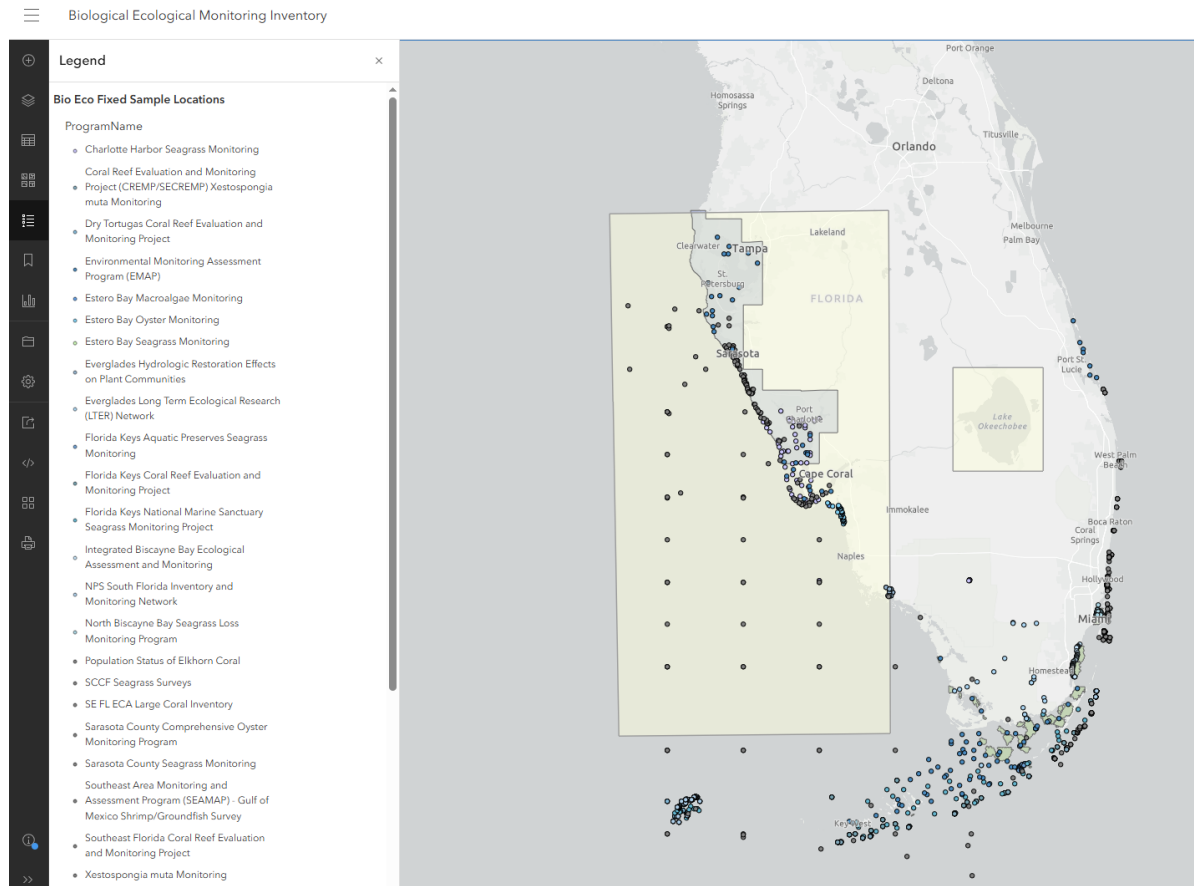


Florida's Coral Reef Water Quality Data Compilation, Analysis, and Decision Support Year 5



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Final Report

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Management Summary

The water quality data compilation, analysis, and decision support project was tasked with creating a single unified water quality monitoring dataset for Florida's Coral Reef. Initially, the project comprehensively reviewed available water quality data and programs, compiled comparable datasets, visualized trends, and constructed inclusion criteria to improve data interoperability. In year 5, the water quality team updated the nutrient and water clarity database with data from 2024 from each of the 8 programs meeting the inclusion criteria. Following feedback from stakeholders and data providers, the team rebuilt the database using an improved QA/QC process and including additional historic data. The team was involved with both the Florida's Coral Reef Coordination Team (FCRCT) and the Florida's Coral Reef Resilience Program Water Quality Team meetings to support reef-wide water quality monitoring efforts and research. The team completed two inventories and methods analyses for 'abiotic parameters' (temperature, salinity, pH, and dissolved oxygen) and biological and ecological monitoring programs to address priority actions for the FCRCT. These inventories included interactive web maps for users to visualize the spatial patterns of these monitoring programs. Additionally, the team developed a document detailing the updates needed to make the data available in the SEACAR Data Discovery Portal match the unified WQ dataset developed in previous years as an outline for a potential future collaboration. Finally, the team looked at fine-scale patterns in water quality and other datasets to identify historical pulse events which may result in degraded water quality. These events include hurricanes, winter storms with high winds, and large-scale precipitation events, including "first flush" events when runoff from the first significant rainfall each spring contains high levels of nutrients and pollutants that have accumulated during the dry season.

Executive Summary

Florida's Coral Reef (FCR) has been facing a range of anthropogenic and biophysical stressors over the last several decades that have led to widespread declines in coral cover. One of the key concerns for FCR has been adverse water quality, which is affected by numerous factors that include pollution, land-use change, weather events, and water diversions. However, FCR stretches 350 miles with diverse localized and regional pressures that cause significant variation in water quality. As a result, efforts to monitor water quality on FCR are made up of a series of discrete regional field sampling programs, continuous sampling with autonomous instruments, and remotely-sensed and satellite-derived analyses. Thus, it is challenging to combine these disparate sources of water quality data to create a comprehensive picture of historical and current water quality trends across FCR. The water quality monitoring data aggregation and analysis project addressed this challenge by developing a unified water quality database ranging from Martin County in the northeast to the Dry Tortugas in the southwest of FCR. During year 5 of this project, the water quality team updated and improved the water quality database made up of 8 programs meeting the compatibility criteria, conducted inventory and methods analyses for 'abiotic' water quality and biological and ecological monitoring programs, contributed to statewide water quality management teams, investigated the capabilities of SEACAR to automate data aggregation, and investigated fine-scale patterns of water quality from pulse events.

The unified water quality database is now updated with data through 2024 for 8 programs collecting discrete nutrient and water clarity that meet inclusion criteria developed in previous years of the project. After feedback from data providers and stakeholders, the team rebuilt the database using a more rigorous and replicable QA/QC process that better represents long-term monitoring datasets. Trend analyses, web maps, and visualization tools were updated to include 2024 data and reflect the improved QA/QC. The team supported and contributed to the Florida's Coral Reef Coordination Team (FCRCT) and FCRRP Water quality team throughout the year by attending and presenting at meetings. The team completed two tasks to directly address priority actions for the FCRCT's Unified Water Quality Monitoring Framework. The team conducted an inventory and methods analysis for programs monitoring abiotic parameters including temperature, salinity, pH, and dissolved oxygen to address action 1, an inventory of water quality monitoring on FCR. The team addressed action 2 by completing an inventory and methods analysis of biological and ecological monitoring programs on the FCR and associated ecosystems. Both inventories have interactive web maps where survey locations can be filtered by parameter, method, and other relevant categories. Using the large collection of data aggregated in this project, the team conducted a fine-scale analysis of water quality trends based on water quality parameters along with in situ observations of abiotic factors such as precipitation, river discharge, and salinity. The water quality and in situ abiotic data is complemented by satellite remote sensing data which provides synoptic views of the study area.

In previous project years, the water quality team identified the Statewide Ecosystem Assessment of Coastal and Aquatic Resources (SEACAR) Data Discovery Interface as a potential solution for automating the unified water quality database. The team met with DEP and SEACAR staff to discuss what integration and automation would require. The research team produced a document investigating the differences between the data availability and QA/QC process on SEACAR and the water quality database to help direct future work on integration.

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1. FLORIDA’S CORAL REEF WATER QUALITY DATA COMPILATION, ANALYSIS, AND DECISION SUPPORT YEAR 5

1.1. Background/Introduction

Pressure on marine ecosystems can manifest in the form of localized hotspots in water quality due to discharges of nutrients from human sources, resuspension events from winds, tides, or currents, or from watershed disturbances due to deforestation and other land-use and land-cover change, nutrient pollution, and water diversions. These factors are all compounded by climate change, sea level rise, changing ocean chemistry, species range expansions, soil transport, and erosion. However, few field studies can frequently collect data in dense geographic grids or consider land and adjacent marine systems as part of a continuum within an ecosystem. Often, data from disparate sources (e.g., in situ and satellite derived data) are required to identify patterns in the water quality in Biscayne Bay, Florida Bay, the Florida Keys National Marine Sanctuary, and Florida’s Coral Reef. These patterns may be those that occur in response to freshwater delivery or other phenomena that are transported to the reef location at landscape scales.

For the past five years, research scientists from the Florida Fish and Wildlife Conservation Commission and the University of South Florida have comprehensively reviewed the wide array of water quality data collected in southern Florida, compiled comparable datasets, visualized trends in water quality data, and constructed a set of criteria for standards between monitoring programs that would allow for increased interoperability. These efforts resulted in the development of a unified water quality monitoring (UWQ) database of nutrient and water clarity data from eight monitoring programs. The UWQ dataset continues to be updated and improved, and communication tools such as interactive web maps, trend analyses, and visualization tools are produced with each update.

The breadth of information provides an opportunity for the research team to support managers and practitioners who wish to incorporate unified water quality information into their decision-making processes. This includes the Florida’s Coral Reef Coordination Team (FCRCT) - a multi-agency team created to “regionally integrate and coordinate management and restoration-related activities to conserve and restore Florida’s Coral Reef”, which requested technical support to examine datasets, indicators, and map layers created by the WQ research team. The FCRCT has developed the Unified Water Quality Monitoring Framework as a plan to create a monitoring network to answer questions about the impacts of Everglades restoration efforts on FCR and effects of water quality on coral reef health. The research team has been heavily involved in contributing to the first two priority actions within this framework which address inventories of existing water quality and biological and ecological monitoring programs.

We proposed providing technical support to the FCRCT to aid in the assessment of water quality trends and helping complete priority actions for the Unified Water Quality Monitoring Framework. During the 5th year of this project, we updated the existing unified water quality monitoring database, parameter analyses, and web maps with new data and programs. We also informed and provided open-ended technical support at the FCRCT and FCRRP Water Quality team meetings to assist with interpretation of existing data products including GIS layers, data visualization tools, and data analyses. Further, we conducted two inventories and methods analyses for abiotic water quality parameters and biological and ecological monitoring programs to address two priority actions for the FCRCT. We worked with SEACAR to better understand the steps that would be required for a long-term integration. Finally, we conducted a fine-scale

analysis of water quality data that examined local water quality trends following acute events and disturbances.

1.2. Methods

1.2.1. *Updating the unified water quality monitoring database*

Staff reviewed water quality monitoring programs to determine if previously included programs continued to meet inclusion criteria and if previously excluded programs now meet the same inclusion criteria. The five inclusion criteria were 1) sampled within South Florida 2) sampled at least four water quality parameters of interest 3) contained unique sampling data 4) active sampling and 5) have at least 5 years of continuous data. The water quality parameters of interest include Chlorophyll-a, nitrate (NO₃), nitrite (NO₂), nitrate + nitrite (NO_x), ammonia (NH₄), soluble reactive phosphorus (PO₄), silica (Si), turbidity, total Kjeldahl nitrogen (TKN), total nitrogen (TN), and total phosphorus (TP). For programs which met these criteria, staff reached out to the contacts to get access to the processed 2023 data for existing programs and full datasets for new programs. These monitoring program partners were: NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML), FIU Southeast Environmental Research Center (SERC), Miami-Dade County Department of Environmental Resource Management (DERM), Florida Department of Environmental Protection (FDEP), Broward County (BC), City of Miami Beach (MB), FDEP Biscayne Bay Aquatic Preserves (BBAP), and Palm Beach County (added this project year for the first time in order to include water quality trends in the Lake Worth Lagoon at FDEP's request).

The preferred source of data was the Watershed Information Network (WIN) database, which contains data from 6 of the 8 providers. Obtaining data from WIN requires both an "Organization ID" and "Project ID" in order to select the correct sampling program. Table 1 provides the two ID's needed to access data for the six programs available in WIN.

The WIN database only contains data from approximately 2015 depending on the data provider. Historical data from applicable programs is obtained from a separate Florida Florida STORET (STORage and RETrieval) Public Access website, which is also linked to from the WIN platform. For programs that have historical data, those data were merged with recent data. Data from the AOML program for all years is served from a Github repository that is not currently public, but will be soon. The project team obtained that data directly. For the Miami Beach data, the project team obtained historical data from the SEACAR database and recent files directly from the data provider.

Data ingested from each provider is converted into a report using R and Quarto, which is then used to standardize the naming conventions of each analyte, longitude and latitude formats, date format, and units. R scripts are used to combine all of the selected monitoring programs' data per analyte, organizing the data into a common format by location and timescale, and splitting dates into year/month/day for later summarizing and visualizing manipulations. Additional QA/QC to check dates, coordinates, and remove repeated observations was completed along with tests to ensure that all data were included in each merged database created per analyte.

Table 1. List of data providers, WIN ID's and duration of data collected.

Program	WIN Organization ID	WIN Project ID	Data duration
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FIU SERC	21FLFWC	WQMP	6/27/1989 - 6/19/2023
BBAP	21FLBBAP	JTDIEOFF	2/4/2019 - 2/5/2025
DEP-ECA	21FLCRCP	FRTWQA	9/20/2017 - 12/19/2024
DERM	21FLDADE	BBWQ	10/18/1993 - 12/5/2024
Palm Beach County	21FLPBCH	ERMWQ	3/18/2002 - 3/20/2025
Broward County	21FLBROW	PROJ-001	1/26/1999 - 5/28/2024
AOML	N/A	N/A	12/1/2014 - 11/17/2024
Miami Beach	N/A	N/A	8/16/2016 - 12/30/2024

Staff then conducted trend analyses on the processed and cleaned data using scripts developed in previous years and updated this project year. To identify “hotspots” and trends where water quality may be worsening over time (e.g., where turbidity is “increasing” over time), time series were extracted from each sampling location for each analyte and assessed using a seasonal Mann-Kendall test following the methods in Millette et al. 2019. The Mann-Kendall test estimates the Theil-Sen slope, or the rate of change of a parameter over the period that data were collected.

To ease interpretation, we categorized the Theil-Sen slope, or rate of change, as generally increasing or decreasing for each parameter of interest (Chlorophyll-a, nitrate (NO₃), nitrite (NO₂), nitrate + nitrite (NO_x), ammonia (NH₄), soluble reactive phosphorus (PO₄), silica (Si), turbidity, total Kjeldhal nitrogen (TKN), total nitrogen (TN), and total phosphorus (TP)), at each monitoring site.

Once the database was updated with the processed and cleaned 2024 data from existing programs and data from new programs and subsequent trend analyses, staff updated web maps, mapping applications, and data visualization tools. A link to the code for the data ingestion, merging, quality control and Sen’s slope calculations can be found in the associated ‘FWRI WQ Project Links 2025.pdf’ document.

1.2.2. Open-ended technical advisory support for FCRCT and water quality meetings and development of biological and ecological monitoring inventory

Staff were asked to attend and provide open-ended technical support for the Florida’s Coral Reef Coordination Team meetings during 2024-2025. Staff were on hand to present overviews and results of the water quality aggregation project and contribute to answering questions identified in the Unified Monitoring Framework for Florida’s Coral Reef. Staff also attended Florida’s Coral Reef Resilience Program Water Quality Team meetings to collaborate with water quality monitoring managers across FCR and contribute to the actions to meet the priorities of the FCRCT.

Staff compiled an inventory of biological and ecological monitoring programs along Florida’s Coral Reef Tract and in the nearshore coastal waters of South Florida. Programs were initially selected if they sampled for at least one biotic parameter, using online repositories such

as SEACAR or Florida Coastal Everglades Long-Term Ecological Monitoring (LTER), as a starting point. Staff also reached out to leads of monitoring programs that have limited or no submissions in online data repositories to gather additional information and ensure their inclusion in the inventory. This includes programs such as the Queen Conch monitoring surveys conducted by FWC, the Mission Iconic Reef monitoring sites, and others. For each program, staff compiled metadata including data source, type of taxa collected, collection period and frequency, region, parameters, methods, and contacts.

Once staff had a comprehensive inventory of monitoring programs, they were further refined to include only those that sample in South Florida (including the Florida Reef Tract and any other nearshore coastal waters that fall south of Lake Okeechobee), conduct repeated sampling events, and provide unique datasets. Sample locations for programs meeting these requirements were collated into three layers: two point layers of programs that 1) re-sample at the same locations and 2) use random sampling methods. The third layer is polygons that represent coverage areas for programs that either sample with remote sensing techniques or conduct regular sampling (random or fixed) within predetermined polygon boundaries.

Once the inventory was complete, staff created a public web map for programs included in the three data layers and a table for all monitoring programs for the purpose of data sharing and visualization. Progress for the biological and ecological inventory is ongoing as the project team intends to share the inventory with partners for comment and will continue to update the inventory as needed to incorporate new programs that meet the inclusion criteria, while continuing to maintain the metadata for each program and the web map accordingly.

1.2.3. Integration of water quality monitoring database and associated maps and visualization products into the SEACAR data discovery portal

Project staff completed an analysis to compare the unified database with the SEACAR database. For each of the 8 data providers, comparisons were run between datasets retrieved from the Florida SEACAR Data Discovery web interface. Both standardized data in the WIN format and raw data uploaded to SEACAR by each provider were compared to the year 4 version of the unified database, which was updated with data through the end of 2023. Comparisons were made to assess sampled parameters (analytes), sampling locations, and location IDs.

Staff updated the 'Florida's Coral Reef Unified Water Quality Monitoring Database' SEACAR program page with new ArcGIS online web maps and products, and uploaded excel files with the biological and ecological monitoring, and abiotic inventories.

1.2.4. Inventory and analysis of programs monitoring 'abiotic factors' including temperature, salinity, pH, and dissolved oxygen

The team compiled information for programs monitoring abiotic parameters including temperature, salinity, pH, and dissolved oxygen across Florida and the Southeast US that could be found in SEACAR, WIN and other online repositories. For inclusion in the abiotic water quality monitoring inventory, staff further narrowed down these programs with a modified version of the database inclusion criteria, each program was evaluated for their potential inclusion based on 1) their sampling period and frequency, 2) their geographic scope, 3) if they provide unique datasets. For each program, staff compiled metadata including data source, type of taxa collected, collection period and frequency, region, parameters, methods, and contacts.

Sample locations for programs meeting these requirements were collected from the different programs pages and combined into one GIS layer. All sample locations were

standardized so they would include the monitoring Location identifier, the Monitoring Location Name, the Project identifier, the Project Name, if the location is currently sampled, what parameter is sampled (whether pH, water temperature, DO or salinity), the frequency of sampling and the sampling depth. Using that layer, staff created a public web map for programs included in the inventory to visually represent the sampling locations of included monitoring programs.

The research team also extracted all temperature, salinity, dissolved oxygen, and pH data from all monitoring programs in Monroe, Miami-Dade, Broward, Palm Beach, and Martin Counties available in WIN, but did not download the large amount of data collected by the other programs.

1.2.5. Fine scale analysis of water quality to identify historical pulse events and responses to Everglades restoration

Using the unified water quality monitoring database, the WQ team conducted broad-scale analyses of regional water quality across Florida's Coral Reef. Additionally, the breadth and depth of the water quality database provides opportunities to conduct finer-scale analyses of water quality. The research team complemented the unified water quality database with other datasets, including satellite observations, river discharge data and in-situ measurements of abiotic factors, particularly salinity and precipitation, which can be used to assess water flow from the Everglades which reaches Florida's Coral Reef (FCR). The research team compiled the following datasets:

1. Daily precipitation measured at seven locations in South Florida.
2. Precipitation over South Florida from NASA's Global Precipitation Mission (GPM), specifically the Integrated Multi-satellite Retrievals for GPM (IMERG) product. This is a daily gridded product based on several satellite sensors which estimates precipitation at 10-km resolution globally.
3. River discharge from approximately 20 USGS and USACE locations in South Florida which report data on a daily basis.
4. The unified water quality database compiled by the research team in 2023, which contains data through the end of 2023.
5. Continuous measurements of salinity and temperature measured at several buoys in Florida Bay that are maintained by the National Park Service.
6. Satellite derived estimates of water quality parameters obtained from four different ocean color sensors:
 - Moderate Resolution Imaging Spectrometer (MODIS-Aqua); 1-km, daily
 - Visible Infrared Imaging Spectrometer Suite (VIIRS-SNPP); 750-m, daily
 - Sentinel-3 Ocean and Land Colour Instrument (OLCI); 300-m, daily
 - Plankton Aerosol Cloud and ocean Ecosystem Ocean Color Instrument (PACE-OCI); 1-km daily, hyperspectral

Time series of water quality from the unified database have been analyzed for periods and locations where water quality is degraded. Events which may result in degraded water

quality include hurricanes, winter storms with high winds, and large scale precipitation events, including “first flush” events when runoff from the first significant rainfall each spring contains high levels of nutrients and pollutants that have accumulated during the dry season. Since most of the provider programs sample monthly, time periods with anomalous “spikes” in water quality parameters were then compared to datasets with continuous observations such as precipitation, river discharge, in situ salinity and satellite observations. By combining discrete water quality measurements with continuous observations, the project team was able to identify not only time periods of degraded water quality, but also some of the drivers of those events and satellite maps of how widespread those events may have been. The confirmation of pulse events with degraded water quality using multiple data sources also increases confidence in the individual water quality observations in the unified database.

1.3. Results

1.3.1. Updates to the unified water quality monitoring database

The project team compiled, collated, and mapped water quality data for the south Florida coral reef ecosystem by merging the sampling results from different monitoring partners. The annually updated unified water quality databases for each analyte include all data collected from all monitoring partners in 2024. This project now includes 8 actively sampling monitoring programs- four more than the first year of the project.

When obtaining data from WIN, it is important to monitor for changes to the formatting/type of analytes in the individual monitoring partner’s yearly updated data, and emphasize to monitoring partners that any changes result in an inability to compare trends in analytes between years and compare with the larger merged and unified South Florida water quality database. It is also important that analyte naming conventions are standardized within WIN itself, perhaps as a drop down menu option when monitoring partners enter each year’s data, since this team has found multiple instances of analytes having slight differences in naming which causes problems when working with data in R. This project effort would benefit from a request by DEP as a funding agency to any funded monitoring partners, to upload their yearly data to WIN in a timely manner in each spring, in order to allow for project analysis and tool building. It would also be helpful if DEP as the funding agency could emphasize the need to upload and share all years of current as well as historical data to WIN, rather than splitting it between WIN, SEACAR, and STORET. Future planned work on this project should help to resolve this issue.

The results of the 2024 update to the unified water quality database and trend analysis are available in a publicly available web map and are incorporated into the data visualization tool that was developed in year 4 of the project. The unified database is also available as a merged comma-separated text file.

1.3.2 Open-ended technical advisory support for FCRCT and water quality meetings and development of biological and ecological monitoring inventory

Staff attended 17 meetings of the FCRCT, FCRRP, and additional relevant water quality programs. The team presented this project to the FCRCT, to the FCRRP, during the FCRRP Water Quality Workshop, at the Stetson University Nitrogen Symposium, at the Greater Everglades Ecosystem Restoration Conference, and as a webinar to the Lower Keys Guide Association.

For the biological and ecological monitoring inventory, the project team compiled information on 116 programs, including data source, type of taxa collected, collection period and frequency, region, parameters, methods, and contacts. Out of these 116 programs, 34 met the criteria for inclusion and were considered relevant and useful for long-term analysis for water quality effects on Florida's Coral Reef and related coastal ecosystems. These programs encompass a diverse range of taxa, including corals and other benthic invertebrates, fish and sharks, vegetation such as seagrass and mangroves, as well as harmful algae and plankton. Of the 34 included programs, 23 were monitoring fixed sampling locations, 8 conducted random sampling methods, and 3 utilized repetitive remote sensing techniques.

A public web map was created on ArcGIS Online that allows users to separately view the layers featuring programs that use either repeat or random sample locations (Figure 1). Users can also filter sampling locations by specific parameters of interest, such as sampling frequency or type of taxa sampled, or spatially. Unlike the previously developed abiotic inventory, the biological and ecological web map incorporates both points and polygons—where polygons represent programs monitoring through remote sensing techniques or conduct regular sampling (random or fixed) within predetermined polygon boundaries.

The web map is intended to support improved coordination, data discovery, and gap analysis for water quality monitoring efforts across Florida's Coral Reef and adjacent coastal ecosystems, but it does not provide access to the actual data collected by these programs. More specific information for parameters collected for each monitoring program, such as monitoring parameters or methods, can be found in Table 2. The project team intends to share the inventory with partners for review and will update it to include new programs that meet the inclusion criteria, while continuing to maintain accurate and consistent metadata for each program. The web map will also be updated accordingly.

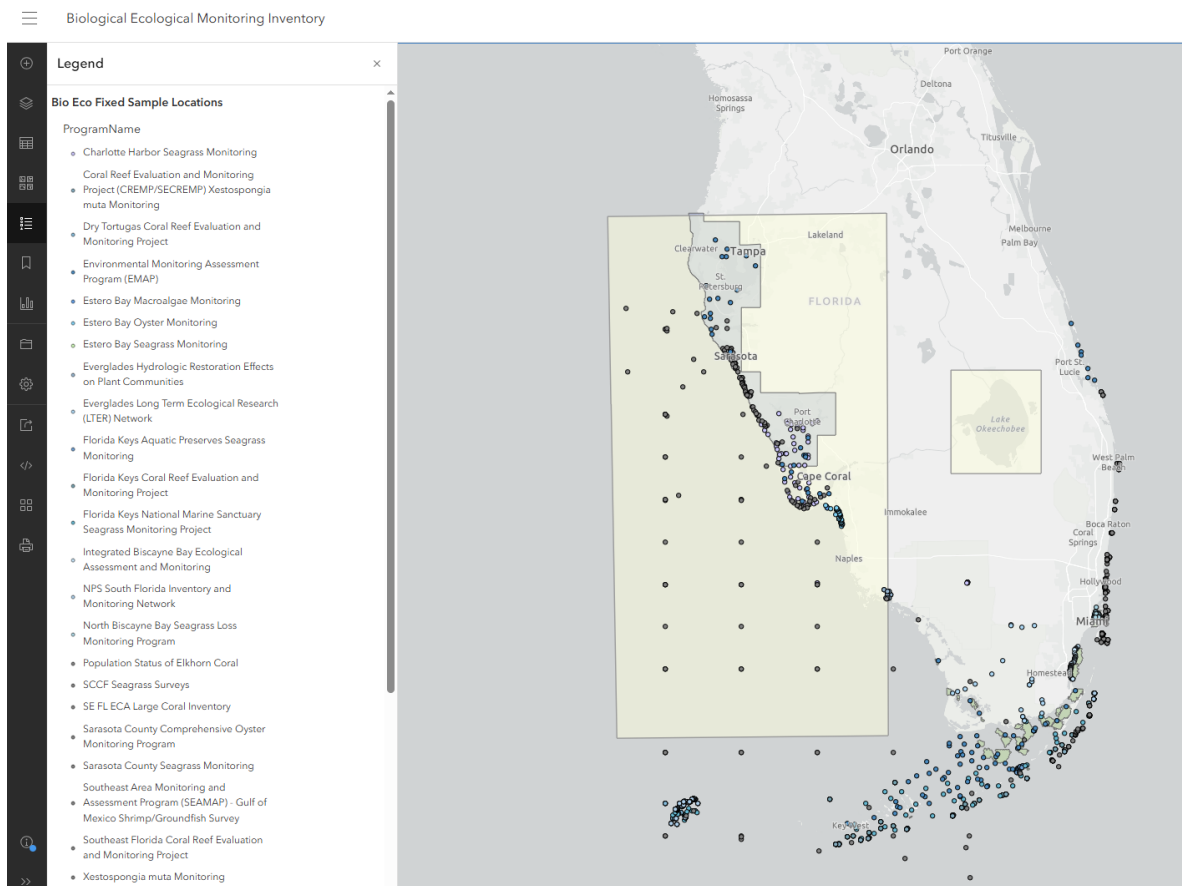


Figure 1. Snippet of the Biological and Ecological Inventory Map showing the sampling locations from the 23 programs that re-sample at the same locations.

Table 2. List of the fields and its associated description in the biological and ecological inventory matrix. Information was collected for every field whenever possible for each monitoring program.

Column Name	Column Description
Program	Name of the monitoring program
Institution(s)	Organizations associated with the monitoring program
Contacts	Email or phone number associated with the primary contact for the monitoring program
Present in the web map	If the sample locations are included in the publicly available web map
Repository	Where the data is located
Data type	If the sampling data is discrete or continuous
Frequency	Sampling frequency (periodicity) of the monitoring program
Collection Period	Start and end date (or current if sampling is ongoing)

Region	Regions in Florida (SE, SW, NE, or NW) sampling occurs in
Included Counties	Counties sampling occurs in
Includes FCR	Checkbox if sampling occurs in Florida's Coral Reef
Includes FCR/ Everglades/ Okeechobee	Checkbox if sampling occurs in Florida's Coral Reef or includes coverage of lake Okeechobee Discharges
Parameters	All biological or ecological parameters sampled
Methods	Methods used by the monitoring program
Coral	Y or N if Corals are monitored
Cnidaria other	Y or N if Cnidarians are monitored
Crustacean	Y or N if Crustaceans are monitored
Porifera	Y or N if Porifera are monitored
Molluscs other	Y or N if other Molluscs are monitored
Oysters	Y or N if Oysters are monitored
Gastropods	Y or N if Gastropods are monitored
Urchins	Y or N if Urchins are monitored
Fish	Y or N if Fish are monitored
Sharks	Y or N if Sharks are monitored
Salt Marsh	Y or N if Salt Marsh is monitored
Seagrass	Y or N if Seagrass vegetation is monitored
Mangrove	Y or N if Mangroves are monitored
Sawgrass	Y or N if Sawgrass vegetation is monitored
Macroalgae	Y or N if Macroalgae is monitored
Coastal Wetlands other	Y or N if other Coastal Wetlands are monitored
SAV other	Y or N if SAV are monitored
HAB	Y or N if HAB is monitored
Plankton other	Y or N if other Plankton monitored
Temp	Y or N if water temperature is monitored
SST	Y or N if Sea Surface Temperature is monitored
additional parameters	Y or N if additional parameters are sampled
Notes	Any other notes associated with the monitoring program

1.3.3. Integration of water quality database and associated maps into SEACAR data discovery portal

Based on the comparison of data from the 8 discrete water quality monitoring programs contained in the unified database, the main differences between SEACAR and the unified database are listed here:

1. Differences between SEACAR and the unified database were found both with sampled parameters and sampling location IDs. Some sampling locations in the unified database which are referenced by a single ID are referenced by multiple SamplingLocationIDs in SEACAR (e.g. Program 3 - AOML). This presents an issue where a user of the SEACAR database cannot select or filter for a particular sampling location based on ProgramLocationID. There are also cases where text prefixes are added to some SamplingLocationIDs (e.g. Program 297 - Florida Keys National Marine Sanctuary Water Quality Monitoring Project).
2. Nitrate and silica do not appear in the SEACAR database, even when present in the raw files.
3. There are two programs in the unified database that are missing from SEACAR (Palm Beach County and Broward County).
4. Point of contact information for several programs in the SEACAR DDI are out of date. This makes it difficult to contact the individual programs to request information.

The project team will continue to assist the SEACAR team by updating the “Florida’s Coral Reef Unified Water Quality Monitoring Database” program page, including checking for duplicates with existing program pages and helping ensure consistency in the datasets for the programs included in the unified database.

1.3.4. Inventory and analysis of programs monitoring ‘abiotic parameters’ including temperature, salinity, pH, and dissolved oxygen

Staff identified over 125 potential monitoring programs for the abiotic water quality monitoring inventory and compiled key metadata for each, including data source, collection period and frequency, region, water quality parameters, methods, and contacts. Based on the established inclusion criteria, 60 of these programs were selected and incorporated into a publicly available web map.

Continuous and non-continuous sampling locations are symbolized differently on the publicly available map in ArcGIS Online, allowing users to easily distinguish between the two sampling types at a glance (Figure 2). The map also enables users to filter sampling locations by specific parameters of interest, such as sampling frequency or depth of sampling, or spatially. More specific information on the information collected for each abiotic monitoring program can be found Table 3. This resource is intended to support improved coordination, data discovery, and gap analysis for water quality monitoring efforts across Florida’s Coral Reef and adjacent coastal ecosystems. While it enables users to visualize the geographic coverage of programs monitoring temperature, salinity, dissolved oxygen (DO), and pH, it does not provide access to the actual data collected by these programs.

The inventory will be shared with partners for review and will be updated to incorporate new programs that meet the inclusion criteria, with metadata maintained to ensure accuracy and consistency. The web map will also be updated accordingly.

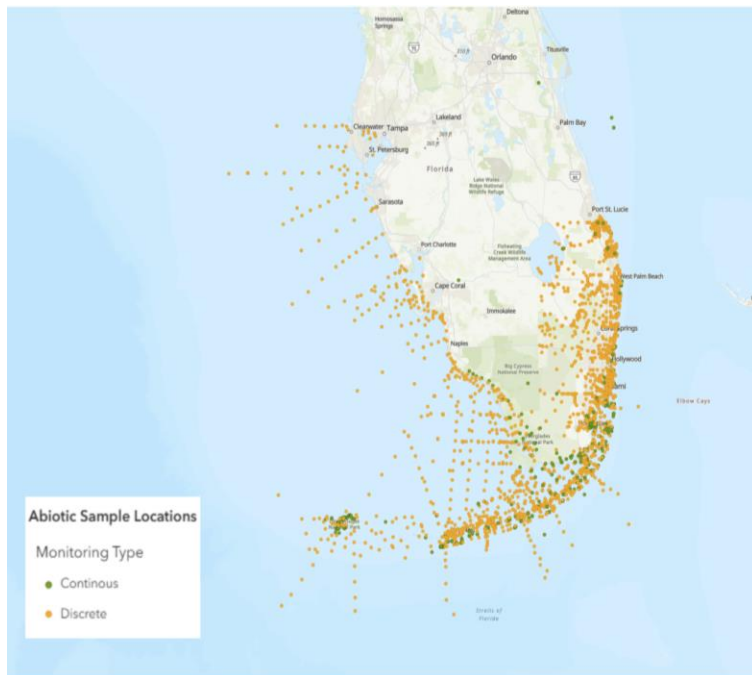


Figure 2. Snippet of the Abiotic Inventory Web Map showing the sampling locations from the 60 programs identified as relevant in the inventory. The orange locations represent sites from discrete monitoring programs, while the green locations represent continuous monitoring sites.

Table 3. List of the fields and its associated description in the abiotic water quality inventory matrix. Information was collected for every field whenever possible for each monitoring program.

Column Name	Column Description
Program	Name of the monitoring program
Institution(s)	Organizations associated with the monitoring program
Locations present in web map	If the sample locations are included in the publicly available web map
Parameters	All parameters sampled with pH, Dissolved Oxygen, salinity or temperature parameters bolded
Temperature	Checkbox if water temperature is sampled
Salinity	Checkbox if salinity is sampled
DO	Checkbox if DO is sampled
pH	Checkbox if pH is sampled
Dates	Start and end date (or current if sampling is ongoing)
Currently Sampling	Checkbox if the program is currently sampling
Methods	Methods used by the monitoring program
Regions	Regions in Florida (SE, SW, NE, or NW) sampling occurs in
Includes FCR	Checkbox if sampling occurs in Florida's Coral Reef
Includes FCR or Everglades or Okeechobee Discharges	Checkbox if sampling occurs in Florida's Coral Reef or includes coverage of lake Okeechobee Discharges
Frequency	Sampling frequency of the monitoring program
Continuous	Checkbox if sampling is continuous
Unique Program	Checkbox is sampling project is unique
Link	Link to the program page if it exists
Notes	Any other notes associated with the monitoring program
Included in the 8 programs (Unified WQ database)	Checkbox if program is included in the unified water quality monitoring database

1.3.5 Inventory and analysis of programs monitoring 'abiotic parameters' including temperature, salinity, pH, and dissolved oxygen

The results of the fine-scale analysis of water quality trends is available as a separate report. The study area was divided into four subregions based on clusters of sampling locations. A map showing precipitation, river discharge and temperature and salinity observations along with the

subregions is shown in Figure 3. Precipitation in particular is spatially heterogeneous, so using precipitation observations as close as possible to the water quality sampling locations is desirable. Subregions 3 and 4 are very sparsely populated and there are no direct observations of precipitation. For these regions, the project team chose to use satellite-based precipitation estimates from NASA's Global Precipitation Mission which combines data from a large suite of satellites for these two subregions. There are two main approaches to look for anomalous events. The first is to survey discrete water quality observations in each subregion to find "spikes" in the time series of a particular analyte followed by examination of the continuous abiotic data (precipitation, river discharge and salinity) to look for time periods where water quality became degraded. The second approach is to identify anomalous events in the continuous abiotic data and then look in the discrete water quality record. One limitation of the 2nd approach is that discrete water quality observations in the unified database are sampled approximately once a month, so episodic events that occur between sampling times will be missed.

1.3. Discussion and Management Recommendations

This project was motivated by the need to easily understand water quality patterns at different spatial and temporal scales along Florida's Coral Reef, and to ultimately assess the effect of efforts to improve water quality locally. The need to aggregate and visualize data from different observing programs, and an analysis of water quality hotspots, trends, and data gaps, were identified among the management goals of the Florida Keys National Marine Sanctuary (FKNMS) and as a priority within the sanctuary's Water Quality Protection Program (WQPP), co-chaired by the US Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (DEP).

In year 5, the research team continued to address this overall need to understand the patterns of water quality and monitoring programs across the FCR. The team updated the unified water quality database with 2024 data from the eight programs monitoring nutrients and water clarity. Further, the team rebuilt the database from the source data to create a more replicable and rigorous quality assurance and quality control process. The updated database was used to update the reef-wide trend analyses for each parameter, which were then included in updated web maps showing water quality sampling and trends. The data visualization tool, developed in previous years to more easily show time-series information, was also updated with the new data. During year 5 of the project, web maps and visualization products were presented to a large number of stakeholders including the FCRCT, FCRRP water quality team, and at conferences and webinars. The feedback received from these stakeholders was incorporated when the maps were updated with data from 2024.

Because of the team's experience working with water quality across the FCR, the team has been working closely with the FCRCT in a technical advisory role. The FCRCT's mission to understand how Everglades restoration affects water quality on the FCR was outlined in the Unified Water Quality Monitoring Framework, and the research team was tasked with completing two additional inventories to address priority actions. The team conducted the abiotic inventory and methods analysis, when combined with the unified water quality database, completed the requirements for priority action 1, an inventory of water quality monitoring across the FCR. The team addressed priority action 2 by completing an inventory and methods analysis of biological and ecological monitoring programs. Both of these actions are critical to understand the state of monitoring on the FCR and will help guide the future recommendations, funding, and actions when investigating the effects of water quality on the FCR and associated ecosystems.

The inventories and methods analyses were presented to the FCRCT, and the research team will continue to improve the inventories with feedback from the FCRCT and other stakeholders.

Throughout year 5, the research team has found collaboration and outreach to be a critical component of the project. Ultimately, the database, maps, and visualization products are meant to provide a simple and user-friendly way to access these data coming from disparate sources, so understanding the needs of users like scientists, managers, and the public is crucial. Multiple researchers from universities in Southeast Florida have used the database in coral reef research projects, and their insight into the usability of the database has allowed the team to improve access and metadata. The team will continue to incorporate feedback into the database and products with special consideration to find historical programs that may provide valuable insight into longer-term trends. Further, outreach efforts have identified a need to incorporate a broader group of stakeholders when planning longer-term and larger-scale monitoring efforts. For example, after a webinar to the Lower Keys Guide Association, fishing guides in the Florida Keys were eager to provide information about areas that have experienced major and rapid changes to habitats that were historically healthy fishing areas. This type of specialized local knowledge will be critical to incorporate into a unified monitoring framework.