Southeast Florida Reef Tract Water Quality Monitoring Plan

Prepared for Southeast Florida Coral Reef Initiative and Florida Department of Environmental Protection

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Background

Water quality problems, including sedimentation and over enrichment of nutrients, have the potential to adversely impact coral reef ecosystems. Coral reefs evolved in oligotrophic waters, but over the past century have been subjected to increasing levels of nutrients due to human activities. Excess nutrient loads can cause increases in macroalgal growth and can have deleterious effects on corals, such as macroalgae outcompeting and overgrowing corals (D'Angelo and Wiedenmann 2014). Furthermore, nitrogen and phosphorus can impact corals directly by lowering fertilization success (Harrison and Ward, 2001), and reducing both photosynthesis and calcification rates (Marubini and Davis, 1996). However, threshold values, above which coral impacts are likely, have not been well established. As more research on threshold values becomes available, it is important that method detection limits are sufficiently low to capture ecologically relevant levels.

Land based contributions of nutrients to coastal systems originate from a variety of sources. Phosphorus and reactive nitrogen can enter the environment from chemical fertilizers (residential, commercial and agricultural uses), industrial sources, animal waste, and human waste (Galloway et al., 2003). Additionally, nitrogen can be contributed from biological nitrogen fixation and atmospheric nitrogen deposition (originating from fossil fuel combustion and ammonia volatilization from agriculture; Mathews et al., 2002).

Elevated sedimentation levels have been linked to several types of reef degradation including fewer coral species, less live tissue cover, reduced recruitment, lower growth rates and calcification, altered species composition and lower rates of reef accretion (ISRS, 2004; Rogers, 1990). Sedimentation can cause burial and smothering of corals and tissue necrosis (Erftemeijer et al., 2012).

The study region, referred to here as the southeast Florida reef tract, extends from Biscayne Bay in the south to St. Lucie Inlet in the north. The adjacent watersheds encompass four counties (Miami-Dade, Broward, Palm Beach and Martin) and there are nine major inlets that contribute freshwater inflows, containing land based sources of pollution, to coastal waters. These inlets are: Government Cut, Baker's Haulover, Port Everglades, Hillsboro, Boca Raton, South Lake Worth (Boynton Inlet), Lake Worth, Jupiter and St. Lucie (Figure 1).

The reef ecosystems in the study region provide habitat to important fisheries (Ferro et al. 2005, SAFMC 2009). The ecosystem consists of a mix of contiguous coral reefs, soft substrate habitats (e.g. tidal sand flats and mud flats), seagrass, oyster reefs, mangroves, offshore hardbottom and nearshore hardbottom. The reefs generally occur within 3 to 4 km from shore (Banks et al. 2007, Gilliam 2010), and include limestone ridges colonized by reef organisms such as sponges, octocorals, macroalgae and stony corals. Nearshore hardbottom habitats range from flat expanses of exposed rock with little relief to patch reef-like vertical mounds in depths from 0 to 4m. The benthic assemblages of nearshore hardbottom habitat include octocoral, macroalgae, sponge and stony corals (Gilliam 2010).

Local stakeholder perception is that water quality is negatively impacting the reef. However, there is currently little evidence to support that contention partially due to a relative lack of water quality data in the reef habitats (Boyer et al. 2011).

Land based sources of pollution can reach the southeast reef tract via multiple pathways including both point and non-point sources (Caccia and Boyer 2005, Trnka et al. 2006, SFWMD 2009b). Wastewater disposal methods in Florida include: ocean outfalls, surface discharges, deep well injection, and water reuse (Bloetscher and Gokgoz 2001). Pollution, such as nutrients from septic systems and agricultural runoff, reaches the coastal ocean via inlets or groundwater discharge (Trnka et al. 2006, Singh et al. 2009, Bloetscher et al. 2010). Stormwater discharges, associated with urban development (Caccia and Boyer 2005, BCEPD 2007) carry excess nutrients (e.g. from lawn chemicals and pet waste), suspended and dissolved organic matter, and other pollutants to the estuaries (Caccia and Boyer 2005, BCEPD 2007, SFWMD 2009b, Carsey et al. 2011).

The hydrology of the land area draining to the coast is highly modified by agricultural drainage canals and urban flood control systems. These modifications serve as vectors for pollutants to southeast Florida estuarine waters (Caccia and Boyer 2005, SFWMD 2009a, Carsey et al. 2011). Discharge from water management canals can lead to rapid salinity changes, turbidity (SFWMD 2009a, SFWMD 2009b), sedimentation and siltation (PBC 2008). Coastal inlets are an important component of water dynamics in southeast Florida, representing a major flux of runoff and associated pollutants from the estuaries to the near coastal waters. Previous studies have shown that the outgoing tides leaving inlets contained significant amounts of pollutants (Carsey et al. 2011). While there is an existing network of water quality monitoring stations within the freshwater canals, remnant major rivers, adjacent estuaries, and the Atlantic Intracoastal Waterway, there is no offshore water quality monitoring program that would be relevant to reef health.

Submarine groundwater discharge (SGD) may also be an important flux of nutrients and other pollutants to the coastal environment, although there is very little data available on the quantity and composition of groundwater inputs offshore from southeast Florida (Trnka et al. 2006, Bloetscher et al. 2010). Because the reefs can be up to several kilometers offshore, and there is no sampling program to measure the impact, it is not clear whether the groundwater is being transported all the way to the reef (Paytan et al. 2006).

Wastewaster outfall discharges to the coastal ocean are also a source of nutrients and other pollutants to the system (Carsey et al. 2010). There are currently six wastewater effluent outfalls in the study area (Figure 2); one outfall (Delray) has recently been decommissioned (although it is still permitted to discharge during high rainfall/runoff events). These outfalls discharge secondary treated wastewater. This effluent undergoes secondary treatment to remove biodegradable organics and suspended solids (DEP 2010), but does not remove dissolved nutrients, pharmaceuticals, heavy metals or personal care products (Bloetscher and Gokgoz 2001). All outfalls are scheduled to be decommissioned by 2025. Physical oceanographic processes are critical driving factors behind the rate at which nutrients and other pollutants are diluted or taken up in the offshore environment. Due in part to relatively low relief watershed and low erosional rates, sedimentation may be more related to beach nourishment projects, port development and re-suspension than due to watershed sources. Recent studies (Miller et al, 2016; Barnes et al., 2015) have shown that sediment from the recent Miami dredging project has negatively impacted corals, but the linkages have not been demonstrated region wide.

Project History, Goals and Timeline

In 2003, in response to concerns about pollution impacts on the reef and with guidance from the US Coral Reef Task Force, the Florida Department of Environmental Protection, and the Florida Fish and Wildlife Conservation Commission (FWC) established the Southeast Florida Action Strategy Team (SEFAST) to develop Local Action Strategies targeting the coral reefs off mainland southeast Florida, from the northern border of Biscayne National Park in Miami-Dade County to the St. Lucie Inlet in Martin County. In 2004, SEFAST's membership was expanded by FDEP Coral Reef Conservation Program (CRCP) to include non-agency representatives; in 2005, SEFAST was renamed the Southeast Florida Coral Reef Initiative (SEFCRI) Team. The mission of the SEFCRI is to develop and support the implementation of an effective strategy to preserve and protect southeast Florida's coral reefs and associated reef resources, emphasizing balance between resource use and protection, in cooperation with all interested parties.

The SEFCRI Team was established to formulate, coordinate, and provide recommendations to the FDEP CRCP Manager regarding the development and implementation of the SEFCRI Local Action Strategy (LAS) program, targeting coral reefs and associated reef resources in the southeast Florida region (Miami-Dade, Broward, Palm Beach, and Martin counties).

In 2014, the Florida Department of Environmental Protection began preliminary discussions with NOAA scientists about the need for more water quality monitoring data for the southeast Florida reef tract. This is a State – Federal partnership, with 3 years of anticipated project funding through NOAA's Coral Reef Conservation Program, to include field sampling and analysis. The end goal is to initiate a lasting reef water quality monitoring program that will be run by SERCRI partners. The first year of the project, 2015, was used to convene relevant local, state and federal managers to discuss the best sampling design for water quality monitoring, taking into account data needs, scientific questions, and logistical considerations. This document represents the culmination of these discussions. In 2016, the water quality monitoring was begun as a joint NOAA-SEFCRI effort, with the goal of transitioning to a solely SEFCRI effort in 2017.

Overall Goal: This project seeks to develop and implement a sustainable environmental monitoring program that will provide data and information to evaluate water quality and to track trends over time such that appropriate management measures can be implemented to protect and sustain reef health.

Desired Outcomes: In addition to the overall goal (above), the following outcomes were highlighted by the design team.

1. Develop a nutrient baseline, including the current status of nutrients in the system, recognizing that the reef is impaired from 100+ years of human related inputs. This is important for change detection and for use in performance metrics for evaluating the effectiveness of management actions.

2. Determine the interactions and synergistic effects of turbidity, sediments and nutrients, and evaluate the potential for stress from multiple pollutants.
3. Explore sources and pathways for nutrients and sediment reaching the reefs, including groundwater nutrients. If possible, tease out natural versus anthropogenic sources of nutrients.
4. Gather data in such a way as to support our understanding of cause and effect relationships, i.e. measuring the biological impact of the measured water quality stressors.

The intent of the monitoring program is to measure water quality conditions that will allow us to assess the current status of water quality in the coral reef ecosystem and to track changes in water quality over time. This program will also allow us to evaluate the efficacy of implemented management actions to improve reef water quality. In addition to stressors related to water quality, corals can also be affected by ocean acidification, disease, overfishing and physical damage from boats or divers. It is important to acknowledge that coral health is a multiple stressor issue, and while we are focusing on water quality here, this may have additive and/or synergistic relationships with other stressors. Wherever possible, this monitoring design will leverage existing monitoring programs (e.g. biological), and will encourage future studies (e.g. coral genetics, toxic pollutants) to add to the sampling framework proposed here. It is also acknowledged that water quality issues vary throughout the SEFCRI region, and the data required to support related management decisions may vary as well. While the sampling framework will be consistent throughout the study area so as to be comparable, additional data may be required to fulfill the needs of a specific sub-region or watershed.

Sampling Design

The most useful design to address the desired outcomes stated above is one that considers both trends over time, as well as the current status of the system. The former is best achieved using fixed and/or targeted sites and the latter can be assessed using a stratified random design. As such, this sampling design will include both fixed and random sites.

The number of samples required to provide statistical robustness depends on the variability of the system (in both space and time), our willingness to reject the null hypothesis when it is in fact true (α value) and our desire to statistically assess relatively weak environmental correlations (see Table 1). The number of samples is also limited by resources/logistics, i.e. the project partners do not have infinite resources or staff to conduct this monitoring. Given the need to balance logistical constraints with statistically robust sampling design, we acknowledge that we may not be able to assess the entire study region in the first year of the assessment. The design will be such that the study geography can be segmented and sampling phased in over the larger region over time.

Previous work (Pickering and Baker, 2015) has delineated the inlet contributing areas (ICAs) for the region (Figure 3). This assessment will utilize that framework, further subdividing each ICA when appropriate (e.g. if there is a desire to capture sites both north and south of the inlet). Within each ICA (or substrata), a subset of sites was randomly selected from pre-existing Reef Visual Census (RVC) (NOAA 2016) sites. Each of these sites has biological data associated with the RVC program, and although the biological sampling is not reoccurring (i.e. each site is only sampled once by the RVC), co-locating the water quality sites allows for leveraging of these important data.

Sampling sites will be limited to relatively shallow reefs (10m depths of less) due to limitations of sampling equipment (water samples will be collected from both surface and bottom), although it should be noted that shallower reefs may be more likely to be impacted by land based sources of pollution (LBSP). In addition to these randomly selected sites, targeted sites were also selected to capture the influences of point sources (inlets and outfalls). Outfall sites will be sampled "at the boil", when visible, but investigators acknowledge that the exact location of the outfall maybe not be sampled each time because the location is not static. The sites will be visited once per month for water quality sampling.

In the first year of sample, two ICAs will be monitored: St. Lucie and Government Cut/Miami Harbor Inlet. These two were selected given the available greater resource support (i.e. boats and personnel, supplemental funds for sampling gear and lab reagents, bottles, etc.) available in those places than in the other locations and as well, to represent the geographical range of the sampling. The goal is to build up the number of ICAs being sampled over time, as resources permit. Sampling sites are shown in Figures 4 and 5.

Sample Timing

Water quality samples will be collected on a monthly time step. All sites will be collected within a day or two, irrespective of tidal cycle. Over time, all portions of the tidal cycle will be captured at each site, allowing us to understand the role of tides in the water quality status of a given site. Four times per year (quarterly), some stations will be targeted at ebb tide in order to make sure the flow from inlets is adequately captured. Efforts will be made to plan some of the sampling around storm/runoff events or planned releases of water from water management structures to capture flows from inlets.

Analytes

There are a multitude of water quality and biological variables that would enhance our understanding of the southeast Florida reef tract. This monitoring program will focus on the most critical water quality parameters which will make up the backbone of this program. However, other researchers are encouraged to perform additional analyses at these monitoring sites to leverage this monitoring backbone.

Table 2 shows the parameters selected for monitoring. The complete list of analytes represents discussions among technical experts and stakeholders; only a subset of these analytes will be measured in the first year of field monitoring. Additionally, Table 1 notes whether the parameter is a field measurement or if a grab sample is taken for analysis at the laboratory.

Field, Laboratory and QA Procedures

In order to make data gathered during this effort as useful as possible to both state and local management agencies, field and lab practices will be aligned with pre-existing Standard Operating Procedures (SOPs) from the state of Florida.

Data Analysis and Products

For the first year of data, NOAA and FDEP staff will collaborate on analyzing and interpreting the water quality data, and produce data products relevant to management needs. Analysis will include appropriate statistical (likely non-parametric) tests and geospatial (i.e. GIS) techniques. In the out years, FDEP will assume sole responsibility for data analysis. Products will include written reports, data maps and the raw data itself.

Data Storage/Access

All data from this monitoring program will be publically available and will be housed in the Florida STOrage and RETrieval (FL STORET) database (http://storet.dep.state.fl.us/DearSpa/). Backups of original data files will be stored in multiple places (NOAA and Florida DEP Coral Reef Conservation Program). Data will also be linked through NOAA's Coral Reef Information System (CoRIS).

Further Discussion

Data from this monitoring program may also be useful for modeling exercises that link hydrodynamics with biogeochemical information to help us better understand/predict the movement of nutrients and sediments on the reef tracts.

References

Banks, K.W., B.M. Reigl, E.A. Shinn, W.E. Piller, R.E. Dodge. 2007. Geomorphology of the southeast Florida continental reef tract (Miami-Dade, Broward, Palm Beach Counties, USA). Coral Reefs 26(3):617-633

Barnes, B.B., C. Hu, C. Kovach, R. Silverstein. 2015. Sediment plumes induced by the Port of Miami dredging: Analysis and interpretation using Landsat and MODIS data. Remote Sensing of Environment 170: 328-339.

Bloetscher, F., D.E. Meeroff, J.D. Plummer. 2010. Evaluation of coastal ocean discharges and environmental impacts in southeast Florida. Environmental Practice. 12:285-303.

Bloetscher, F. and S. Gokgoz. 2001. Comparison of water quality parameters from south Florida wastewater treatment plants versus potential receiving waters. Florida Water Resources Journal. June 2001:37-39.

Boyer, J. H.O. Briceno, J. Absten, D. Gilliam, D. Dodge. 2011. 2011 Annual Report of the Water Quality Monitoring Project for the Southeast Florida Coral Reef Initiative (SEFCRI) http://dpanther.fiu.edu/sobek/FI14051606/00001

BCEPD. 2007. Broward County Florida Water Quality Atlas: Freshwater Canals 1998-2003. Broward County Development and Environmental Regulation Division. Technical Report Series TR:07-03. 164 pp.

Caccia, V.G. and J.N. Boyer. 2005. Spatial patterning of water quality in Biscayne Bay, Florida as a function of land use and water management. Marine Pollution Bulletin 50:1416–1429 44

Carsey,T., H. Casanova, C. Drayer, C. Featherstone, C. Fischer, K. Goodwin, J. Proni, A. Saied, C. Sinigalliano, J. Stamates, P. Swart, J.-Z. Zhang. 2010. FACE Outfalls Surveys CruiseOctober 6-19, 2006. NOAA Technical Report. OAR AOML-38. NOAA-AOML. Miami, FL. 130pp.

Carsey, T., J. Stamates, N. Amornthammarong, J. Bishop, F. Bloetscher, C. Brown, J. Craynock, S. Cummings, P. Dammann, J. Davis, C. Featherstone, C. Fischer, K. Goodwin, D. Meeroff, J. Proni, C. Sinigalliano, P. Swart J.-Z. Zhang. 2012. Boynton Inlet 48-Hour Sampling Intensives: June and September 2007. NOAA Technical Report. OAR AOML-40 NOAA-AOML. Miami, FL. 55pp.

D'Angelo, C., and J. Wiedenmann. 2014. Impacts of nutrient enrichment on coral reefs: new perspectives and implications for coastal management and reef survival**.** Current Opinion in Environmental Sustainability 7: 82–93.

DEP 2010. Implementation of Chapter 2008-232, Laws of Florida Domestic Wastewater Ocean Outfalls 2010 Annual Report. Florida Department of Environmental Protection. Tallahassee, FL. 19 pp.

Ferro, F., L.K.B. Jordan and R.E. Spieler. 2005. The marine fishes of Broward County, Florida: Final Report of 1998-2002 survey results. NOAA Technical Memorandum NMFS-SEFSC- 532. 73pp.

Gilliam, D.S. 2010. Southeast Florida Coral Reef Evaluation and Monitoring Project 2009 Year 7 Final Report. Florida Department of Environmental Protection, Coral Reef Conservation Program Report #RM085. Miami Beach, FL. pp. 42.

Miller, M.W., J. Karazsia, C.E. Groves, S. Griffin, T. Moore, P. Wilber, K. Gregg. 2016. Detecting sedimentation impacts to coral reefs from dredging the Port of Miami, Florida USA. PeerJ 4: DOI 10.7717/peerj.2711.

NOAA. 2016. South Florida Reef Fish Visual Census (RVC). http://floridakeys.noaa.gov/sac/othermaterials/20150616rvc.pdf

Paytan G., G. Shellenbarger, J. H. Street, M. E. Gonneea, K.Davis, M. B. Young, and W. S. Moore. 2006. Submarine groundwater discharge; an important source of new inorganic nitrogen to coral reef ecosystems. Limnology and Oceanography. 51: 343–348.

PBC. 2008. Lake Worth Lagoon Management Plan. Palm Beach County Department of Environmental Resources Management. West Palm Beach, FL 154 pp.

Pickering, N. and Baker, E. 2015. Watershed Scale Planning to Reduce the Land-Based Sources of Pollution (LBSP) for the Protection of Coral Reefs in Southeast Florida. Prepared for the National Oceanographic and Atmospheric Administration. Horsley Witten Group. Sandwich, MA. 84 pp.

SAFMC. 2009. Fishery Ecosystem Plan of the South Atlantic Region. Available on-line: www.safmc.net/ecosystem/Home/EcosystemHome/tabid/435/Default.aspx

SFWMD. 2009 a. St. Lucie River Watershed Protection Plan. South Florida Water Management District, West Palm Beach, FL. 274pp.

SFWMD. 2009b. Lake Worth Lagoon Watershed and Stormwater Loading Analysis. South Florida Water Management District. West Palm Beach, FL. 200pp.

Singh, S. P., A. Azua, A. Chaudhary, S. Khan, K.L. Willet, P. R. Gardinali. 2009. Occurrence and distribution of steroids, hormones and selected pharmaceuticals in South Florida coastal environments. Ecotoxicology 19:338-350.

Trnka, M., K. Logan, P. Krauss and N. Craig. 2006. Land-Based Sources of Pollution Local Action Strategy Combined Projects 1 &2. Nova Southeastern University, Oceanographic Center. Dania Beach, Florida. 207pp.

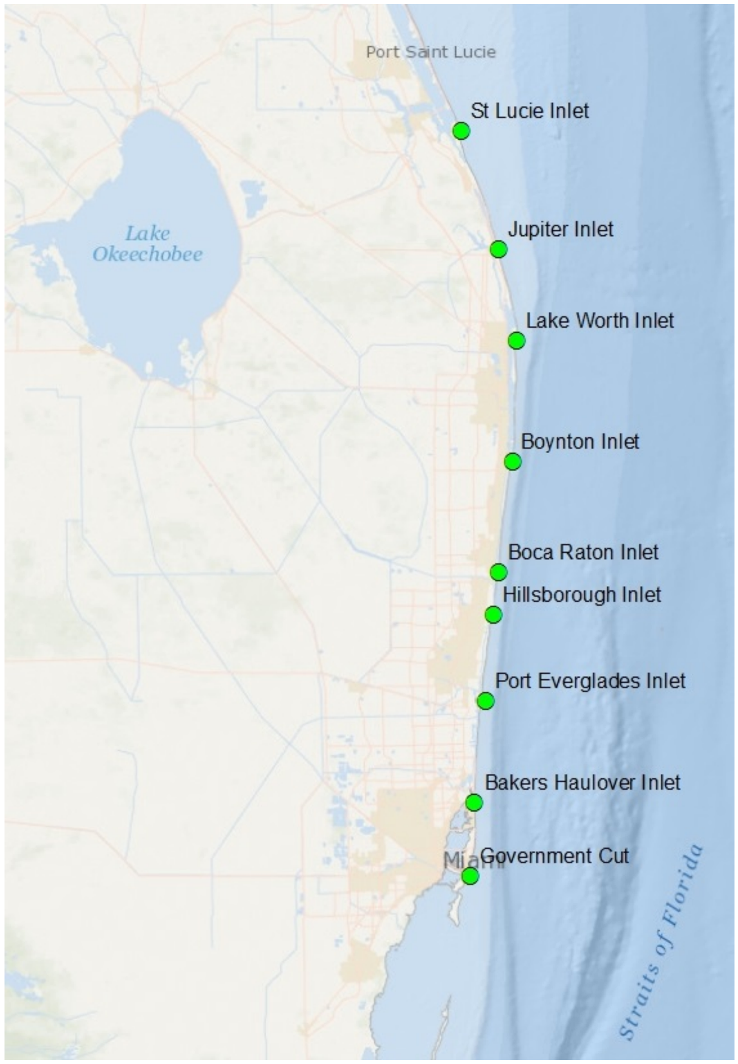

Figure 1: Inlet locations in SEFCRI region.

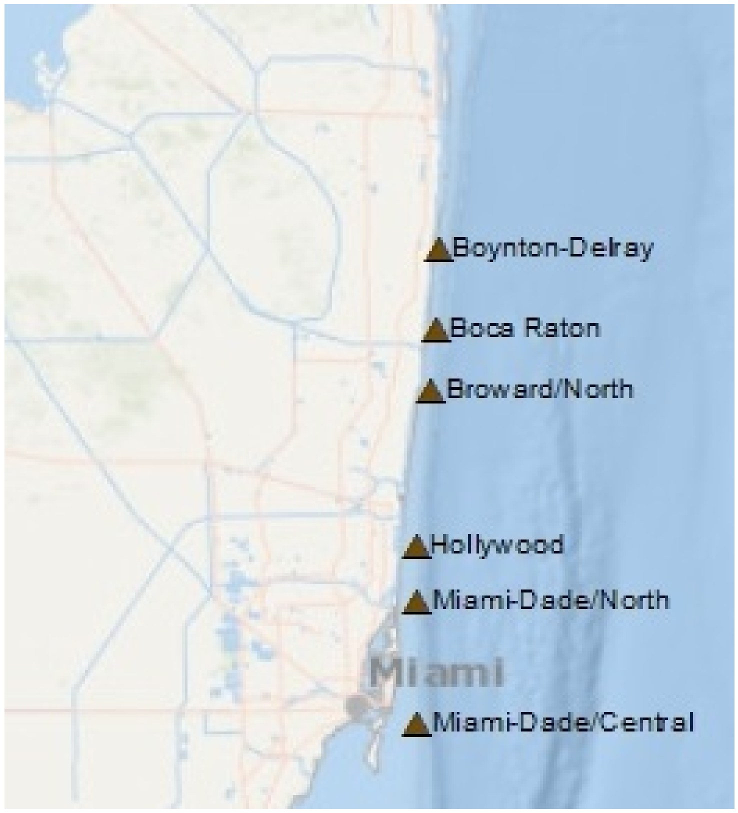

Figure 2: Outfall locations in SEFCRI region.

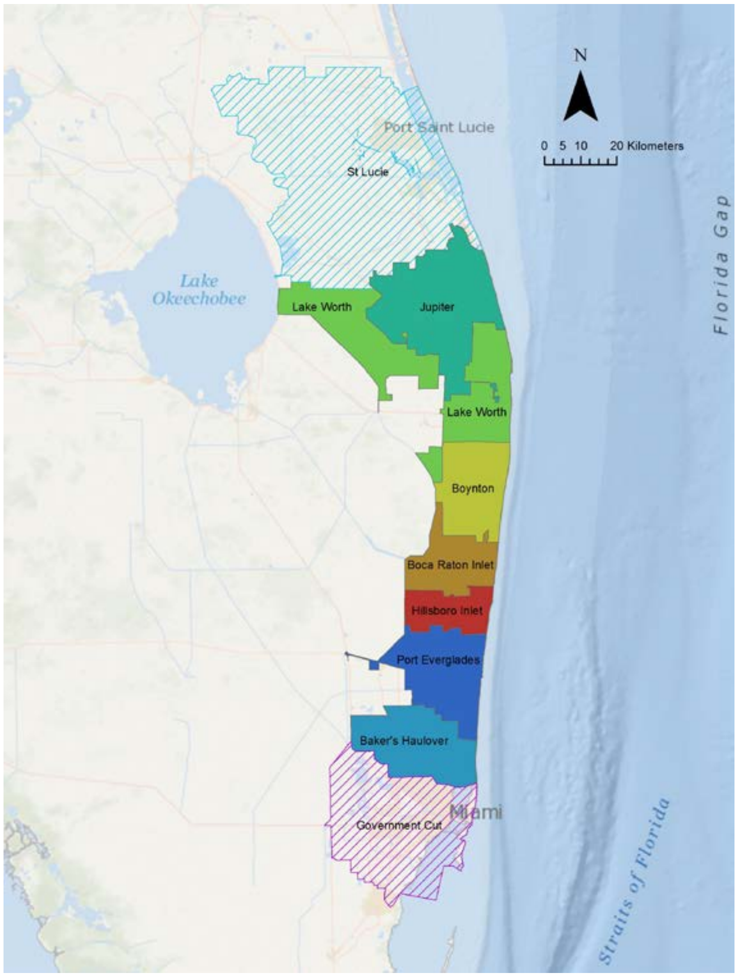

Figure 3: Inlet contributing areas (ICA) for SEFCRI region.

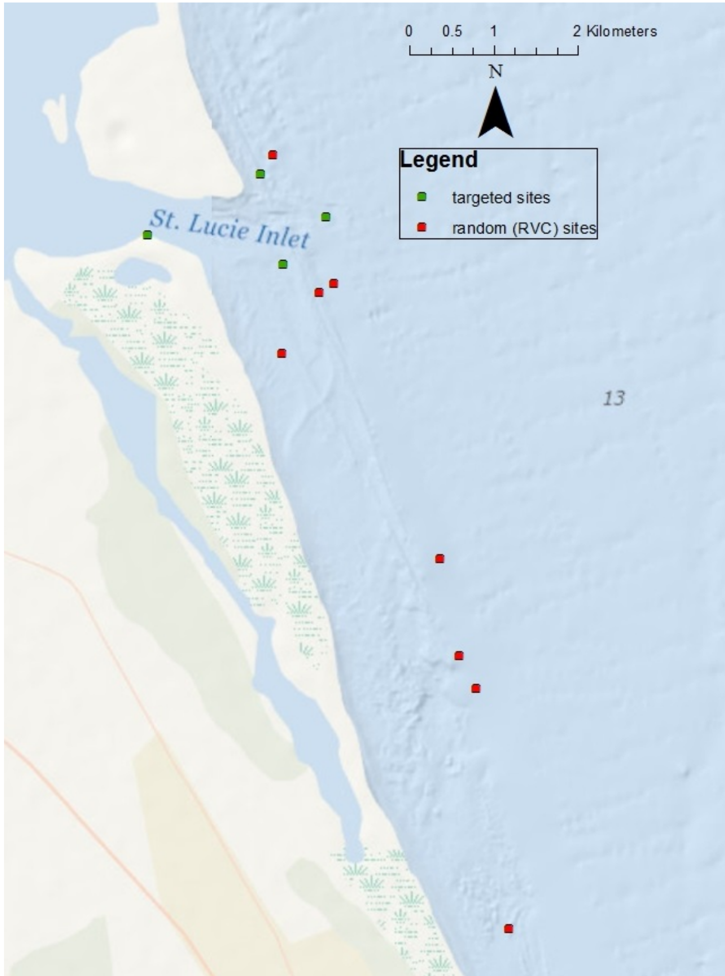

Figure 4: Sampling sites for St. Lucie ICA.

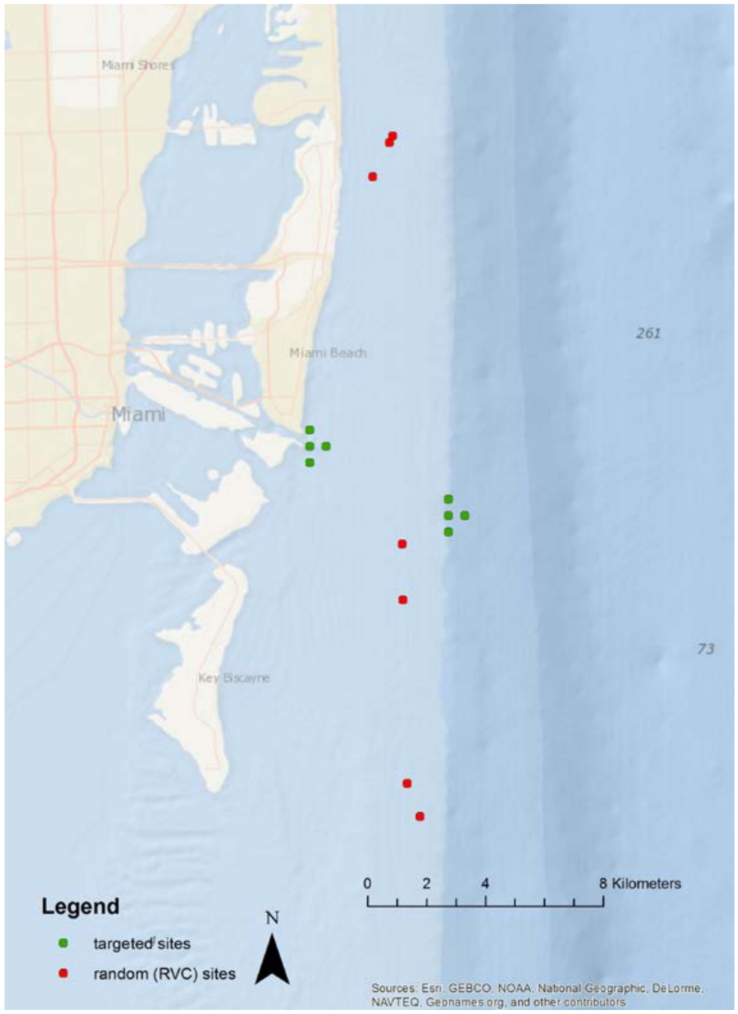

Figure 5: Sampling sites for Government Cut ICA.

Table 1: Number of samples needed to detect a given strength of correlation (α=0.05)

n	Minimum detectable correlation
4	0.950
5	0.878
6	0.811
7	0.754
8	0.707
9	0.666
10	0.632
11	0.602
12	0.576
13	0.553
14	0.532
15	0.514
16	0.497
17	0.482
18	0.468
19	0.456
20	0.444
25	0.396
50	0.279
100	0.196

Table 2: Routine monitoring parameters. Parameters in green are being measured in 2016.

Parameters in black maybe useful to add in the future.

Analyte	Category	Type	Rationale
Total Nitrogen	Chemical	grab sample	Nutrient impacts
Nitrate/nitrite	Chemical	grab sample	Nutrient impacts
Ammonium	Chemical	grab sample	Nutrient impacts
Total Phosphorus	Chemical	grab sample	Nutrient impacts
Orthophosphate	Chemical	grab sample	Nutrient impacts
Silica	Chemical	grab sample	indicator of freshwater sources
Chlorophyll a	Biological	grab sample	Water column phytoplankton affects light attenuation
TSS	Physical	grab sample	Sedimentation and light attenuation
Dissolved Oxygen	Chemical	Field/probe	Potential hypoxia/anoxia issues
Salinity	Physical	Field/probe	Influence of freshwater inputs
Temperature	Physical	Field/probe	Important for coral bleaching; needed for salinity calculation
Conductivity	Physical	Field/probe	Needed for salinity calculation.
pH	Chemical	field/probe	Important for carbonate chemistry
Secchi depth	Physical	Field/disc	Simple measure of light penetration
Sucralose	Chemical	grab sample	Indicator of human waste
PAR	Physical	Field/meter	light penetration for photosynthesis by zooxanthellae and benthic algae
Turbidity	Physical	Field/probe	light attenuation
Current measurements	Physical	field/meter	Important to understand water movement
CDOM	Chemical	grab sample	Light attenuation