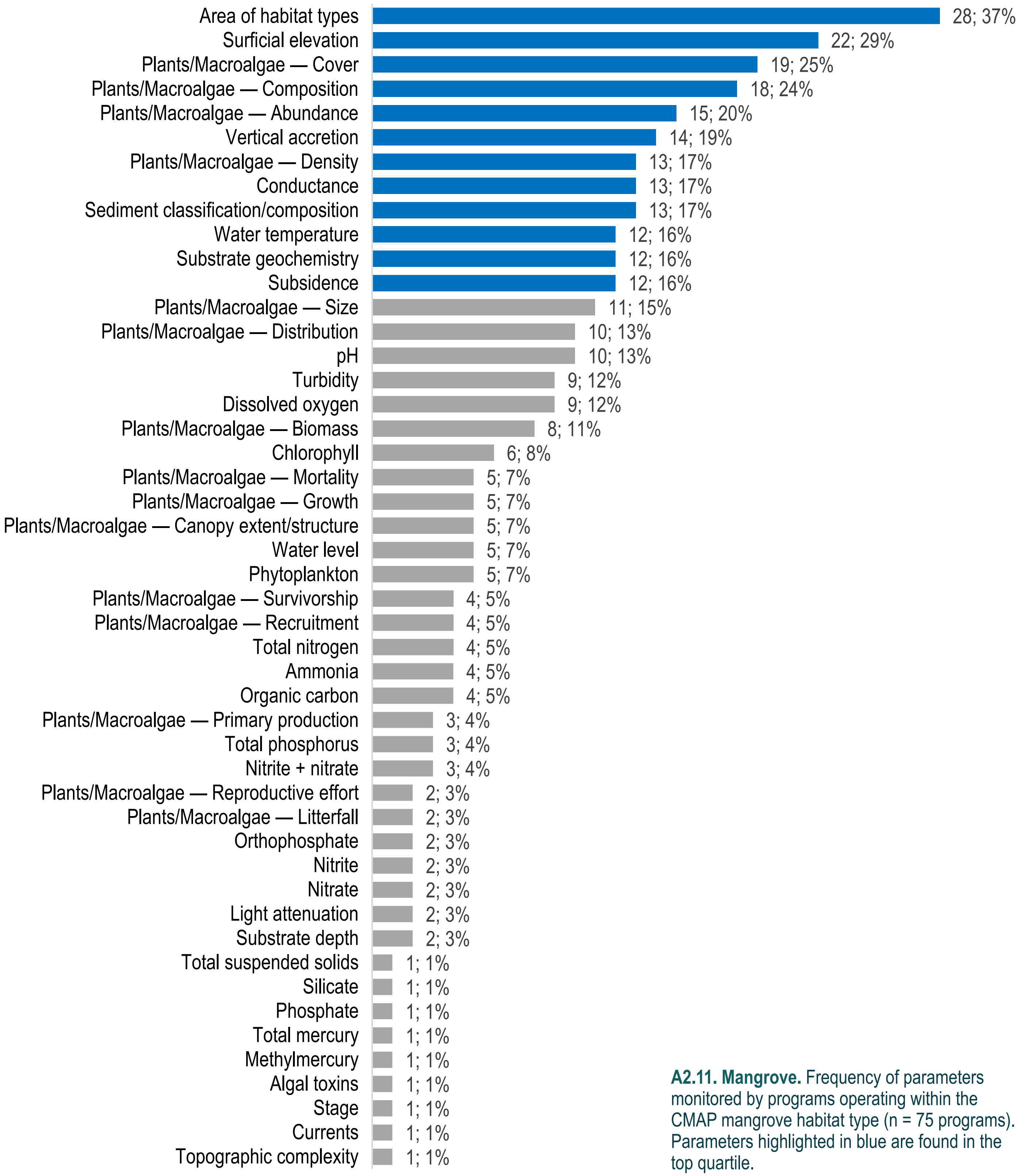
A2.8. Forest. Frequency of parameters monitored by programs operating within the CMAP forest habitat type (n = 73 programs). Parameters highlighted in blue are found in the top quartile.



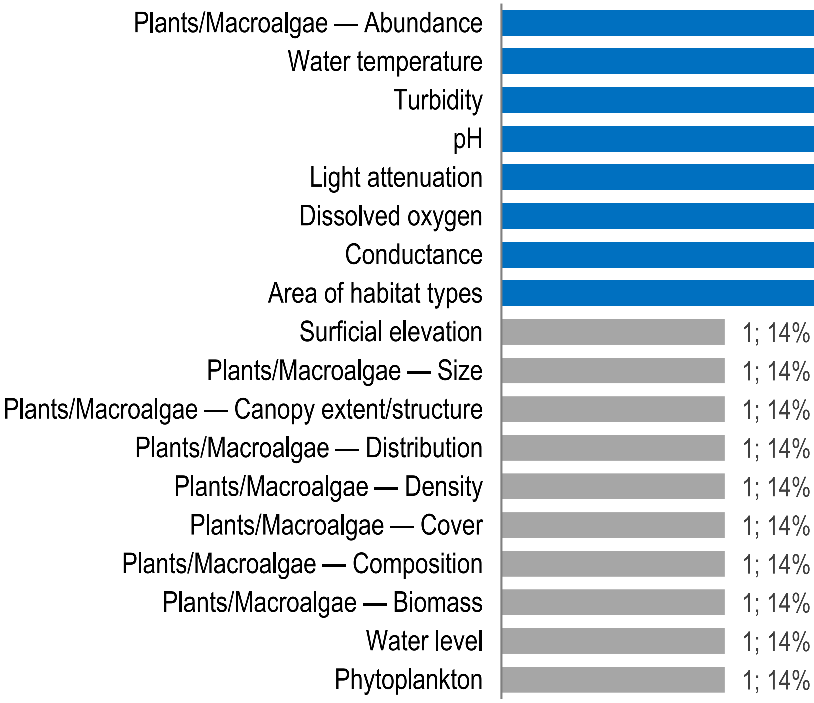
A2.9. Hard bottom. Frequency of parameters monitored by programs operating within the CMAP hard bottom habitat type (n = 62 programs). Parameters highlighted in blue are found in the top quartile.



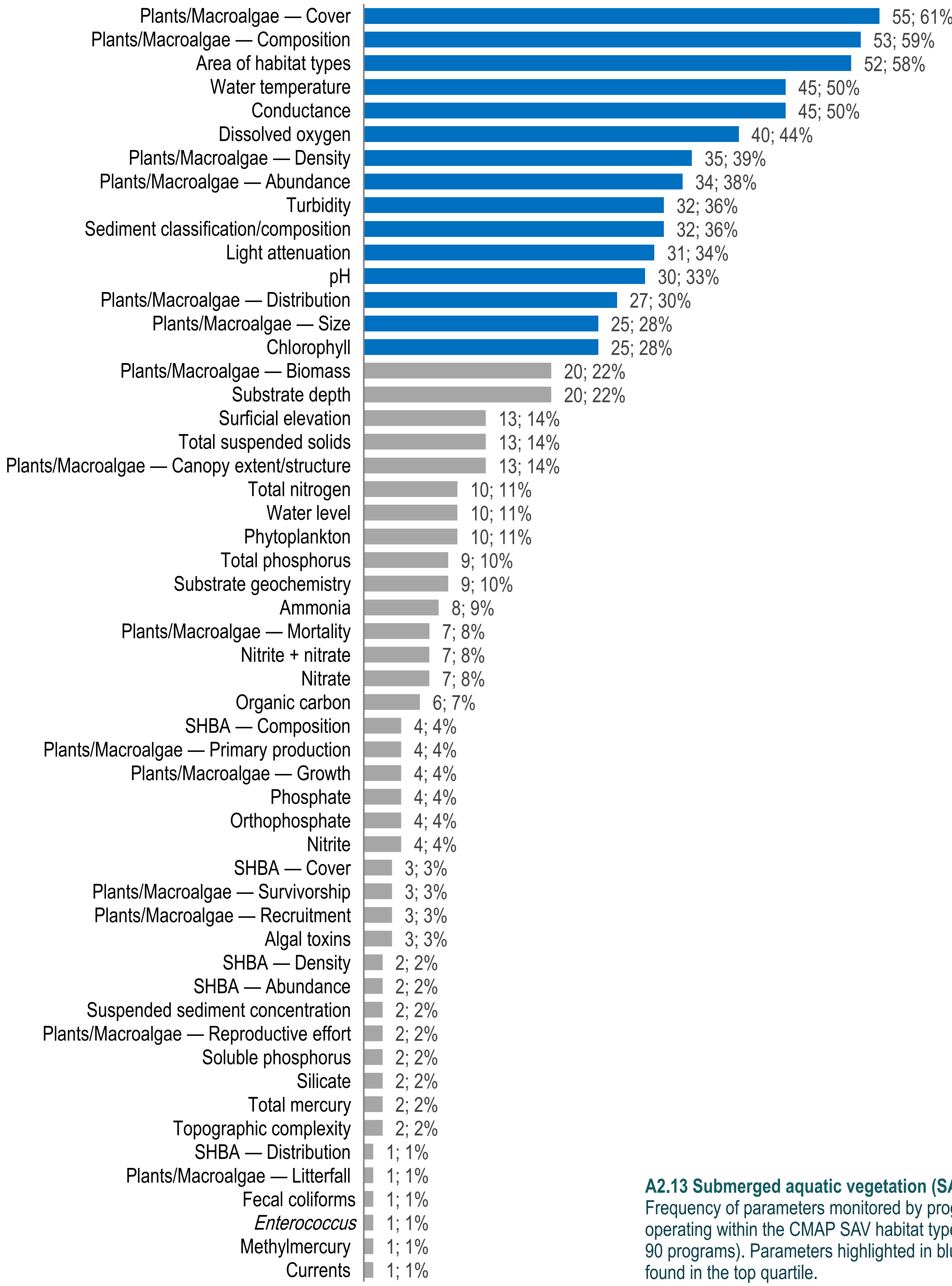
A2.10. Karst/barren. Frequency of parameters monitored by programs operating within the CMAP karst/barren habitat type (n = 15 programs). Parameters highlighted in blue are found in the top quartile.



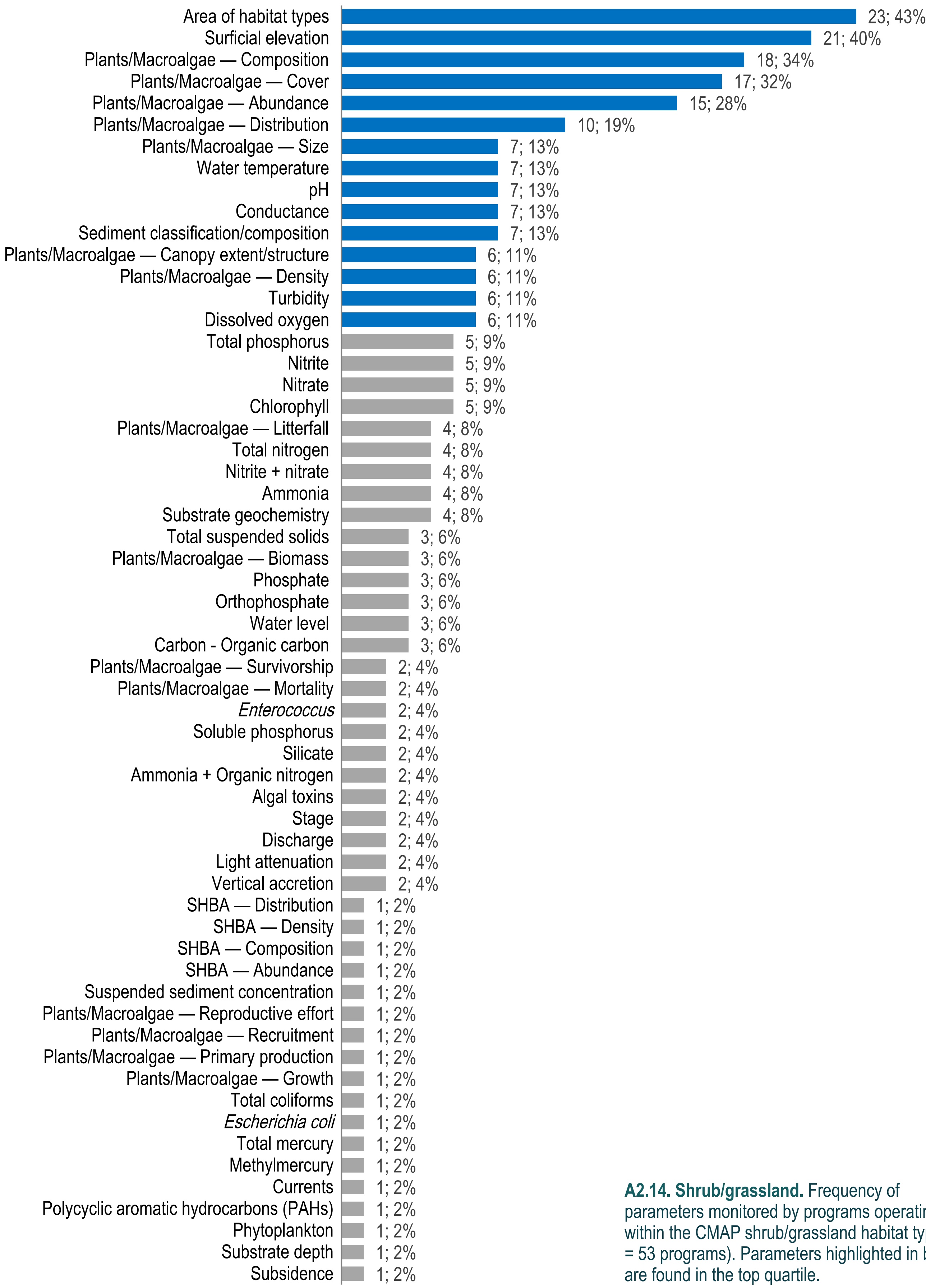
A2.11. Mangrove. Frequency of parameters monitored by programs operating within the CMAP mangrove habitat type (n = 75 programs). Parameters highlighted in blue are found in the top quartile.



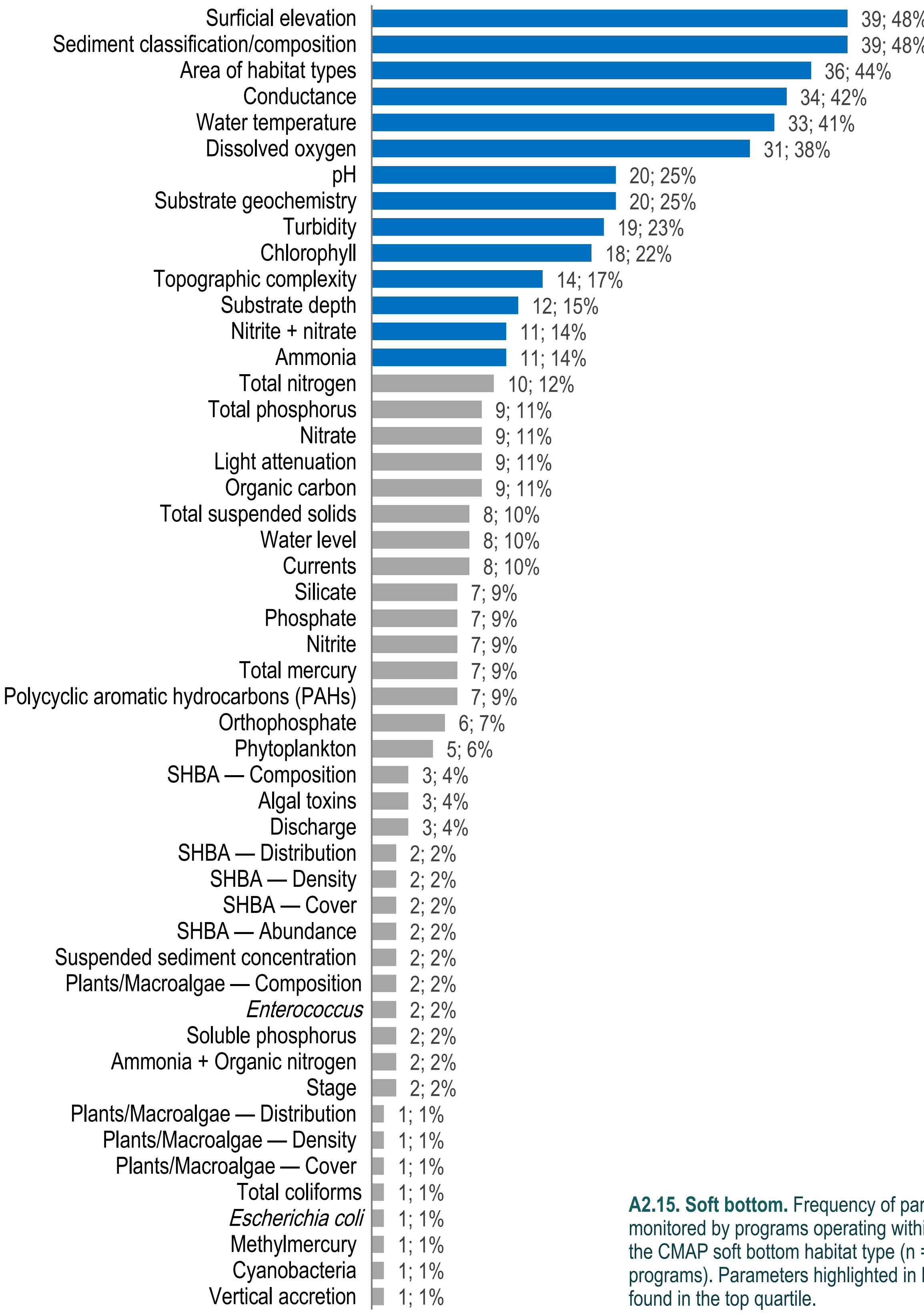
A2.12. Sargassum/floating macroalgae. Frequency of parameters monitored by programs operating within the CMAP sargassum/floating macroalgae habitat type (n = 7 programs). Parameters highlighted in blue are found in the top quartile.



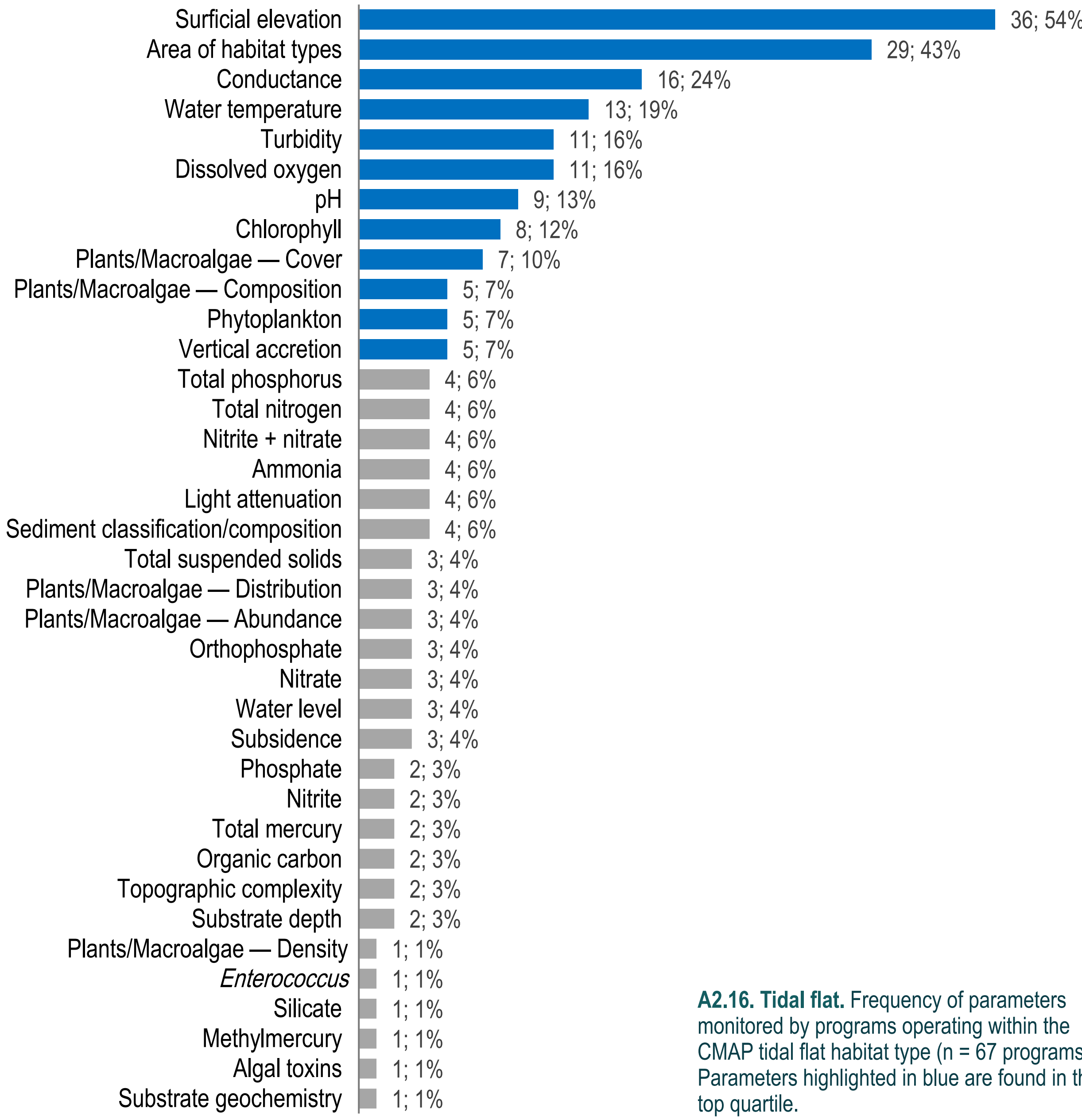
A2.13 Submerged aquatic vegetation (SAV). Frequency of parameters monitored by programs operating within the CMAP SAV habitat type (n = 90 programs). Parameters highlighted in blue are found in the top quartile.



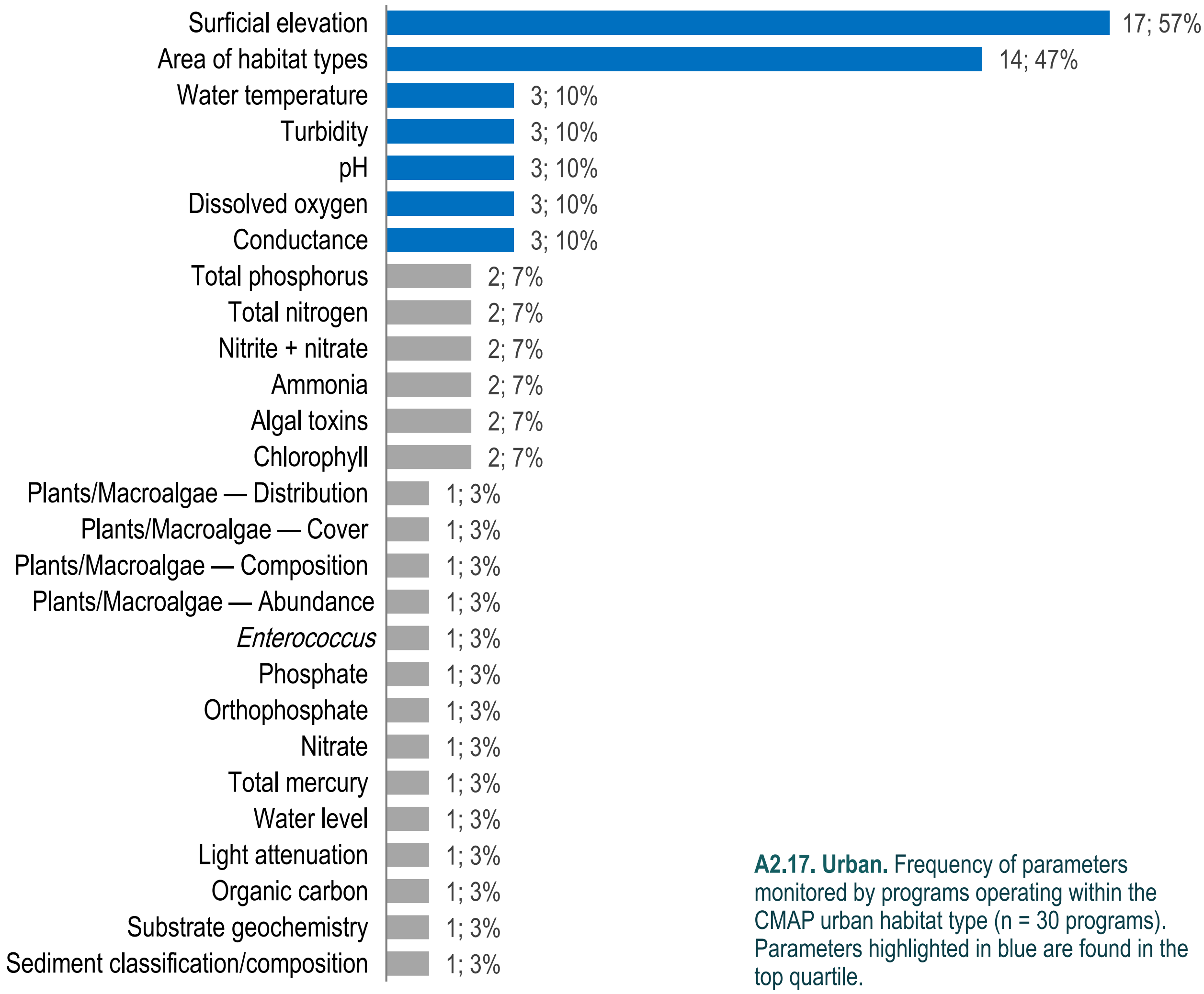
A2.14. Shrub/grassland. Frequency of parameters monitored by programs operating within the CMAP shrub/grassland habitat type (n = 53 programs). Parameters highlighted in blue are found in the top quartile.



A2.15. Soft bottom. Frequency of parameters monitored by programs operating within the CMAP soft bottom habitat type (n = 81 programs). Parameters highlighted in blue are found in the top quartile.



A2.16. Tidal flat. Frequency of parameters monitored by programs operating within the CMAP tidal flat habitat type (n = 67 programs). Parameters highlighted in blue are found in the top quartile.



A2.17. Urban. Frequency of parameters monitored by programs operating within the CMAP urban habitat type (n = 30 programs). Parameters highlighted in blue are found in the top quartile.

Appendix 3: Habitat type tables with parameter/methods/units

The tables below show the full tier categorizations for every CMAP parameter for both oyster/bivalve bed and water column habitat types. Refer to the Glossary for parameter, method, and unit definitions. Information for other habitat types can be found in the CMAP data package through NOAA NCCOS' project page (NOAA NCCOS, 2020).

Table A3.1. Oyster/Bivalve bed. Parameters, methodologies, and units identified within the Inventory and additional guidance documents (n = 67 programs). Cells that are highlighted dark green include methodologies that overlap between those documented in protocol documents obtained through Inventory construction and at least one additional guidance document.

Parameter group	Parameter	# programs with parameter	Method	Unit	# programs documenting method	Tier
Mapping	Area of habitat types	37	In situ data collection	km^2; m^2	16	Tier 1
Mapping	Area of habitat types	37	Orthophotography	km^2; m^2	16	Tier 1
Mapping	Area of habitat types	37	Satellite imagery	km^2; m^2	5	Tier 1
Mapping	Area of habitat types	37	Sonar	m^2	4	Tier 1
Mapping	Area of habitat types	37	Other imagery	m^2	1	Tier 1
Mapping	Area of habitat types	37	Unmanned aerial systems (UAS)	-	2	Tier 1
Mapping	Area of habitat types	37	Surficial elevation	-	7	Tier 1
Mapping	Area of habitat types	37	Seismic/ subbottom profiles	-	1	Tier 1
Mapping	Area of habitat types	37	Ancillary data	-	1	Tier 1
Field parameters	Conductance	31	Sensor	mS/cm; ppt; psu; µmhos/cm; µS/cm	7	Tier 1
Field parameters	Conductance	31	Refractometer	ppt; µS/cm	2	Tier 1
Field parameters	Conductance	31	SM 2520	ppt; µS/cm	5	Tier 1
Field parameters	Conductance	31	EPA 120.1	ppt; µS/cm	5	Tier 1
SHBA	Size	23	Instrument/tool measurement	cm; in; mm	14	Tier 1
SHBA	Size	23	GPS	cm; m	1	Tier 1
SHBA	Size	23	Water displacement	L/m^2	1	Tier 1
SHBA	Size	23	Level/rod	m	1	Tier 1
SHBA	Size	23	Survey equipment	cm; m	0	Tier 1
SHBA	Size	23	Sonar	cm; m	0	Tier 1
Field parameters	Dissolved oxygen	22	Sensor	mg/L; ppm	6	Tier 1
Field parameters	Dissolved oxygen	22	EPA 360.1	mg/L	4	Tier 1
Field parameters	Dissolved oxygen	22	Titration-based drop count	-	0	Tier 1
SHBA	Density	19	Visual observation	# individuals/m^2; # live individuals/ft^2; # live or dead/m^2; % live of mean; # seed (spat/seed/sack)/acre; # seed (spat/seed/sack)/m^2	13	Tier 1
SHBA	Settlement/Recruitment	18	Visual observation	# individuals/m^2; # seed (spat/seed/sack)/m^2	9	Tier 1
SHBA	Settlement/Recruitment	18	Spat monitoring array	# seed (spat/seed/sack)/shell/month	1	Tier 1
SHBA	Settlement/Recruitment	18	Settlement tile	-	1	Tier 1
SHBA	Settlement/Recruitment	18	Plankton tow	-	0	Tier 1
SHBA	Settlement/Recruitment	18	Instrument/tool measurement	-	0	Tier 1
SHBA	Mortality	14	Visual observation	# live or dead/m^2; %	11	Tier 1
SHBA	Mortality	14	Instrument/tool measurement	mm	1	Tier 1
Field parameters	Water temperature	31	Sensor	C; F	7	Tier 2
Field parameters	Water temperature	31	EPA 170.1	C	5	Tier 2
Field parameters	Water temperature	31	Thermometer	C	0	Tier 2

SHBA= Submerged habitat-building animals

Table A3.1. ***Oyster/Bivalve bed continued.***

Parameter group	Parameter	# programs with parameter	Method	Unit	# programs documenting method	Tier
SHBA	Abundance	19	Visual observation	# individuals/m^2; # seed (spat/seed/sack)/m^2	8	Tier 2
			Instrument/tool measurement	%	1	
			Calculation/Extrapolation	-	1	
			Sonar	# individuals/m^2	0	
			RTK GPS	# individuals/m^2	0	
SHBA	Composition	18	Visual observation	-	7	Tier 2
SHBA	Distribution	14	Sonar	-	1	Tier 2
			GPS	mean % oysters/size class; m^2; # individuals/size class	0	
			Imagery	mean % oysters/size class; m^2; # individuals/size class	0	
			Measure	mean % oysters/size class; m^2; # individuals/size class	0	
			Acreage change	-	0	
			Orthophotography	m^2	0	
Field parameters	Turbidity	14	EPA 180.1	NTU	2	Tier 2
			Sensor	NTU	2	
			Wagner et al., (2006)	NTU	0	
Mapping	Surficial elevation	12	-	-	-	Tier 3
SHBA	Disease	11	Visual observation	categorical; %	3	Tier 3
			Ray's fluid thioglycollate method	categorical; %	3	
			Paraffin histology method	%	0	
			PCR amplification	%	0	
Field parameters	pH	13	Sensor	Standard Unit	5	Tier 4
			EPA 150	Standard Unit	2	
			Test kit	Standard Unit	0	
SHBA	Biomass	12	Instrument/tool measurement	g/m^2	3	Tier 4
			Visual observation	-	1	
			Calculation/extrapolation	-	1	
SHBA	Cover	11	Visual observation	acres; km; %	1	Tier 4
			Sonar	acres; km; %	0	
			GPS	acres; km; %	0	
			Photo/video imagery	%	0	
			Poling	-	0	
			Unmanned aerial system	-	0	
Abiotic	Sediment classification/composition	9	Visual and/or tactile observation	categorical	2	Tier 4
			Sieve analysis	-	0	
			Pipette analysis	-	0	
			Laser analysis	-	0	
Aquatic primary producers	Chlorophyll	8	Fluorometer	mg/L; %; µg/L	1	Tier 4
			SM 10200	µg/L	2	
			Sensor	µg/L	1	
SHBA	Survivorship	8	Visual observation	# live or dead/m^2	3	Tier 4
			Calculation/Extrapolation	# live or dead/m^2	1	

SHBA= Submerged habitat-building animals

Table A3.1. ***Oyster/Bivalve bed continued.***

Parameter group	Parameter	# programs with parameter	Method	Unit	# programs documenting method	Tier
Nutrients	Total nitrogen	7	EPA 353.2	mg/L	2	Tier 4
			EPA 351.2	mg/L	2	
			Autoanalyzer	mg/L	1	
			Automate colorimetric method	-	0	
Nutrients	Total phosphorus	6	EPA 365.1	mg/L	3	Tier 4
Field parameters	Water level	5	Weighted line	m	2	Tier 4
			Sensor	m	1	
Abiotic	Topographic complexity	5	Chain and tape method	-	0	Tier 4
			Orthophotography	-	0	
			Sonar	-	0	
Nutrients	Nitrite + Nitrate	5	EPA 353.2	mg/L	1	Tier 4
Aquatic primary producers	Phytoplankton	5	-	-	-	Tier 4
Sediment	Total suspended solids	4	EPA 160.2	mg/L; ppm	0	Tier 4
Nutrients	Nitrite	4	EPA 353.2	mg/L	1	Tier 4
Nutrients	Nitrate	4	EPA 353.2	mg/L	1	Tier 4
Abiotic	Substrate depth	4	-	-	-	Tier 4
Nutrients	Ammonia	4	EPA 350.1	mg/L	1	Tier 4
Abiotic	Substrate geochemistry	3	Elemental analysis	-	0	Tier 4
Nutrients	Orthophosphate	3	EPA 365.1	mg/L	1	Tier 4
Field parameters	Light attenuation	3	Secchi disk	cm; lux; m; μE/s/m^2	2	Tier 4
			Sensor	cm; lux; μE/s/m^2	0	
Carbon	Organic carbon	3	SM 5310	mg/L	2	Tier 4
SHBA	Spawning	2	Visual observation	categorical	1	Tier 4
Nutrients	Phosphate	2	EPA 365.1	mg/L	1	Tier 4
Pathogens	Total coliforms	2	-	-	-	Tier 4
Nutrients	Silicate	2	-	-	-	Tier 4
Sediment	Suspended sediment concentration	2	-	-	-	Tier 4
Freshwater inflow	Discharge	2	Calculation	m^3/s	0	Tier 4
			Acoustic Doppler Current Profiler (ADCP)	m^3/s	0	
			Stream gauge	m^3/s	0	
			Acoustic Doppler Velocity Meter (ADVM)	m^3/s	0	
Nutrients	Ammonia + Organic nitrogen	1	-	-	-	Tier 4
Pathogens	Enterococcus	1	-	-	-	Tier 4
Pathogens	Vibrio	1	qPCR	mpn/100 mL	1	Tier 4
			Gene probe	mpn/100 mL	1	
Mercury	Total mercury	1	EPA 7473	ng/L	1	Tier 4
			EPA 1631	ng/L	1	
Mercury	Methylmercury	1	-	-	-	Tier 4
Freshwater inflow	Stage	1	-	-	-	Tier 4

SHBA= Submerged habitat-building animals

Table A3.2. Water column. Parameters, methodologies, and units identified within the Inventory and additional guidance documents (n = 358 programs). Cells that are highlighted dark green include methodologies that overlap between those documented in protocol documents obtained through Inventory construction and at least one additional guidance document.

Parameter group	*Parameter*	*# programs with parameter*	*Method*	*Unit*	*# programs documenting method*	*Tier*
Field parameters	Water temperature	313	Sensor	C; F	96	Tier 1
			EPA 170.1	C	51	
			USGS TWRI 9	C	5	
			SM 2550	C	1	
Field parameters	Conductance	304	Sensor	mS/cm; ppt; psu; µmhos/cm; µS/cm	93	Tier 1
			EPA 120.1	ppt; psu; µmhos/cm; µS/cm	52	
			SM 2520	ppt; µS/cm	44	
			SM 2510	ppt; µmhos/cm; µS/cm	9	
			Refractometer	ppt; psu	7	
			USGS TWRI 9	µS/cm	5	
			EPA 120.6	µS/cm	3	
			EPA 120.7	µS/cm	1	
Field parameters	Dissolved oxygen	247	Sensor	mg/L; %; ppm; ppt	78	Tier 1
			EPA 360.1	mg/L	52	
			Winkler titration	mg/L; ppm	6	
			Test kit	mg/L; ppm	4	
			EPA 360.2	%	1	
Field parameters	Turbidity	183	EPA 180.1	NTU	47	Tier 1
			Sensor	NTU	22	
			SM 2130	NTU	15	
			Turbidimeter	NTU	8	
			Test kit	NTU	2	
			USGS I-3860-85	NTU	2	
Nutrients	Total phosphorus	132	EPA 365.1	mg/L; µg/L	52	Tier 1
			EPA 365.4	mg/L	17	
			SM 4500 P	mg/L; µg/L	13	
Nutrients	Total nitrogen	128	EPA 351.2	mg/L	33	Tier 1
			EPA 353.2	mg/L	30	
			Auto analyzer	mg/L; µg/L	9	
			SM 4500 N	mg/L	8	
			EPA 351.1	mg/L	6	
			Spectrophotometer	mg/L; µg/L	5	
			EPA	mg/L	3	
			USGS OFR 00-170	mg/L	2	
			USGS OFR 93-125	mg/L	2	
			USGS I-3556-77	mg/L	1	
Nutrients	Ammonia	124	EPA 350.1	mg/L	49	Tier 1
			Auto analyzer	mg/L; µmol/L	10	
			SM 4500 NH3	mg/L	9	
			USGS OFR 93-125	mg/L	3	

Table A3.2. ***Water column continued.***

Parameter group	Parameter	# programs with parameter	Method	Unit	# programs documenting method	Tier
Field parameters	pH	210	Sensor	Standard Unit	76	Tier 2
			EPA 150	Standard Unit	32	
			EPA 150.1	Standard Unit	11	
			EPA 150.6	Standard Unit	3	
			Test kit	Standard Unit	3	
			SM 4500 H+B	Standard Unit	2	
Aquatic primary producers	Chlorophyll	154	SM 10200 H	mg/m^3; µg/L	46	Tier 2
			EPA 445.0	µg/L	20	
			EPA 446.0	µg/L	15	
			Fluorometer	µg/L	14	
			SM 10300 C	µg/L	5	
			Sensor	µg/L	3	
			Spectrophotometer	µg/L	2	
Nutrients	Nitrite + nitrate	105	EPA 353.2	mg/L	42	Tier 3
			SM 4500 NO3	mg/L	7	
			SM 4110	mg/L	5	
			EPA 300.0	mg/L	5	
			EPA 300.6	mg/L	5	
			Auto analyzer	µmol/L	3	
			USGS TM 5-B8	mg/L	1	
Field parameters	Water level	105	Sensor	ft; m	33	Tier 3
			Weighted line	m	19	
			USGS TWRI 3	ft	4	
			Measuring stick	m	3	
Pathogens	Fecal coliforms	65	SM 9222 D	cfu/100 mL	16	Tier 3
			Coliscan Easygel	cfu/100 mL; mpn/100 mL	5	
			SM 9221 E	mpn/100 mL	2	
			Colilert	cfu/100 mL; mpn/100 mL	2	
Nutrients	Ammonia + Organic nitrogen	60	EPA 351.2	mg/L	21	Tier 3
			EPA 350.1	mg/L	3	
			SM 4500 NH3	mg/L	2	
			USGS OFR 00-170	mg/L	2	
			Auto analyzer	-	1	
Freshwater inflow	Discharge	51	Flowmeter	cfs; m/s	10	Tier 3
			USGS TWRI 3	cfs	9	
			Calculated	cfs	2	
Field parameters	Light attenuation	116	Secchi	cm; ft; in; m	64	Tier 4
			Photometer	kpar	29	
			Transmissometer	-	2	
Sediment	Total suspended solids	106	SM 2540 D	mg/L	28	Tier 4
			EPA 160.2	mg/L	15	
			USGS TWRI B5-A1	mg/L	1	

Table A3.2. ***Water column continued.***

Parameter group	Parameter	# programs with parameter	Method	Unit	# programs documenting method	Tier
Nutrients	Nitrate	95	EPA 353.2	mg/L	26	Tier 4
			EPA 300.0	mg/L	7	
			Auto analyzer	mg/L; µmol/L	7	
			SM 4500 NO3	mg/L	6	
			EPA 300.6	mg/L	3	
			SM 4110 B	mg/L	3	
			Spectrophotometer	mg/L; µmol/L	3	
			USGS TM 5-B8	mg/L	2	
			Test kit	mg/L	1	
			Sensor	-	1	
Nutrients	Nitrite	93	EPA 353.2	mg/L	27	Tier 4
			EPA 300.0	mg/L	7	
			SM 4500 NO2	mg/L	6	
			Auto analyzer	mg/L; µmol/L	6	
			EPA 300.6	mg/L	2	
			USGS TM 5-B8	mg/L	2	
			SM 4110 B	mg/L	2	
			Spectrophotometer	mg/L; µmol/L	2	
Carbon	Organic carbon	72	SM 5310	mg/L	30	Tier 4
			EPA 415.1	mg/L	4	
			SW 9060	mg/L	2	
			Analyzer	mg/L	2	
			EPA 415.2	mg/L	1	
Nutrients	Orthophosphate	67	EPA 365.1	mg/L	22	Tier 4
			EPA 365.2	mg/L	4	
			SM 4500 P	mg/L	3	
			Auto analyzer	mg/L; µmol/L	2	
			Test kit	mg/L	1	
			USGS I-2604-77	mg/L	1	
			USGS I-4601-85	mg/L	1	
			USGS I-4650-03	mg/L	1	
Nutrients	Phosphate	57	EPA 365.1	mg/L	19	Tier 4
			Auto analyzer	mg/L; µmol/L	3	
			SM 4500 P	mg/L	1	
Pathogens	Enterococcus	49	EPA 1600	cfu/100 mL	13	Tier 4
			Enterolert	mpn/100 mL	9	
			ADEM 2064	cfu/100 mL	2	
			USGS TWRI 9A	cfu/100 mL	2	
			SM 9230 D	cfu/100 mL	1	
Nutrients	Soluble phosphorus	43	EPA 365.1	mg/L	10	Tier 4
			ADEM 2062	mg/L	5	
			Auto analyzer	mg/L	2	
Freshwater inflow	Stage	39	USGS TWRI 3	ft	6	Tier 4
			Sensor	ft	2	
			USGS WRIR 01-4044	ft	1	

Table A3.2. Water column continued.

Parameter group	Parameter	# programs with parameter	Method	Unit	# programs documenting method	Tier
Field parameters	Currents	32	Current meter	cm/s	4	Tier 4
			USGS TWRI 3	cm/s	1	
Aquatic primary producers	Phytoplankton	31	Flow cytometer	cell abundance	1	Tier 4
			High performance liquid chromatography (HPLC)	-	1	
			Sedgewick-Rafter counting chamber	cells/mL	1	
Nutrients	Silicate	30	EPA 370.1	mg/L	4	Tier 4
			Auto analyzer	mg/L	4	
			EPA 366.0	mg/L	3	
			SM 4500 Si	mg/L	3	
Mercury	Total mercury	29	EPA 1631	ng/L; ppb; µg/L	8	Tier 4
			EPA 245.1	µg/L	3	
			EPA 245.6	µg/g; µg/L	3	
			EPA 7473	ng/L; ppb	3	
			EPA 245.7	ng/L; ppm; µg/g	3	
			Test kit	µg/L	2	
			EPA 245.2	µg/L	1	
			USGS WRIR 01-4132	µg/L	1	
Pathogens	Escherichia coli	27	SM 9223 B	cfu/100 mL; mpn/100 mL	9	Tier 4
			Coliscan Easygel	cfu/100 mL; mpn/100 mL	7	
			EPA 1603	cfu/100 mL	4	
			USGS TWRI 9	cfu/100 mL	2	
Pathogens	Total coliforms	26	SM 9222 B	cfu/100 mL	5	Tier 4
			Coliscan Easygel	cfu/100 mL	2	
			USGS TWRI 9	cfu/100 mL	2	
Sediment	Suspended sediment concentration	23	USGS TM 5-C1	mg/L	3	Tier 4
Carbon	Polycyclic aromatic hydrocarbons (PAHs)	15	Gas chromatography/Mass spectrometry (GC/MS)	ng/g	3	Tier 4
			USGS WRIR 03-4318	µg/kg	1	
Mercury	Methylmercury	9	EPA 1631	ng/L; ppt	3	Tier 4
			Test kit	µg/L	1	
			USGS OFR 01-445	ng/L	1	
Harmful agal bloom indicators	Algal toxins	9	EPA	µg/L	2	Tier 4
			Cylindrospermopsin immunoassay	µg/L	1	
			EPA 8321 B	-	1	
			Immunosorbent assay (ELISA) ADDA kits	µg/L	1	
			Sedgewick-Rafter counting chamber	cells/mL	1	
			USGS OGRL 5400	µg/L	1	
Harmful agal bloom indicators	Cyanobacteria	4	-	-	4	Tier 4
Pathogens	Vibrio	1	Gene probe	mpn/100 mL	1	Tier 4
			Quantitative polymerase chain reaction (qPCR)	mpn/100 mL	1	

Appendix 4: Summary tables of methods and techniques for other mapping themes

The following tables summarize the detailed information CMAP compiled about mapping programs in the Gulf of Mexico. Programs were categorized by one or more map themes based on the habitats of focus and the types of maps that were created. These map themes included oyster reef, coral/artificial reef, benthic—SAV, benthic—general, wetlands, beach/dune, land use/land cover, and shoreline position. A summary of programs under the oyster reef map theme is highlighted in the report (Table 5), while the additional map themes are summarized below.

Each table notes the total number of programs that produce products that include classes for the map theme. The tables also include information on program classification schemes, including custom local schemes--such as Laswell et al. (1990) and the Everglades Vegetation Classification System—and national standardized schemes—such as Anderson et al. (1976), Cowardin et al. (1979), and Comer et al. (2003). Details on map classes, data sources, mapping unit development, and mapping algorithms are also included. Finally, each table summarizes additional programmatic information, including the percentage of programs with an assessment of the accuracy of area of habitat type maps (i.e., accuracy assessment), with an analysis of change between area of habitat type maps (i.e., change analysis), and with web-accessible data and metadata.

Table A4.1. Beach/Dune. Summary of methods and techniques used by programs mapping beach and dune habitats (n = 17).

Classification standard	*% of programs*	*Definition*
Custom local scheme	65%	Classification scheme tailored to the habitats and land cover of a particular State, region, or locality, or customized for a certain program or project. Examples include Laswell et al. (1990) and the Everglades Vegetation Classification System.
National standardized scheme	29%	Widely used classification schemes that can be applied to large regions or the entire United States. Examples include Anderson et al. (1976), Cowardin et al. (1979), and Comer et al. (2003).

Classification details	*% of programs*	*Definition*
Association level	6%	Includes detail at the association level in the U.S. National Vegetation Classification (USNVC) system, which often includes information from many factors including vegetation species, soil types, geology, and hydrology.
Beach/dune combined	65%	Includes beach and dune as the same class.
Beach/dune separated	24%	Includes beach and dune as different classes.
Modified Anderson	59%	Includes classes modified from the Anderson et al. (1976) land use and land cover classification system.
Sediment type	18%	Includes information on the sediment type (e.g., mud, sand).
Wetlands near beach/dune	94%	Includes wetland classes near beach/dune environments (e.g., estuarine intertidal emergent marsh, palustrine emergent wetland).

Data sources	*% of programs*	*Definition*
Ancillary data	24%	See the Glossary for definitions.
In situ data collection	76%	
Orthophotography	94%	
Other imagery	6%	
Satellite imagery	29%	
Surficial elevation	53%	
Unmanned aerial systems (UAS)	18%	

Table A4.1. Beach/Dune continued.

Mapping unit development	% of programs	Definition
Pixel-based	24%	Method of map development in which each pixel is classified individually.
Object-based	29%	Method of map development in which neighboring pixels with similar characteristics are grouped as an initial step in the mapping process.
Digitizing	82%	Method of converting an image into vector data (i.e., polygons or lines) that involves manual development of linework using photointerpretation.

Mapping algorithm	% of programs	Definition
Unsupervised	6%	Method of unsupervised image classification that groups mapping units into classes based on user-defined settings.
Maximum likelihood classifier	6%	A parametric supervised classification technique that assigns a map unit into the class with the maximum likelihood based on a set of training data.
Machine learning	29%	Method that utilizes either supervised or unsupervised nonparametric classification algorithms.
Rule-based	29%	Method of supervised image classification in which a user defines one or more if-then rules for the computer to follow (e.g., thresholds).
Photointerpretation	94%	Manual method of classification or editing in which a trained user visually identifies classes in a remotely sensed image using feature appearance, context, and/or expert opinion.

Other information	% of programs	Definition
Accuracy assessment	76%	Programs that assess the accuracy of area of habitat type maps.
Change analyses	88%	Programs that analyze change between area of habitat type maps.
Data accessible	76%	Programs with web-accessible data.
Metadata accessible	59%	Programs have metadata that are available on the web.

Table A4.2. Benthic–SAV. Summary of methods and techniques used by programs mapping submerged aquatic vegetation (SAV), which includes seagrass beds and benthic macroalgae (n = 25).

Classification standard	*% of programs*	*Definition*
Custom local scheme	92%	Classification scheme tailored to the habitats and land cover of a particular State, region, or locality, or customized for a certain program or project. Examples include Laswell et al. (1990) and the Everglades Vegetation Classification System.
National standardized scheme	8%	Widely used classification schemes that can be applied to large regions or the entire United States. Examples include Anderson et al. (1976), Cowardin et al. (1979), and Comer et al. (2003).

Classification details	*% of programs*	*Definition*
Condition	8%	Includes information on SAV condition or health (e.g., presence and severity of scarring).
Patchy/continuous	60%	Includes detail on the level of SAV coverage in the area (e.g., patchy, continuous, discontinuous, or total coverage).
Patchy/continuous with species information	8%	Includes detail on both coverage and species of SAV (e.g., patchy sparse offshore Halophila sp. and rhizophytic algal stands).
Presence/absence	48%	Includes the presence and/or percent cover of a single SAV class.
Presence/absence with species information	4%	Includes species information along with presence/absence (e.g., percent cover of *Ruppia maritima*).

Data sources	*% of programs*	*Definition*
Ancillary data	8%	See the Glossary for definitions.
In situ data collection	92%	
Orthophotography	92%	
Other imagery	4%	
Satellite imagery	36%	
Seismic/subbottom profiles	4%	
Sonar	16%	
Surficial elevation	28%	
UAS	8%	

Mapping unit development	*% of programs*	*Definition*
Pixel-based	12%	Method of map development in which each pixel is classified individually.
Digitizing	92%	Method of converting an image into vector data (i.e., polygons or lines) that involves manual development of linework using photointerpretation.

Mapping algorithm	*% of programs*	*Definition*
Unsupervised	4%	Method of unsupervised image classification that groups mapping units into classes based on user-defined settings.
Maximum likelihood classifier	4%	A parametric supervised classification technique that assigns a map unit into the class with the maximum likelihood based on a set of training data.
Machine learning	4%	Method that utilizes either supervised or unsupervised nonparametric classification algorithms.
Photointerpretation	92%	Manual method of classification or editing in which a trained user visually identifies classes in a remotely sensed image using feature appearance, context, and/or expert opinion.

Other information	*% of programs*	*Definition*
Accuracy assessment	68%	Programs that assess the accuracy of area of habitat type maps.
Change analyses	60%	Programs that analyze change between area of habitat type maps.
Data accessible	56%	Programs with web-accessible data.
Metadata accessible	52%	Programs have metadata that are available on the web.

Table A4.3. Coral/Artificial reef. Summary of methods and techniques used by programs mapping coral and artificial reef habitats (n = 9).

Classification standard	*% of programs*	*Definition*
Custom local scheme	78%	Classification scheme tailored to the habitats and land cover of a particular State, region, or locality, or customized for a certain program or project. Examples include Laswell et al. (1990) and the Everglades Vegetation Classification System.
National standardized scheme	22%	Widely used classification schemes that can be applied to large regions or the entire United States. Examples include Anderson et al. (1976), Cowardin et al. (1979), and Comer et al. (2003).

Classification details	*% of programs*	*Definition*
Artificial reef	33%	Includes the presence of artificial reef.
Coral reef	11%	Includes the presence of coral reef.
Coral reef with structure	67%	Includes the presence of coral reef with details on structural characteristics (e.g., patchiness, density, formations, reef rubble).
Coral reef with zonation	22%	Includes the presence of coral reef with details on tidal zonation (i.e., subtidal vs. intertidal).

Data sources	*% of programs*	*Definition*
Ancillary data	11%	See the Glossary for definitions.
In situ data collection	89%	
Orthophotography	78%	
Satellite imagery	33%	
Seismic/subbottom profiles	33%	
Sonar	56%	
Surficial elevation	44%	

Mapping unit development	*% of programs*	*Definition*
Digitizing	100%	Method of converting an image into vector data (i.e., polygons or lines) that involves manual development of linework using photointerpretation.

Mapping algorithm	*% of programs*	*Definition*
Photointerpretation	100%	Manual method of classification or editing in which a trained user visually identifies classes in a remotely sensed image using feature appearance, context, and/or expert opinion.

Other information	*% of programs*	*Definition*
Accuracy assessment	56%	Programs that assess the accuracy of area of habitat type maps.
Change analyses	22%	Programs that analyze change between area of habitat type maps.
Data accessible	67%	Programs with web-accessible data.
Metadata accessible	56%	Programs have metadata that are available on the web.

Table A4.4. Land use/land cover. Summary of methods and techniques used by programs mapping land use and land cover types (n = 19).

Classification standard	*% of programs*	*Definition*
Custom local scheme	58%	Classification scheme tailored to the habitats and land cover of a particular State, region, or locality, or customized for a certain program or project. Examples include Laswell et al. (1990) and the Everglades Vegetation Classification System.
National standardized scheme	32%	Widely used classification schemes that can be applied to large regions or the entire United States. Examples include Anderson et al. (1976), Cowardin et al. (1979), and Comer et al. (2003).

Classification details	*% of programs*	*Definition*
Association-level	5%	Includes detail at the association level in the U.S. National Vegetation Classification (USNVC) system, which often includes information from many factors including vegetation species, soil types, geology, and hydrology.
Detailed agriculture	5%	Includes information on crop types.
Land/water	16%	Includes the presence of land and water classes.
Modified Anderson	74%	Includes classes modified from the Anderson et al. (1976) land use and land cover classification system.
Shoreline protection	21%	Includes shoreline protection structures (e.g., seawalls, riprap, breakwaters).

Data sources	*% of programs*	*Definition*
Ancillary data	21%	See the Glossary for definitions.
In situ data collection	68%	
Orthophotography	84%	
Other imagery	5%	
Satellite imagery	47%	
Seismic/subbottom profiles	5%	
Sonar	11%	
Surficial elevation	58%	
UAS	11%	

Mapping unit development	*% of programs*	*Definition*
Pixel-based	32%	Method of map development in which each pixel is classified individually.
Object-based	26%	Method of map development in which neighboring pixels with similar characteristics are grouped as an initial step in the mapping process.
Digitizing	74%	Method of converting an image into vector data (i.e., polygons or lines) that involves manual development of linework using photointerpretation.

Mapping algorithm	*% of programs*	*Definition*
Unsupervised	5%	Method of unsupervised image classification that groups mapping units into classes based on user-defined settings.
Maximum likelihood classifier	5%	A parametric supervised classification technique that assigns a map unit into the class with the maximum likelihood based on a set of training data.
Machine learning	37%	Method that utilizes either supervised or unsupervised nonparametric classification algorithms.
Rule-based	21%	Method of supervised image classification in which a user defines one or more if-then rules for the computer to follow (e.g., thresholds).
Photointerpretation	84%	Manual method of classification or editing in which a trained user visually identifies classes in a remotely sensed image using feature appearance, context, and/or expert opinion.

Other information	*% of programs*	*Definition*
Accuracy assessment	68%	Programs that assess the accuracy of area of habitat type maps.
Change analyses	68%	Programs that analyze change between area of habitat type maps.
Data accessible	63%	Programs with web-accessible data.
Metadata accessible	53%	Programs have metadata that are available on the web.

Table A4.5. Shoreline position. Summary of methods and techniques used by programs mapping shoreline position (n = 15).

Classification standard	*% of programs*	*Definition*
Custom local scheme	87%	Classification scheme tailored to the habitats and land cover of a particular State, region, or locality, or customized for a certain program or project. Examples include Laswell et al. (1990) and the Everglades Vegetation Classification System.
National standardized scheme	0%	Widely used classification schemes that can be applied to large regions or the entire United States. Examples include Anderson et al. (1976), Cowardin et al. (1979), and Comer et al. (2003).

Classification details	*% of programs*	*Definition*
Shoreline position	87%	Includes information on shoreline position.
Shoreline position with type	13%	Includes information on both shoreline position and shoreline type (e.g., sandy slope, fan delta, spit, back-barrier marsh).

Data sources	*% of programs*	*Definition*
Ancillary data	20%	See the Glossary for definitions.
In situ data collection	53%	
Orthophotography	87%	
Other imagery	7%	
Satellite imagery	20%	
Seismic/subbottom profiles	7%	
Sonar	13%	
Surficial elevation	73%	
UAS	7%	

Mapping unit development	*% of programs*	*Definition*
Pixel-based	7%	Method of map development in which each pixel is classified individually.
Object-based	13%	Method of map development in which neighboring pixels with similar characteristics are grouped as an initial step in the mapping process.
Digitizing	60%	Method of converting an image into vector data (i.e., polygons or lines) that involves manual development of linework using photointerpretation.

Mapping algorithm	*% of programs*	*Definition*
Rule-based	33%	Method of supervised image classification in which a user defines one or more if-then rules for the computer to follow (e.g., thresholds).
Photointerpretation	67%	Manual method of classification or editing in which a trained user visually identifies classes in a remotely sensed image using feature appearance, context, and/or expert opinion.
Other	13%	Any mapping algorithms that do not belong to an existing category.

Other information	*% of programs*	*Definition*
Accuracy assessment	53%	Programs that assess the accuracy of area of habitat type maps.
Change analyses	87%	Programs that analyze change between area of habitat type maps.
Data accessible	40%	Programs with web-accessible data.
Metadata accessible	40%	Programs have metadata that are available on the web.

Table A4.6. Wetlands. Summary of methods and techniques used by programs mapping wetland habitats (not including SAV or oyster reefs) (n = 27).

Classification standard	*% of programs*	*Definition*
Custom local scheme	63%	Classification scheme tailored to the habitats and land cover of a particular State, region, or locality, or customized for a certain program or project. Examples include Laswell et al. (1990) and the Everglades Vegetation Classification System.
National standardized scheme	26%	Widely used classification schemes that can be applied to large regions or the entire United States. Examples include Anderson et al. (1976), Cowardin et al. (1979), and Comer et al. (2003).

Classification details	*% of programs*	*Definition*
With tidal regime	52%	Includes the presence wetland classes with information on the tidal regime (e.g., subtidal, intertidal).
Without tidal regime	48%	Includes types of wetland classes, such as saline marsh, emergent marsh, and scrub/shrub wetland, but does not indicate tidal regime.

Data sources	*% of programs*	*Definition*
Ancillary data	22%	See the Glossary for definitions.
In situ data collection	74%	
Orthophotography	85%	
Other imagery	4%	
Satellite imagery	41%	
Surficial elevation	37%	
UAS	11%	

Mapping unit development	*% of programs*	*Definition*
Pixel-based	30%	Method of map development in which each pixel is classified individually.
Object-based	19%	Method of map development in which neighboring pixels with similar characteristics are grouped as an initial step in the mapping process.
Digitizing	78%	Method of converting an image into vector data (i.e., polygons or lines) that involves manual development of linework using photointerpretation.

Mapping algorithm	*% of programs*	*Definition*
Unsupervised	4%	Method of unsupervised image classification that groups mapping units into classes based on user-defined settings.
Maximum likelihood classifier	4%	A parametric supervised classification technique that assigns a map unit into the class with the maximum likelihood based on a set of training data.
Machine learning	26%	Method that utilizes either supervised or unsupervised nonparametric classification algorithms.
Rule-based	19%	Method of supervised image classification in which a user defines one or more if-then rules for the computer to follow (e.g., thresholds).
Photointerpretation	89%	Manual method of classification or editing in which a trained user visually identifies classes in a remotely sensed image using feature appearance, context, and/or expert opinion.
Other	4%	Any mapping algorithms that do not belong to an existing category.

Other information	*% of programs*	*Definition*
Accuracy assessment	63%	Programs that assess the accuracy of area of habitat type maps.
Change analyses	70%	Programs that analyze change between area of habitat type maps.
Data accessible	56%	Programs with web-accessible data.
Metadata accessible	44%	Programs have metadata that are available on the web.

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