Memorandum

MIAMI-DADE COUNTY

Agenda Item No. 2B3
February 5, 2019

Date: January 28, 2019

To: Honorable Chairwoman Audrey M. Edmonson and Members, Board of County Commissioners

From: Carlos A. Gimenez Mayor

Subject: Report on the Findings of the County's Study on the Decline of Seagrass and Hardbottom Habitat in Biscayne Bay- Directive No. 171537

This report is being provided to the Board of County Commissioners (Board) pursuant to Resolution No. R-876-17, which directed the Mayor's Office to produce a report containing the findings, hypotheses, and/or recommendations resulting from the study of the decline of seagrass and hardbottom habitat in Biscayne Bay.

In accordance with Ordinance 14-65, this memorandum and report will be placed on the next available Board meeting agenda.

If you have any questions or concerns, please contact Lee N. Hefty, Assistant Director, Department of Regulatory and Economic Resources, Division of Environmental Resources Management at (305) 372-6754 or heftyl@miamidade.gov.

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REPORT ON THE FINDINGS OF THE COUNTY'S STUDY ON THE DECLINE OF SEAGRASS AND HARDBOTTOM HABITAT IN BISCAYNE BAY

Executive Summary

Biscayne Bay is a subtropical, shallow estuary within the Everglades watershed where freshwater from the mainland mixes with water from the Atlantic Ocean. Historically, Biscayne Bay received freshwater along its shoreline as water traveled south and east. Today, natural freshwater flows have been replaced by pulsed, point source discharges from dredged canals, intended to offer flood protection and move water away from inland areas. Canals can intercept groundwater, and more than half of the freshwater received by the bay enters via the northernmost canals. Runoff from the watershed which can be affected by various activities taking place on land can impact the quality of the water entering Biscayne Bay via canal conveyance. The timing, source, and quality of freshwater delivered to the bay can influence the health, diversity, and distribution of the flora and fauna that comprise the Biscayne Bay ecosystem. Seagrasses provide habitat for ecologically and economically important fisheries such as shrimp, lobster, and various fish species and provide services such as stabilizing sediments and attenuating wave energy from storms.

Biscayne Bay has experienced seagrass die-offs, most notably several that have occurred within the last decade. The Miami-Dade County Department of Regulatory and Economic Resources, Division of Environmental Resources Management (DERM) has maintained ongoing monitoring programs for bay water quality and bay habitat over many years. These ongoing monitoring programs are valuable tools to help evaluate the overall health, status, and trends of the bay ecosystem. This long-term data set provides important information on past, present, and future conditions as we continue to study the recent decline of seagrass and hardbottom habitat noted in Biscayne Bay. The seagrass losses identified over the past decade are associated with three regions of the bay. They include the Barnes Sound and Manatee Bay basins which have experienced a decrease in seagrass of approximately 93 percent; the central portion of the bay near Coral Gables which has experienced a decrease in seagrass of approximately 85 percent; and the basins north of the Rickenbacker Causeway which have experienced loss of seagrass ranging from approximately 66 percent - 89 percent.

A rigorous study of DERM's water quality and seagrass survey data, as well as review of scientific literature and academic studies cited therein as part of this investigation, indicate that chronic, low-level nutrient loading and/or acute, pulsed nutrient loading is likely linked to seagrass loss in Biscayne Bay. Excess nutrients can lead to a shift from a seagrass dominated habitat with clear water, low turbidity, and low levels of algae in the water column, to an algae-based ecosystem that is turbid and contains reduced fisheries habitat.

Seagrass communities play an important role in regulating water quality by stabilizing bay sediments and cycling nutrients. Therefore, full recovery of seagrass communities to prior levels and species composition following a significant loss can be a complicated ecological process that may take several years to achieve if full recovery does occur. Regardless, working to reduce anthropogenic impacts to water quality and seagrass habitat provides the best opportunity for promoting seagrass recovery.

County staff recommendations to address this challenge include: maintaining and improving the county's water quality and habitat monitoring programs; maintaining and improving the county's bay habitat restoration program activities; maintaining the county's support for state and federal regional restoration programs; ensuring the county's coastal construction and regulatory program adequately protects existing bay resources; and improving public awareness through outreach.

Study Findings and Recommendations

Biscayne Bay is the largest estuary on the southeast coast of Florida encompassing 428 square miles, bordered by barrier islands to the east and the mainland to the west. The bay has historically been regarded as a shallow subtropical estuary, where freshwater from the mainland mixes with saltwater from the Atlantic Ocean. The waters that comprise Biscayne Bay are designated by the state as Outstanding Florida Waters, affording the waterbody one of the highest levels of protection in Florida. Biscayne Bay is home to Biscayne National Park and two state aquatic preserves - the Biscayne Bay Aquatic Preserves - which border the national park to its north and south [See Figure 1- Boundaries of Biscayne Bay Aquatic Preserves and Biscayne National Park]. Biscayne Bay is naturally connected to the Kissimmee-Okeechobee-Everglades watershed and historically received freshwater through the downslope movement of water, or sheetflow, which traveled from the Kissimmee area down through Lake Okeechobee and eventually into the Everglades ecosystem to Florida Bay and Biscayne Bay [1]. Tributaries and transverse glades that carved through the Atlantic Coastal Ridge facilitated freshwater sheetflow to the coast. The shoreline of Biscayne Bay consisted of mangroves and freshwater and saltwater marsh habitat. Consistent estuarine salinities, suitable water quality conditions, and sandy sediment composition allowed bay bottom habitat to be dominated largely by seagrasses, along with hardbottom community characterized by marine algae, sponges, and several hard and soft coral species. Biscayne Bay depends on significant quantities of freshwater, once received as sheetflow prior to development, to maintain its estuarine ecosystem [1], [2].

Most of Biscayne Bay's natural tributaries were dredged and channelized and new canals were created to facilitate water flow away from inland areas as population along the coast increased. As a result, the volume, timing, and delivery of freshwater to Biscayne Bay were radically and permanently altered [2]. These changes impacted the salinity gradient along the shoreline that is important for both estuarine flora and fauna to thrive [3]. Today, the South Florida Water Management District manages the complex system of canals, levees, and water control structures that have largely replaced freshwater sheetflow to the bay with pulsed discharges of freshwater at canal mouths. Cantillo et al [2] and Stalker et al [4] identified the three principle sources of freshwater received by Biscayne Bay as canal discharge, precipitation, and submarine groundwater discharge from the Biscayne Aquifer. Prior to the construction of the canal system, groundwater readily flowed up through the porous limestone aquifer and the existence of freshwater springs within the bay and along the shoreline are well documented [2]. The creation of the canal network effectively lowered the groundwater table thereby reducing groundwater contribution to the bay through these freshwater upwellings. Several studies have been conducted by the U.S. Geological Survey and local universities to determine the ratio of freshwater input from canal discharge, precipitation, and groundwater sources. Models run by Stalker et al [4] documented the freshwater input into Biscayne Bay from canals to be approximately 40 percent, the input from precipitation to be approximately 50 percent, the input from groundwater to be approximately 10 percent, with slight variation between the wet and dry season. The results of the study are consistent with Langevin's [1] prior work and indicate that freshwater inputs to Biscayne Bay are dominated by canal discharge near the western shoreline, while areas further east and closer to the ocean are dominated by precipitation as the main source of freshwater. Langevin [1] also concluded that canals intercept fresh groundwater that might otherwise have discharged directly to Biscayne Bay. Per Caccia and Boyer [3], the portion of Biscayne Bay north of the Rickenbacker Causeway receives freshwater from five canals including Snake Creek, Arch Creek, Biscayne Canal, Little River and Miami River [See Figure 2 - North Miami-Dade Seagrass Loss Areas by Region]. The central part of the bay is influenced by three canals, including Coral Gables Waterway, Snapper Creek, and Cutler Drain [See Figure 3 - South Miami-Dade Seagrass Loss Areas by Region]. Caccia and Boyer [3] found that Snake Creek, Little River, and Miami River delivered more than 50 percent of the total freshwater contribution into Biscayne Bay for the period studied from 1994 through 2002. Caccia and Boyer's study focused on quantifying the nutrient loads in each of the sources of freshwater reaching Biscayne Bay (i.e., canals, precipitation, and groundwater discharge), largely drawing from DERM's water quality monitoring dataset. Freshwater input via natural sheetflow and submarine groundwater discharge has largely been eliminated and replaced mostly by pulsed discharges from canals. Given that canals can intercept groundwater and convey it as surface water to Biscayne Bay, and given that more than 50 percent of the freshwater that Biscayne Bay receives comes from the northern canals, it is critically important to consider the quality of the water entering Biscayne Bay via canal conveyance. In summary, water quality is largely dependent on land use and influences from the watershed. The findings from Caccia and Boyer [3], Stalker et al [4], and Cantillo et al [2], and other peer-reviewed literature indicate that the timing and sources of freshwater delivery into an estuarine system affects not only the water quality but thereby the health, diversity, and distribution of flora and fauna such as seagrasses, juvenile fish, and other benthic organisms.

Seagrasses are marine flowering plants that grow in the bay bottom sediments and play a fundamental role in the overall health of the bay. Seagrasses provide a host of benefits to the ecosystem, both directly and indirectly benefiting humans. Seagrasses provide habitat and shelter for juvenile species of recreationally- and commercially-important fish. Both recreational and commercial fishers make their living on Biscayne Bay collecting species from baitfish to stone crab, blue crab, shrimp and lobster. Seagrasses support the diving industry in South Florida by providing habitat to juvenile fish that colonize reefs later in their development. Perhaps one of the most important benefits seagrasses provide is their ability to enhance shoreline protection and prevent erosion by stabilizing sediments with their roots, helping to make shorelines and inland infrastructure that much more resilient to storm surge and other deleterious storm effects. In the process of stabilizing sediments and taking up nutrients, seagrasses help maintain water quality and clarity. Through the process of storing energy through photosynthesis, seagrasses oxygenate the water column, further supporting populations of fish and invertebrates. They serve as a direct food source for various animals, including the federally protected manatee and sea turtles [5], [6]. Within the last decade, the scientific community began to better understand and quantify the role that coastal vegetative communities such as seagrasses and other submerged aquatic vegetation, mangroves and tidal wetlands play in sequestering and storing carbon. Seagrasses sequester carbon dioxide in their root systems for decades to hundreds of years, far exceeding the carbon-sequestering capacity of terrestrial trees and plants. The ability of seagrasses and mangroves to remove carbon dioxide from the atmosphere has significant implications for climate change and potential mitigating actions [7]. Lastly, seagrasses cycle nutrients out of the water column and they also help stabilize sediments, further aiding in maintaining water quality and clarity.

Miami-Dade County is unique in being one of a handful of counties that are home to all seven species of seagrasses found in the state of Florida. The seven species include *Thalassia testudinum* (Turtle grass), *Syringodium filiforme* (Manatee grass), *Halodule wrightii* (Shoal grass), *Halophila decipiens* (Paddle grass), *Halophila johnsonii* (Johnson's seagrass), *Halophila engelmannii* (Star grass), and *Ruppia maritima* (Widgeon grass, a seagrass associate and not a true seagrass). Johnson's seagrass was the first marine plant to be listed under the Endangered Species act and it is designated as Threatened. The entire worldwide distribution of Johnson's grass ranges from northern Biscayne Bay through Sebastian Inlet in Brevard County [8]. To survive, seagrasses have certain requirements to complete their life cycle and provide the aforementioned ecosystem services. Water quality and habitat preferences may vary by seagrass species, however, in general certain physical characteristics relating to substrate, depth, salinity, pH, and temperature are required for each. Additionally, seagrasses require suitable water clarity for light penetration to reach blades to allow for photosynthesis to occur. Like all plants, seagrasses require nutrients, derived from the water column and sediments via root systems, to survive and grow. However, an ecosystem that becomes over-enriched with nutrients can negatively impact seagrass growth and survival [9], [10].

Biscayne Bay has historically been an oligotrophic estuary (i.e., low in nutrients), where availability of the nutrients nitrogen and phosphorus drive the health and growth of seagrass communities. Seagrasses cycle nutrients by removing them from sediments and the water column and use these nutrients for growth. Phosphorus is considered to be the limiting nutrient, or is less available, as it binds to the calcium carbonate sediments that are characteristic of Biscayne Bay [11]. Availability of phosphorus is largely considered the determining factor in plant growth in the marine environment. Cantillo et al [1], Caccia and Boyer [3], Greening and Janicki [6], Unsworth et al [9], Burkholder et al

[10], and several other scientific articles acknowledge or directly attribute seagrass decline and/or catastrophic loss to ecosystems becoming eutrophic, or nutrient over-enriched. Burkholder et al [10] specifically note that "...eutrophication or nutrient over-enrichment, especially of nitrogen and phosphorus, has degraded many coastal waters and has been invoked as a major cause of seagrass disappearance worldwide." Burkholder et al go on to state that the cause of a seagrass die-off in a particular seagrass bed is rarely established and the factors likely involved in the decline are more often established through corroborating results from studies. However, Burkholder et al [10] further note that there is "compelling evidence from a wealth of field observations and experiments, and a limited number of cases of seagrass recovery ... [to support] eutrophication as an underlying factor in seagrass disappearance." The conclusions of the various authors cited herein support the findings of the County's study of the recent seagrass die-off events. The study included a review of the relevant scientific literature, technical discussions with agency and academic partners regarding their respective work on this issue, and a rigorous review of data collected by DERM over many years.

DERM manages various environmental monitoring programs, including programs that collect data to document the status and trends of water quality and benthic habitats in Biscayne Bay on an ongoing basis. The ability to evaluate for any changes or trends in Biscayne Bay nutrients is an important component of the monitoring program. The County's surface water quality monitoring program was established in 1979 and collects data that include various physical, chemical and biological water quality parameters within all major canals across the County and throughout Biscayne Bay on a monthly basis [See Figure 1A – Biscayne Bay Water Quality Monitoring Plan]. The program includes data collection for parameters that are typical indicators of the overall health of Biscayne Bay and its tributaries, as well as collecting parameters that help identify the impact that the urbanized watershed has on water resources throughout the County. For example, sampling includes analysis for the presence of bacteria in the water column which can be an indication of impacts from sewage releases or faulty infrastructure. Other sampling includes measurements of dissolved oxygen levels or chemical analysis for various nutrient concentrations in surface waters, both of which correlate to the ecological health and vulnerability of water resources such as Biscayne Bay. Currently, the County monitors surface water quality at 99 stations in major canals across the County and throughout Biscayne Bay on a monthly basis.

The County's Biscayne Bay Benthic Habitat Monitoring Program was established in 1985 and collects data on the health and presence of benthic resources such as seagrass, macroalgae, sponges, hard corals and soft corals at various locations throughout Biscayne Bay on an annual basis. The monitoring program includes identifying the type of bay bottom habitat that is present, as well as collecting data on the abundance of these resources, such as percent seagrass cover. Both the surface water quality and benthic (bottom dwelling) habitat monitoring programs provide important data that is used to determine current conditions, short- and long-term trends, and to identify problem areas where water quality is degraded. This information can be used to evaluate how upland and water management activities affect water quality in drainage canals and how that affects water quality and bottom habitat in Biscayne Bay.

Miami-Dade County staff continues to work collaboratively with state and federal agencies as well as academic institutions to leverage resources and technical knowledge to address critical issues when needed and to better understand the health of the bay. In Caccia and Boyer's [3] work using DERM's data in part to better understand nutrient loading in freshwater contributions to Biscayne Bay, the authors were able to quantify which canals contributed a substantial input of nutrients. In their work to calculate monthly loading of nutrients for each canal in 2007, they identified that the Miami River, Little River, and Snake Creek in the north part of Biscayne Bay contributed the highest annual loading of total phosphorus [See Figure 2 - North Miami-Dade Seagrass Loss Areas by Region]. These three canals accounted for 60 percent of the total phosphorus load to Biscayne Bay and a total of 16 percent of the total load of nitrogen. These findings are consistent with the update to the South Florida Water Management District's Surface Water Improvement and Management (or "SWIM") plan for Biscayne

Bay. Various forms of measuring nitrogen in the water column, such as ammonia, ammonium, or nitrate/nitrite, can help identify potential sources. For example, Caccia and Boyer [3] found that Miami River, Little River, and Snake Creek contributed 74 percent of the total load of ammonium, a species of nitrogen associated with human waste.

Sources of nutrients that can lead to eutrophic or nutrient enriched conditions include both point and non-point sources such as stormwater that can convey pet waste, fertilizers, and potentially water that has come in contact with human waste via proximity to aging, leaky sewer lines. Septic tanks may also impact surface waters of the bay, particularly when septic tanks are close to canals that are known to openly exchange with groundwater and eventually with surface water [3], [10]. Cantillo et al [1] stated that "Contaminants can enter the aquifer by direct infiltration from land surface or controlled canals, septic tanks and other drainfields, drainage wells, and solid waste dumps. Most of the contamination is concentrated in the upper 20 to 30 feet of the aquifer." Cantillo et al [1] note that while major sewers discharging directly into Biscayne Bay were closed in the late 1950s, pollution inputs to the Bay during the 1970s were attributed to runoff from the metropolitan areas introduced via the canals and rivers and that "sewage pollution continued to occur and further monitoring of Bay conditions was recommended." The Miami River is a focus of their discussion about sewage contamination, and these findings are consistent with the results from data collected as part of the County's ongoing monitoring program [See Figure 4 – Bacteria – Percent Non-Compliance]. Specifically, it is stated that chronic bacteria contamination is "characterized by coliform levels tens of times higher than standards and is primarily caused by contamination of storm drains by raw sewage." In addition to coliform and *E. coli* being sampled, *Enteroccus* was added as the EPA-identified and state-adopted parameter most suitable for detecting bacteria-related inputs into estuaries or saltwater environments. Figure 4 provides an overview of the areas most often out of compliance with amended state standards, including and most notably the Miami River samples being out of compliance between 75 percent and 100 percent of the time. Also noted in Figure 4 are the septic tanks across the County, concentrated somewhat near the center of the city and further north, and the drainage basins, as identified by the state, that are out of compliance with state standards.

Utilizing the Biscayne Bay water quality data, conclusions drawn by researchers at Florida International University as well as the National Oceanic and Atmospheric Administration (NOAA) support County staff's findings that phosphorus and chlorophyll-a have trended higher in the Bay over the last twenty years [12]. Chlorophyll-a is a pigment that allows organisms such as plants and algae to photosynthesize to obtain their energy. Measuring the amount of chlorophyll-a provides an indication of the concentration of algae in the water column. The frequency of algal bloom conditions and seagrass loss events have increased since 2005 [See Figure 5 – Timeline of Seagrass Loss Events]. The association between bacteria indicators, ammonia, and phosphorous has been documented [3] and more recent analysis has linked these with the artificial sweetener, sucralose, and isotopes of nitrogen - both of which are linked to human waste [13], [14]. Consistent with other published work using the County's and other data, County staff's analysis of monitoring data document phosphorous discharging in the region from Oleta River south to Snapper Creek to be significantly higher than the values found in less impacted areas and that ammonia, in several locations, exceed the County standard of 0.5 mg/L. The parts of the bay receiving waters from some of the most nutrient-rich canal inputs include the basins where seagrass die-off has occurred [See Figure 6 – Decrease in Seagrass by Basin]. The total percent decrease in seagrass acreage across the affected basins ranges from 77 percent to 93 percent.

The Burkholder et al [10], Greening and Janicki [6], and Borum et al [15] describe the phenomenon by which seagrasses are impacted by eutrophication. Different species have different needs related to nutrients, light, salinity, depth, and other parameters. These needs depend on the species composition of the seagrass beds as well as various stressors that might affect species success such as lack of freshwater, storm events, and nutrient inputs at various frequencies and loads. Not having basic physiological needs met along with environmental stressors can contribute to the decline of seagrass beds. It is difficult to determine the exact quantity of nutrients such as nitrogen or phosphorus that lead to the precipitous decline in seagrass because nutrients are constantly being cycled through the ecosystem via the water column, water deep within the sands of the bay bottom, and seagrass roots and leaves. Nutrients also interact with other flora and fauna such as marine algae and contribute to the overall process of nutrient cycling. For example, in a study by Asmus and Asmus [19], organic nitrogen, a parameter monitored by the County, is taken up more readily by dense seagrass beds than by sparse seagrass beds. Then, through normal biogeochemical processes that take place in the water column and in the root zone of seagrasses, some nitrogen may be released either in the root zone or the water column. This internal nutrient loading process from sediments to the water column is difficult to quantify. In addition, seagrass beds serve as sinks for nutrients like phosphorus, and the limit to which they can uptake nutrients and cycle them may be dictated by the species, species density, and other stressors in the environment like temperature and salinity. Furthermore, Asmus and Asmus [19] state that nutrient enrichment can manifest as sudden shifts in biomass rather than a gradual or continuous change in growth in parallel with rate of nutrient additions. This could indicate that the monthly monitoring of nutrients in the water column may not capture an increase or decrease in nutrients into the water column because those nutrients could be taken up by seagrasses, or conversely, cycled and expelled by them. Consequently, there is not necessarily a direct linear relationship between the highs and lows observed in the County's nutrient data and the loss of seagrass in a particular basin. However, the long-term trends in the nutrient data and monitoring of the seagrass resources can and do provide insight into the overall health and condition of Biscayne Bay's seagrass habitat.

Chronic, low-level nutrient loading or acute, pulsed nutrient loading is linked to seagrass loss worldwide within highly urbanized and developing coastal zones, per Burkholder et al [10]. Catastrophic losses can occur in bodies of water with limited tidal flushing, such as the Julia Tuttle Basin in north Biscayne Bay, and nutrient loads that are both concentrated and frequent. These conditions can cause seagrass habitat to shift to a macroalgae- or phytoplankton-based system. Phytoplankton are microscopic algae in the water column that thrive when nutrients are available. When these algae "bloom", it results in cloudy, green- or brown-tinted water that prevents sunlight from reaching resources on the bay bottom. Valentine and Duffy [18] describe the altered states that seagrass habitat can devolve into following a die-off. One such state, should stressors be removed affording seagrass beds an opportunity to recover, is a seagrass-dominated habitat. A seagrass-dominated habitat is characterized by low biomass of algae, including macroalgae and phytoplankton (as evidenced by low levels of chlorophyll-a), and provides habitat for fish and invertebrates. The altered state exists when seagrass loss and failure to remove the stressors result in an algae-dominated habitat. Algae-dominated habitat persists under high nutrient, low light regimes, and is not conducive to seagrass re-establishment. Burkholder et al. [10] cite the work of several scientists who documented that the effects of eutrophication, or nutrient over-enrichment, are additive. Effects of eutrophication include anoxia, or a lack of oxygen, as a result of high photosynthetic activity by organisms like seagrass and phytoplankton taking up available nutrients and oxygen. A prolonged state of anoxia increases the energy demand of seagrasses to transport oxygen to root systems, impacting the plant's physiological capacity to carry out basic metabolic functions and to protect against other stressors. Elevated nutrients, respiration and anoxia can promote increased sulfide concentrations in the sediment which can impact the ability of seagrass to photosynthesize, metabolize, and grow [10].

In the northern region of the bay, the Julia Tuttle Basin historically supported a dense seagrass community that was largely dominated by a single species, *Syringodium filiforme,* or manatee grass, which can thrive under higher nutrient conditions. Manatee grass found in this region grew to densities and physical proportions that were indicative of nutrient enrichment. Changes in seagrass cover became apparent in 2016 when seagrass density at the fixed transect monitoring station in this basin indicated a sudden and severe die-off within a two-month period [See Figure 7 – In-situ photographs of seagrass die-off and Figure 8 Julia Tuttle Basin Time Series of Seagrass Die-Off]. Staff then reviewed data collected over time at the site. While data indicated that density at the fixed transect monitoring location did not change appreciably until 2016, a review of aerial photography indicated that seagrasses along the northern edge of the basin had receded notably as evidenced by 2012 through 2016 aerial photographs. Researchers from Florida International University (FIU) and the Florida Fish and Wildlife Conservation Commission concluded from past studies in Florida Bay that high density seagrass beds are susceptible to die-off under low-oxygen conditions created by the increased demand in oxygen needed to sustain the density of seagrass. A review of historical data of two water quality stations in the basin showed record nitrogen values in 2012 and 2014, and peaks in phosphorus in 2013 and 2014 [See Figures 9-13 for Trends in Water Quality]. The highest monthly average of chlorophyll-a was documented in 2014 as well. Approximately 1,300 acres of seagrass has been lost in this basin, and to date there is no evidence of seagrass recovery. County staff also directly consulted with Dr. Jim Fourqurean, a local academic expert and leading seagrass ecologist from Florida International University, who suggested that the species composition and extraordinary biomass in the basin was indicative of nutrient enrichment and that die off was likely driven by the significant oxygen demand needed to sustain the high biomass. Surveys and analyses conducted recently indicate that seagrass habitat has been reduced in the Julia Tuttle Basin by approximately 77 percent.

The 79th Street Basin lost seagrass in 1998 and although not as heavily investigated at the time, a review of the data shows species composition and high biomass similar to what was in the Julia Tuttle Basin. It is included in this report to provide a complete picture of losses in Biscayne Bay in the northern urban watershed. Based on recent monitoring efforts, seagrass habitat in the 79th Street Basin has been reduced by approximately 89.6 percent.

Seagrass die-off has also been documented in the central region of Biscayne Bay, noted as the *Anadyomene Bloom Area* in Figure 6. A large area of seagrass in the area from Coconut Grove to Matheson Hammock has died off as a result of a benthic macroalgal bloom. Unlike phytoplankton, macroalgae are visible to the naked eye and often grow attached to or rest on the bay bottom. Seagrass data collected adjacent to the Coral Gables Waterway and Snapper Creek Canal indicated that the area was mostly comprised of dense seagrasses, with some macroalgal cover. However, between annual sampling events in 2009 and 2010, a shift was observed in the makeup of the vegetation from mainly seagrass to mostly macroalgae. In 2010, County staff conducted additional monitoring to better understand the extent and cause of the bloom by completing over 80 transect surveys to document the presence of the bloom. In 2011 and 2012, when the bloom did not dissipate, staff worked to identify the full spatial extent of the bloom. As a result of these observations, County staff biologists collaborated with the Florida Department of Environmental Protection (FDEP), FIU, and the University of Miami to comprehensively study the bloom. A focused study of the macroalgal bloom, which is comprised of two species of the genus *Anadyomene*, included monitoring of 165 stations that were established between 2010 and 2014 to identify the extent of the bloom. Scientific literature and the County's partnership with other agencies and universities provided insight into the mechanism of the bloom's effect on seagrass. Seagrasses serve as a holdfast for the macroalgae to latch onto; the competition for oxygen and other resources create oxygen-poor conditions in the water column, sediments, and seagrass root systems thereby exacerbating hydrogen sulfide stress [19]. Additionally, the overgrowth of algae prevented adequate light from reaching the photosynthetic elements in the seagrass blades, all leading to the stress and eventual death of the seagrasses. Water quality samples as well as samples of both seagrass and macroalgae tissue were collected within the bloom affected area by FIU and FDEP. The samples were analyzed for known indicators of anthropogenic nutrient inputs, including analysis for a stable isotope of nitrogen and the chemical sucralose. Results of analyses indicate that nutrients from anthropogenic sources, such as canal discharges, sewage releases or seepage from septic tank systems, likely contributed to this macroalgae bloom. Seagrass habitat in the *Anadyomene* bloom area has been reduced by approximately 84.5 percent. While the overall density of the macroalgal bloom has since decreased, seagrass in the affected area has not recovered. County staff continues to monitor this area and collaborate with other agency and research partners. The bloom has been consistently monitored by DERM in collaboration with academic partners, and the key findings suggest a linkage between algae growth and anthropogenic sources of nitrogen. Specifically, analysis of algae tissue samples showed that ratios of nitrogen to phosphorus were higher within the bloom area, decreased with increases in distance from shore and were distinctly different than the Reference Region location in Biscayne National Park. Additionally, heavier isotopic nitrogen followed the same pattern and was indicative of human sources [14].

The southernmost region of Biscayne Bay, Manatee Bay and Barnes Sound, experienced a seagrass die-off event following Hurricane Katrina in 2005, which was followed by a phytoplankton bloom that persisted for two years. Storm events such as these are often accompanied by high-volume discharges from regional canals as part of flood control and management activities before and after a storm, and often contain high levels of nutrients, and may also dramatically alter salinity. Data collected by DERM, the South Florida Water Management District, and NOAA supports the hypothesis put forth by the SFWMD that two major storm events, nutrient-laden stormwater discharge, and nutrient inputs from mangrove removal in association with the US1 road expansion likely contributed to the seagrass die-off and subsequent phytoplankton bloom in this area [15], [16]. It is estimated that seagrass habitat was reduced by approximately 93.4 percent in this basin. To date, seagrass recovery is minimal and chlorophyll-a remains elevated. Various agencies continue to monitor conditions in these basins.

Dozens of peer-reviewed articles discuss the impaired state of seagrasses on a global scale, largely because of urbanization and resulting eutrophication. Given this fact, and given the current state of Biscayne Bay, it is important to know that recovery of seagrass habitat is still possible. In Tampa Bay, there was a 90 percent decline in seagrass between 1948 and 1982. Decisive measures were taken, including the formation of a technical team to expressly investigate how to reduce nutrient loading. Following a 57 percent reduction in nitrogen loading between the 1980s and 2002, there was a marked decrease in phytoplankton biomass and improved water clarity, which lead to the recovery of extensive seagrass coverage. A similar effort was undertaken in Sarasota Bay which led to a 46 percent reduction in nitrogen loading and subsequent resurgence of seagrass habitat [16]. Thinking beyond restoration of Biscayne Bay to building resilience is critical in the face of potential impacts from climate change, including the frequency and strength of storms. Per Asmus and Asmus [19], the amount of nutrient particles in tidal waters can increase by tenfold during storms, an impact that may further degrade water quality, seagrass, and hardbottom habitat in Biscayne Bay if the bay is not resilient enough to process the nutrient loading from storms over time. Researchers like Unsworth et al. [9] created a framework for building resilient seagrass ecosystems where deliberate steps can be taken to halt and/or recover from decline [See Figure 14]. The County's work thus far with academic and agency partners in this effort, whose efforts are noted herein, is bolstered by the recent designation of Biscayne Bay as a Habitat Focus Area as part of NOAA's Habitat Blueprint Program. The framework is meant to address work in partnership to restore regionally-significant habitats. The first of four goals set forth by the Biscayne Bay Habitat Focus Area Team, which includes technical staff from DERM, is to develop a tool that will help to calculate and later reduce nutrient loading, as well as reduce the frequency and extent of algal blooms [19].

Recommendations

Various factors have the potential to impact the health of seagrass and hardbottom communities in the Biscayne Bay. They may be the direct result of anthropogenic activities on land or in the bay, or they may be the result of some naturally occurring event. These include impacts from canal discharges and stormwater runoff, periodic extreme weather events (drought, storms, hurricanes), development activities along the shoreline and directly in the bay, or evolving threats to the bay's ecosystem as a result of changing conditions from sea level rise. While it is not feasible to eliminate all threats to the bay, the best approach to protecting the bay's resources starts with minimizing human impacts that are within our control as a community. Miami-Dade County has a long history of established policies and programs that directly relate to the protection of the bay and its resources through the use of knowledge, action, regulation, and advocacy. The County's efforts include ongoing water quality and habitat monitoring programs, bay shoreline and bay habitat restoration programs, regulatory programs that govern coastal construction in tidal waters throughout the county including all of Biscayne Bay, participation in state and federal regional restoration interagency technical teams, as well as using education and outreach to emphasize the importance of protecting the bay through an annual Baynanza Shoreline Clean-up Day event held each year.

Seagrass communities play an important role in regulating water quality by stabilizing bay sediments and cycling nutrients. Therefore, full recovery of seagrass communities to prior levels and species composition following a significant loss can be a complicated ecological process that may take several years to achieve if recovery does occur. Regardless, working to reduce anthropogenic impacts to water quality and seagrass habitat provides the best opportunity for promoting seagrass recovery. The following recommendations are provided to help direct the County's approach to protecting these important bay resources.

A. Continue and update the County's established Surface Water Quality Monitoring Program as necessary (Long Term)
    a. Review and revise WQ program as necessary to better identify and evaluate existing as well as evolving threats to bay water quality. This may include adding stations to better capture evolving impacts from sea level rise. (short term)
    b. Develop and conduct special studies as needed to better identify any specific sources or pathways for water quality impacts to the bay (short term)
        i. This includes further evaluation of both nutrient and bacterial sources.
        ii. Evaluate and implement the use of evolving technology to better identify and distinguish human related sources. (i.e. N15, Sucralose, Microbial DNA fingerprinting).
        iii. Review relationship between canal surface water quality and associated groundwater quality to help identify sources or land use activities that impact water quality.
        iv. Identify stormwater drainage basins that exhibit poor water quality characteristics that may be impacting Bay water quality contributing to observed algal blooms and seagrass die-offs.
    c. Use the results of ongoing monitoring data as well as special studies to identify any needed infrastructure improvements, or to help guide policy decisions in the regulatory approval process. (short term)
    d. Work with responsible utilities/entities/municipalities to facilitate planning, funding and construction of any infrastructure improvements needed to address identified sources of water quality impacts. (short and long term)

B. Continue and update the County's Biscayne Bay Benthic Habitat Monitoring Program as necessary (Long Term)
    a. Review and revise the bay habitat monitoring program to expand data gathering detail and spatial coverage in the northern bay basins. (Short Term)

C. Continue the County's bay habitat restoration programs (Long-Term)
    a. Continue and expand efforts under the Biscayne Bay Restoration and Enhancement Program

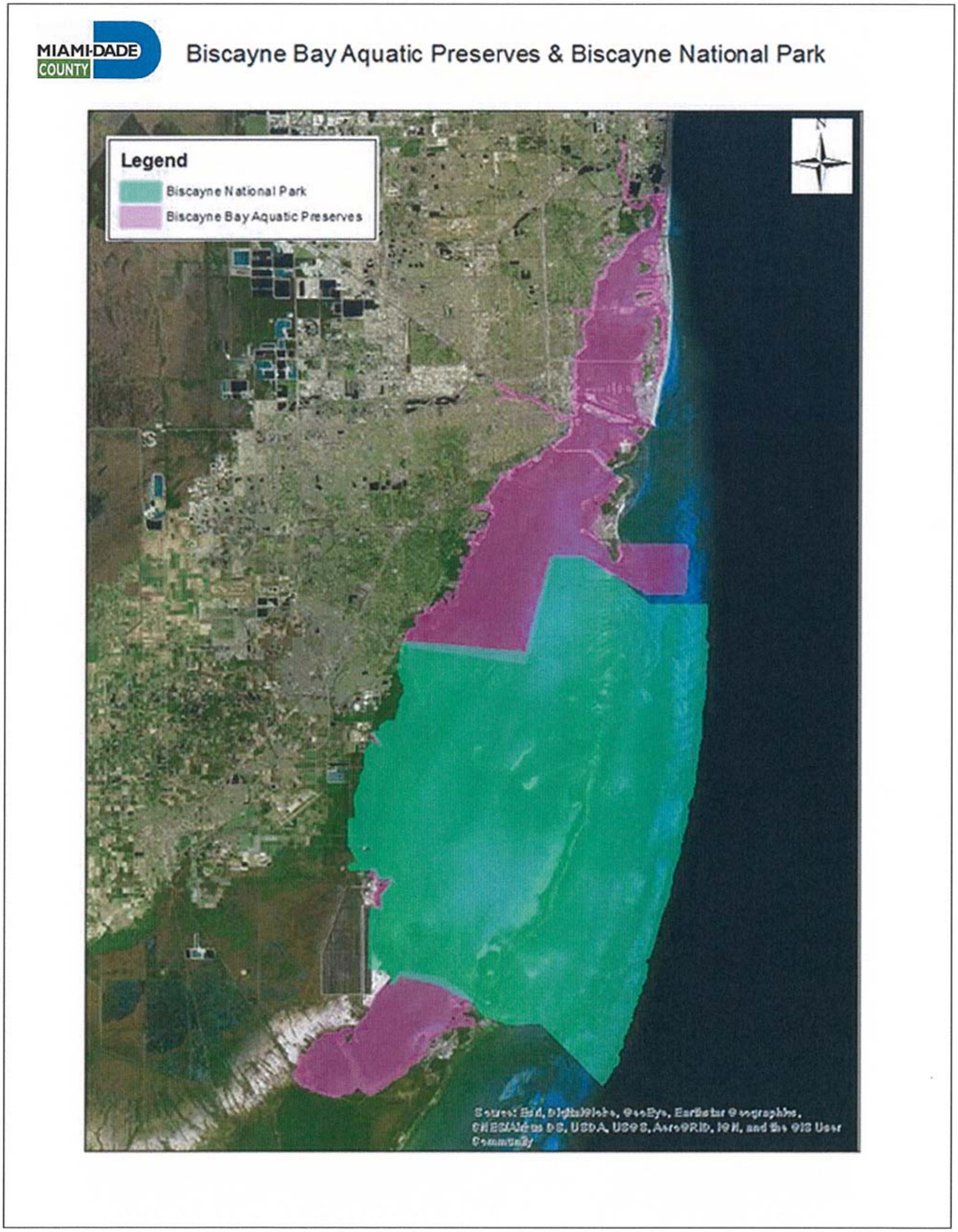
    i. Review and identify opportunities for habitat restoration projects involving creation or restoration of seagrass and hard bottom community habitat.
  b. Continue and expand efforts under the Biscayne Bay Inshore Artificial Reef Program.
  c. Continue and expand County efforts to remove and properly dispose of derelict vessels from Biscayne Bay.

D. Continue County support for state and federal regional restoration programs
  a. Continue to provide county technical staff participation in planning and project development teams.
  b. Support the Comprehensive Everglades Restoration Program and the Biscayne Bay Coastal Wetlands project.

E. Continue County regulation of coastal construction activities through effective permitting. (Long Term)
  a. Review existing regulatory process and approach with an emphasis on managing for effective natural resource protection. (short term)
  b. Identify and implement any regulatory changes needed to simplify the review and approval processes while maintaining and improving resource protection outcomes.
  c. Discourage avoidable impacts to existing bay resources (seagrass and mangrove habitat) by requiring reasonable project alternatives or project layout alternatives during permitting. (short term)

F. Promote greater collaboration between County, state and municipal agencies, as well as the academic community, and local interest groups, on identifying additional strategies for protecting Biscayne Bay.
  a. Develop outreach and raise awareness regarding the health and importance of protecting Biscayne Bay.
  b. Develop and implement management strategies that focus on reducing nutrient loading to support restoration and resilience of Biscayne Bay.
  c. Better inform residents on how their activities can have negative impacts on the bay and its resources (i.e. litter, fertilizers, faulty septic systems, lawn clippings).

Figure 1. Boundaries of the Biscayne Bay Aquatic Preserves and Biscayne National Park



Miami-Dade County
Biscayne Bay Water Quality Monitoring Plan

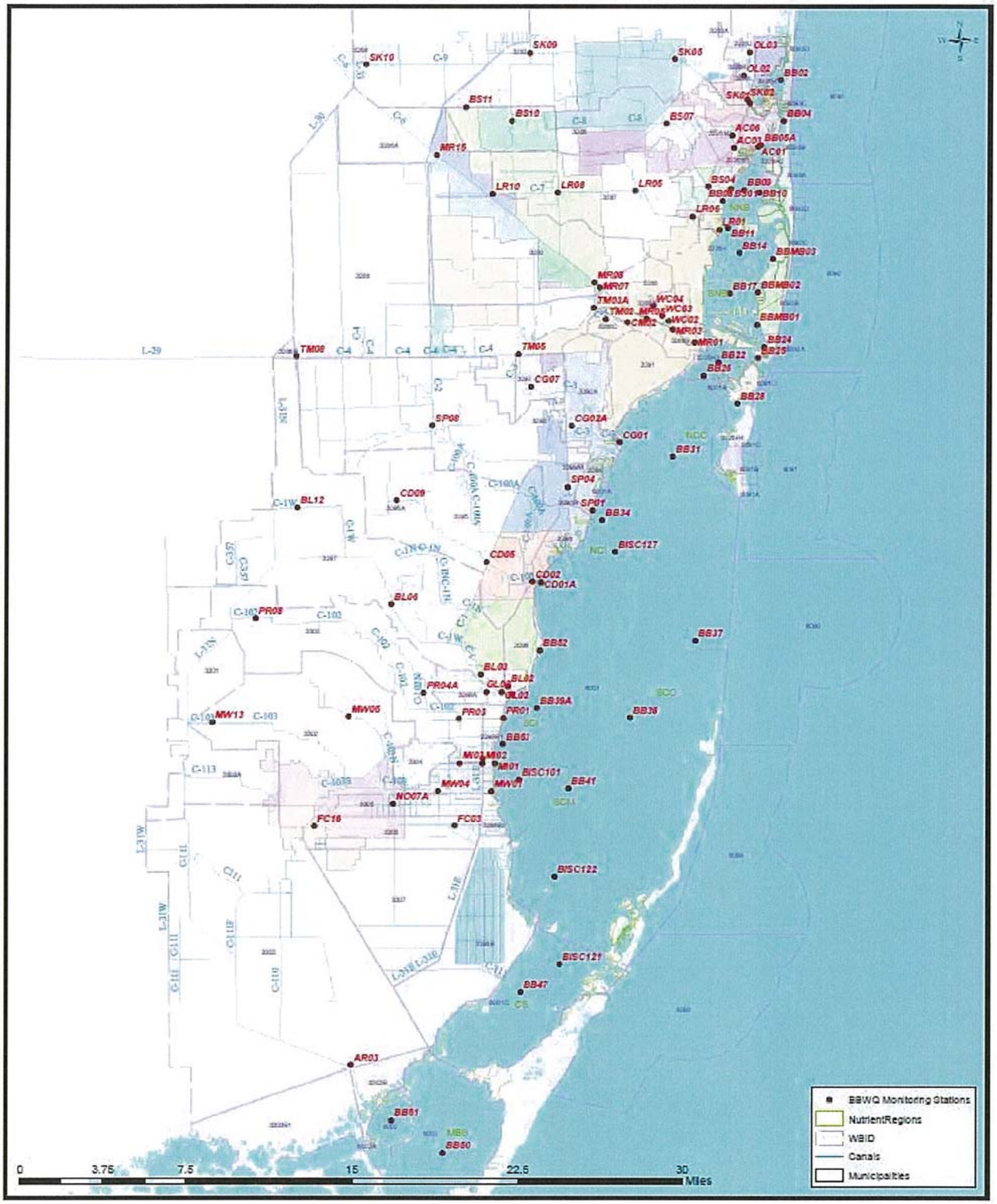


Figure 2. – Study period 2005 - 2018.

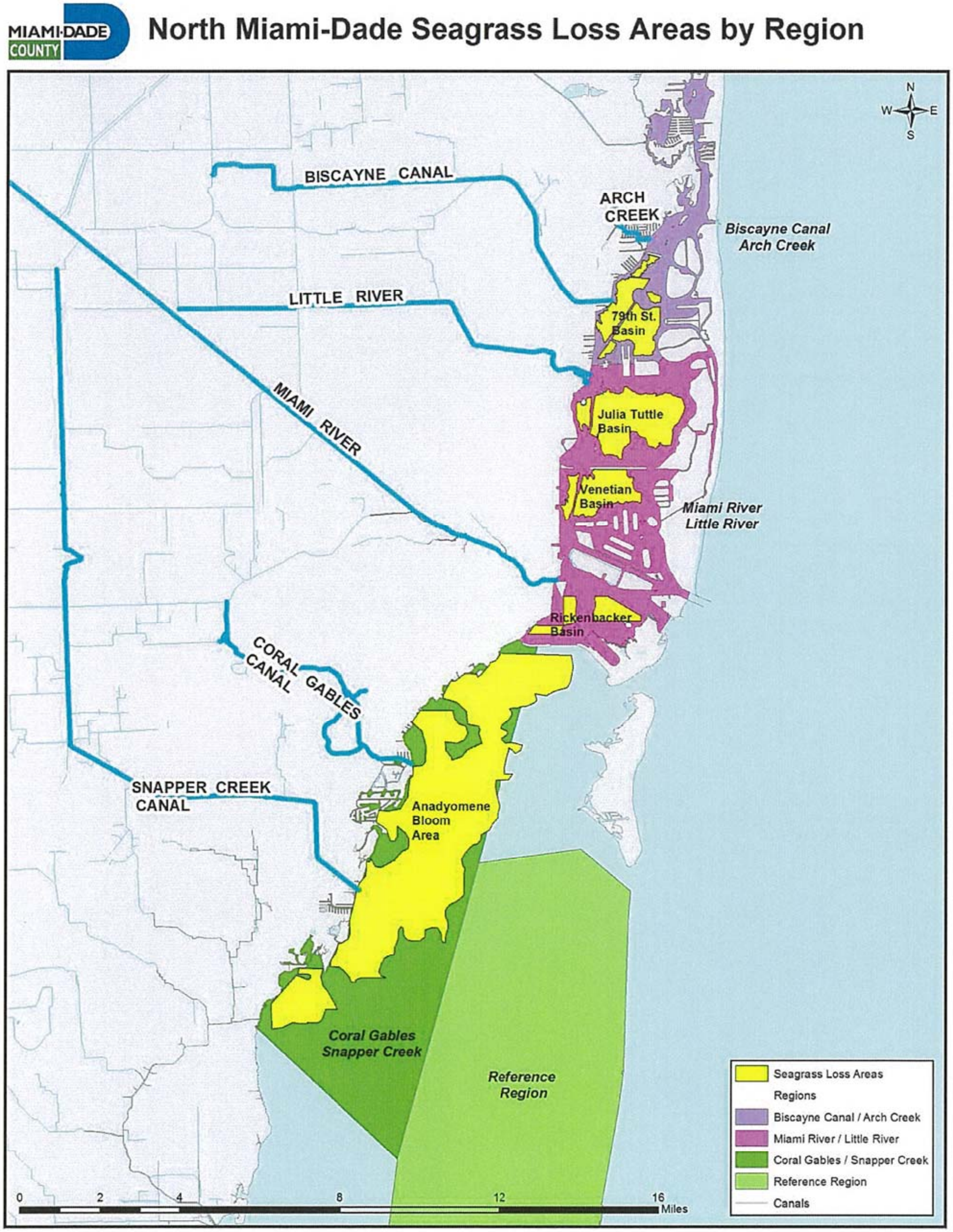


Figure 3. Study period 2005 - 2018.

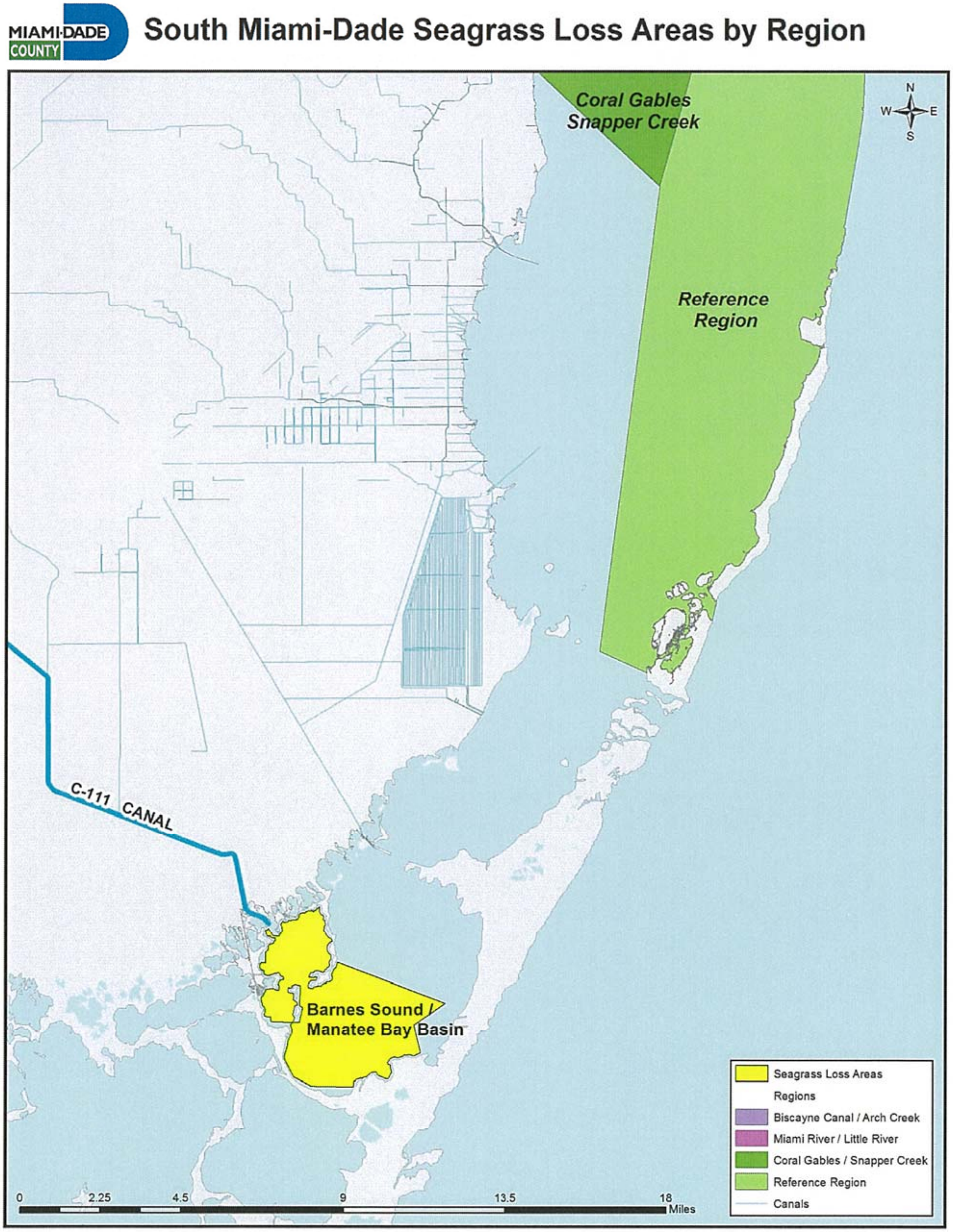


Figure 4. Percentage of time bacteria values (including *E.coli* and *Enterococcus*) exceeded the state standard for human health (from June 2017 – June 2018).

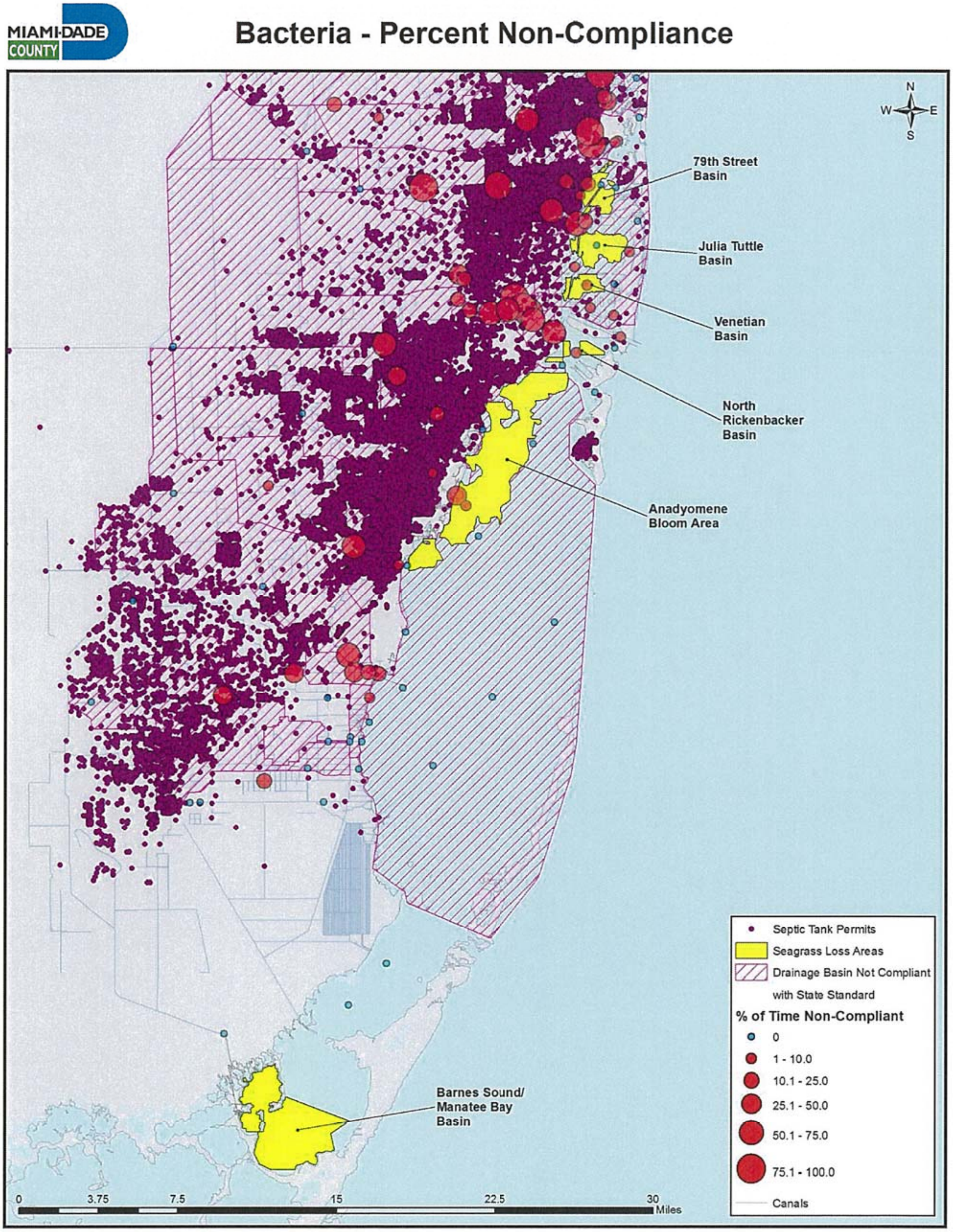
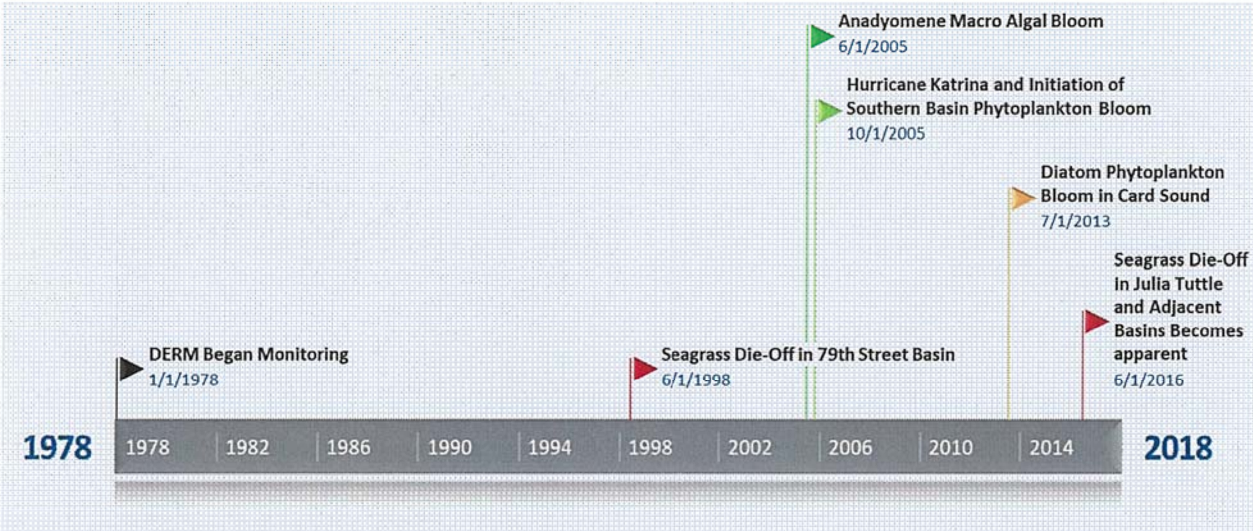
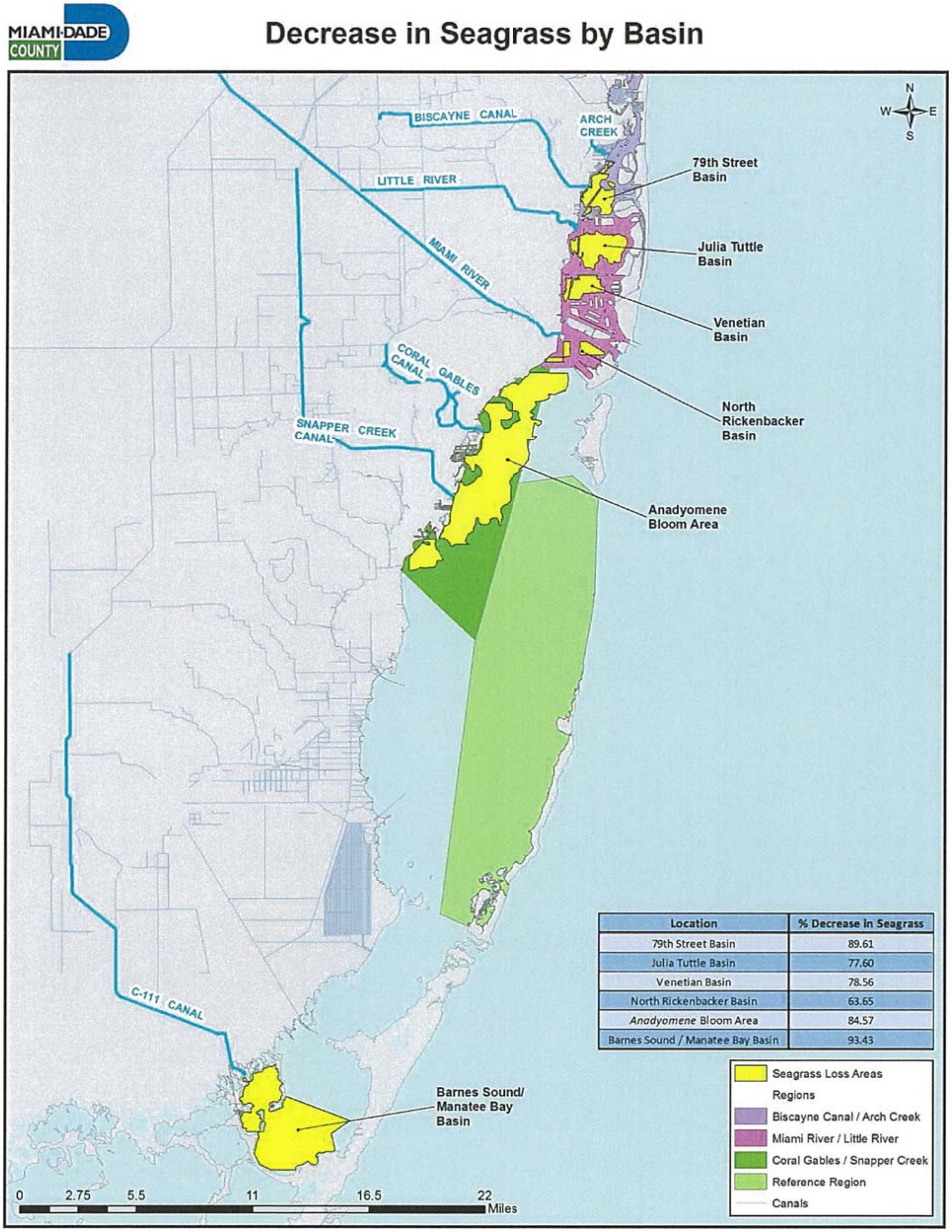


Figure 5. Timeline of Seagrass Loss Events and Total Reduction in Seagrass by Basin.



Location	Total Area (Acres)	Area of Seagrass Reduction (Acres)	% Decrease in Seagrass
79th Street Basin	1,441	1,291	89.61%
Julia Tuttle Basin	2,503	1,942	77.60%
Venetian Basin	1,232	968	78.56%
North Rickenbacker Basin	931	592	63.65%
Anadyomene Bloom Area	14,113	11,936	84.57%
Barnes Sound Basin - Manatee Bay	9,041	8,447	93.43%

Figure 6. Study period 2005 - 2018.



Location	% Decrease in Seagrass
79th Street Basin	89.61
Julia Tuttle Basin	77.60
Venetian Basin	78.56
North Rickenbacker Basin	63.65
Anadyomene Bloom Area	84.57
Barnes Sound / Manatee Bay Basin	93.43

Figure 7. A time series of aerial images of the Julia Tuttle Basin Seagrass die-off.

Figure 8. In-situ photographs of seagrass die-off at fixed sampling location BH 14 from June 2016, September 2016, and June 2017, respectively.

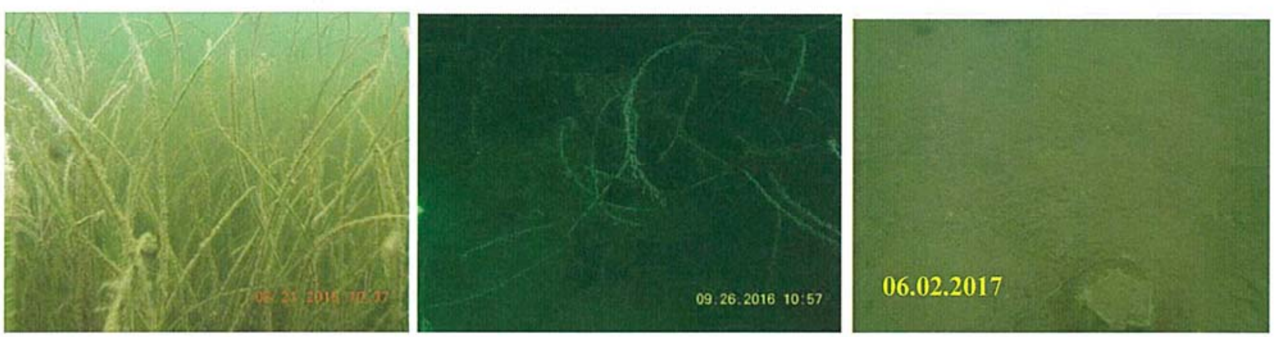
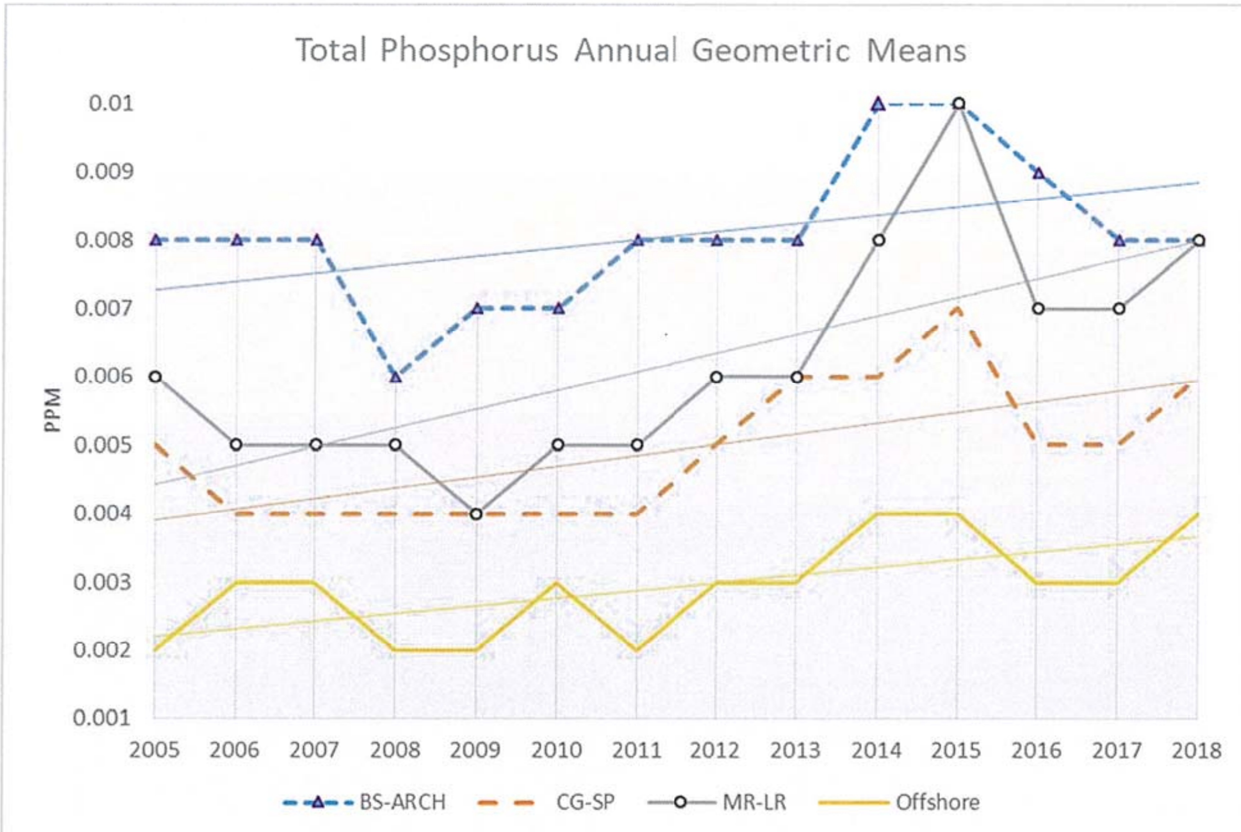


Figure 9. Total Phosphorus trending upward in key basins experiencing algal blooms and/or seagrass die-off.



BS/ARCH = Biscayne Canal / Arch Creek
CG/SP = Coral Gables / Snapper Creek
MR/LR = Miami River / Little River
Offshore = Reference Region

Figure 10. Total Phosphorus Annual Mean per basin, showing an increase over time.

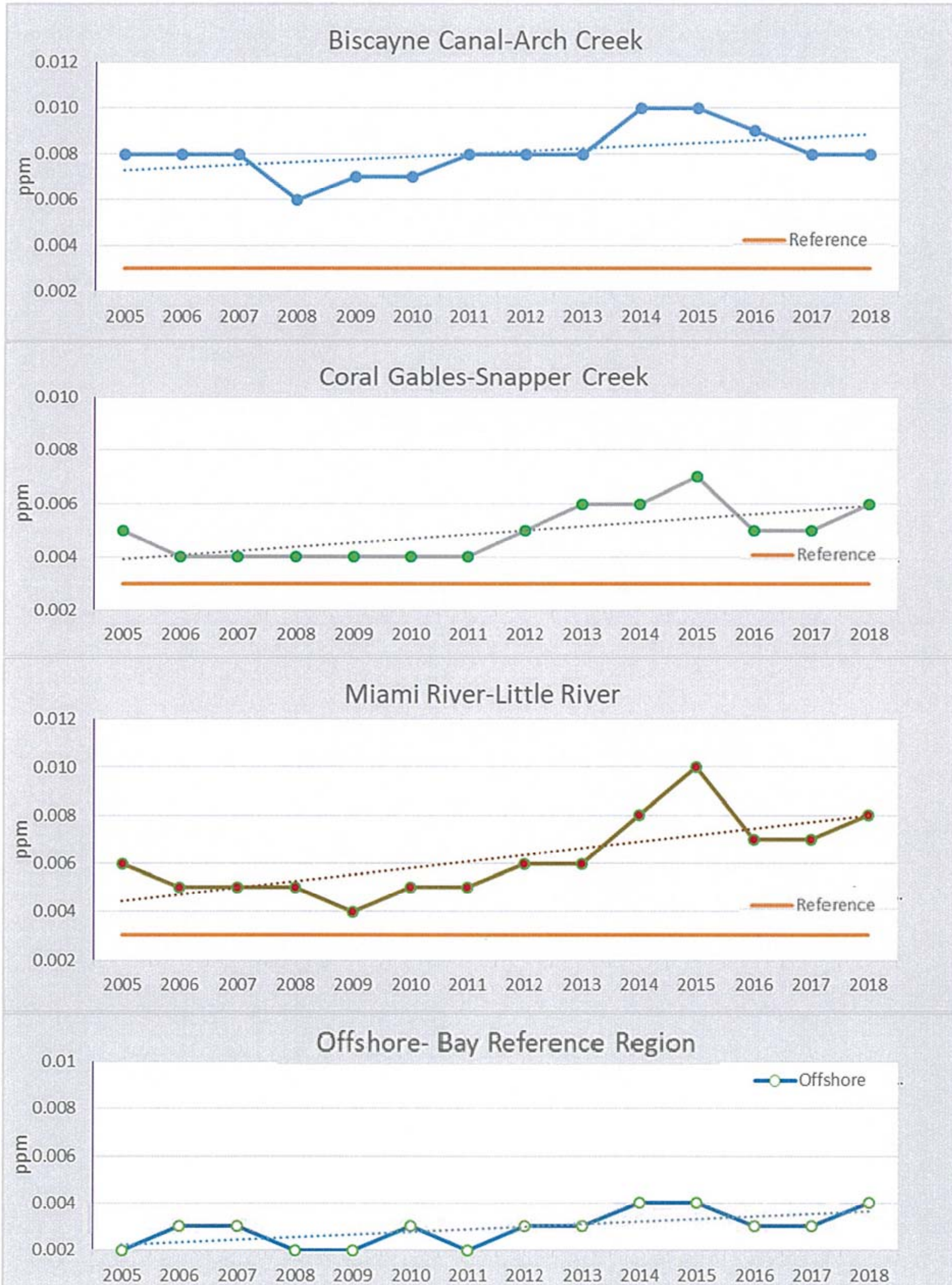


Figure 11. Total Ammonia Annual Mean per basin, decreasing in Biscayne Canal – Arch Creek and Miami River – Little River basins, increasing in Coral Gables – Snapper Creek basin.

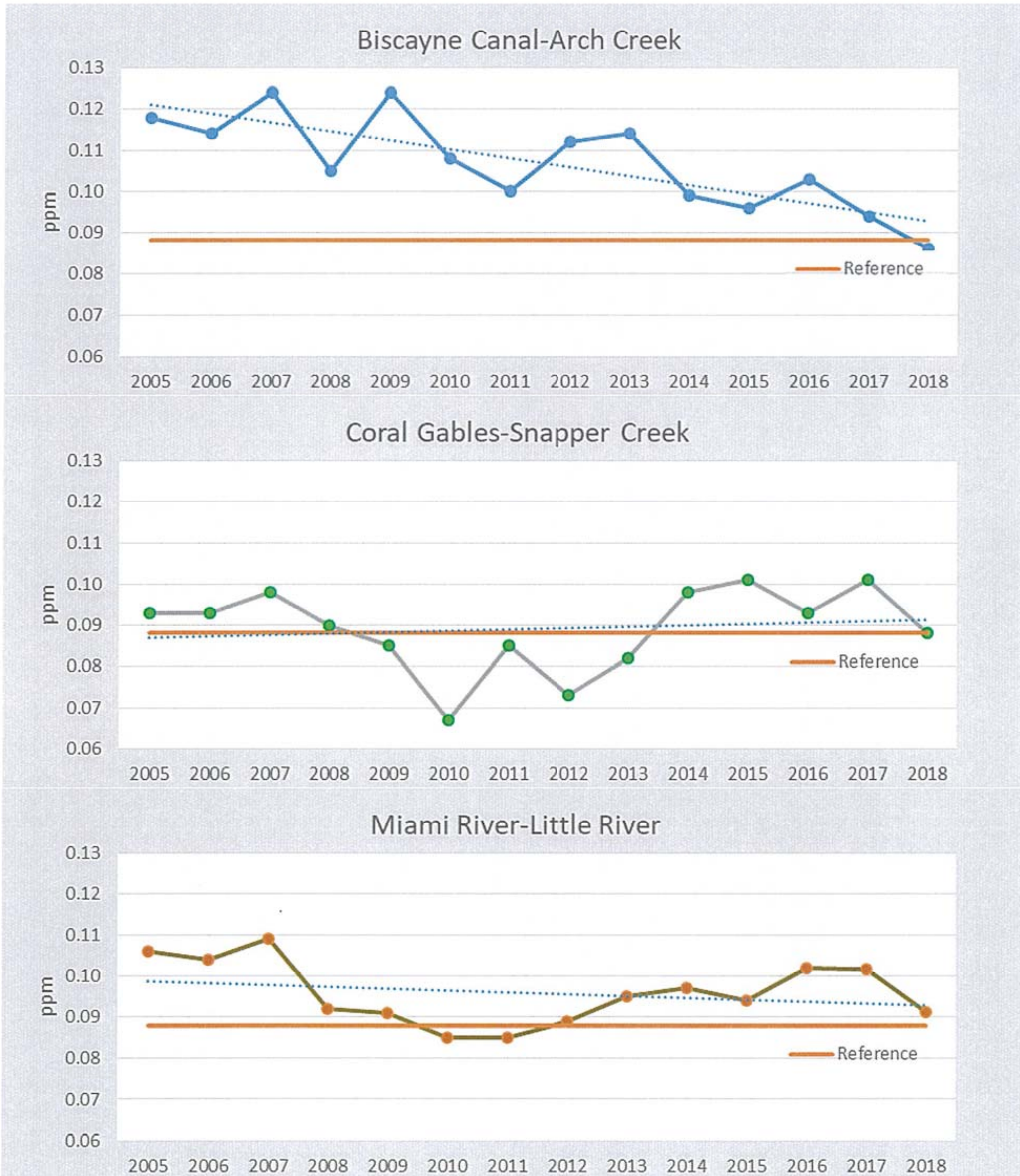


Figure 12. Nitrate Annual Mean per basin, increasing over time in Coral Gables-Snapper Creek and Miami River-Little River basins.

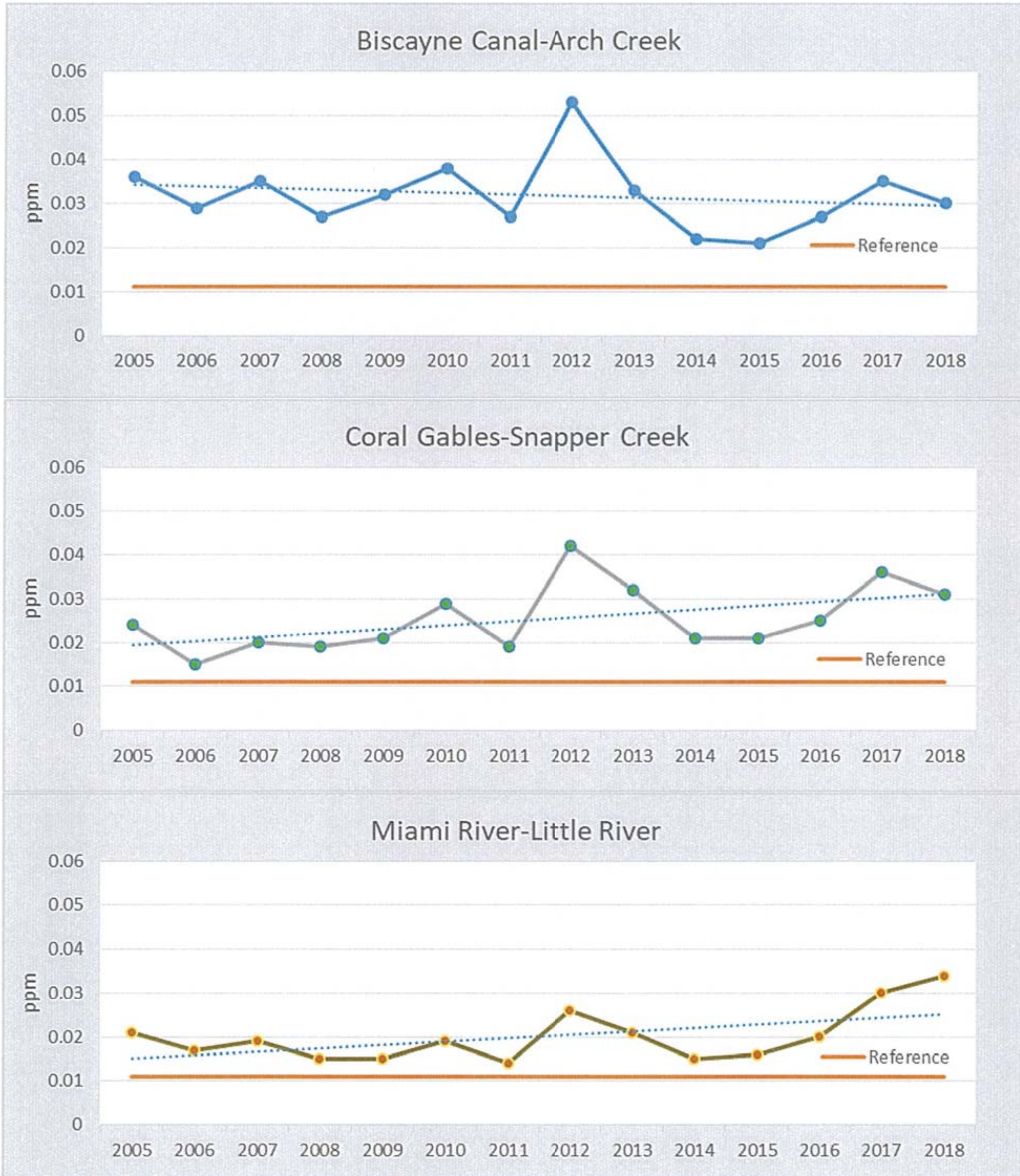


Figure 13. Chlorophyll-a Annual Mean per basin, increasing over time.

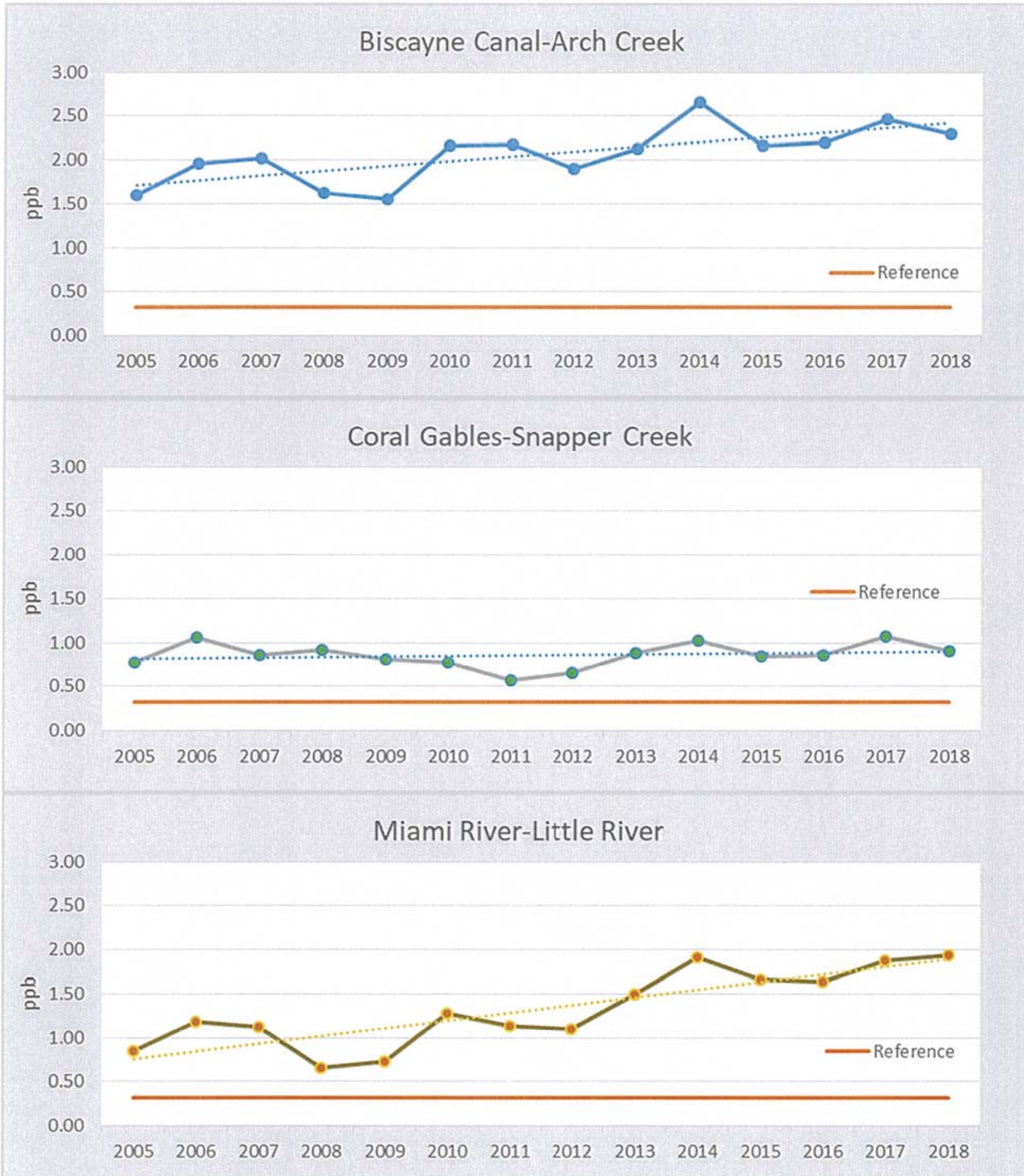
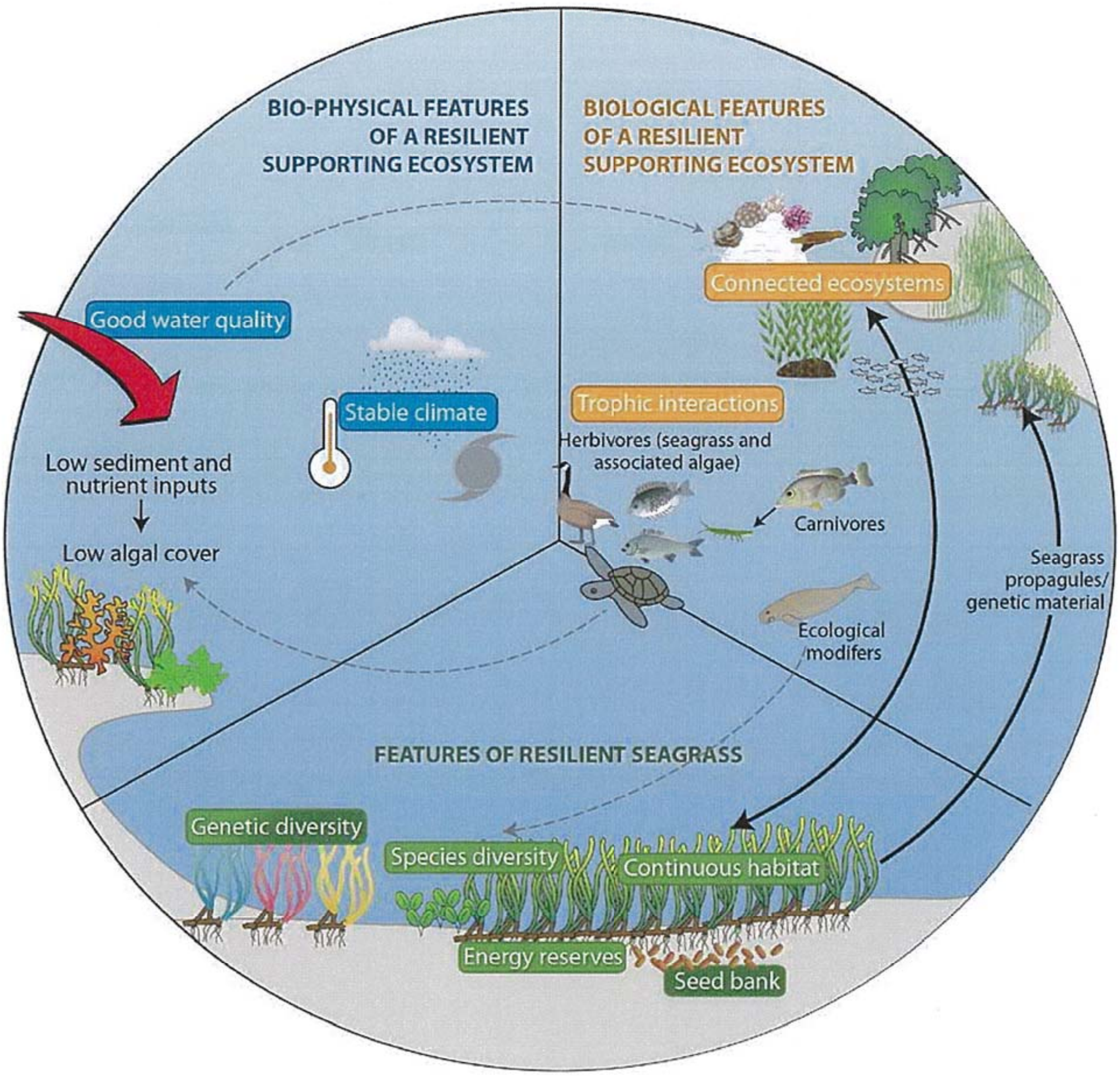


Figure 14. Unsworth et al. Framework for Resilience Seagrass Ecosystems.
In this illustration, building resilience begins with good water quality, including low nutrient inputs.



References

[1] Langevin, C.D. 2003. Simulation of submarine ground water discharge to a marine estuary: Biscayne Bay, Florida. Ground Water 41, no. 6: 758–771

[2] Cantillo, A.Y., Hale, K., Collins, E., Pikula, L., Caballero, R., 2000. Biscayne Bay: environmental history and annotated bibliography. NOAA Technical Memorandum NOS NCCOS CCMA 145

[3] Caccia, V.G., Boyer, J.N., 2007. A nutrient loading budget for Biscayne Bay, Florida. Marine Pollution Bulletin 54, 994-1008

[4] Stalker, J.C., Price, R.M., Swart, P.K., 2009. Determining spatial and temporal inputs of freshwater, including submarine groundwater discharge, to a subtropical estuary using geochemical tracers, Biscayne Bay, South Florida. Estuaries and Coasts. 32, 694–708

[5] Nordlund L.M., Koch E.W., Barbier E.B., Creed J.C., 2017. Correction: Seagrass Ecosystem Services and Their Variability across Genera and Geographical Regions. PLOS ONE 12(1): e0169942

[6] Greening H.S., Janicki A., 2006. Toward reversal of eutrophic conditions in a subtropical estuary: Water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida, USA. Environmental Management 38:163–178

[7] Fourqurean J.W., Duarte C.M., Kennedy H., Marba N., Holmer M., et al. 2012. Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience. 5:505–9

[8] Florida Department of Environmental Protection. 2011, in draft. Management Plan for Biscayne Bay Aquatic Preserves, Florida Coastal Office, 154 pp

[9] Unsworth, R.K.F., Collier, C.J., Waycott, M., McKenzie, L.J. & CullenUnsworth, L.C., 2015. A framework for the resilience of seagrass ecosystems. Marine Pollution Bulletin, 100, 34–46

[10] Burkholder, J.M., Tomasko, D.A., Touchette, B.W., 2007. Seagrasses and eutrophication. Journal of Experimental Marine Biology and Ecology 350, 46-72

[11] McGlathery, KJ, Berg P, Marino R (2001b) Using porewater profiles to assess nutrient availability in seagrass-vegetated carbonate sediments. Biogeochemistry 56:239–263

[12] Millette, N.C., Kelble, C., Linhoss, A., Ashby, S., Visser, L., 2018. Shift in baseline chlorophyll a concentration following a three-year *Synechococcus* bloom in southeastern Florida. Bulletin of Marine Science 94, No. 1: 3-19

[13] Briceño, H., Serna, A., Huba, A., Gardinali, P., 2016. Sucralose: A wastewater tracer or a water quality indicator? Poster session presented at SETAC North America 37th Annual Meeting, Orlando, 6 – 10, November 2016

[14] Collado-Vides, L., Avila, C., Blair, S., Leliaert, F., Rodriguez, D., Thyberg, T., Schneider, S., Rojas, J., Sweeney, P., Drury, C. & Lirman, D. 2013. A persistent bloom of *Anadyomene J.V. Lamouroux* (Anadyomenaceae, Chlorophyta) in Biscayne Bay, Florida. Aquatic Botany 111:95–103

[15] Borum, J., Pedersen, O., Greve, T.M., Frankovich, T.A., Zieman, J.C., Fourqurean, J.W., Madden, C.J., 2005. The potential role of plant oxygen and sulphide dynamics in die-off events of the tropical seagrass, *Thalassia testudinum*. Journal of Ecology 93, 148–158

[16] Boyer, J.N., Kelble, C.R., Ortner, P.B., Rudnick, D.T., 2009. Phytoplankton bloom status: chlorophyll a biomass as an indicator of water quality condition in the southern estuaries of Florida, USA. Ecological Indicators 9S, S56–S67

[17] Jarossy, S.M., 2016. An Evaluation of the Seagrass Habitat in North Biscayne Bay, Florida, in Relation to a Changing Environment and Urbanization in the Port of Miami Harbor Basin 2005-2011 (Dissertation)

[18] Valentine, J.F., Duffy, J.E., 2006. The central role of grazing in seagrass ecology. In: Larkum, A.W.D., Orth, R.J., Duarte, C.M., Seagrasses: Biology, Ecology and Conservation, pp. 463–501

[19] Asmus, H., Asmus, R., 2000. Material exchange and food web of seagrass beds in the Sylt-Rømø bight: how significant are community changes at the ecosystem level? Helgoland Marine Research 54, 137–150

[20] National Oceanic and Atmospheric Administration. 2018. Biscayne Bay Habitat Focus Area. Retrieved from https://www.habitatblueprint.noaa.gov/habitat-focus-areas/biscayne-bay-florida/