2019 EVERGLADES SYSTEM STATUS REPORT

Assessment period of 2012–2017

A product of the Comprehensive Everglades Restoration Plan (CERP) REstoration COordination and VERification (RECOVER) program

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ACKNOWLEDGMENTS

As a product of the REstoration COordination and VERification (RECOVER) Monitoring and Assessment Plan (MAP), this report details the evaluation of systemwide performance measures and their targets (or goals) using the ecological tools developed over the past several years under the RECOVER's MAP program to measure restoration progress. The key findings detailed in the System Status Report can assist decision-makers with the timing of planning and implementation of Comprehensive Everglades Restoration Plan (CERP) features, such as those in the Central Everglades Planning Project (CEPP). This report also serves as a mechanism to inform the scientific community in south Florida.

The 2019 System Status Report will also provide input into the 2020 Report to Congress, required by the Water Resources Development Act of 2000. Produced every five years, the intent of the Report to Congress is to inform the highest levels of the U.S. government on the progress made toward the goals and objectives of CERP.

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ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASUREMENT

°C	degrees Celsius
µg/L	microgram per liter
µm	micrometer
ac-ft	acre-feet
ANOVA	analysis of variance
BBCA scale	Braun-blanquet cover/abundance scale
BBCW Project	Biscayne Bay Coastal Wetlands Project
BCWPA	Broward County Water Preserve Areas
C&SF	Central and Southern Florida Project
C-111 SCWP	C-111 Spreader Canal Western Project
CEM	conceptual ecological model
CEPP	Central Everglades Planning Project
CERP	Comprehensive Everglades Restoration Plan
cfs	cubic feet per second
CGM	CERP Guidance Memorandum
chla	chlorophyll a
cm	centimeter
c/n	chicks per nest
CRE	Caloosahatchee River Estuary
CY	Calendar Year
DBHYDRO	SFWMD's hydrometerologic, water quality and hydrogeologic data retrieval system
DIN	dissolved inorganic nitrogen
DPM	Decomp Physical Model
EAA	Everglades Agricultural Area
EDEN	Everglades Depth Estimation Network
EDD	MAPS Early Detection and Distribution Mapping System
EDRR	early detection rapid response
EIS	environmental impact statement
ENP	Everglades National Park
ERTP	Everglades Restoration Transition Plan

ET	evapotranspiration
FDEP	Florida Department of Environmental Protection
FWC	Florida Fish and Wildlife Conservation Commission
FY	Fiscal Year (begins October 1 and ends September 30 of the following year)
g/m^2	grams per square meter
GE	Greater Everglades (region)
GIS	geographic information system
GPS	global positioning system
ha	hectare
HHD	Herbert Hoover Dike
IBBEAM	Integrated Biscayne Bay Ecological Assessment and Monitoring Project
IOP	Interim Operational Plan
kg	kilogram
km	kilometer
km^2	square kilometer
LO	Lake Okeechobee (region)
LOSOM08	2008 Lake Okeechobee System Operations Manual
LRD	Loxahatchee River District
LRE	Loxahatchee River Estuary
LSU	landscape sampling units
LWL	Lake Worth Lagoon
m	meter
m^2	square meter
MAP	Monitoring and Assessment Plan
MFL	minimum flows and levels
mg/L	milligram per liter
Miami-Dade DERM	Miami-Dade County Department of Environmental Resources Management
mm	millimeters
N	nitrogen
NAVD 88	North American Vertical Datum of 1988
NE	Northern Estuaries (region)
NGVD	National Geodetic Vertical Datum

NGVD 29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NTU	Nephelometric Turbidity Unit
P	phosphorus
PIR	project implementation report
POR	period of record
ppb	parts per billion
ppt	parts per thousand
PSRP	Picayune Strand Restoration Project
PSU	Primary Sampling Unit
RECOVER	Restoration Coordination and Verification
Sy	specific yield difference
SAV	submerged aquatic vegetation
SCS	Southern Coastal Systems (region)
SD	standard deviation
SE	standard error
SFWMD	South Florida Water Management District
SGGE	Southern Golden Gate Estates
SIRL	Southern Indian River Lagoon
SLE	St. Lucie Estuary
SRP	soluble reactive phosphorus
SRS	Shark River Slough
SSR	System Status Report
TTI	Ten Thousand Islands
TN	total nitrogen
TP	total phosphorus
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

VEC	Valued ecosystem components
WCA	Water Conservation Area
WY	Water Year (Begins May 1 and ends April 30 of the following year)

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Aerial view of Rookery Bay. Photo by Franco Tobias.

INTRODUCTION

1.1 EVERGLADES RESTORATION

Restoring the Everglades is important for south Florida and beyond

The Florida Everglades encompasses a network of sub-tropical freshwater wetland and estuarine ecosystems across south Florida. Although it suffered the impact of development during the 20th century, the Everglades remains an invaluable ecological resource. People from around the world visit south Florida because of the unique environment and ecological attributes of the Everglades region. South Florida is home to five national parks, dozens of state parks, refuges and preserves, and numerous rare and endangered species. Tourism and outdoor recreation make a significant contribution to the regional economy. The nearly eight million residents of south Florida depend on the Everglades for their water supply and flood protection. The condition of the Everglades' ecosystem is critical to many people who live in south Florida, the US, and around the world.

Rapid growth and development in south Florida comes at a cost to the Everglades, and threatens the essential natural services that it provides. At the beginning of the past century most of south Florida was a wilderness area. Fewer than 50,000 people lived there in 1900. Today, about 8 million people live there, 41% of Florida's total population. About half of the original Everglades has been converted for farming and urban land use. The Miami/Fort Lauderdale region is now one of the most densely populated areas in the United States. Beginning in 1948, construction of the Central and Southern Florida Project (now operated by the South Florida Water Management District) for drainage, water supply, and flood protection has permanently altered the region's hydrology (Figure 1.1). By 2018, over 2,100 miles of canals, 2,000 miles of levees, 657 water control structures, and 77 major pump stations have been constructed to control water levels and flow over an area of 18,000 square miles from Orlando to the Florida Reef Tract. The impacts of changes in regional hydrology on the ecological health of the remaining natural areas of the Everglades were immediate and alarming.

In response to this crisis, the State of Florida and US Federal Government have embarked on a joint effort to restore the Everglades, the largest ecosystem restoration ever attempted. The Comprehensive Everglades

Restoration Plan (CERP) is one of the main components of this work. When launched in 2000, the CERP included 68 projects designed to reverse the unintended consequences on Everglades' ecosystems of the Central and Southern Florida Project. Although it is proceeding more slowly than anticipated, the implementation of some initial key projects and changes to the operation of the regional water management system have begun to show results in some areas, especially the coastal wetlands and estuarine areas in the southern part of the Everglades region.

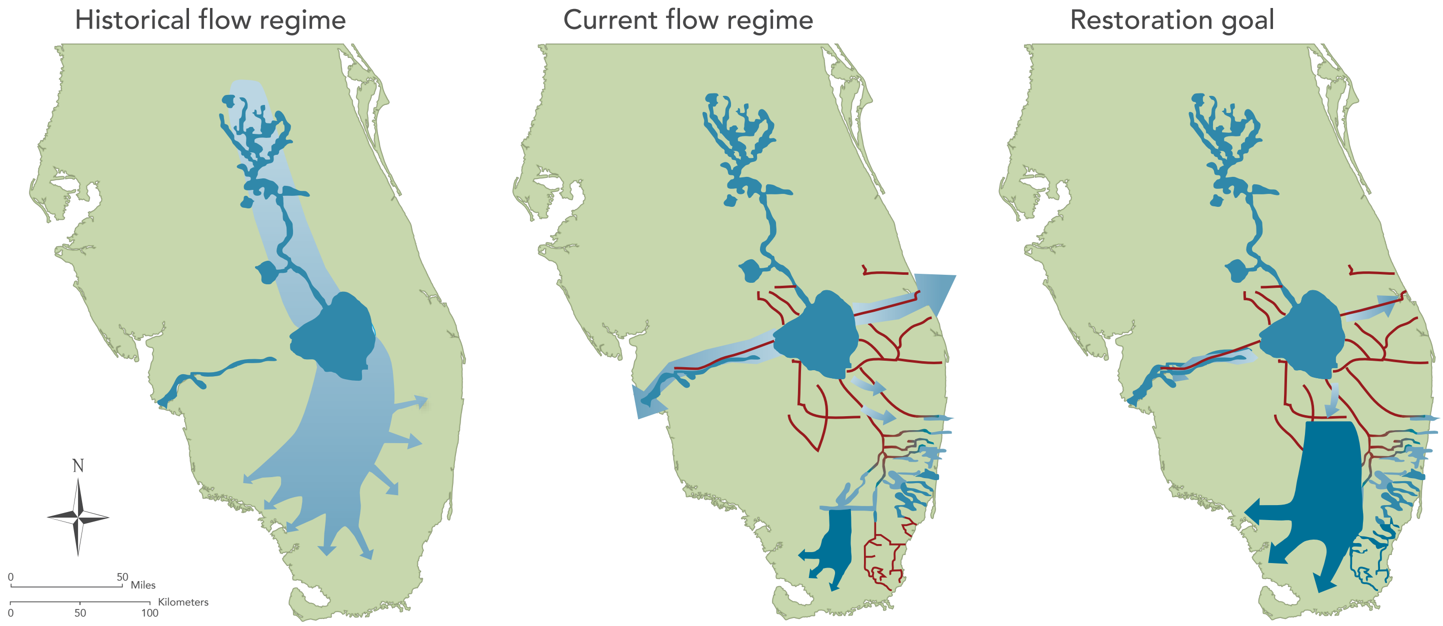


Figure 1.1. The removal of water in the Everglades through a system of drainage canals (red lines) converted wetlands into areas suitable for farming and land development. Reestablished freshwater flows in the future will improve hydrologic conditions throughout south Florida and decrease salinity levels in Florida Bay and Biscayne Bay.

Restoration progress is tracked through evaluating Everglades condition

The greatest challenge of restoration is how to balance what needs to be done to restore the Everglades' ecosystems against the needs of a rapidly growing human population. CERP combines these objectives. The overall goal of CERP is "restoration, preservation, and protection of the south Florida ecosystem while providing for other water-related needs of the region, including water supply and flood protection." Uncertainties introduced by climate change and rising sea level add to this challenge.

Because of its size and complexity, Everglades restoration must take an adaptive approach to implementation and management. Adaptive management relies on data of current conditions to guide the planning and implementation of restoration projects and operation of water management facilities. System-wide monitoring and assessment collects and interprets data on how the Everglades' ecosystems function to help guide restoration activities. This helps managers address the challenge of balancing ecosystem restoration against other water-related needs of south Florida residents.

CERP's greatest strength is that it integrates natural and human objectives into a single design, and thereby re-couples an array of public interests into a common strategy for the future of south Florida. Success is defined in terms of restoring and preserving ecosystem function. The restored Everglades will have a smaller footprint than it had in its pre-drainage condition at the beginning of the 20th century. Everglades restoration will be successful if the restored ecosystems function as a hydrologically integrated whole, as in the past, rather than currently as a disconnected set of managed wetlands.

1.2 THE RECOVER TEAM REPORTS PROGRESS

About RECOVER

The REstoration COordination and VERification program (RECOVER) works with scientists, planners, engineers, hydrologists, water managers, project managers, and program managers to identify and implement priority adaptive management strategies to inform CERP projects. The Monitoring and Assessment Plan (MAP) gathers data on hydrology, water quality, and key ecological components, such as vegetation, wading birds, alligators, and oysters, and helps evaluate their responses to changes in regional hydrology as CERP projects are completed. Every five years, scientists and engineers gather all these data together in this System Status Report, to answer the question, "How is the Everglades doing?"

RECOVER is a multi-agency team of scientists, modelers, planners, and resource specialists who provide essential support to the CERP effort. They do this by applying a system-wide and integrative perspective to the formulation and implementation of the plan. RECOVER conducts scientific and technical evaluations and assessments, and communicates the results with managers, decision makers, and the public. The primary components of RECOVER are monitoring, assessment, adaptive management, and evaluation, which includes the development and application of performance measures to simulated ecosystem conditions.

RECOVER has had many accomplishments since its inception in 2000. It has provided support to CERP projects; assisting them with adaptive management plans, performance measures, and evaluation of system-wide impacts of alternative project designs. RECOVER analyzed the data collected across the greater Everglades ecosystem and has published the results in six System Status Reports (SSRs): 2006 (pilot report), 2007, 2009, 2012 (interim update), 2014, and now this 2019 report (RECOVER 2007a, 2007b, 2010, 2012, 2014a).

Monitoring encompasses many aspects of the Everglades system

The Monitoring and Assessment Plan (MAP) is designed to test ideas about what can be done to restore the ecosystem and to determine whether changes seen in the ecosystem are the result of restoration activities or other factors, such as climate and rising sea level.

- **System-wide hydrology:** The characteristics of water (amount, quality, depth, volume, flow rate) that cause change throughout the entire ecosystem.
- **Integrated regions:** Data is assessed in each geographic region through a regional storyline of the conditions that drive changes in the responses of multiple ecological attributes in each region.
- **Indicators/performance measures/targets:** Tools based on a set of ecosystem restoration indicators (stressors, ecosystem responses, and ecological attributes) used to predict the degree to which proposed plans are likely to meet restoration objectives.
- **Targets:** Goals are set for each performance measure, and achievement of these targets is used to evaluate CERP projects, assess restoration success, and/or to determine if adaptive strategies are necessary.
- **Scales:** Ecosystem restoration indicators reflect ecosystem responses over different spatial and temporal scales.
- **Scientific hypothesis:** Testing specific hypotheses to determine whether changes to the system and its indicators are due to restoration projects or climate and other issues.

RECOVER's five-year plan

RECOVER has determined the most crucial tasks that must be accomplished to assist CERP implementation between Fiscal Years 2017 and 2021 by considering the pace of CERP implementation in recent years, new knowledge gained on drivers and stressors in the Everglades and estuaries, and the past ten or more years of monitoring and development of restoration planning tools. These tasks include (1) RECOVER involvement in project implementation during design, construction, and operation; (2) refinement and reporting CERP's progress in achieving Interim Goals and Interim Targets; (3) evaluation and integration of Everglades science through the update of Conceptual Ecological Models (CEMs), a vulnerability analysis and ultimately a revision of the MAP; (4) targeted adaptive management to inform CERP progress; and (5) communication of CERP science to maximize its usefulness to decision makers and CERP audiences.

In implementing this plan, RECOVER will consider findings from the 2014 and 2019 SSRs, the 2015, 2016, and 2017 RECOVER Science Meetings, input from the National Academies of Sciences Biennial Reviews, the CERP Program Level Adaptive Management Plan, the time horizons of MAP components, CERP and South Florida Ecosystem Restoration project construction contract schedules, and Interim Goals requirements. This effort will consider assessment of emerging models, sampling techniques, and equipment; new scientific findings; evaluations of hypothesis clusters; and resources needed for performance measure revisions. This work plan is based on a strategy for determining the CERP science needs. The ability of RECOVER to accomplish its mission relies heavily on open communication between RECOVER scientists and other groups including water managers and decision makers, restoration teams, networks of scientists, and diverse audiences and stakeholders of CERP.

Highlighted restoration projects

CERP and non-CERP projects that are examined in this report include:

- **Planning Phase**. Loxahatchee River Watershed Restoration Project (LRWRP), Big Cypress—L 28 Interceptor Modifications (referred to as Western Everglades Restoration Project) (WERP), Lake Okeechobee Watershed Restoration Project (LOWRP), Broward County Water Preserve Areas (WPA), and Central Everglades Planning Project (CEPP).
- **Implementation.** Biscayne Bay Coastal Wetlands (BBCW), Indian River Lagoon—South C-23, C-24 and C-25 Basins (IRL-S), Combined Operational Plan (COP) and C-111 Spreader Canal Western Project (C-111 SCWP), Caloosahatchee River (C-43) West Basin Storage Reservoir Project, C-44 Reservoir and Stormwater Treatment Area Project (IRL-S), and Picayune Strand Restoration Project (PSRP).

1.3 ABOUT THE SYSTEM STATUS REPORT

Background

This System Status Report documents the measurement of ecological indicators and performance measures and their application to assess conditions in the Everglades' ecosystems for the years 2012–2017. This information provides feedback to decision-makers on the ecological response to past restoration activities and informs the timing of planning for CERP projects yet to be implemented. This report also informs adaptive management actions, and identifies uncertainties that need further study to assure restoration success.

This 2019 System Status Report also provides the scientific basis/foundation for the 2020 Report to Congress, required by the Water Resources Development Act of 2000. Produced every five years, the intent of the Report to Congress is to inform the highest levels of the U.S. government on the progress made toward restoration.

How to use this document

The 2019 System Status Report is designed to be user-friendly and easy to update as new information becomes available. This is accomplished through an interactive web-based platform with easy navigation. The 2019 report also includes for the first time a Report Card on the current status of key indicators across the system (Section 1.4). This high-level communication tool is designed to convey the complex and detailed science in a succinct way for use by high level managers, congressional aids, and stakeholders. The report card and high-level summaries allow quick and easy reading and interpretation of indicator health for different regions and across the whole system, while the embedded web links are available to lead those readers who want it to more detailed information. The website allows the reader to navigate to areas of interest such as a specific region or indicator.

The System Status Report is divided into five geographic regions: the overall System, Northern Estuaries, Lake Okeechobee, Greater Everglades, and the Southern Coastal Systems. This organization helps facilitate the monitoring and analysis but is not meant to imply that the Everglades ecosystem is a series of discrete, unconnected habitats. On the contrary, it is a complex, vast, and inter-connected system of lakes, estuaries, freshwater marshes, and forests that needs to be considered as a whole. The final chapter in the System Status Report looks ahead to the future of restoration, with discussion on projects in the planning and implementation phases, and new science being developed over the next five years.

Hydrologic conditions (2012–2017)

Hydrologic conditions in the Everglades are characterized by an annual cycle of distinctly wet and dry seasons (Figure 1.2). Water managers and ecologists measure time using a "water year" synchronized with the annual hydrologic cycle instead of the calendar year. The water year (WY) begins on May 1 of the preceeding calendar year and ends on April 30. May 1 marks the beginning of the wet season, and November 1 marks the beginning of the dry season. For example, WY2013 began on May 1, 2012 and ended on April 30, 2013.

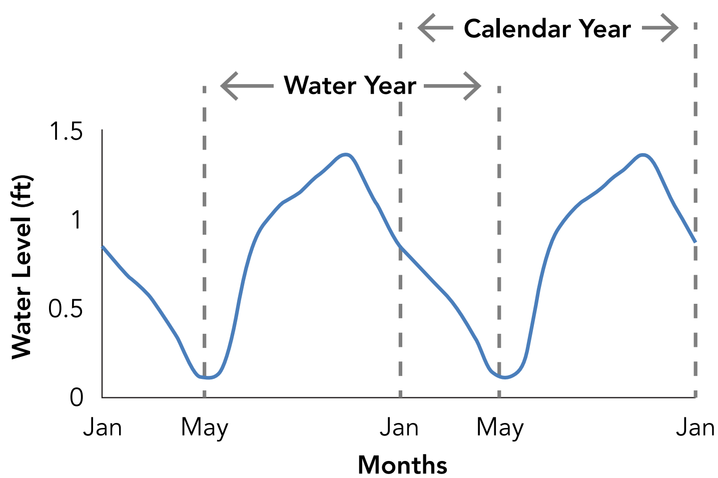


Figure 1.2. Difference between water year and calendar year in an annual cycle.

Rainfall
South Florida rainfall averaged over the entire period was close to the historic average rainfall. Rainfall from 2012 through 2017 was affected by an El Niño event that began in 2014 and strengthened in 2016. This resulted in a wetter-than-usual dry season from November 2015 through April 2016, helping to pull the Southern Coastal Systems out of drought conditions. Out of the five water years one was close to normal rainfall (WY2013), two years were above normal (WY2014, WY2016) and two years were below normal (WY2015, WY2017). Rainfall in the Greater Everglades region was slightly higher in the Water Conservation Areas and a little lower in Everglades National Park.

Surface flow

Surface flows between regions from 2012–2017 reflect the influence of heavy rainfall during WY2014 and WY2016 (Figure 1.3). Surface water flows reflect the water year rainfall conditions modified by water management decisions. Water held in storage at the end of the previous water year influences flow volumes for the following water year. Generally, the 5-year average flows were higher or about equal to historical averages. High rainfall during the WY2016 dry season (fall 2015 and winter 2016) prompted large regulatory releases into the Northern Estuaries early in WY2017 in order to reduce lake levels before the wet season.

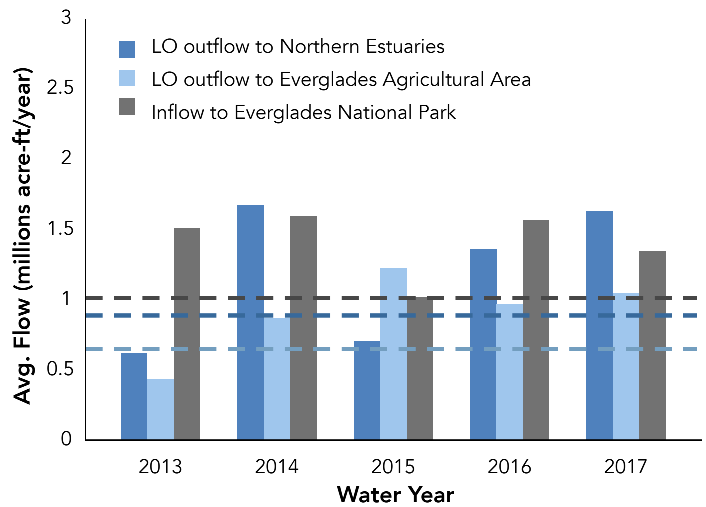


Figure 1.3. Annual flows between regions for WY2013–WY2017 compared with the historic averages for the period 1972–2017.

1.4 2012–2017 EVERGLADES REPORT CARD

What is a report card?

An ecosystem health report card assesses and synthesizes environmental data to evaluate overall ecosystem condition. Similar to school report cards, ecosystem health report cards use performance-driven metrics compared against a goal or ecologically relevant threshold. Report cards integrate large, complex datasets into an overarching score that's easily understood by the public. This report card is an important component of conservation and restoration planning in south Florida, as it is designed to clearly communicate the status of ecosystem health of the Florida Everglades to a broad audience.

The Florida Everglades report card is a 6-page stand-alone document that reports on the status of the Everglades ecosystem from May 1, 2012–April 30, 2017 (dates which correspond to water years 2013–2017). It was produced by the University of Maryland Center for Environmental Science's Integration and Application Network in collaboration with many south Florida scientists at the request of RECOVER. The report card provides a transparent, timely, and geographically detailed assessment of the Everglades status measured by the defined ecosystem indicators and performance measures of the CERP. This section outlines the basic steps in the report card process and the results of the Everglades report card in more detail than can be found in the printed document. For specific methods for each indicator, please see the Methods document (Integration and Application Network 2019).

The report card serves primarily as a communication tool to a broad audience (Figure 1.4). The intention is to provide a quick, easily understood summary of Everglades ecosystem health as it relates to the defined ecosystem indicators and performance measures. More detailed information about Everglades health, restoration, and management is provided in this System Status Report. However, the System Status Report serves a different function than the report card.

The report card process

The report card process is separated into five key steps: Conceptualize, choose indicators, determine thresholds (or goals), calculate scores, and communicate results (Figure 1.4).

Step 1 – Create a conceptual framework
Determining key geographic features, and issues and threats is a first step to understanding and creating an integrated assessment of the Everglades. Understanding the conceptual framework under which the report card is produced guides the process and narrows the focus to the most appropriate indicators.

Step 2 – Select indicators that convey meaningful ecological information and can be measured reliably
Indicator selection is based on factors such as spatial and temporal resolution, covariance between indicators, and ecosystem representativeness. Indicators should have a direct connection to the key values and threats expressed in the conceptual framework. Indicators can be grouped within indices that integrate individual indicators into a meaningful holistic assessment.

Step 3 – Define thresholds and method of measuring threshold attainment
Once a set of metrics is determined that represent the conceptual framework, evaluation of that data compared to thresholds or goals is needed in order to score those indicators as "good", "fair", or "poor". These thresholds can be based on a variety of information, including regulatory or management guidelines, biological limits, reference conditions, or others.

Step 4 – Calculate indicator scores and combine into overarching report card index values
Data are next analyzed according to the methods and thresholds established in Step 3. Once indicator scores for different regions have been calculated, they will be combined into overarching index values and can be converted to report card scores with colors and descriptions.

Step 5 – Communicate effectively through mass media
A printed report card is prepared using desktop-publishing software, and typically includes a variety of visual elements, including photos, maps, figures, and conceptual diagrams. This can also include a web-based document or content-rich website, and a press event.

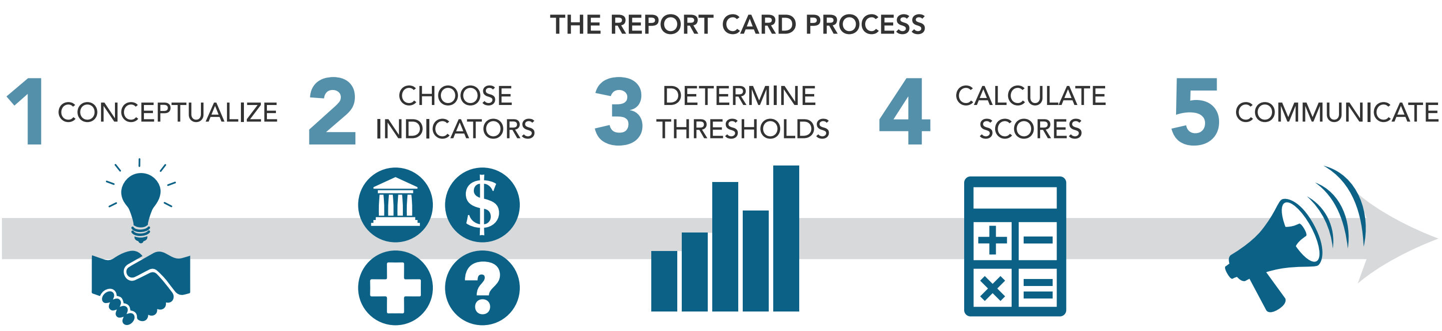


Figure 1.4. The report card process can be broken down into five simple steps.

How this report card is scored

The Florida Everglades report card evaluates a wide variety of indicators in four distinct regions. The indicators and metrics are specific to each region (Table 1.1). The four regions in this report are the RECOVER reporting regions: Northern Estuaries (with three sub-regions; Caloosahatchee River Estuary, St. Lucie Estuary and Southern Indian River Lagoon, and Loxahatchee River Estuary), Lake Okeechobee, Greater Everglades, and Southern Coastal Systems (with three sub-regions; Florida Bay, Biscayne Bay, and the Southwest Coast) (Figure 1.5).

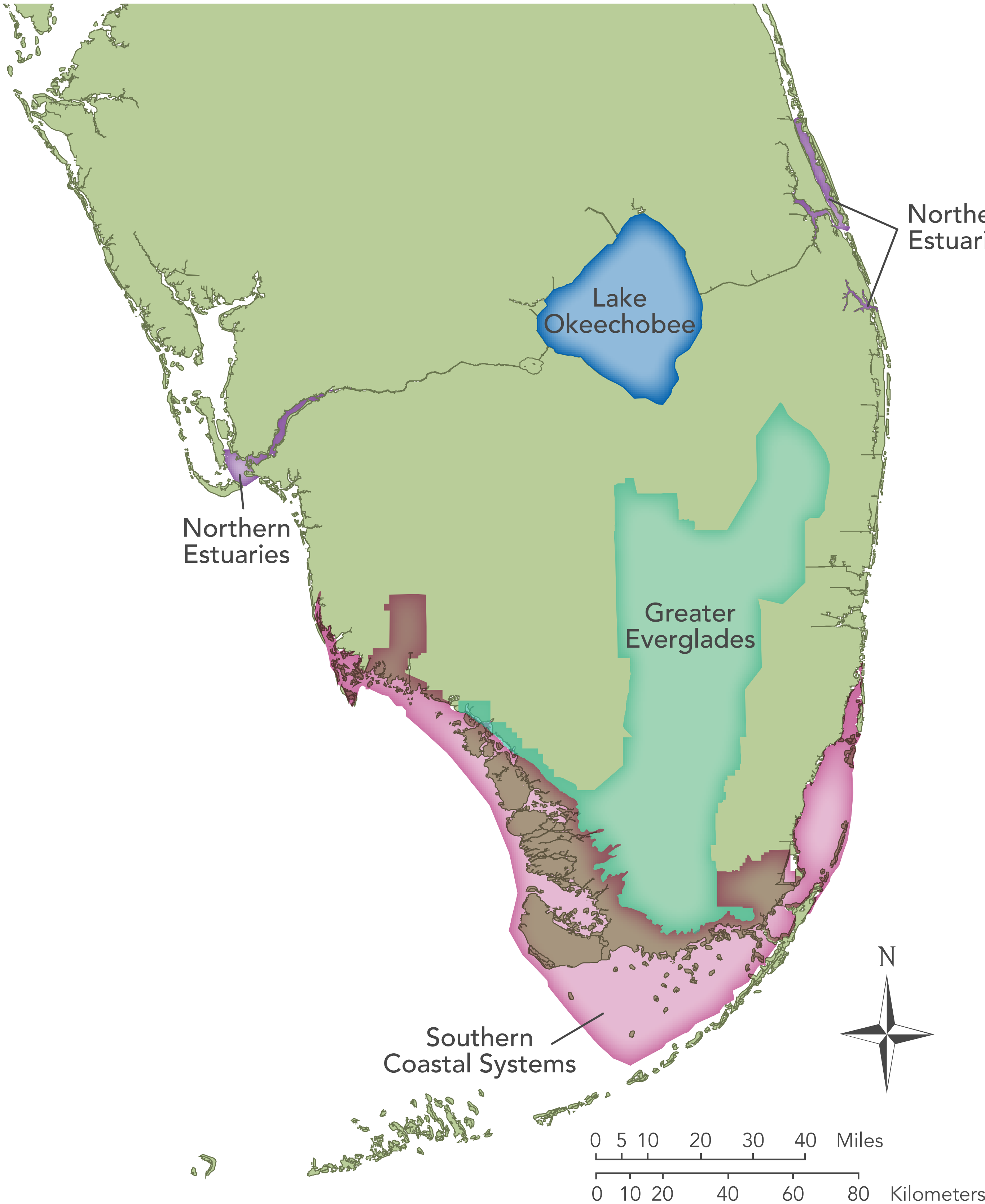


Figure 1.5. The four geographic regions of the Everglades system.

The indicators for each region are listed below. For each indicator, the appropriate measurement and ecological value/threshold/reference were determined by experts in the field (see Methods document for details [Integration and Application Network 2019]).

Table 1.1. The regions, sub-regions, and indicators evaluated in the Everglades Report Card. Colors indicate the condition of the indicator or region and are based on five possible statuses, ranging from "very poor" to "very good".

Overall Everglades	Northern Estuaries	Caloosahatchee River Estuary	Submerged aquatic vegetation
			Oyster
			Chlorophyll *a*
			Salinity
		St. Lucie Estuary and Southern Indian River Lagoon	Submerged aquatic vegetation
			Oyster
			Benthics
			Chlorophyll *a*
			Salinity
		Loxahatchee River Estuary	Submerged aquatic vegetation
			Oyster
			Chlorophyll *a*
			Salinity
	Lake Okeechobee		Fish
			Submerged aquatic vegetation
			Emergent aquatic vegetation
			Wading bird proportion
			Wading bird interval
			Chlorophyll *a*
			Water clarity
			Lake stage
	Greater Everglades		Periphyton
			Alligator
			Invasive reptiles
			Nonnative fish
			Wading birds
			Dry season prey availability
			Prey abundance
			Ridge and slough landscape
			Marl prairie
			Tree islands
	Southern Coastal Systems	Biscayne Bay	Crocodile
			Chlorophyll *a*
			Salinity
			Submerged aquatic vegetation
			Gold spotted killifish
			Gulf pipefish
		Florida Bay	Crocodile
			Chlorophyll *a*
			Salinity
			Submerged aquatic vegetation
			Spotted seatrout
			Spoonbill nesting
			Prey community
		Southwest Coast	Alligator
			Chlorophyll *a*
			Salinity
			Fish

Very poor | Poor | Fair | Good | Very good

Key findings (2012–2017)

The key finding of the 2012–2017 Everglades Report Card is that ecosystem health is in fair condition. Everglades' ecosystems are vulnerable to further ecological degradation and is providing minimal ecosystem functions. Essential ecological functions are degraded and unsustainable, leading to inadequate habitats for plants and animals. The overall condition is an area-weighted average of the four sub-region scores. The Southern Coastal Systems scored poorly while Lake Okeechobee, Northern Estuaries, and Greater Everglades scored fair (Figure 1.6).

Each region has a different set of indicators that reflect the health of that region (Table 1.1). For example, the Lake Okeechobee region has lake stage as an indicator, which is relevant for the lake, but not for the other regions. The indicators and results are discussed in detail in the report card and on the website at www.evergladesecohealth.org.

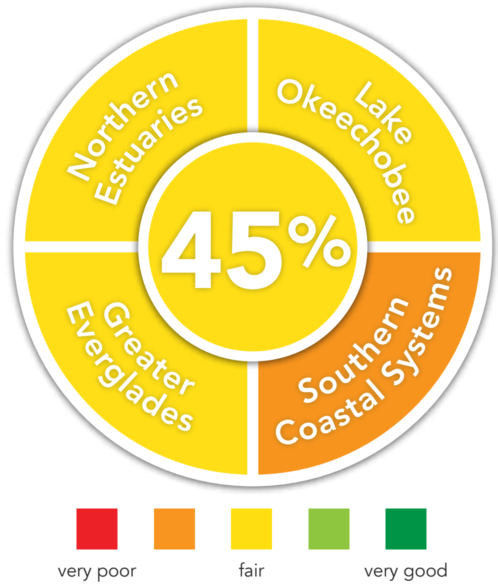


Figure 1.6. The overall Everglades report card score and region scores.

Discussion and recommendations

Tracking the health of the Everglades' ecosystems over time is critical to understanding if restoration efforts are working. Overall, the Florida Everglades is struggling to survive in the face of sustained pressure from human activities and the increasing impacts of climate change. The poor to fair scores reflected in the report card indicate that the region's ecosystems are degraded and the anticipated ecological benefits of restoration are still to be realized. This is not an unexpected result and improvement is possible. Report card results in other iconic regions, like the Chesapeake Bay, have started to reflect the impact of restoration activities (i.e., nutrient reductions) on the health of the system (Integration and Application Network 2018). For the first time, Chesapeake Bay health is significantly improving and is reflected in the overall Chesapeake Bay score. This can also happen for the Everglades.

The report card communicates the need for continued support for Everglades restoration. Some of the restoration projects such as the Modified Water Deliveries (Section 2.5), Picayune Strand Restoration Project (Section 6.5), and phase 1 of the Biscayne Bay Coastal Wetlands (Section 6.5) are showing benefits already, and the report card can help highlight and show those improvements. Within the regions, there are specific projects that will improve Everglades ecosystem health, such as the C-43 and C-44 Reservoir and Stormwater Treatment Areas (Section 3.5) in the Northern Estuaries, The Lake Okeechobee Watershed Restoration Project (Section 4.5) in Lake Okeechobee, Broward County Water Preserve Areas (BCWPA) project (Section 5.5) in the Greater Everglades, and the C-111 Spreader Canal Phase I (Section 6.5) in the Southern Coastal Systems.

The Everglades report card, initiated with the 2019 System Status Report, has been successful in focusing attention on the health of the Everglades' ecosystems, but there is room for improvement in future reports. As expected, the process of compiling the report card highlighted some data and monitoring gaps within the Everglades regions. Other limitations include not having well defined thresholds or goals for several indicators, and some thresholds needing to be updated with more current information. Therefore, it is important to repeat the report card over time to not only track ecosystem health, but also become more effective within the adaptive management cycle and in restoration efforts.

Mangroves in river of grass. Photo by G. Gardner.

SYSTEM-WIDE SCIENCE

2.1 INTRODUCTION

The Everglades' ecosystems are in a state of transition. The 5-year period covered by this System Status Report, 2012–2017 (WY2013–2017), is short compared with the 50-year time span required to fully implement the CERP. Conditions in the Everglades reflect ecological responses to short- and medium-term variation and change in the south Florida hydrologic system and the restoration activities that have been undertaken. Variation and change in regional hydrology are from natural sources, e.g. weather events and climate change, and deliberate changes made in water management.

The south Florida hydrologic system extends from the headwaters of the Kissimmee River to Florida Bay, connecting four ecologically-distinct regions that make up the Everglades system: Northern Estuaries, Lake Okeechobee, Greater Everglades, and Southern Coastal Systems (Figure 2.1). Water flows from the Kissimmee River to Lake Okeechobee, and then into the Northern Estuaries and the Greater Everglades. The connection between the Lake and the Greater Everglades occurs through the Everglades Agricultural Area and through constructed canals. The Greater Everglades is a key source of freshwater that sustains the estuaries of the Southern Coastal Systems and south Florida's fast-growing cities.

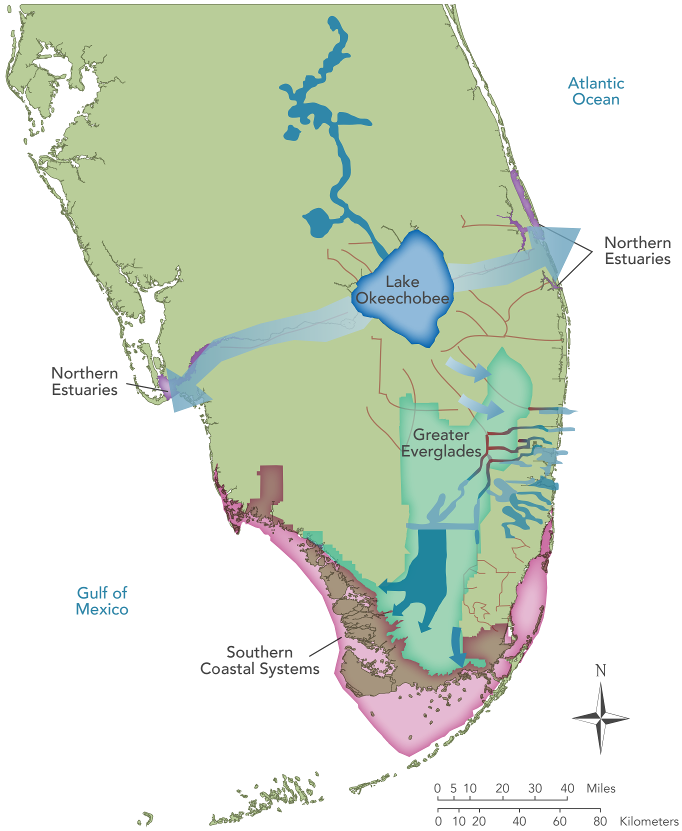


Figure 2.1. Regional hydrology, showing direction and magnitudes of water flows connecting regions.

Several important events occurred from 2012–2017. A very strong El Niño during 2016 and Hurricane Irma in September 2017 had significant impacts on ecological conditions in the Everglades. These events caused a seagrass die-off in Florida Bay, harmful algal blooms in Lake Okeechobee and the St. Lucie estuary, and massive mortality of mangroves along the southwest coast. Hurricane Irma occurred outside the 5-year period covered in this System Status Report and the Everglades Report Card, and therefore is not included in the data sets presented. A preliminary assessment of the impacts of Hurricane Irma is found in Section 2.4.

Events related to changes in regional water management include progress of several restoration projects that allow increased flow of freshwater into Everglades National Park and Florida Bay. There was also progress on the development of techniques for removing levees and canals to restore sheetflow and active management to restore degraded wetland vegetation communities.

2.2 KEY FINDINGS (2012–2017)

The Everglades is struggling to maintain ecosystem functions that support south Florida's tourism, recreation, and economy because pressures like hurricanes, drought, development, and agriculture impact all aspects of the system. Essential ecological functions are degraded and unsustainable, leading to often unsuitable habitats for plants and animals. In the past five years, plants, like submerged aquatic vegetation, and animals like oysters, fish, and birds, have all been negatively impacted by fluctuating weather patterns and human disturbances. One hundred years ago, the Everglades' ecosystems existed within a fully integrated hydrologic system. Construction of the canals and dikes of the Central and Southern Florida System reduced the connectivity of the hydrologic system, leaving the component ecosystems more vulnerable to disruption and change. Fortunately, management and restoration of all regions of the Everglades is underway to help mitigate these impacts.

CERP aims to restore the characteristics of a hydrologically integrated Everglades, which will provide the best habitat for plants and animals, leading to a healthy Everglades system. The results achieved by individual projects such as Picayune Strand, Biscayne Bay Coastal Wetlands Part 1, and the bridging of Tamiami Trail are encouraging. Taken together, these regional activities are critical to managing the trans-boundary conditions that are essential to system-wide health. These projects provide insight into what can be achieved at larger scales, but are currently limited in their scale and influence. Restoring the historical hydrologic characteristics of the Everglades awaits further progress on larger scale projects that are now either underway or in the planning stages. Within the regions of the Everglades, research and restoration projects have improved the management of hydrologic flows and increased water storage, which are key to achieving the restoration goals of improving wetland hydroperiods and flows of freshwater into coastal areas.

Overlaying the entire restoration plan for the Everglades are climate-related changes in rainfall and accelerated sea level rise. These changes introduce new stresses on the Everglades' ecosystems, which highlights the need to increase resilience and reduce their vulnerability to disruption. Skilled management is required to dampen hydrological extremes and mitigate system-wide impacts from the increasing frequency and intensity of weather-related episodic events. Ongoing research and monitoring provide essential support to adaptively managing of the restoration process. Consequently, regional research, project development, and implementation play important roles in restoring and sustaining the Everglades.

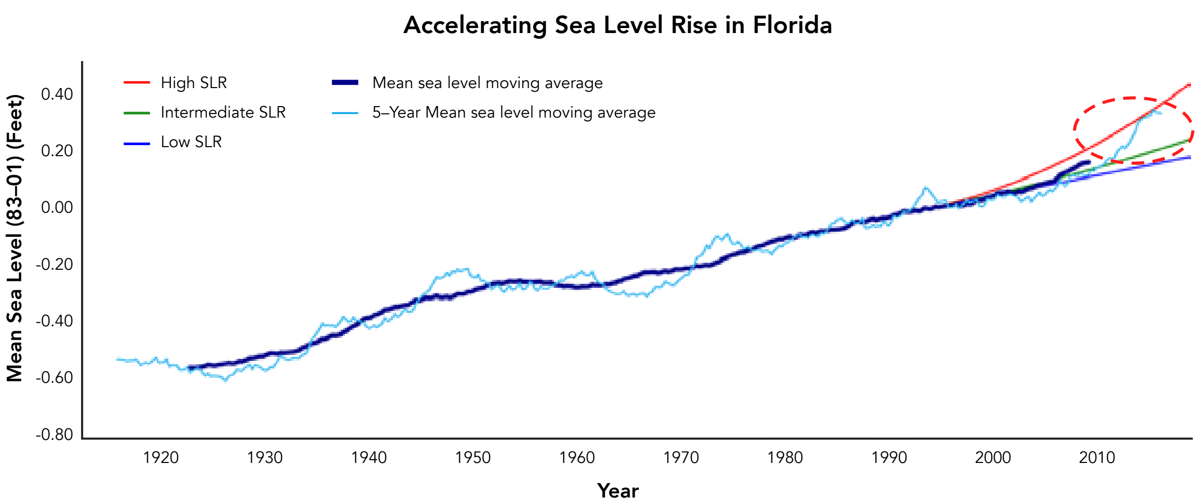
2.3 CLIMATE CHANGE

Actions to restore the Everglades must allow for the growing influence of climate change. Climate change and related phenomena are major drivers of ecological change. In south Florida, climate change will result in changes in sea level, air and water temperatures, precipitation, and global acidification. These changes must be addressed to accomplish CERP goals of restoring a healthy Everglades ecosystem and sustaining it for future generations. A few of these changes that are most important for 2012–2017 are discussed below.

Sea level rise

Sea level rise in south Florida is happening faster than anticipated during development of the CERP. Not only are ecosystems in natural areas being impacted, but sea level rise also negatively affects water supply, causes salinity intrusion, and increases flood risks for developed areas. Coordinated long-term adaptation strategies need to be developed for natural areas served by the CERP and developed areas served by the larger Central and Southern Florida Project (C&SF Project). CERP Interim Goals and Interim Targets may need to be updated with consideration of changing future conditions.

The 105-year record of tide data at Key West shows that sea level in south Florida has risen by 11 inches since the 1920s (Figure 2.2) (USACE 2017a). Applying a moving average filter to these data reveals that the rate of sea level rise has varied, and these variations are linked with multi-year variations in prevailing winds, ocean currents, and other ocean dynamics. The increase in the rate of sea level rise evident in recent years may be a sign of potential future increase in local long-term sea level rise rates. However, as Figure 2.2 shows, the five-year moving average has been both above and below the long-term average rate of sea level rise. It is uncertain how long this increased short-term local rate of sea level rise will be sustained.



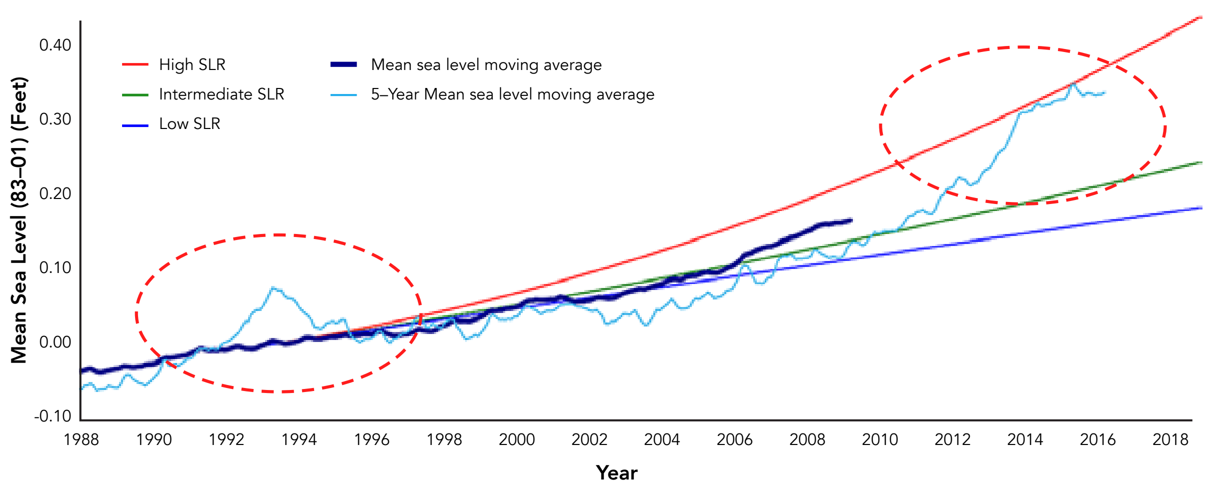


Figure 2.2. (Top) USACE sea level rise (SLR) curves for Key West with tide data moving averages over 105 years from January 1913 to 2018. (Bottom) 30 years of tide data show prolonged acceleration of sea level rise since 2012.

Regulations now require CERP projects to consider potential impacts across the project life cycle for the entire range of possible future rates of sea level rise. The guidance to planners in south Florida is to anticipate that sea level in 2050 will be between five inches and 26 inches higher than it was in 1995. The sea level rise scenarios (Figure 2.3) represent potential low (historic), intermediate, and high rates of future sea level rise based on local historic rates of sea level rise and two alternative future rates based on National Research Council guidance. These scenarios are recognized by USACE as the most credible and the high rate scenario is included in sea level rise projections currently in use by counties in the Southeast Florida Climate Compact (Monroe, Miami-Dade, Broward, and Palm Beach).

The current guidance departs from the approach taken when the water management systems were originally planned. Design of the C&SF Project made no allowance for future sea level rise. Canals and structures still in use were designed to operate with water levels six to nine inches above the elevation of average high tide (MHW datum) in 1948. Future sea level rise was included in formulating the CERP. However, the upper limit on the increase in sea level by 2050 was set at only six inches.

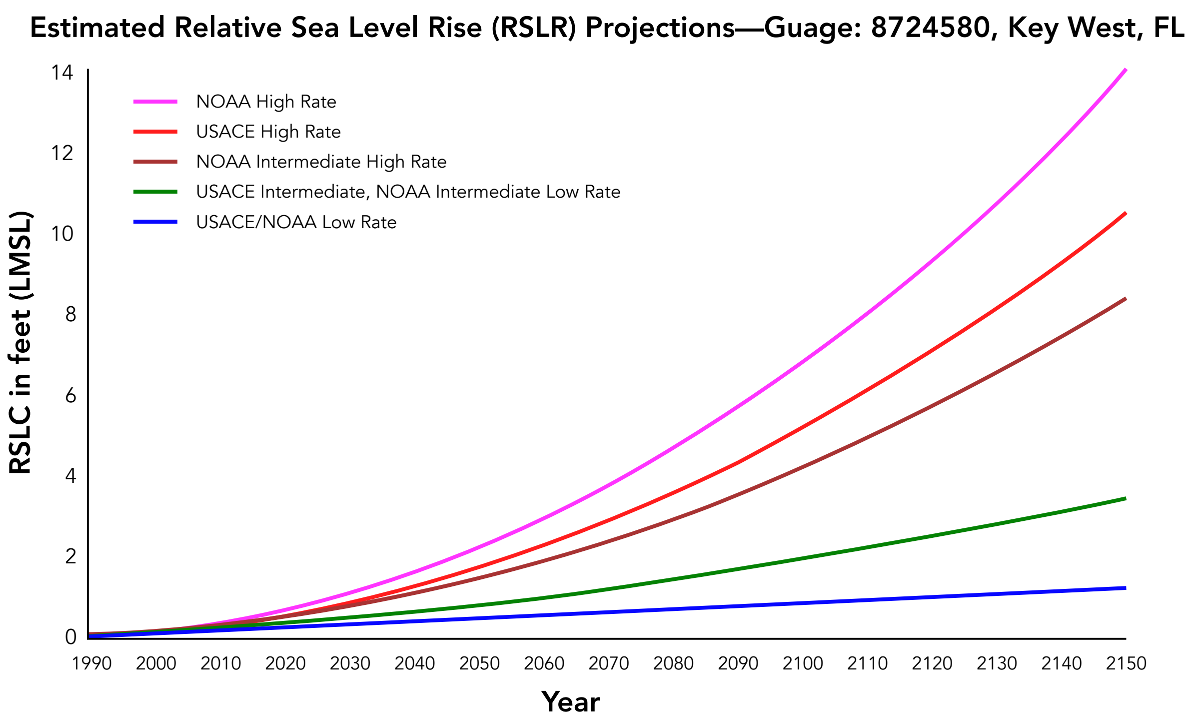


Figure 2.3. USACE 2013 and NOAA 2012 Sea level rise curves for Key West, FL. Sea level projections from the USACE Sea Level Change Curve Calculator (USACE 2017a).

Increasing air temperature

Average annual temperature for south Florida shows a warming trend beginning around 1980 (Figure 2.4). The NOAA Southern Regional Climate Center (SRCC) and the Southern Climate Impacts Planning Program (SCIPP) have created data tools to analyze regional scale temperature and precipitation records in the National Climate Data Center. These data suggest that within CERP project areas average annual temperatures are now regularly 2–3 degrees (Fahrenheit) warmer than the 1895 to 1945 period, and are likely to rise in coming years. Higher temperatures mean that evaporation losses have increased relative to historic conditions. More water storage, increased water supplies, and water reuse will be required to meet water needs in natural and developed areas in south Florida. The higher average annual temperatures also mean higher extreme temperatures with increased stresses on plants, animals, and people.

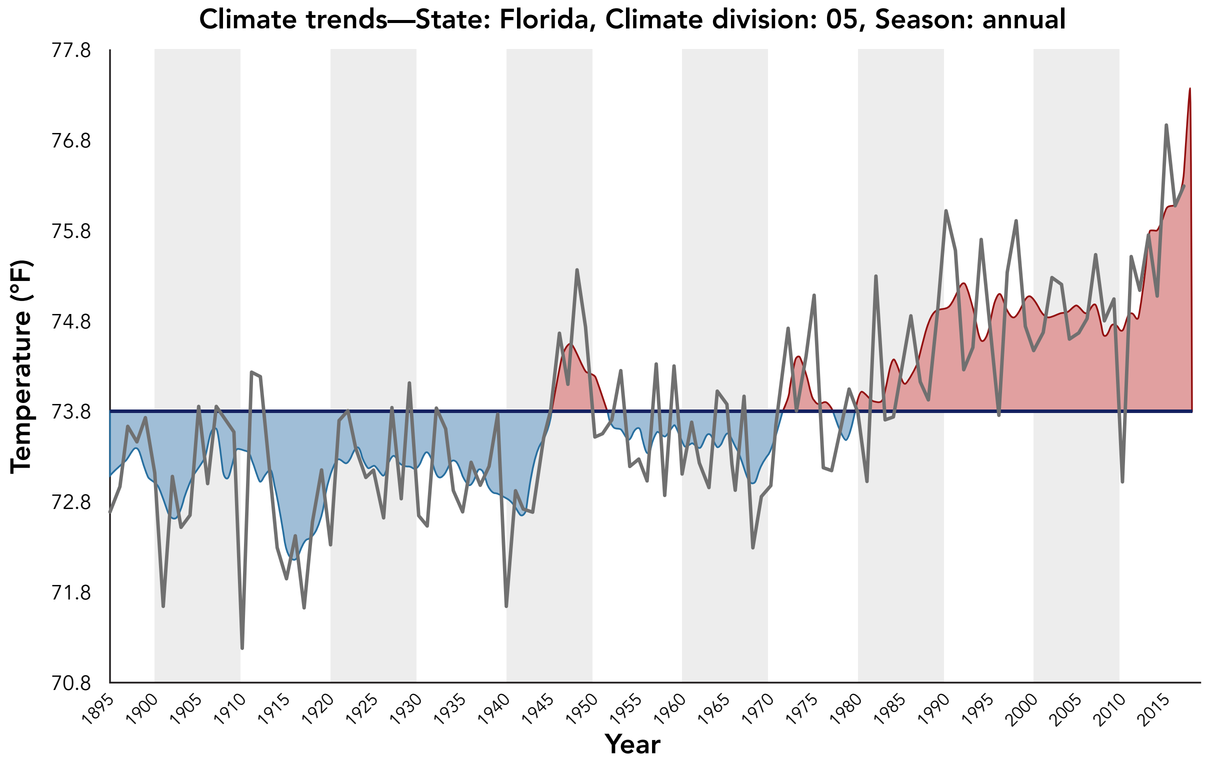


Figure 2.4. Average annual temperature versus average temperature 1895–2018 for south central Florida climate division #5, which corresponds approximately with the extent of the Greater Everglades region. The red shaded area indicates a warmer period than the historic average, while a blue shaded area is a period cooler than the historic average.

Increasing water temperature

Related to increased air temperatures noted above, temperatures are increasing in both freshwater and marine water bodies. The decline in healthy coral reefs in south Florida is likely linked, in part, to warming marine water temperatures. Rising water temperatures in south Florida are likely to produce impacts to freshwater aquatic ecosystems in the Everglades, and in tidal and marine ecosystems. The frequency of algal blooms has increased in recent years in Lake Okeechobee. There are many species of algae, and they are sensitive to different nutrients (nitrogen and phosphorus) and other environmental conditions including water temperatures and light availability. Algal blooms are most likely when local waters are generally calm, required nutrients are easily available in the water column or bottom sediments, water temperatures are warmer than normal, and daylight hours are long. The increase in south Florida water temperatures may contribute to increased algal blooms even if other variables are constant.

Climate-related hydrologic changes

Climate-related changes in historic rainfall patterns along with more frequent or intense extreme weather events may impact the performance of the CERP, and the C&SF project, leading to the need for development of new adaptation strategies. Extreme weather is more prevalent due to rising temperatures. However, it is not yet clear how climate change will affect precipitation in south Florida (NRC 2014). The USACE requires consideration of potential climate-related changes in historic hydrologic patterns. That includes changes in the frequency, intensity, duration, and seasonal timing of rainfall, and related impacts on required water management, water storage, and flood damage reduction systems. It may also include the potential for more rapid and sustained intensification of tropical storms and related flood or storm damage risks.

2.4 EVENTS OF ECOLOGICAL SIGNIFICANCE (2012–2017)

Several discrete events that occurred from 2012–2017 (WY2013–WY2017) had a profound impact on the Everglades system. These include the seagrass die-off in Florida Bay and harmful algal blooms in the St. Lucie River and Estuary. Hurricane Irma is also included in this report as an event of ecological significance. Although it occurred outside of the period of this report, Hurricane Irma arrived while the report was being written. Therefore, a preliminary assessment of Irma's impacts in the Everglades is included, but a complete assessment must wait until the next report in 2024.

Seagrass die-off in Florida Bay

In 2015, Florida Bay experienced a crisis where up to 20% of the seagrass meadow was lost. Thousands of acres of *Thalassia testudinum* died, leaving entire basins denuded and carpeted by decaying biomass. Florida Bay has one of the largest seagrass meadows in the world, which contributes to the diversity and productivity of its unique ecosystem. Submerged aquatic vegetation (SAV), composed of seagrass and benthic macroalgae, provides critical habitat, structure, food, and nutrient sequestration throughout Florida Bay. It is important to understand the causes and extent of the 2015 seagrass die-off, the rate of habitat recovery, and the potential of SFWMD's Florida Bay Initiative in the C-111 Basin to reduce the probability of future die-offs.

A previous major seagrass die-off occurred in 1987 after which causal factors were investigated. Many of the hypotheses developed in 1987 were tested during the 2015 die-off. The most important was the SAV Cascading Feedback Hypothesis (Koch et al. 2007; Madden et al. 2010; Hall et al. 2016). According to the this hypothesis (Figure 2.5), SAV die-off is the result of the co-occurrence of several conditions. The events and feedback loops are driven by low precipitation and water management actions upstream that reduce freshwater inflow, leading to hypersalinity in the bay followed by high temperatures, causing stress in dense beds of seagrass. This exacerbates anoxic conditions, leading to seagrass death. The loss of seagrass induces a negative feedback where decomposing dead seagrass reduces oxygen further and releases nutrients that promote algal blooms. Higher turbidity from algae and destabilized sediments reduces light and inhibits seagrass regrowth.

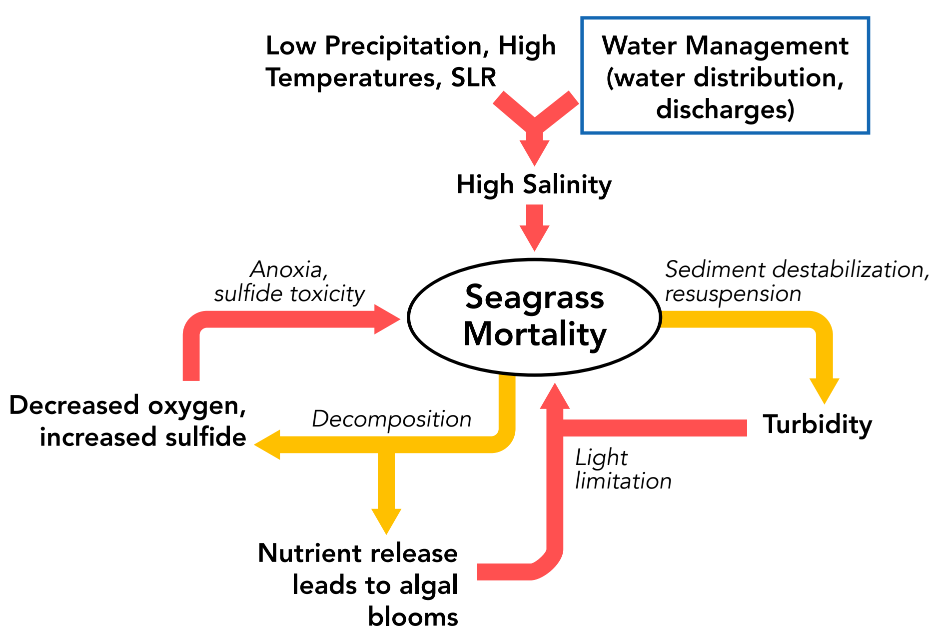


Figure 2.5. Summary of the Cascade Effect and seagrass mortality in Florida Bay.

When the 2015 die-off occurred, bay waters were clear and nutrient concentrations low. SAV densities had been increasing for many years (Hall et al. 2016; Cole et al. 2018). The cause of this die-off was the combination of high salinity, high temperatures, and low oxygen concentrations in the sediment. A severe precipitation deficit and lack of freshwater inflow during WY2015 and early in WY2016 led to unusually high salinities in June 2015 relative to long-term averages (Figure 2.6). Within central and western Florida Bay, salinities exceeded 70 PPT and water temperatures were 2–3 degrees Fahrenheit above-average (Madden et al. 2017; Koch et al. 2007; Hall et al. 2016). Low oxygen concentrations, especially at night (Borum et al. 2005), a result of the lack of water column mixing and dense vegetation, created a further barrier to complete mixing and created a high nighttime respiratory demand. These factors pushed the system beyond a tipping point, resulting in rapid die-off (Koch et al. 2007). By August 2015, visual observations found large areas of dead seagrass within Garfield Bight and Rankin Lake. Mapping in October 2015 found additional die-off in parts of Whipray Basin, Rabbit Key Basin, and Johnson Key Basin (Figure 2.7).

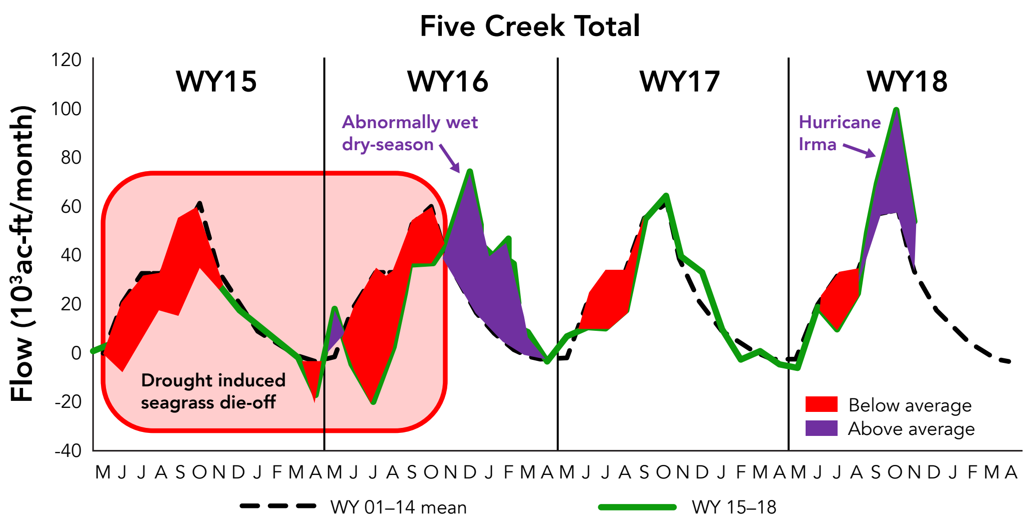


Figure 2.6. The extended drought of 2014 and 2015 created hypersaline conditions in central Florida Bay and may have also created above average water temperatures that lead to the seagrass die-off. This die-off may have continued for many more months were not for the significant dry-season precipitation.

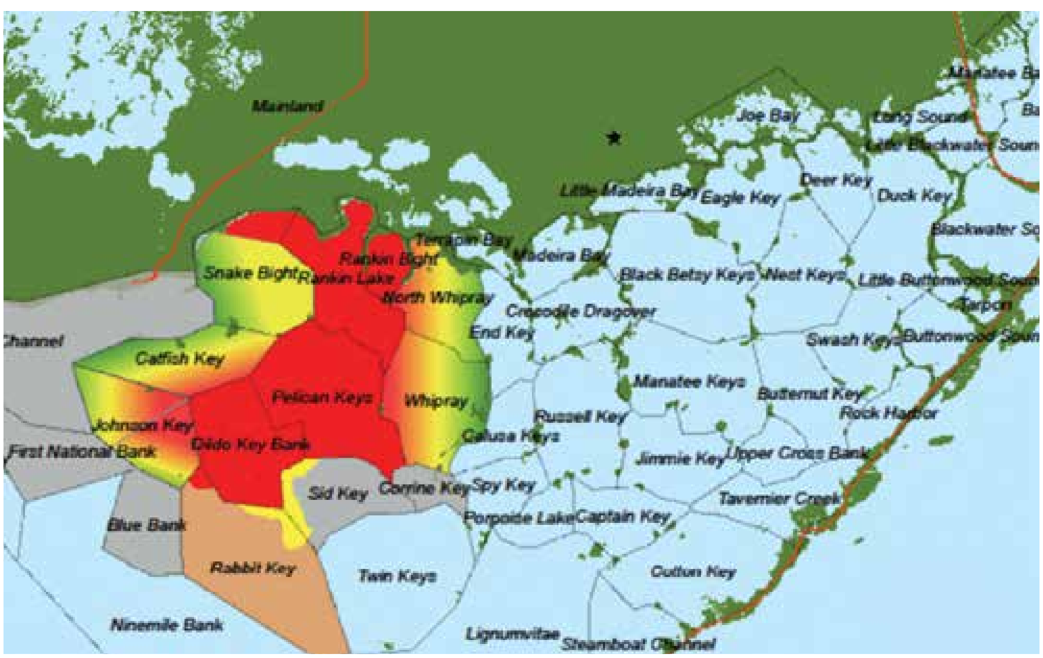


Figure 2.7. The area of hypersalinity in central and western Florida Bay correlated with the most severe seagrass loss during the 2015 die-off. Color indicates severity of SAV loss. Courtesy of Everglades National Park.

An algal bloom developed in Florida Bay following the seagrass die-off. The bloom was concentrated in the Central and Western bays in WY2017, fed by nutrients released from decaying seagrass (Figure 2.8). The nutrient monitoring program shows total phosphorus (TP) concentrations below long-term averages prior to, during, and following the die-off, only increasing above average concentrations in April the following year, nine months after the die-off began. Chlorophyll *a* increased almost immediately, concurrent with increasing TP. The high-nutrient high-chlorophyll condition lasted five months before returning to low background levels in December 2016.

In July 2016, a plan was implemented to mitigate future droughts and severe dry-season flooding of agricultural fields, by delivering fresh water to Florida Bay. Increased freshwater inflow reduces salinity levels in the bay and promotes the regrowth of seagrasses. Water managers identified projects that would reduce flood risks in urban and agricultural areas of Miami-Dade County and provide fresh water to estuarine natural areas. These operational and structural projects were incorporated into ongoing and upcoming efforts in C-111 projects. Water management initiatives such as the C-111 Spreader Canal Western Project and the Florida Bay Restoration Project are designed to reduce the impacts of high salinity by retaining more water in Taylor Slough and supplying more fresh water to central Florida Bay. Modifications to C-111 in the vicinity of the headwaters to Taylor Slough came with an adaptive management plan to evaluate if the increased flow could have any negative effects.

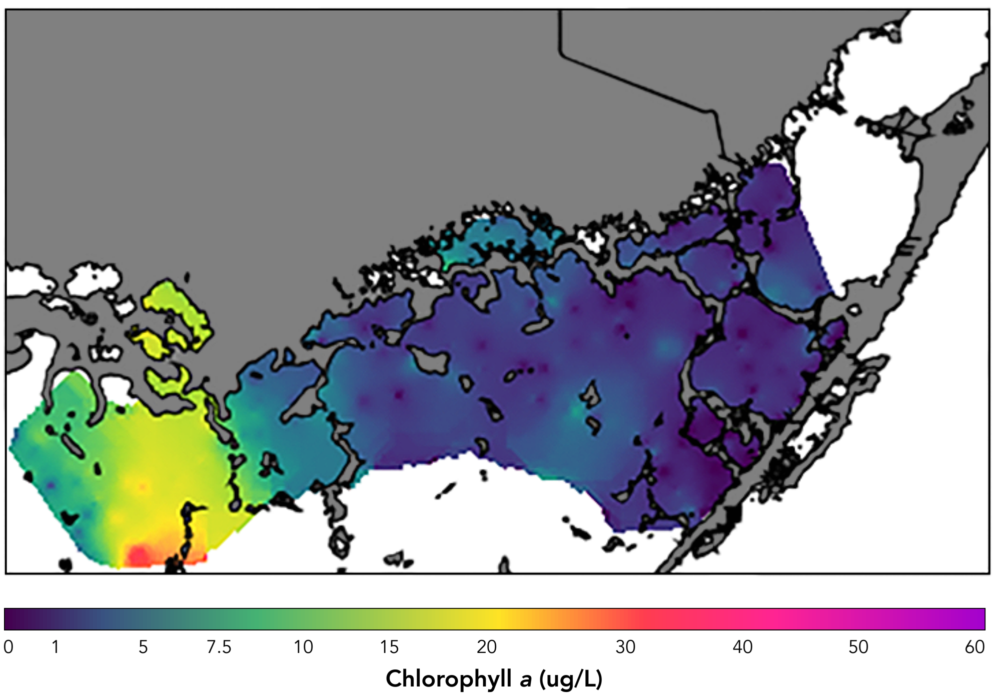


Figure 2.8. An algal bloom initiated several months after the die-off began and was centered in the areas most affected by die-off.

Harmful algal blooms in 2016

Lake Okeechobee and the Northern Estuaries

Blooms of toxin-producing cyanobacteria occurred in Lake Okeechobee and the St. Lucie Estuary during spring and summer 2016. Algal blooms are naturally occurring, common in summer, and can appear in any body of water with the right environmental conditions. Blue-green algae can produce harmful toxins and the blooms that occurred in the spring of 2016 caused exceptional problems. Several factors combined to magnify the size and intensity of the blooms including elevated nutrient levels, warm temperatures, long hours of daylight, and stagnant conditions.

Restoration efforts target these factors with the goal of reducing the frequency of bloom conditions in Lake Okeechobee. However, the frequency of bloom conditions in the lake has increased in the past 5 years compared with the previous 5-year period. Algal blooms are defined by the South Florida Water Management District (SFWMD) as equivalent to chlorophyll *a* concentration of >40 µg/l. Since WY2008, the target of <5% algal bloom frequency was met once in the nearshore region and four times in the pelagic region. Recently, the target has not been met in four of the past five water years in either region, with blooms occurring most frequently from June through October.

Wetter than normal conditions from November 2015 to May 2016 created an explosive plankton bloom in Lake Okeechobee beginning in May 2016 (Figure 2.9). June chlorophyll data indicated the presence of bloom level concentrations (>=40 µg/l) at widespread locations in the lake. Most elevated chlorophyll levels were found in the southern end of the lake and detection of microcystins in water samples confirmed a cyanobacteria bloom of the species *Microcystis aeruginosa*.

Runoff from the unusually high winter and spring rainfall in 2016 increased the water level of Lake Okeechobee. This prompted the release of large volumes of water into the St. Lucie and Caloosahatchee estuaries in order to prevent flooding. Meanwhile, prevailing winds pushed the bloom east toward the entrance to the St. Lucie Canal, where it was carried into the St. Lucie Estuary. In the estuary, the nutrient- and bloom-laden releases from the lake combined with additional nutrients in runoff from the rest of the watershed, and intense algal blooms were observed throughout the estuary and several miles into the Atlantic Ocean. The first detection of microcystin toxin in the estuary occurred on June 20, 2016, and the last sample with toxin detected was on July 26, 2016.

Figure 2.9. The 2016 algal bloom in Lake Okeechobee.

Cyanobacteria can, but do not always, produce toxins harmful to humans, pets, and wildlife. Microcystins are the most widespread cyanobacterial toxins. Cyanotoxins can be produced by a variety of planktonic cyanobacteria. Some of the most commonly occurring genera are *Microcystis*, *Anabaena*, and *Planktothrix* (*Oscillatoria*). Cyanotoxins can affect the liver, nervous system, and skin (EPA 2018). *Microcystis* blooms accumulate along shores and scums that dry on the shores may contain microcystin for several months, allowing toxins to dissolve in the water even when the cells are no longer alive. Toxins bioaccumulate in common aquatic vertebrates and invertebrates such as fish, mussels, and zooplankton. Blooms also cause poor water clarity (not suitable for seagrass), produce high levels of chlorophyll, and when algae dies, the decay of this organic matter consumes the available oxygen, causing fish kills.

Harmful cyanobacterial blooms will continue to be a problem in Lake Okeechobee and the Northern Estuaries until effective action is taken to address factors that contribute to the growth and transport of cyanobacteria. The WY2016 bloom event brought attention to the need to build projects planned for the CERP and for the state of Florida to act. Concern from residents in the vicinity of the St. Lucie Estuary resulted in expedited planning of additional reservoir and stormwater treatment area (STA) storage south of Lake Okeechobee, which was approved on March 8, 2018.

On March 26, 2018, the South Florida Water Management District submitted its plan for the Everglades Agricultural Area (EAA) Storage Reservoir for federal review, approval, and submittal to Congress. In accordance with state law, the Post Authorization Change Report seeks to increase the storage, treatment, and conveyance of the congressionally authorized Central Everglades Planning Project. The Tentatively Selected Plan, which was authorized, was developed to be consistent with the CERP and meet the goals set forth by the Florida Legislature when it passed Senate Bill 10. The plan will reduce undesirable regulatory releases to the northern estuaries, deliver clean water for Everglades restoration, and achieve water quality standards.

Hurricane Irma

Hurricane Irma made landfall in southwest Florida on September 10, 2017 (WY2018). Hurricanes are part of the natural cycle in south Florida. The Everglades' ecosystems are typically resilient to their effects, and past hurricanes provide insight into what to expect following Irma. Signs of ecological recovery appeared in the first months following the storm. However, Irma's full impact will play out over an extended period of time. Therefore, a complete assessment of Irma's impact on the Everglades must wait until the 2024 System Status Report.

Hurricane Irma made landfall on the lower Florida Keys (Cudjoe Key) as a Category 4 storm with 130 mph winds. The path of the eye crossed Florida Bay, and the storm made final landfall in Marco Island, FL, as a category 3 storm with 115 mph sustained winds. Peak storm surges of 3–6 ft above high tide levels occurred along the west coast 6–12 hours following the passage of the eye. Then Irma turned inland, weakened in strength, and was a tropical storm when it crossed into Georgia on September 11. Rainfall totals from the storm were 8"–10" across the peninsula.

The highest storm surge was recorded near the mouth of Shark River Slough where an 11.5 ft range in water level occurred in an 18-hour span (Figure 2.10). For the first half of September 10, water levels were 1.5 ft below low tide levels, exposing bare ground in nearshore areas, followed by a rapid increase to 6.5 ft above recent high tides, a condition that was sustained for a few hours when water levels returned to the typical ~3.5 ft depth range in the early hours of September 11. This storm surge pattern was common along the Gulf coast and in Florida Bay after the storm. Storm surges were less significant along the east coast of Florida and in the interior marshes of Everglades National Park (ENP).

The ecological consequences of the storm to the Everglades are caused primarily by three stressors—high winds, storm surge, and high rainfall—leading to rapid increases in water levels. Direct effects from the storm were caused by the immediate impact of individual stressors, and because these direct effects were widespread and pervasive, cascades of ecological consequences occurred. This short summary identifies direct consequences, compares these effects to other storm events from the past few decades, describes short-term effects in coastal waters, and provides the initial evidence for long-term consequences that may take months to years to become evident in the regional system.

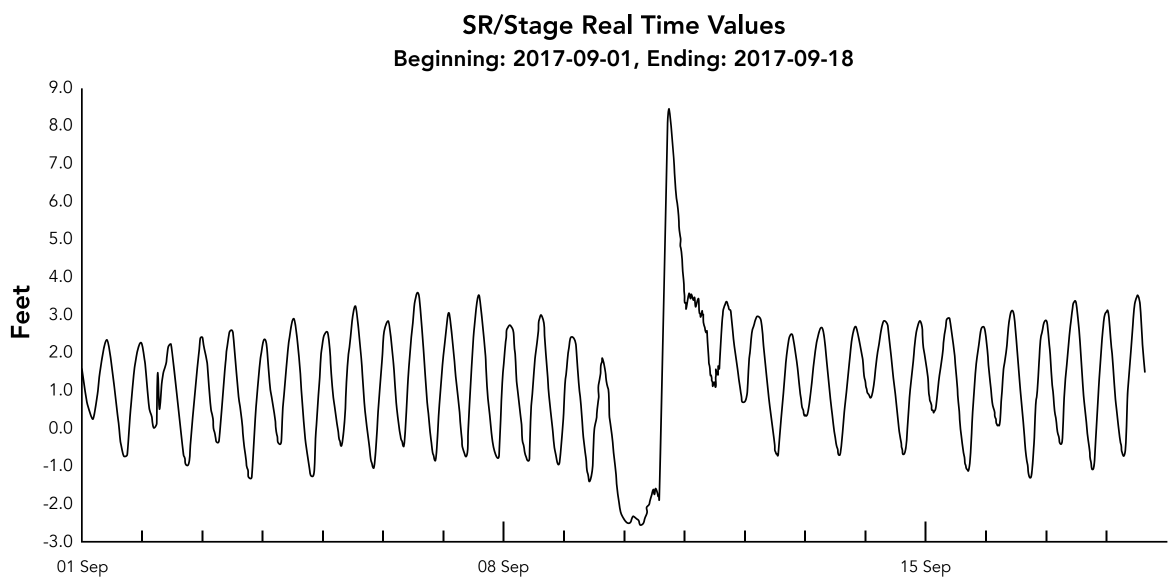


Figure 2.10. Real-time stage values at SR station positioned along the Gulf Coast of ENP in Shark River Slough.

Lake Okeechobee

Hurricane Irma passed about 60 miles west of the lake with sustained winds in the central portion of the lake between 50 and 60 mph. These winds caused lake stages to increase over 6 feet in the north and west sides of the lake, while dropping stages more than 4 feet in the south and east sides of the lake; causing a wind seiche of more than 10 feet from east to west at its peak (Figure 2.11). The enormous rainfall associated with the storm added nutrients to the water column. Total phosphorus inflows and resuspension from the sediments resulted in a one week increase in concentrations of 223 µg/L (165 pre- to 388 µg/L post) in the nearshore zone and 201 µg/L (112 pre- to 313 µg/L post) in the pelagic zone. Turbidity, rose from 7 Nephelometric Turbidity Unit (NTU) in the nearshore areas to 74 NTU, while the pelagic areas went from 13 NTU to 86 NTU. Strong winds associated with cold fronts in January 2018 caused even further sediment resuspension, causing the highest turbidity levels since devastating hurricanes in 2004 and 2005; with pelagic turbidity reaching 185 NTU. The combined physical effects of wave action and deep water, combined with poor water quality for months following the storm, reduce the prospect of improving indicator status in the near term.

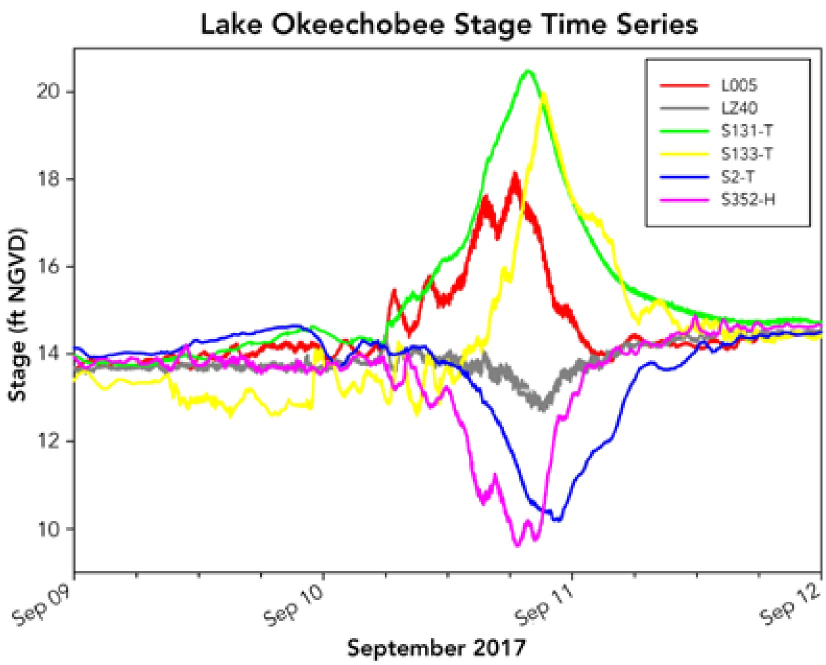


Figure 2.11. Lake stage at different water level monitoring stations on Lake Okeechobee from September 9–12, 2017. S352-H and S2-T are located on the east and southeast shorelines, respectively, while S131-T and S133-T are located on the west and north shorelines, respectively.

If the experience following hurricanes in water years 2005 and 2006 are any indication, water quality may remain degraded for several years due to the impacts of Hurricane Irma. Even with subsequent droughts in WYs 2008–2009, it still took several years for recovery. While conditions appear more favorable in the months following Hurricane Irma than they did in WY2007, dramatically lower lake stages (e.g. <11.0 ft NGVD for at least three months during the growing season) are likely needed to jumpstart the recovery of nearshore SAV and the cascade of beneficial effects that follows (Havens 2003). Without low lake stages, conditions will likely remain poor throughout several of the next five years.

Northern Estuaries

Hurricane Irma brought heavy rainfall over the watersheds north of Lake Okeechobee and the watersheds of the Northern Estuaries. Runoff from the hurricane resulted in high inflows of freshwater from local basin runoff and Lake Okeechobee regulatory releases, as well as nutrients to the Northern Estuaries. The inflow of freshwater suppressed salinity values, decimating oyster populations in the St. Lucie Estuary. Based on the response to large inputs of freshwater resulting from past hurricanes and El Niño events, oysters are expected to recover once inflows subside and the salinity regime returns to "normal."

Hurricane Irma caused an estimated 3 ft storm surge in St. Lucie Estuary and brought sustained winds of 70 mph to St. Lucie with maximum speeds of 100 mph (Cangiolosi et al. 2018). From September 10–11 total rainfall over St. Lucie River basin was 36.3 inches (Figure 2.12). Daily average inflow to the St. Lucie Estuary for the period from September 10 and the post-storm cruise (October 12) was 7,872 cfs (Figure 2.13). Over this period 28% of the total inflow contribution was from Lake Okeechobee and 59% from the watershed (Figure 2.13).

Freshwater inflow disrupted the estuarine salinity gradient observed in July 2017, producing oligohaline conditions with an average salinity of 0.7 PPT, from the headwaters to the lower estuary where salinity was only 6 PPT (Figure 2.14 left panel). High colored dissolved organic matter from watershed runoff pervaded through to the lower estuary and highly turbid water, originating from the South Fork, elevated estuary-wide turbidity values in the post-storm sampling, both contributing to severe reductions in light availability system-wide (Figure 2.14 middle two panels). Reduced light availability, but primarily reduced residence time due to high flushing rates, likely drove the uniform and reduced concentration of chlorophyll *a* throughout the system in the October post-storm sampling (Figure 2.14 right panel). While a November 2017 cruise observed similar conditions as the October cruise, a cruise in January 2018 observed the pre-storm gradients in salinity had returned, estuarine turbidity had significantly reduced, but overall system conditions were more similar to wet-season pre-Hurricane Irma characteristics than dry-season.

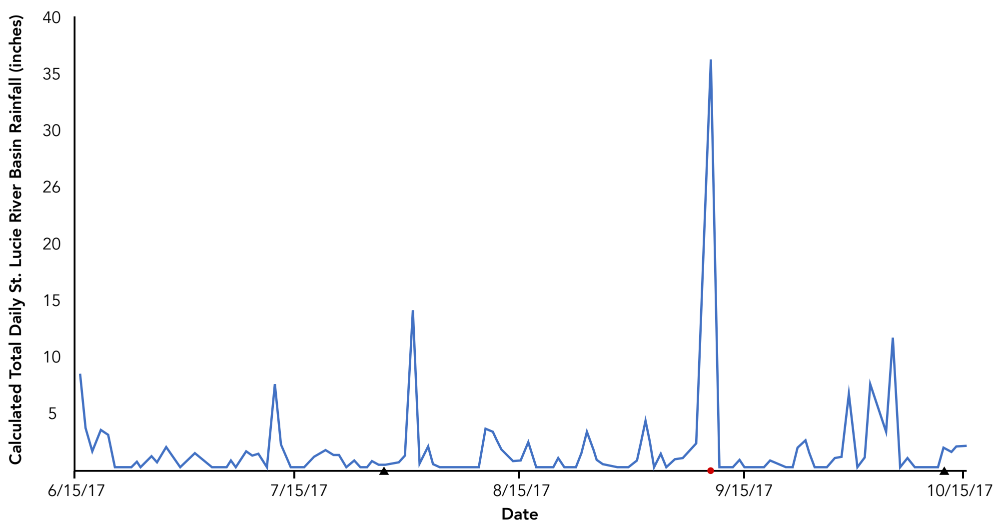


Figure 2.12. Total daily St. Lucie River Basin rainfall (SFER 2019). Black triangles indicate sampling cruise dates, red circle is Hurricane Irma Florida landfall date.

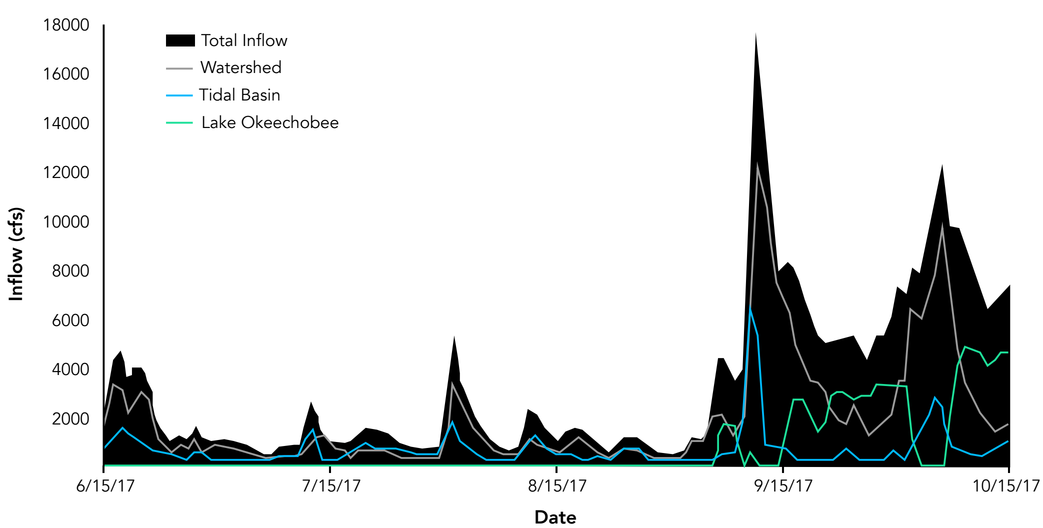


Figure 2.13. St. Lucie Estuary inflow total (black fill) and inflow from the watershed (dark grey line), tidal basin (blue line) and Lake Okeechobee (green line) in cubic feet per second (cfs) (SFER 2019).

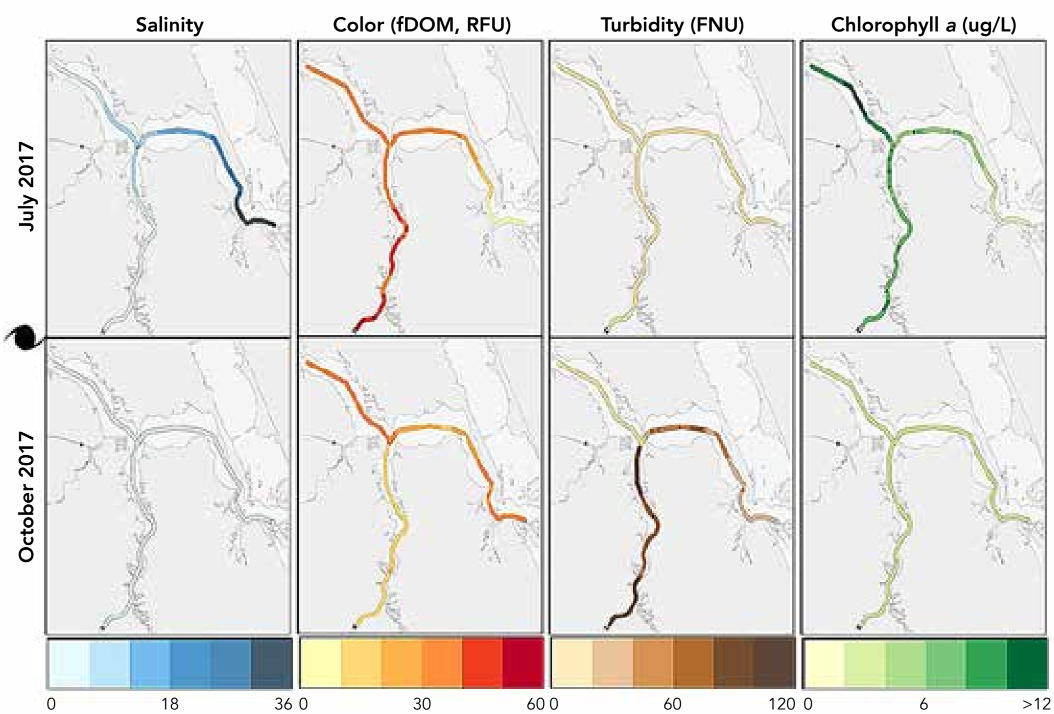


Figure 2.14. Water quality data maps from the SERFIS cruises in St. Lucie Estuary, before (07/27/2015) and after (10/12/2017) Hurricane Irma (represented by the cyclone symbol). Maps from left to right represent salinity (blues), fluorescent Dissolved Organic Matter (fDOM) (relative fluorescence units [RFU], oranges), turbidity (FNU, browns), and Chlorophyll a *(μgL^{-1}, greens). Lighter colors represent lower values and darker colors represent higher values in each parameter. Water quality data collected at a rate of 5 sec, interpolated over 0.1 km.*

Greater Everglades

Hurricane Irma created conditions in which more than 90% of the tree islands, for which data were available, were inundated. Water levels were already high in September 2017 due to the accumulated rainfall through the wet season. High rainfall from Irma pushed water depths in the freshwater wetlands of the Greater Everglades to record levels. 2017 was an extreme year, with a very dry season when more than 90% of tree islands remained dry. During the wet season 80% of the tree islands were inundated with a monthly average of 20 days of inundation. To observe the effect of Hurricane Irma during 2017, Figure 2.15 shows the spatial inundation pattern during the month of October in 2015, 2016, and 2017.

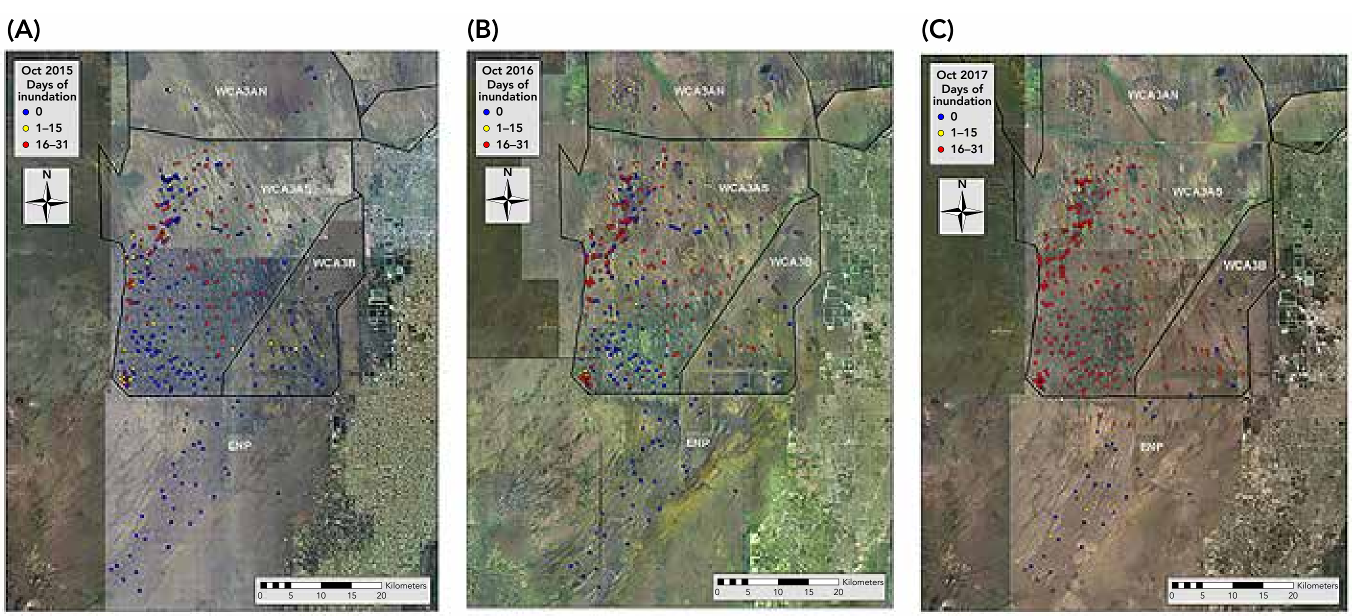


Figure 2.15. Spatial pattern of number of days of inundation on tree islands distributed in the Water Conservation Area 3 and Northeast Shark River. Figures show spatial pattern during the month of October in a) 2015, b) 2016 and c) 2017.

In 2017, several tree islands were hit hard by Hurricane Irma. A preliminary analysis of tree data collected at eight islands in Everglades National Park suggests high tree damage from Hurricane Irma. When trees stressed by the hurricane experience drought or high water conditions in next few years, tree island vegetation is likely to be adversely affected.

Southern Coastal Systems

Storm surge and high winds were the predominant stressors that caused direct impacts in the Southern Coastal Systems (SCS) region. Storm surge from Hurricane Irma was impactful throughout the SCS Region (Figure 2.16). Along the southeast coast of Florida, north of Biscayne Bay, storm surge ranged from 2–4 feet. In Biscayne Bay, there was 4–6 feet of storm surge. Florida Bay had 4–6 feet of storm surge with some places receiving 5–8 feet. The southwest coast of Florida from Whitewater Bay to Marco Island received the strongest storm surge at 6–10 feet. Rainfall north and within the SCS Region was substantial ranging from 8.19–14.48 total inches of rainfall. Examples of rainfall totals are:

- Avon Park: 9.42 in
- Big Cypress National Park: 8.23 in
- Big Pine Key: 12.54 in
- Biscayne Bay National Park: 8.19 in
- Clewiston: 9.65 in
- Cudjoe Key: 9.76 in
- Ft. Lauderdale: 9.57 in
- Golden Gate Estates: 10.41 in
- Homestead: 9.16 in
- Immokalee: 14.48 in
- Marathon: 9.42 in
- Naples: 11.46 in
- Plantation: 10.81 in

High winds extensively damaged the mangroves along Florida's southwest coast. Large trees across more than 51,200 hectares had leaves stripped from branches, broken canopies, and snapped stems, or were uprooted by wind (Figure 2.17). This exceeds the extent of damage caused by previous hurricanes to hit this area, notably Hurricane Andrew in 1992.

An aerial survey of coastal conditions six months after Hurricane Irma indicates that there may be more patches of coastal mangrove forest where high rates of mortality occurred compared to previous storms. Preliminary rough estimates suggest that as many as 15,000 hectares (150 km^2) of mangrove forests have not yet re-sprouted and may be standing dead trees. A second, widespread form of wind effect is the piling of vegetation (often described as wrack lines) along coastal shorelines. An analogous phenomenon occurs along ridge ecotones, where the submerged aquatic vegetation found in sloughs (often vegetation wrapped in periphyton) is piled along a nearby ridge.

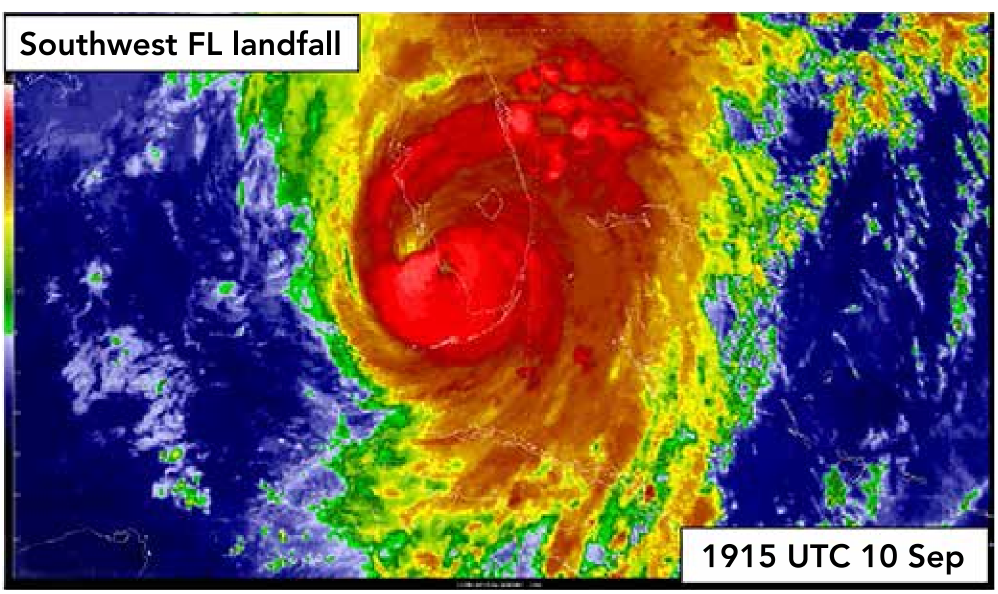


Figure 2.16. Hurricane Irma storm surge over the Southern Coastal Systems.

Figure 2.17. Widespread damage to trees along the coastline in Florida Bay.

Due to the recent passing of Hurricane Irma, full ecological impact has yet to be ascertained. Observations after Hurricane Irma revealed damage to the coral reefs near Biscayne Bay. Damage to seagrass beds in Florida Bay are expected. Snook and bull shark populations significantly decreased or dropped to zero in the Lower Southwest Coast estuaries following Hurricane Irma due to the increase in freshwater inflow. Other impacts due to the amount of rainfall include erosion, increased nutrient loading throughout the water column, short term increase in turbidity, short term water temperature changes, and extended natural and structural freshwater discharges throughout the SCS region. Current drainage conditions throughout south Florida drained the system relatively quickly. For example, the Picayune Strand Restoration Project Area, where regional rainfall totals were highest, was back at normal water levels within two weeks. Additional information on Hurricane Irma can be found at: https://www.nhc.noaa.gov/data/tcr/AL112017_Irma.pdf .

2.5 ADAPTIVE MANAGEMENT PROJECTS

Modifying freshwater flow

The aim of the Modified Water Deliveries (MWD) operational tests is to increase water deliveries from Water Conservation Area 3A through Northeast Shark River Slough to Everglades National Park. The construction phase of the MWD project was completed in 2018. USACE began testing new operating rules for water management facilities in the MWD project area (Figure 2.18) in October 2015.

The MWD field test is a planned series of three sequential efforts that will result in a comprehensive integrated water control plan, or the Combined Operational Plan (COP). This plan dictates the operation of the water management infrastructure associated with the MWD and C-111 South Dade Projects. This approach will 1) allow interim benefits toward restoration of the natural systems, 2) reduce uncertainty of operating the components of the projects, and 3) provide information to complete the Plan efficiently.

Development of the COP started in 2017. It will be informed by several field tests in addition to the information collected during the planned and emergency deviations from 2016–2018. Although the hydrologic conditions during 2016–2018 have limited the frequency of C&SF operations according to the incremental field tests, the deviations have provided accelerated opportunities to increase water deliveries to Northeast Shark River Slough (NESRS) and have provided monitoring data to inform the subsequent field tests and COP.

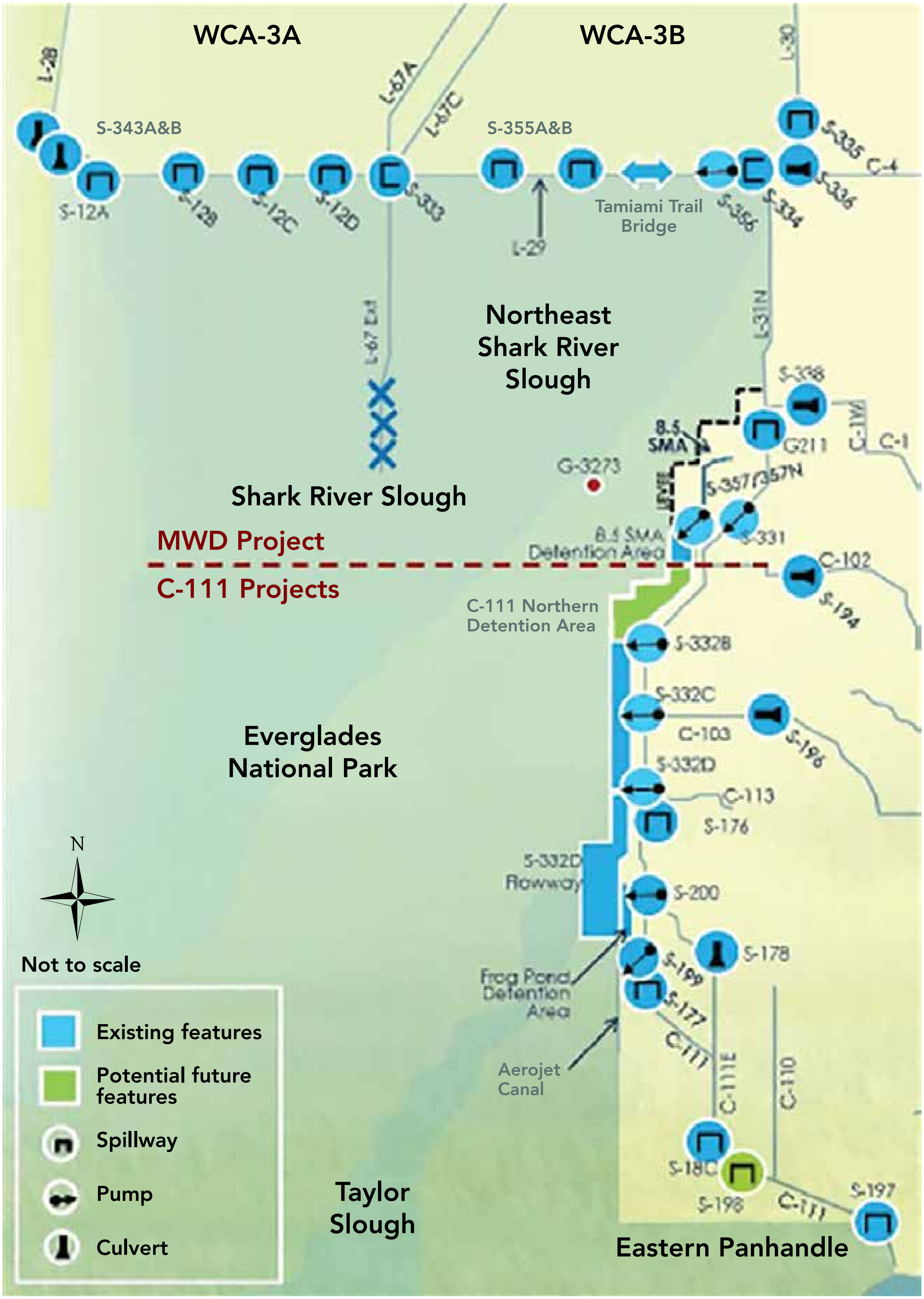


Figure 2.18. Location and elements of the MWD project (NRC 2016 Biennial Review).

Since the start of the MWD field tests stage levels within NESRS have routinely exceeded the upper quartile (top of blue band) of the 2002–2015 operational, pre-project baseline conditions, including prolonged durations above the pre-project baseline maximums (Figure 2.19). Two of the three highest annual inflow volumes to NESRS (since water year 2003) have occurred since the start of the field test in water year 2016.

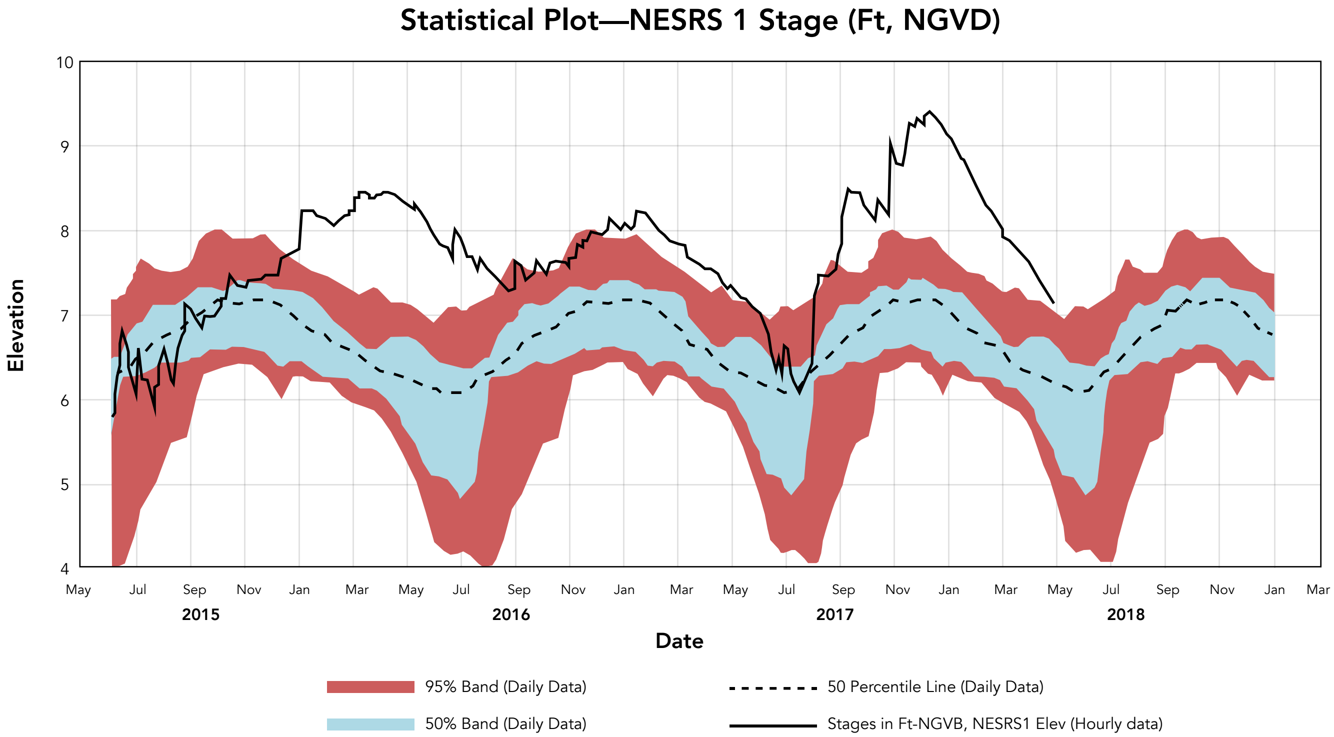


Figure 2.19. NESRS-a Stages during MWD field test period compared to the pre-project baseline (2002–2015).

Decompartmentalization Project

The purpose of the Water Conservation Area 3A Decompartmentalization and Sheetflow Enhancement Project is to hydrologically reconnect a significant component of the Everglades and restore sheetflow and water movement in the Everglades landscape. This project includes modification or removal of levees, canals, and water control structures in Water Conservation Area (WCA)-3A. This area is a 786 square-mile labyrinth of tree islands set in a matrix of wet prairies, sawgrass ridges, and aquatic slough communities.

Restoration of natural hydrologic conditions in the Everglades requires removing miles of levees and backfilling canals. This is a process known as decompartmentalization which is at the core of the effort to restore the Everglades. Decompartmentalization is needed to restore the sheetflow that created and sustained the Everglades as a "river of grass". When the CERP was launched in 2000 no one knew exactly what characteristics of sheetflow, like depth and velocity of flow, are required to sustain the ecosystem, or how to achieve them (Sklar et al. 2009). The Decompartmentalization Physical Model (DPM) was developed to answer these questions and establish design criteria for the restoration.

The DPM is a landscape-scale, active adaptive management field test to evaluate sheetflow enhancement and canal backfilling options. It evaluates ecosystem response to sheetflow in an area that is indicative of regions that have lost microtopography and north-to-south directionality. The DPM, situated between WCA-3A and WCA-3B, consists of ten gated control culverts (S-152; max capacity 21 m^3/s or 750 cfs) on the L-67A levee, a 914-meter (3,000-foot) gap in the L-67C levee with three 305-meter (1,000-foot) canal backfill treatments. Treatment options include no backfill, partial backfill, and complete backfill using adjacent levee material (Figure 2.20).

Figure 2.20. The DPM is situated between WCA-3A and WCA-3B. The distance between the L-67s is 1.2 mi (1.9 km) (adopted from SFWMD and USACE facts & Information sheet, Sep. 2014).

DPM compares three baseline years and four flow events, which started in fall 2013 (November–December, WY2014), 2014 (November–January, WY2015), 2015 (November–January and February–May, WY2016), and 2016 (October–January, WY2017). Fish responses to changes in habitat connectivity by canal filling and levee removal were evaluated separately for small (<8 cm standard length) and large fishes (>8 cm standard length). To evaluate periphyton and algal-based responses to phosphorus load, four sites were located in open water sloughs along a flow gradient at 250, 400, 500, and 800 meters east of the S-152 structure (Figure 2.21). Artificial substrates were attached to floating racks and placed in the slough of each site.

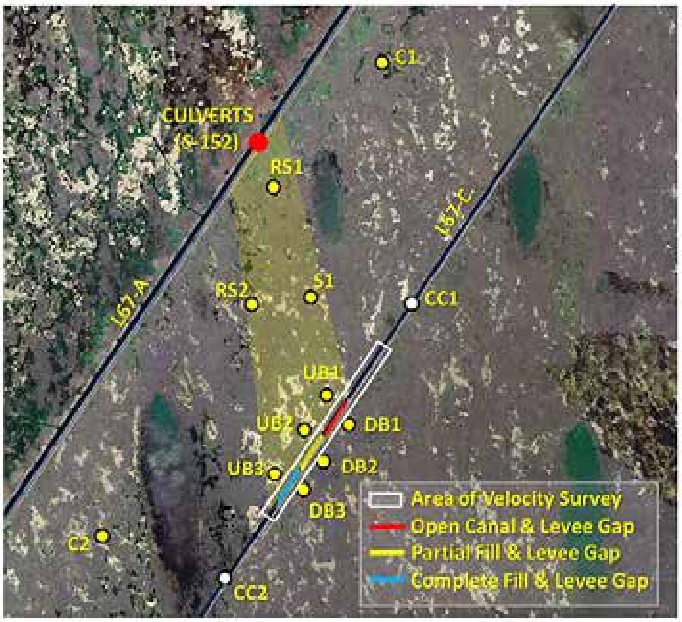
Modeling studies suggest particle transport is an essential mechanism for the development and maintenance of the Everglades ridge and slough landscape by redistributing entrained sediments (Larsen and Harvey 2011). Horizontal traps showed that higher-velocity sloughs transport significantly greater sediment transport than ridges. Transport during the high flow periods were 5-fold higher (5.9 mg/cm^2 frontal area/d) than during the baseline period (1.1 mg/cm^2/d).

Sediment transport increased 12- to 15-fold above pre-flow values. Sediment transport in the sloughs increased with time and flow velocity despite the constant discharge rates at the S-152 inflow structure. High flow may have caused slough floating periphyton to sink and disintegrate thereby reducing hydraulic resistance to flow.

Total phosphorus (TP) concentration at the site closest to the DPM inflow, E250, generally increased immediately after the structure was opened. Over time, a significant gradient in TP concentrations developed, with elevated concentrations (9 ppb) at sites closer to inflow than sites farther away (4–5 ppb). This continued one month after flow ceased. Phosphatase, on the other hand, was suppressed at the sites ≤500 m from inflow. This decreased activity during the initial month of flow indicated an increase in P availability in response to increasing flows. Though preliminary, the results suggest that even under low water TP conditions, P loading due to high velocities may be important in governing algal community type and biomass, and the production and cycling of organic matter and P.

Concerning the effect on fish: fish density was up to 300% greater in plots adjacent to fill treatments, compared to a 50% increase at no fill and control sites. Hydroscape alteration changed small fish movement behavior in 5 of 8 species examined. Fill treatments increased the area of vegetated habitat supporting high fish density and species composition similar to the littoral zone of the canal control areas.

DPM has another 3–4 years of data collection before findings can be conclusive. The findings that appear most significant currently include: 1) Surface water flows are not following the historic ridge and slough flow-paths; 2) Sustained flows and high velocities can rebuild the ridge and slough topography, increases in TP loads in the sloughs cause a food-web change that still needs to be evaluated; and 3) Canals with limestone fill can prevent sediment build-up, improve habitat quality for fish, cap the legacy phosphorus and reduce sediment phosphorus transport downstream.



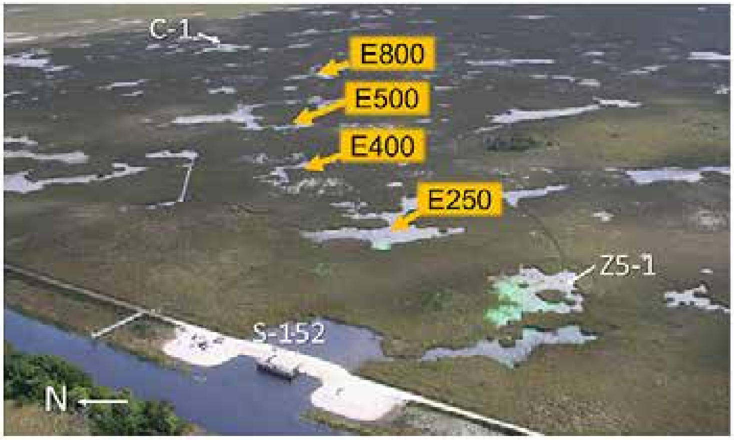


Figure 2.21. DPM study located between the L-67A and L-67C canal/levees, showing 11 marsh and 5 canal sites (left). Area outlined in white indicates location of spatial survey of velocities along the L-67C canal. Location of east transect sites (highlighted in orange) for additional monitoring of P loading effects on periphyton communities (right). (Note: green-colored water at site Z5-1 is a fluorescein dye used to track flow.)

Active Marsh Improvement Plan

The Active Marsh Improvement Program was established with the recognition that restoration of areas impacted by high phosphorus requires not only a reduction in phosphorus loads and concentrations, but also active management efforts to promote the replacement of invasive vegetation with native vegetation (Hagerthey et al. 2008, Newman et al. 2017b). Several projects have been conducted within this program, including the Cattail Habitat Improvement Project (CHIP) and Active Marsh Improvement (AMI) Projects 1–3. AMI has also been incorporated into the DPM project (Section 2.6). Data obtained from these projects contribute significant findings to key restoration uncertainties.

Vegetation management effects on flow paths
In areas of dense vegetation, restoration of flow alone is not expected to recreate a historic ridge and slough landscape without intervention. Application of a broad-spectrum herbicide (glyphosate) to open up these areas was effective in increasing flow speed, changing flow direction, and increasing the spatial extent of flow restoration within the DPM footprint in WCA-3B. This increased flow velocities radially from ~500 m from the S-152 inflow to >1000 m from inflow (Figure 2.22. Zweig et al. 2017; Zweig et al. 2018).

Vegetation management effects on plant communities
If the vegetation community is dominated by *Typha*, restoration of more desirable plants can be achieved using imazamox, which successfully treats *Typha*, with limited non-target damage (Rodgers & Black 2012). In the case of CHIP, after initial treatments with broad spectrum herbicide and fire, which produced a submerged aquatic vegetation (SAV) and algal community, a switch to imazamox resulted in greater plant diversity, as documented by the establishment of extensive *Eleocharis* spp. communities (Newman et al. 2017a).

Vegetation management effects on biogeochemistry
One of the most immediate benefits of vegetation removal in dense emergent marsh areas was an increase in average dissolved oxygen concentrations (Hagerthey et al. 2014). However, in nutrient enriched areas, there were also some anticipated initial negative biogeochemical responses. In CHIP, the vegetation management activity caused a significant increase in the TP content of the floc layer, attributable to the mass load of detritus to the sediment from the vegetation that was below the water surface upon burning (Newman et al. 2017a). The increase was greater in the most enriched, compared to moderately enriched (transitional), plots due to higher original nutrient content in those areas. However, 10 years since project initiation, new sediments produced by SAV have lower TP contents than adjacent *Typha* dominated areas (Newman et al. 2018). In low nutrient environments, vegetation management may produce a short-term nutrient pulse similar to a wildfire, but to what extent is unknown.

South Florida Water Management District

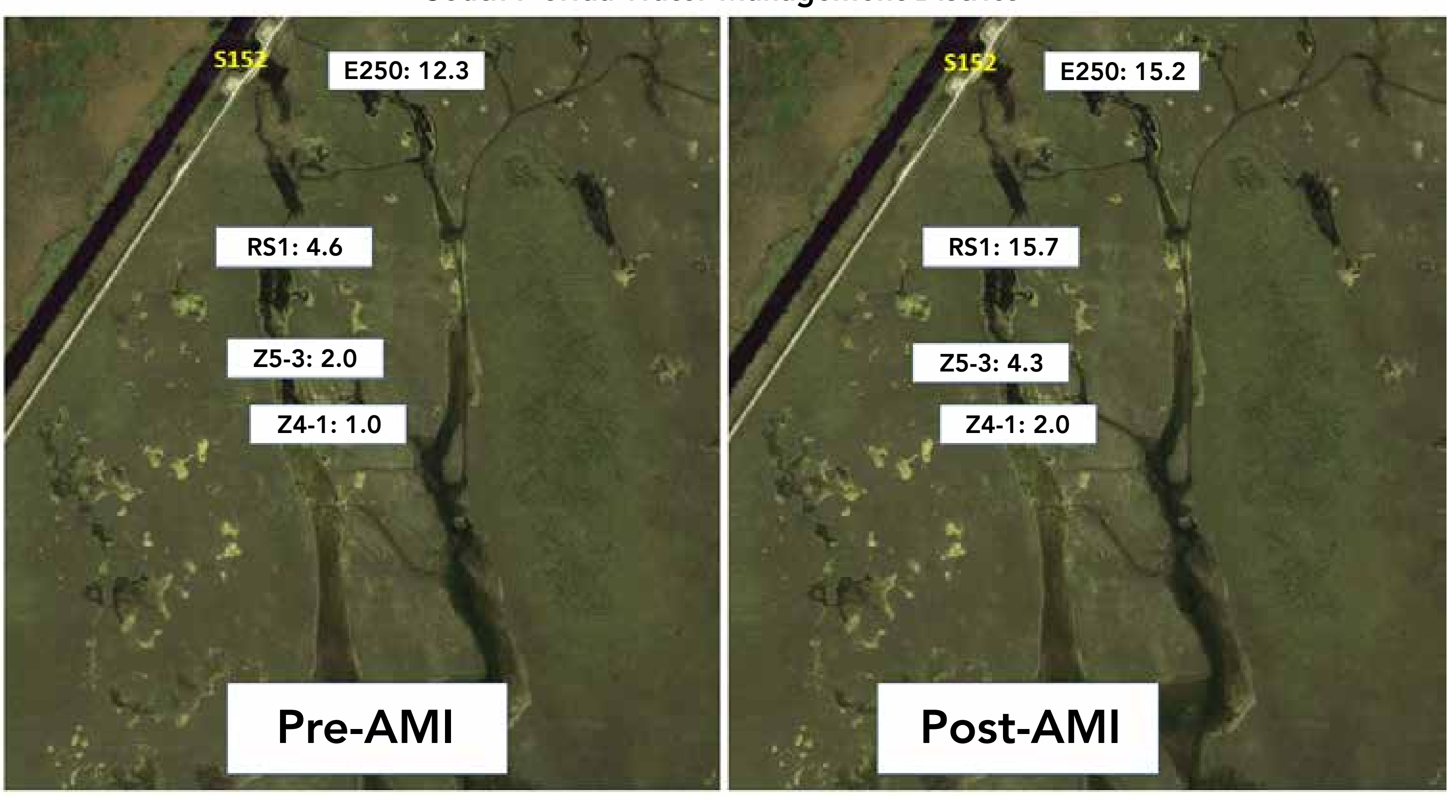


Figure 2.22. Flow velocities (cm/s) downstream from the S-152 structure pre- (left panel) and post- (right panel) implementation of active vegetation management.

Vegetation management effects on aquatic faunal use

A key benefit of vegetation management is the faunal response. Habitat created by vegetation management strategies in nutrient enriched areas has proven highly attractive to foraging wading birds (Newman et al. 2017a). Birds in the eutrophic regions foraged in large numbers for many weeks while in the oligotrophic region peak feeding time was limited. Wading bird foraging in AMI is not constrained by the typical mechanisms that drive prey availability in the Everglades such as water level recessions and shallow conditions that function to concentrate limited prey resources (Frederick et al. 2009). Birds in AMI foraged effectively over a greater range of hydrological conditions, including during water-level reversal events and with deeper conditions. AMI therefore plays a critical role as a refugia for foraging birds when hydrologic conditions preclude effective foraging elsewhere in the ecosystem.

Active marsh improvement studies suggest that vegetation management has a strong influence on ecosystem restoration, ranging from increasing flow velocities, to biogeochemical changes, to faunal responses. Given the potential for different temporal responses, adaptive management needs to evaluate vegetation management strategies over both the short and long-term.


Indian River Lagoon. Photo by Leesa Souto.

NORTHERN ESTUARIES

3.1 INTRODUCTION

The Northern Estuaries (NE) region includes the St. Lucie Estuary (SLE) and the southern Indian River Lagoon (SIRL) and the Loxahatchee River and Estuary (LRE) both on the Atlantic coast, and the Caloosahatchee River and Estuary (CRE) on the Gulf coast (Figure 3.1). These estuaries were historically altered in the volume, distribution, circulation, and temporal patterns of freshwater inflows via Central and Southern Flood Control District (C&SF) canals, and subsequent urban and agricultural development after enhanced flood control and drainage throughout the region (RECOVER 2007a). Under current conditions, lack of sufficient storage in the watersheds and regulation of water levels in Lake Okeechobee disrupts the inflow of freshwater to the estuaries. This alters the salinity regime, causing degradation of habitat and harm to resident species. Estuarine species require conditions in which salinity is variable and ranges from oligohaline to polyhaline depending on the species. Following wet season rains and tropical storm events (hurricanes), flood control measures result in extreme high flows of freshwater from the watershed and regulatory releases from Lake Okeechobee, causing these brackish water systems to become fresh for extended durations. Further, water supply demands may result in extreme low inflows during the dry season, especially during drought years. This results in higher salinities not conducive to support brackish water species. CERP restoration projects aim to regulate freshwater inflows and establish beneficial salinity regimes by creating additional water storage and allowing greater flexibility in watershed and Lake Okeechobee operations (RECOVER 2007a, 2014a).

St. Lucie Estuary and Southern-Indian River Lagoon

The St. Lucie Estuary (SLE) and the southern Indian River Lagoon (SIRL) are located on Florida's southeast coast. The SLE intersects the SIRL at the St. Lucie Inlet, an outlet to the Atlantic Ocean, in Stuart, Florida. The western boundary of the SLE extends to open-channel headwaters of the north and south forks, with inflows from Lake Okeechobee coming through S-80 in the C-44. There is also an extensive influence from the watershed in the SLE—the watershed-to-estuary ratio is high (about 100:1; SFER 2018) due to urban and agricultural development and the accompanying drainage canal network (Sime 2005). The entirety of the Indian River Lagoon (IRL) exceeds the bounds of the RECOVER program: it is approximately 251 km long,

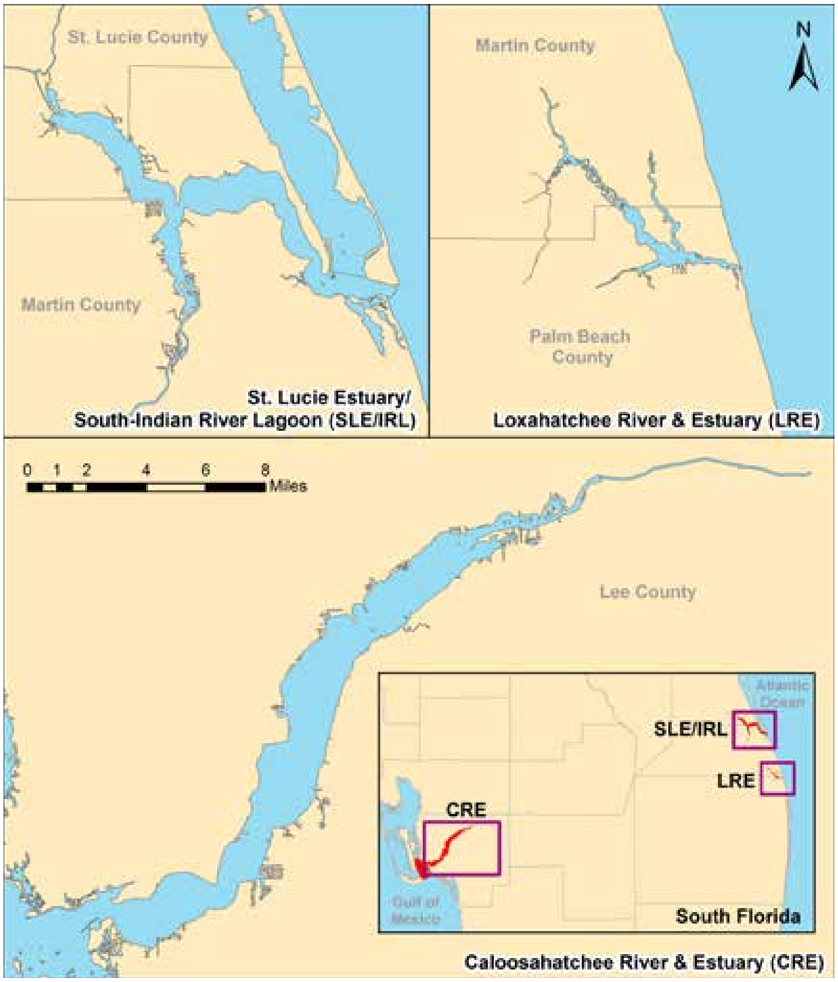


Figure 3.1. The Northern Estuaries region of the CERP RECOVER program. The South Indian River Lagoon (SIRL), St. Lucie Estuary (SLE), and Loxahatchee River and Estuary (LRE) are on the southeast Atlantic coast of Florida; and the Caloosahatchee River and Estuary (CRE) is located on the southwest Gulf coast of Florida.

running south from the Ponce de Leon Inlet in Volusia county to Jupiter Inlet in Palm Beach County. The SIRL extends from the northern St. Lucie County line north of the Ft. Pierce inlet, and south to the Jupiter Inlet (Sime 2005). The distinction between SIRL and the greater IRL is jurisdictional, and coordination with agencies monitoring the remainder of the IRL is ongoing.

As with all the Northern Estuaries, ecological stressors on the SLE include a highly variable salinity. The SLE usually receives sufficient inflows directly from the watershed during the year, except in severe multi-year droughts. High flows and extreme high inflows from the watershed and from regulatory Lake Okeechobee releases, as a response to heavy rain and tropical storm events, are the primary stressors.

For example, since 2004, there have been five major die-offs in SLE oysters following significant rain associated with El Niño and hurricanes, the most recent occurring following Hurricane Irma in September 2017. There has been recovery following past-die-offs in the SLE, and the estuary is expected to recover. However, without sufficient recovery and if die-offs become more frequent, oysters could decline due to loss of substrate and larval availability.

Loxahatchee River and Estuary

The Loxahatchee River and Estuary (LRE) is located south of the SLE in Southern Martin and Northern Palm Beach Counties, and intersects with the southern terminal of the SIRL at the Jupiter Inlet. Its watershed-to-estuary ratio is the largest of the Northern Estuaries (175:1). Historically, the Loxahatchee River and its watershed included 565 km^2 of inland sloughs and wetlands, including pine flatwoods, cypress sloughs, hardwood swamps, marshes, and wet prairies (VanArman et al. 2005). Large areas within this footprint have been developed for urban and agricultural land uses. Today, approximately 435 km^2 of the original watershed drains to the Atlantic Ocean instead of through its historical, natural topography into wetlands and eventually to the Loxahatchee Estuary and Indian River Lagoon (VanArman et al. 2005).

As with the other Northern Estuaries, development, urban and agricultural land use, and changes to hydrology affect the distribution of valued ecosystem components (VEC). The river has become more estuarine due to a lack of sufficient freshwater inflows into the Northwest Fork, and a substantial shift in riverine floodplain vegetation has regressed upstream with the intrusion of salt water. CERP projects such as the Loxahatchee River Watershed Restoration Project (LRWRP) aim to restore greater inflows to establish a fresh water to brackish water gradient. This gradient will support both riverine floodplain vegetation and is expected to reestablish submerged aquatic vegetation, like *Vallisneria americana*, which is excellent habitat for juvenile fish and invertebrates and food for manatees. In addition to the RECOVER program monitoring in the LRE, the Loxahatchee River District (LRD) has an extensive program for the management and monitoring of water and its natural resources (see Section 3.3).

Caloosahatchee River and Estuary

The Caloosahatchee River and Estuary (CRE) is located on Florida's southwest coast and extends 105 km from Lake Okeechobee to San Carlos Bay, entering the Gulf of Mexico near the city of Fort Myers, Florida (Barnes 2005). The freshwater component from Lake Okeechobee extends to the S-79: one of three lock-and-dam structures constructed to control river flow and stage height. The S-79 serves as an impediment to tidal influence and saltwater intrusion, which historically would affect the upstream environment to the town of La Belle, Florida (Barnes 2005; SFWMD 2018a). Pre-development, the river was sinuous and originated near Lake Flirt about 2 miles east of La Belle. The estuary portion of the CRE runs 42 km and has a long and narrow morphology. This configuration results in a dynamic environment.

The prominent hydrologic issues in the CRE are extreme high flows in the wet season, and extreme low-flows in the dry season. High flows may impact oyster and marine SAV species (e.g. *Halophila, Halodule,* and *Thalassia*) in the lower estuary by affecting both the salinity regime and the light environment via colored dissolved organic matter or sediment resuspension and turbidity. Freshwater SAV species such as *Vallisneria americana* (commonly referred to as "Tape Grass" or "American Wild Celery") may be inhibited by higher salinities than it can tolerate during periods of low to no freshwater inflow, and oysters may suffer from stress and disease related to high salinity-high temperature interactive effects, especially during drought.

Conceptual Ecological Models

Conceptual ecological models (CEMs) are non-quantitative tools for managers and others to understand the complexity of the Everglades ecosystem and responses to natural and anthropogenic stresses, to support scientifically informed decision making. The RECOVER program developed a series of CEMs in 2005 for each ecosystem within each RECOVER module, which were all published in a special edition of the journal *Wetlands*. Additionally, the 2009 Monitoring and Assessment Plan (MAP) included hypothesis cluster CEMs, which are specific to ecological attributes monitored under RECOVER. The CEMs define and describe external drivers and ecological stressors for each estuary, ecological effects on system attributes which include oysters, submerged aquatic vegetation, and benthic infauna. Ongoing monitoring efforts, data, and other research can be used to improve understanding of ecosystem dynamics in response to anthropogenic activities and stressors such as water management. RECOVER is finalizing an update to regional (Northern Estuary) and hypothesis cluster CEMs (oyster, SAV) in 2019. These updates will aid in the review of the MAP as part of RECOVER's Five Year Plan (2017–2021).

RECOVER monitoring began in 2003 and has continued under a variety of climatic conditions and during Water Years with highly variable freshwater inflows. For additional information beyond this SSR on the history of the Northern Estuaries, regional monitoring, research projects, and planning and project status for the Northern Estuaries within and outside the scope of RECOVER, see previous System Status Reports (RECOVER 2007b, 2010, 2012, 2014a) and the SFWMD South Florida Environmental Report (SFER 2018 section 3.1.5).

The shared characteristic across the NE as a result of water management is an altered salinity regime. Salinity is a metric used to interpret ecological responses to changes in freshwater inflow (RECOVER 2007c). The valued ecosystem components within the NE, including oysters, submerged aquatic vegetation (SAV), and benthic infauna are important to a functioning ecosystem for the ecological and economic services they provide. For example, oysters are natural "filters" and can improve water quality by reducing nutrients, particulate matter, and controlling phytoplankton (Cerco & Noel 2007; Buzzelli et al. 2012). Valued ecosystem components in the NE are adapted to the natural variability of an estuarine salinity regime, but salinity extremes for extended durations can have significant negative impacts on their health and physiology. The continuous record of monitoring throughout the NE gives water managers and natural resource practitioners an opportunity to observe the state of the system over extended temporal and spatial scales.

3.2 KEY FINDINGS

In general, the indicators for the Northern Estuaries are in fair to good condition (Figure 3.2). SAV declined or remained stable at low densities in all regions of the Northern Estuaries. Oyster scores ranged from poor to good throughout the five years, with mostly fair scores. A cycle of salinity perturbations negatively affects oysters and causes increased disease and reduced survivorship. When salinity conditions are favorable, oysters temporarily rebound. Oysters can be resilient to stress, however with increasing variability they could decline overall. Benthic infauna were in good condition, while salinity and chlorophyll *a* were in good to fair condition. The Northern Estuaries are impacted by human control of flows that alter volume, distribution, circulation, and temporal patterns of freshwater inflows and natural events like hurricanes, El Niño, and drought. These cause sub-optimal salinities that have negative impacts on submerged aquatic vegetation (SAV), oysters, and benthic infauna.

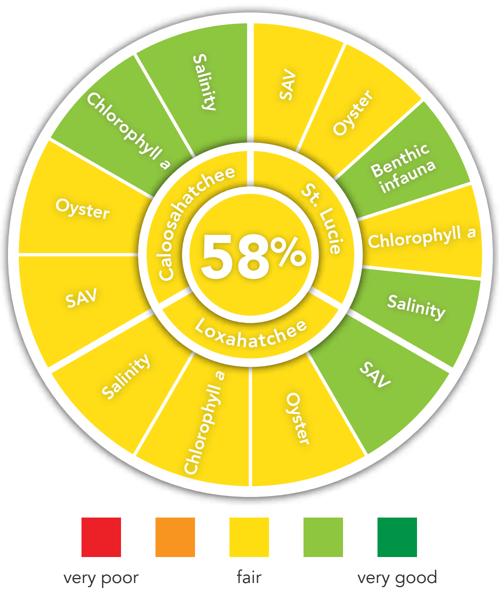


Figure 3.2. Northern Estuaries indicator scores from the 2012–2017 Everglades Report Card.

While there were several events in which salinities were observed as too-high or too-low for either estuary's respective ecological indicators, these suboptimal salinity condition events average out over the 5-year period of record (POR) in the Report Card scores, explaining their "Fair" to "Good" status. Meanwhile, the effect of these high and low salinity events is seen more explicitly in some scores of the indicators such as SAV and oysters, despite the 5-year averaging. This is because it takes longer for ecological indicators to rebound following high and low salinity events—over months or even years—whereas salinities can reach a more suitable range estuary-wide within days or weeks.

- SAV generally declined or remained stable in low densities over the reporting period between estuaries across south Florida, which is consistent with a greater, regional trend in SAV decline in other systems such as the North Indian River Lagoon.

- Oyster populations continue to be negatively affected by the highly variable freshwater inflows that are a result of altered hydrology. CERP projects which incorporate reservoirs and stormwater treatment areas within local watersheds (e.g. Indian River Lagoon-South (IRL-S) and C-43) will decrease inflows into the estuaries from local runoff.
- Periods of extremely low salinities in WY2014 resulted in large-scale mortality of oysters in the SLE. The magnitude, timing and duration of low salinity events strongly affects the recovery time of oyster populations. However, past monitoring indicates that oysters recover when salinities return to favorable conditions for both adult and larval oysters.
- While mesohaline salinities are considered most favorable for oysters, there is evidence that brief periods of lower salinities can reduce disease rates and increase reproductive capacity (La Peyre, 2003). This highlights an important tradeoff for oysters living in these dynamic systems, and the importance of baseflows that will be provided by future reservoirs such as the C-43 on the Caloosahatchee River.
- Benthic infauna in the SLE and SIRL demonstrated clear differences in their community composition as a result of salinity regime and sediments. There is less species diversity at sites with fine-grained, high-water content sediment. This information will help inform the schedule of component construction of the IRL-S which incorporates fine-grained sediment removal.
- Salinity variability continues to be an issue affecting plants and animals as can be seen in the scores of the salinity and the indicators. While the salinity score was good as averaged over the period of record, the indicators were impacted by the high and low salinities, of which the effect of the salinity changes are seen in the indicator scores. CERP projects north and south of Lake Okeechobee (e.g. Lake Okeechobee Watershed Restoration Project (LOWRP) and Central Everglades Planning Project (CEPP), respectively) will allow for operational flexibility by providing additional water storage. This includes diverting water that is currently sent to tide, therefore protecting the estuaries from critically-low salinity, and providing supplementary flows during the dry season and in droughts to prevent saltwater intrusion which effect oligohaline or freshwater species upstream.
- Chlorophyll *a* (chla) scores, a proxy for phytoplankton abundance, capture high-precipitation events by detecting changes from the long-term median. Very poor to fair chla scores are evident following the 2004 hurricanes, and at multiple stations following the 2016 El Niño and Hurricane Irma in 2017.
- These estuaries continue to serve as important habitat for commercially and ecologically important fish, including the endangered smalltooth sawfish, highlighting the importance of maintaining salinity regimes conducive to fishes at specific life history stages.

3.3 INDICATORS

SALINITY AND TEMPERATURE

Because salinity is the primary driver of suitable conditions for the ecological indicators monitored in the Northern Estuaries program, an analysis of salinity and temperature was conducted for the SSR and incorporated into the Everglades Report Card. For this exercise, the salinity envelope used as the standard for scoring was 10–20 ppt, which is based on optimum salinity conditions for the eastern oyster (*Crassostrea virginica*) at specific locations for each estuary. Based on previous modeling efforts, it is generally assumed that, if salinity conditions at these locations are sufficient for oysters, that these conditions would also be suitable for other ecological indicators. This salinity envelope is derived from the 2007 RECOVER Northern Estuaries Salinity Envelope Performance Measure (RECOVER 2007c), and is based on flow envelopes that create the salinities desired at specific locations in the estuaries. Flows were classed into sized flow events and flow events were subsequently correlated to representative median salinities. The target salinity gradients in St. Lucie Estuary were determined by a hydrodynamic salinity model (Morris 1987) combined with estimates of salinity requirements for two indicator species in the estuary: shoal grass (*Halodule wrightii*) and American oyster (*Crassostrea virginica*). While the salinity envelope Performance Measure is based on flows as described above, flow targets are effectively proxies for salinity conditions at specific locations for each estuary. A future update to the Northern Estuaries Salinity Envelope Performance Measure is currently under review and will include a more estuary-wide analysis conducive for multiple VEC species.

St. Lucie Estuary

For the SLE, the 10–20 ppt salinity envelope for oysters is at the Roosevelt Bridge, which is located at the junction of the North Fork, South Fork, and middle estuary (preferred salinity range for the mid-estuary) (Figure 3.3). Salinity and water temperature readings were recorded by data loggers deployed at three sites in the SLE: the Roosevelt Bridge in the middle estuary, the HR1 station in the North Fork, and the Palm City Bridge in the South Fork (Figure 3.3). Temperature and salinity data are not available for the North Fork in WY2014, salinity data is not available for the South Fork from WY2013 to WY2015, and temperature data is not available for the South Fork for all WYs.

Figure 3.3. Water temperature and salinity data loggers (red cylinders) in the North Fork (HR1), South Fork (Palm City Bridge (PC)) and Middle Estuary (Roosevelt Bridge (RB)) of the St. Lucie Estuary on the southeast coast of Florida.

Mean daily water temperatures at the three data logger locations from WY2013–WY2017 reflected typical seasonal patterns with maxima in the summer months ranging from 31° to 33°C and minima in the winter months ranging from 14° to 18°C. The mean temperatures during each WY at the middle estuary and north fork stations were similar and ranged from 24° to 26°C. Mean daily salinities were much more variable at the three logger stations (Figure 3.4). The mean salinity for each WY was within the optimal range during all years salinity and temperature at the Roosevelt Bridge site and during all years except WY2016 at the North Fork site. Mean salinity at the South Fork site was below the optimal range in all years when data was available (WY2016 and WY2017).

Although WY means were often within the optimal range, there were occurrences from WY2013–WY2017 when salinities at one or all the SLE data logger stations fell below or exceeded the optimal range for an extended period (>100 days). These events occurred in WY2014 (June–October; 126 days) and WY2016/2017 (February–November; 209 of 264 days) in the middle estuary. Similar excursions below the optimal range were also recorded in the North Fork in WY2016/2017 (January–November; 303 days). At the South Fork station, salinities were below the optimal range in all but nine days of WY2016, and for 220 days of WY2017. Prolonged excursions above the optimal range occurred in WY2012/2013 (January–July; 178 of 189 days) in the middle estuary and in WY2017/2018 (November–June; 205 days) in the middle estuary and North Fork.

It is important to consider both temperature and salinity when characterizing the estuarine environment as the interaction of the two can greatly influence the resilience and survivorship of local estuarine organisms. Many of the species present in the SLE are commonly exposed to temperatures near their upper physiological tolerance limits and when those organisms are subjected to environmental conditions that meet or exceed those tolerance limits, their energetic capacity to deal with additional stress, such as low salinity or disease, is diminished or lost. In most WYs, low salinity events occurred during the summer months when water temperatures were maximal, thus maximizing physiological stress. In addition, those low salinity events

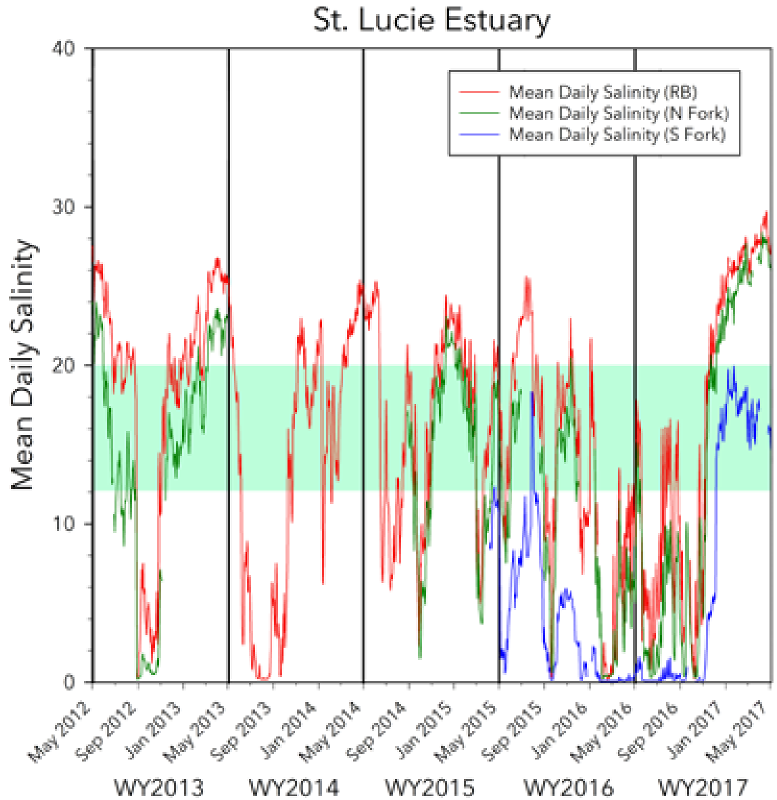


Figure 3.4. Mean daily salinity measured at the US-1 Roosevelt Bridge, HR1 in the North Fork, and at the Palm City Bridge in the South Fork of the SLE. The green band represents the salinity range deemed most favorable for survival and health of juvenile marine fish, oysters and SAV.

were often preceded by a period with above optimal salinities. This variability can compound the problem because rapid shifts between high and low salinity regimes reduce the opportunity for acclimatization by estuarine inhabitants.

Estuarine populations in the SLE continue to be negatively affected by the highly variable freshwater inflows, and associated salinity fluctuations, that are a result of the altered hydrology. The biological responses of estuarine organisms to these salinity fluctuations vary depending on the timing, magnitude and duration of the salinity excursion. Periods of extremely low salinities result in acute damage to biological populations. Extended periods of high salinities result in gradual increases in disease and predation rates that compromise the health and survivorship of local inhabitants. In the SLE, low salinity events have had the most devastating impact on estuarine organisms, but extended periods of high salinities have also occurred. While the salinity scores over the POR were "good", the effect on the SAV and oysters were "fair" due to the response time and the ability to recover from salinities outside the salinity envelope.

Loxahatchee River and Estuary

For consistency of scoring, the salinity envelope of 12–20 ppt (RECOVER 2007c) was employed for analysis of estuarine conditions at specific locations within the estuary (see above). In the Northwest Fork the specific assessment parameter and targets have been identified, which will result in a downstream shift in the typical location of the saltwater wedge (to approximately river mile 7.5). Manatee grass (*Syringodium filiforme*) is a highly productive seagrass species occurring in the Loxahatchee River estuary, and past studies have shown manatee grass to be susceptible to altered freshwater discharges and excessive salinity fluctuations (SFWMD 2006; Ridler et al. 2006). Therefore, the following salinity threshold target with duration is established for manatee grass at river mile 1.74: ≤15 ppt for 6 days, because mean daily salinity ≤15 ppt for 6 days (over a 30 day period) resulted in significant mortality of *Syringodium filiforme* in the Loxahatchee River estuary, thus using the SLE salinity targets is appropriate.

Salinity and water temperature readings were recorded by data loggers deployed in the NW Fork, SW Fork, and near the junction of the two forks of the LRE by the Loxahatchee River District (Figure 3.5). Mean daily water temperatures at the three data logger locations from WY2013 to WY2017 reflected typical seasonal patterns with maxima in the summer months ranging from 31˚ to 33˚C and minima in the winter months ranging from 16˚ to 20˚C.

Figure 3.5. Water temperature and salinity data loggers (red cylinders) in the Northwest and Southwest Forks of the Loxahatchee River Estuary on the southeast coast of Florida; NW Fork (OY), SW Fork (72), and at the junction (PP) of the two forks in the LRE.

The mean temperatures during each WY at the NW Fork and SW Fork stations were similar and ranged from 26˚ to 27˚C. Mean daily salinities were much more variable at the three logger stations, where values from WY2013 to WY2017 ranged from <1 to 38 (Figure 3.6). The mean salinity for each WY was within the optimal range during all years in the Northwest Fork, but consistently exceeded the range in the Southwest Fork and at the junction between the two forks. In fact, mean salinity at the junction exceeded 30 in all water years. This exceedance of the salinity range can be seen in the ecological indicator scores.

More detailed examination reveals that in most WYs, salinities exceeded the optimal range for 300 or more days in the SW Fork and at the junction. The one exception occurred in the SW Fork in WY2018 when that number was reduced to ~250 days; salinities were within the optimal range for 59 days and below the optimal range (following Hurricane Irma) for 55 days in the SW Fork during WY2018. Salinity at the junction station was only within the optimal zone a total of 14 days from WY2012 through WY2018. In the NW Fork, mean daily salinity exceeded the optimal range 170 days per year, fell within the optimal range 125 days per year, and was below the optimal range 60 days per year. Exceptions occurred in WY2014 when there were a greater number of days (127) below the optimal range and in WY2017 when there were very few days (19) below the optimal range.

Recorded water temperatures were similar and as expected at the three data logger stations in the LRE. Many of the species present in the LRE are commonly exposed to temperatures near their upper physiological tolerance limits, and when those organisms are subjected to environmental conditions that meet or exceed those tolerance limits, their energetic capacity to handle additional stresses, such as high salinity and disease, are diminished or lost.

Estuarine populations in the LRE, particularly those that require a specific salinity range, continue to be negatively affected by the variable freshwater inflows, and associated salinity fluctuations, that are a result of the altered local hydrology. The biological responses of estuarine organisms to these salinity fluctuations vary depending on the timing, magnitude, and duration of the salinity excursion. Extended periods of high salinities can result in gradual increases in disease and predation rates that compromise the health and survivorship of local inhabitants. High salinities are a persistent problem in the LRE where freshwater inflows have not been of sufficient magnitude or duration to lower salinities and provide relief from predation and disease pressures. In the LRE, salinities typically exceed the optimal salinity range and only fall within the range intermittently during the wet season. While the salinity scores over the POR were "good", the effect on the SAV and oysters were "fair" due to the response time and the ability to recover from salinities outside the salinity envelope.

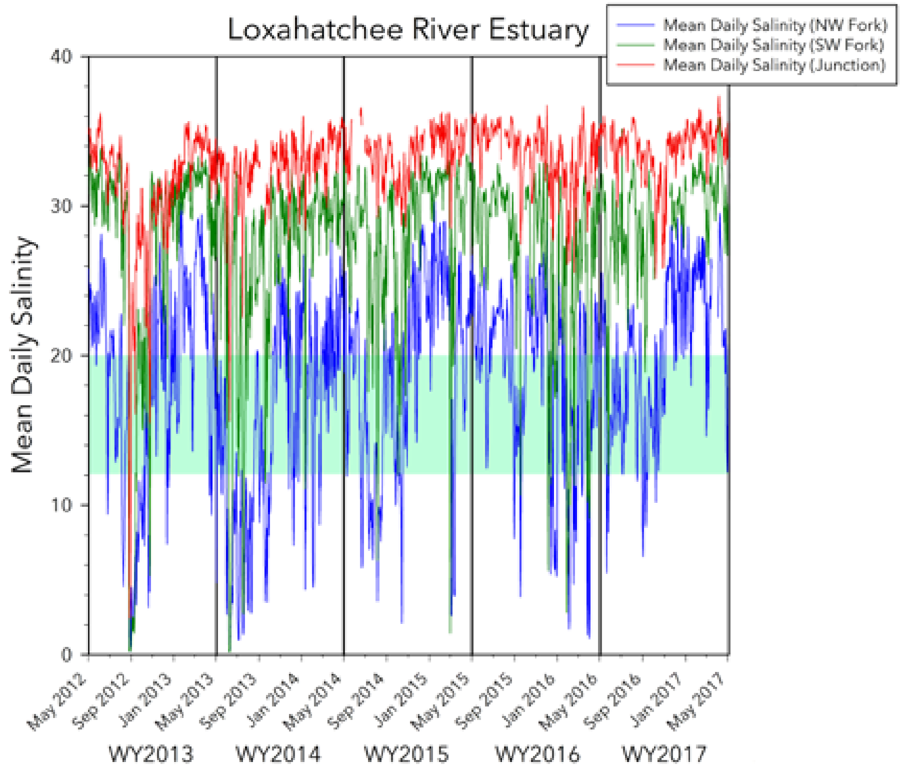


Figure 3.6. Mean daily salinity measured at loggers deployed in the NW Fork (OY), SW Fork (72), and at the junction (PP) of the two forks in the LRE (Loxahatchee River District data). The green band represents the salinity range most favorable for survival and health of juvenile marine fish, oysters, and SAV.

Caloosahatchee River and Estuary

For consistency of scoring, the salinity envelope of 12–20 ppt (RECOVER 2007c) was employed for analysis of estuarine conditions at specific locations within the estuary (see above). The CRE salinity envelope performance measure is based on optimization model outputs, natural variation that would occur during the period 1965–2000, and desirable salinity conditions for existing and potential aquatic resources within the CRE. Targets are based on freshwater discharges from the C-43 canal at the S79 structure to ensure that the average monthly salinity at Ft. Myers (Yacht Basin) is between 10 ppt and 20 ppt based on the targets for *Vallisneria americana*, (tape grass) and *Crassostrea virginica* (American oyster). Therefore, using the SLE salinity targets is appropriate.

Salinity and water temperature readings were recorded by data loggers deployed at upstream and downstream locations by the South Florida Water Management District (Figure 3.7). Mean daily water temperatures at the two data logger locations from WY2013 to WY2017 reflected typical seasonal patterns with maxima in the summer months ranging from 31˚ to 33˚C and minima in the winter months ranging from 13˚ to 17˚C. The mean temperatures during each WY at the upstream and downstream stations ranged from 25˚ to 26˚C. Mean daily salinities were more variable at the two logger stations, where values during WY2013 to WY2017 ranged from <1 to 38 (Figure 3.8). The mean salinity by WY was rarely within the optimal range at either the upstream or downstream locations. Mean salinities at the upstream location were often below the optimal range while those at the downstream location exceeded the optimal range. Exceptions occurred at the upstream location in WY2013 and WY2015 when means were within the optimal range (13–19 ppt).

In WY2013 and WY2015, conditions were moderate as salinities were within the optimal zone at the upstream location an average of 190 days and at the downstream location for 46 days. There were extended excursions below the optimal range in WY2014 (July–September) and WY2016/2017 (February–November 2016).

Figure 3.7. Water temperature and salinity data loggers (red cylinders) in the Caloosahatchee River Estuary on the southwest coast of Florida.

Recorded water temperatures were similar and as expected at the two data logger stations in the CRE. Many of the species present in the CRE are commonly exposed to temperatures near their upper physiological tolerance limits and when those organisms are subjected to environmental conditions that meet or exceed those tolerance limits, their energetic capacity to deal with additional stresses, such as low salinity or disease, is diminished or lost. In those WYs with low salinity events, they occurred during the summer months when water temperatures were maximal, thus maximizing physiological stress. In addition, those low salinity events were often immediately preceded by a period with above optimal salinities. This variability in and of itself can compound the problem because rapid shifts between high and low salinity regimes reduce the opportunity for acclimatization by estuarine inhabitants.

Estuarine populations in the CRE continue to be negatively affected by the highly variable freshwater inflows, and associated salinity fluctuations, that are a result of the altered local hydrology. The biological responses of estuarine organisms to these salinity fluctuations vary depending on the timing, magnitude, and duration of the salinity excursion. Periods of extremely low salinities result in acute damage to biological populations. Extended periods of high salinities result in gradual increases in disease and predation rates that compromise the health and survivorship of local inhabitants. In the CRE, low salinity events have had the most devastating impact, but prolonged high salinity events, especially in the lower estuary, have limited survival and growth of local estuarine organisms. While the salinity scores over the POR were "good", the effect on the SAV and oysters were "fair" due to the response time and the ability to recover from salinities outside the salinity envelope.

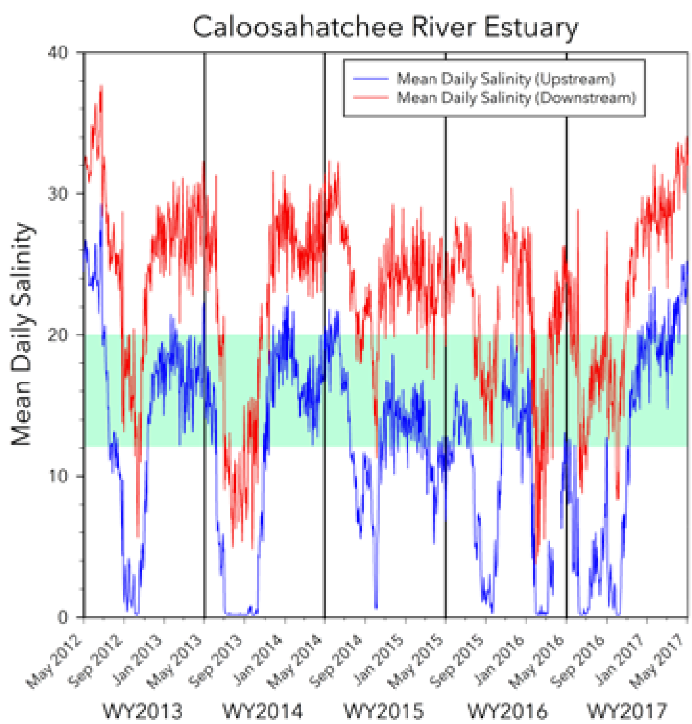


Figure 3.8. Mean daily salinity measured at loggers deployed at upstream (CC) and downstream (SP) locations in the CRE (South Florida Water Management District data). The green band represents the salinity range most favorable for survival and health of juvenile marine fish, oysters and SAV.

CHLOROPHYLL A

Water quality in St. Lucie River Estuary (SLE), Loxahatchee River Estuary (LRE), and Caloosahatchee River Estuary (CRE) was assessed based on the stoplight indicator of chlorophyll *a* (chla; a proxy measure for algal biomass standing stock (Cullen 1982; Boyer et al. 2009; Ferreira et al. 2011)) according to Boyer et al. (2009). This was the first time this method was used for the assessment of the chla indicator status in the northern estuaries. In the context of Everglades Restoration, chla indicator (also referred to as a "bloom indicator") is cautionary, helping to ensure that restoration actions cause no indirect harm to coastal ecosystems via water quality degradation.

Methods

Annual median chla (µg/L) concentrations were compared to the long-term medians at each station (station-by-station comparison) and used in assessments of the overall annual status of the indicator in each estuary (system-wide) based on the average of the annual station-specific scores. Data availability varied by stattion, ranging from 1995–2017 to 2007–2017. The long-term medians were calculated based on the monthly chla (µg/L) data available for each station. The scores were calculated based on the frequency of occurrence of the chla indicator above the long-term median. The higher the scores, the lower the frequency of occurrence of the chla indicator above the long-term median. Green color indicates very good (>80–100% score) or good (>60–80% score), yellow color indicates fair (>40–60% score), and red color indicates poor (>20–40% score) or very poor (0–20% score) chla conditions.

The Kruskal-Wallis test, a rank-based nonparametric test (distribution free), was used to determine if the median concentration of chla differed among stations. Trend analysis was used to determine whether conditions at each station are improving (chla was decreasing) or deteriorating (chla was increasing). Modified Seasonal Kendall test (Hirsch et al. 1982; Hamed & Rao 1998), was used to detect trends in algal biomass and to test the significance of the trends at 5% significance level. The number of the stations, the frequency of sampling at each station and the length of the period of record (POR) used in the assessment differed among the stations within each estuary (Table 3.1). The assessment was based on the long-term monitoring data collected by the South Florida Water Management District (SFWMD) in SLE and CRE, and Loxahatchee River Environmental Control District (LRD) in LRE.

Results

Stoplight indicator

The status of the chla indicator varied inter-annually at each station within each estuary and was moderate in all estuaries in WY2017 (Figures 3.9 a–c and 3.10 a–c). Over the past five years, annual chla medians were mostly above the long-term medians and 75th percentiles at most of the stations in SLE and LRE, and below the long-term 75th percentiles at all the stations in CRE (Figure 3.9 a–c). Concentrations were below the long-term medians at all the stations in SLE and CRE in WY2015. Over the past five years, the system-wide status was mostly fair to poor in SLE, fair in LRE, and fair to good in CRE (Figure 3.9 a–c).

Long-term trends and patterns

St. Lucie River Estuary

There were significant differences in long-term median concentrations of chla (µg/L) among stations and years ($p < 0.05$), and a significant decrease in median concentration and the range of variation was recorded in the direction of the St. Lucie Inlet ($p < 0.05$; Figure 3.9a). The long-term medians of stations HR1 and SE08 were similar ($p > 0.05$) and significantly higher than long-term medians at any other station within the estuary ($p < 0.05$). Over the past five years, the highest median chla (µg/L) concentrations were recorded at stations HR1 in WY2016 and WY2014 (10.7 and 9.6, respectively) and SE08 in WY2017 (10.7; Figure 3.9a). A significant

Table 3.1. List of sites in St. Lucie River Estuary, Loxahatchee River Estuary, and Caloosahatchee River Estuary and their associated chlorophyll a (µg/L) thresholds.

Sites	Period of record (water years)	Sampling frequency	Valid N	25th percentile	Median	75th percentile
St. Lucie River Estuary						
HR1	1996–2018	monthly	268	5.6	9.1	15.5
SE08	1996–2018	monthly	264	5.3	8.0	12.3
SE03	1996–2018	monthly	269	4.0	6.0	10.1
SE02	1996–2018	monthly	267	4.0	5.5	8.2
SE01	1996–2018	monthly	271	3.0	4.4	7.0
SE11	1999–2018	monthly	232	1.8	3.0	4.0
Loxahatchee River Estuary						
10	2007–2018	monthly	138	1.0	1.5	2.8
20	2007–2018	bi-monthly	70	1.0	1.0	1.7
30	2007–2018	bi-monthly	70	2.7	4.3	5.2
40	2007–2018	monthly	139	1.2	2.1	3.8
42	2007–2018	bi-monthly	70	3.0	4.0	5.8
51	2007–2018	bi-monthly	70	2.6	3.7	5.4
55	2007–2018	bi-monthly	67	4.5	6.2	9.2
60	2007–2018	monthly	137	3.8	5.6	7.7
62	2007–2018	monthly	136	3.6	5.9	8.5
65	2007–2018	monthly	137	2.5	4.4	6.6
72	2007–2018	monthly	139	6.4	10.1	14.9
Caloosahatchee River Estuary						
04	2011–2018	monthly	84	3.3	5.2	11.3
05	2011–2018	monthly	84	4.1	5.8	8.5
06	2011–2018	monthly	83	3.1	4.1	6.8
08	2011–2018	monthly	84	1.5	2.2	3.2
09	2011–2018	monthly	84	1.7	2.3	4.0

monotonic downward trend in chla (µg/L) data across all seasons ($p < 0.05$) was detected at station SE03. At the other stations, homogeneity test revealed that the data were non-homogenous, implying presence of the changes in mean, variance or both in chla (µg/L) concentration over time, but no significant long-term trends were detected at those stations ($p > 0.05$).

Loxahatchee River Estuary

There were significant differences in long-term median concentrations of chla (µg/L) among stations and years ($p < 0.05$; Figure 3.9b). A general decrease in mean concentration and the range of variation of chla (µg/L) was detected in the direction of the Jupiter Inlet and from the upper parts of the tributaries toward the main river channel (Figure 3.9b). Long-term median concentration was significantly higher at station 72 compared to any other station within the estuary ($p < 0.05$; Figure 3.9b). Furthermore, long-term median concentrations at stations 55, 60, 62, and 72 were significantly higher compared to stations 10, 20, and 40 ($p < 0.05$; Figure 3.9b) highlighting the differences between the brackish water and marine sites (respectively).

Over the past five years, the highest median chla (µg/L) concentrations were recorded at station 72 in WY2014 (11.5), WY2015 (11.0) and WY2017 (10.5; Figure 3.9b). A homogeneity test revealed that the data were non-homogenous, implying presence of the changes in mean, variance or both in chla concentration over time, but no significant long-term trends were detected at those stations ($p > 0.05$).

Caloosahatchee River Estuary

There were significant differences in long-term median concentrations of chla (µg/L) among stations and years ($p < 0.05$; Figure 3.9c). Long-term median chla (µg/L) concentrations were significantly higher in the upper and middle parts of the estuary (stations 4, 5, and 6) compared to the lower part ($p < 0.05$; stations 8 and 9; Figure 3.9c). Station 5 had significantly higher chla (µg/L) concentration than station 6 ($p < 0.05$; Figure 3.9c). Over the past five years, the highest annual median chla (µg/L) concentrations were recorded at station 4 in WY2013 (16.0), and at station 5 in WY2016 (8.2) and WY2013 (6.7; Figure 3.9c). A homogeneity test revealed that the data were non-homogenous, implying presence of the changes in mean, variance or both in chla concentration over time, but no significant long-term trends were detected at those stations ($p > 0.05$).

A)

Chla Indicator	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
System-wide	51	39	41	40	51	39	64	46	37	21	60	75	62	69	61	61	68	57	43	71	41	44
HR1	7.5	13.5	12.7	9.3	10.4	9.4	6.1	10.3	11.5	15.0	10.5	9.0	9.0	7.0	12.0	9.2	5.4	7.5	9.6	8.4	10.7	7.8
SE08	8.9	9.5	8.1	8.4	6.4	9.2	8.4	8.6	14.0	16.0	5.0	6.0	8.0	8.0	8.0	7.0	5.8	8.2	8.9	7.5	8.9	10.7
SE03	7.4	10.1	5.1	7.2	6.1	7.4	6.2	7.0	10.0	13.0	5.0	4.0	6.0	6.0	7.0	5.3	3.8	4.6	7.0	4.4	5.1	6.8
SE02	6.5	7.0	6.4	5.6	5.2	6.5	3.5	5.7	6.0	8.5	5.0	4.0	4.0	4.5	5.0	5.4	4.6	5.6	8.0	5.0	7.6	5.1
SE01	4.5	5.3	5.1	5.9	4.7	4.8	2.7	4.1	5.9	7.0	5.0	2.0	4.5	2.5	3.5	4.7	3.2	4.2	5.1	3.8	7.4	4.4
SE11				3.5	3.0	3.1	2.0	3.1	3.1	4.0	3.0	2.0	1.5	2.0	2.0	3.0	1.8	2.5	2.2	2.2	4.4	3.9

B)

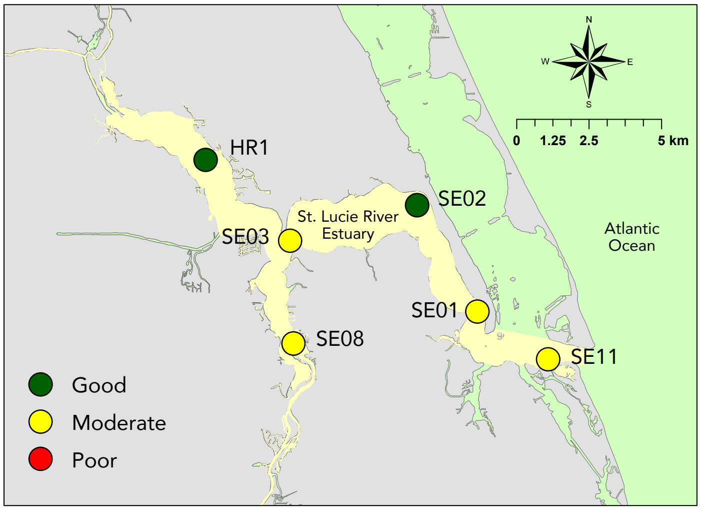
Water Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
System-wide	61	40	55	48	38	56	51	56	43	58	55
10	1.0	2.4	1.5	1.4	1.9	1.5	1.9	1.0	1.5	1.9	2.0
20	1.0	2.0	1.1	1.0	1.2	1.0	1.2	1.0	1.7	1.4	1.2
30	4.6	6.3	3.7	5.3	3.2	4.7	3.4	3.5	5.5	3.7	3.5
40	3.3	3.6	2.0	2.1	2.0	2.0	2.3	1.4	2.1	2.0	2.8
42	2.5	7.5	3.5	3.6	7.8	3.3	3.5	5.1	5.2	3.3	3.0
51	3.8	6.7	2.9	3.6	4.6	3.5	4.3	4.7	4.9	3.0	2.7
55	5.8	6.9	4.8	7.9	9.2	6.9	11.1	6.4	5.2	2.5	5.6
60	3.2	6.4	6.3	5.5	5.0	5.6	6.5	6.9	5.1	5.6	4.2
62	4.9	5.5	7.0	6.8	7.8	5.3	5.5	5.8	6.4	5.1	6.0
65	1.6	4.2	6.0	4.8	5.3	3.1	3.5	3.1	4.7	4.3	3.9
72	7.2	16.4	9.4	9.7	14.9	10.6	10.0	11.5	11.0	7.2	10.5

C)

Water Year	2011	2012	2013	2014	2015	2016	2017
System-wide	57	42	42	49	65	50	57
04	4.8	4.7	16.0	6.1	3.8	4.8	4.3
05	5.8	7.3	6.7	5.4	4.2	8.2	5.4
06	4.0	4.3	4.5	5.0	3.6	3.3	3.6
08	2.1	3.1	1.6	2.5	1.9	2.3	2.4
09	2.2	3.7	2.1	2.5	2.1	2.5	2.9

Figure 3.9. Chlorophyll a (chla) stoplight indicator chart for A) St. Lucie River Estuary, B) Loxahatchee River Estuary, and C) Caloosahatchee River Estuary (CRE). The numbers in the first row indicate estuary-wide (System-Wide) average annual scores (0–100%; see Methods for details). Green color indicates very good (>80–100% score) or good (>60–80% score), yellow color indicates fair (>40–60% score), and red color indicates poor (>20–40% score) or very poor (0–20% score) chla conditions in the estuary. The numbers in the rows below represent site-specific annual median chla concentrations. Red color indicates annual median chla concentration above the long-term 75th percentile, yellow color indicates annual median chla concentration between the long-term median and long-term 75th percentile, green color indicates annual median chla concentration below the long-term median, and gray color indicates lack of data or insufficient data for calculations.

A)



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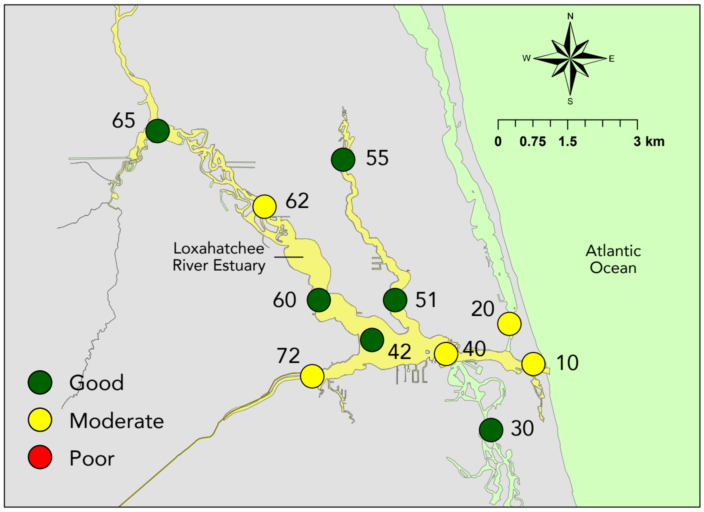


C)

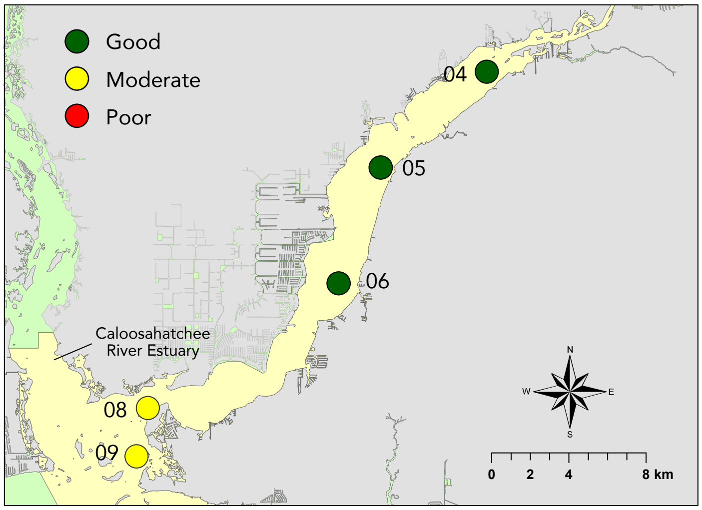


Figure 3.10. Maps of St. Lucie River Estuary (A), Loxahatchee River Estuary (B), and Caloosahatchee River Estuary (C) displaying 2017 chlorophyll a conditions. The circles in each estuary display the current WY status (annual median chla concentrations at each site). Colors indicate system-wide status: Green = Good, Yellow = Moderate, and Red = Poor.

Discussion

Very poor to fair conditions at many stations in the estuaries in WY2016 developed as a result of increased precipitation and subsequent large freshwater inflows into the estuaries during El Niño in dry season of WY2016 (DBHYDRO; NEXRAD; SFER 2018). The super El Niño of 2015–2016 (WY2016) was the biggest and the longest of the El Niño events in the 21st century (Su et al. 2018). This extreme weather event brought heavy rainfall over the watersheds north of Lake Okeechobee (NEXRAD; SFWMD Historical Weather).

These watersheds contain large sources of nutrients from the historic and current agricultural activities and old neighborhoods with leaking septic tanks (Graves et al. 2004; Havens & Gawlik 2005; Ross et al. 2006; Lapointe et al. 2012, 2015 a, b, 2017; Stoner & Arrington 2017; Kramer et al. 2018), and during heavy rainfall these nutrients are flushed down into Lake Okeechobee and the estuaries. The 2015 (WY2016) heavy winter El Niño rains increased the Lake stage to over 14 feet (USACE) in the early 2016 (WY2016), which forced emergency releases of freshwater from the Lake into SLE and CRE in February and March of 2016 (WY2016; DBHYDRO; USACE). These releases, combined with a runoff of freshwater from the watershed, continued at a slower rate throughout the dry season and increased again during the hot summer months of WY2017 (DBHYDRO; USACE). These inflows of nutrient-rich freshwater lowered salinity in SLE and CRE, and introduced freshwater cyanobacteria into the estuaries, which ultimately resulted in cyanobacterium *Microcystis aeruginosa* blooms, which lasted from May to mid-July of WY2017 (Rosen et al. 2017; Lapointe et al. 2017; Kramer et al. 2018).

Overall, the status of algal biomass indicator in SLE, CRE, and LRE appears to be largely influenced by nutrient-rich stormwater runoff (overland flow and via canals) from watersheds, which contain suburban old neighborhoods with septic tanks, golf courses, and agricultural areas (Graves et al. 2004; Havens & Gawlik 2005; Ross et al. 2006; Lapointe et al. 2012, 2015 a, b, 2017; Stoner & Arrington 2017; Kramer et al. 2018). A more biologically meaningful assessment methodology should be developed for all estuaries in Florida, where nutrient and chla criteria meet habitat requirements for biota, which occupy the specific estuarine systems.

SUBMERGED AQUATIC VEGETATION

Submerged aquatic vegetation (SAV) includes both marine and freshwater angiosperms. These species include the marine grasses: shoal grass (*Halodule wrightii*), paddle grass (*Halophila decipiens*), Johnson's grass (*Halophila johnsonii*), star grass (*Halophila engelmannii*), manatee grass (*Syringodium filiforme*), and turtle grass (*Thalassia testudinum*); the brackish species widgeon grass (*Ruppia maritima*); and the freshwater species tape grass or American wild celery (*Vallisneria americana*). Macroalgal species such as *Caulerpa* spp. and drift red algae are a common, natural component of the SAV community.

SAV comprises a major structural element in estuarine and coastal waters, providing a breadth of ecosystem services including food and habitat for invertebrate and vertebrate species, stabilization of sediments, nutrient cycling, and protection of shorelines via wave energy attenuation (Duarte 2002; Duarte et al. 2006). Each of the species monitored has different physiological limitations to salinity, temperature, light, and nutrient environment. Other stressors on the distribution, abundance, and diversity of SAV include, but are not limited to, grazing, hydrodynamics, and sediment grain-size distribution.

St. Lucie Estuary and Southern-Indian River Lagoon

Methods of sampling and details of statistical analyses and results can be found in the RECOVER report by Kahn (2018). Results use Braun-Blanquet Cover and Abundance values (BBCA; Table 3.2).

The northern-most site (FP-NW, Figure 3.11) exhibited a stable trend in total seagrass cover from 2012–2017 (Figure 3.12a). *Thalassia testudinum* is consistently observed at this site, though it has low cover with BBCA values of 1 when present. *Thalassia* did not exhibit variability from 2012–2017, nor did *Syringodium* cover. There were interannual differences in *Halodule wrightii*, with less cover in 2016 and 2015 than the previous three years. There was a trend of increased *Halophila johnsonii* BBCA cover annually from 2012–2016. These observations are described as trends, but lack statistical significance amongst sampling periods (Kahn 2018).

Site OBP exhibited a steady annual decline in total seagrass cover from 2012–2016 (Figure 3.12b), mirrored by the annual decline in *Syringodium* BBCA over this period, with a slight increase observed in 2017. *Halodule* did not change from 2012–2013 but exhibited a decline in 2014, after which BBCA values were low through 2017.

Site 1 and BSI exhibited similar interannual trends. Total seagrass cover declined from 2012–2013, as observed by a *Syringodium* decline, with a sharp decrease in cover observed in 2016 to <5% cover (Figure 3.12c). *Halophila johnsonii* and *Halodule* increased in cover from 2012–2015, and *H. johnsonii* did not exhibit a loss in cover in 2016 at Site 1 relative to BSI compared to 2015 (Figure 3.12 c and d). Total seagrass BBCA values were greater in 2017 than 2016, mainly due to increased cover of *H. johnsonii*.

Table 3.2. BBCA values and the corresponding percent cover interpretation.

Braun-Blanquet	Cover Interpretation
0	0%: Species absent from quadrat
1	<5%: many shoots
2	5–<25%
3	25–<50%
4	50–<75%
5	75–100%

WILL-CR has tidally-driven variability in salinity and light attenuation, and *Halophila johnsonii* and *Halodule wrightii*, species tolerant of variability, are at this site. From 2012–2017, *Halodule* remained relatively stable, though low in cover, but total seagrass cover fluctuated due to variable *H. johnsonii* cover (Figure 3.13a).

At SLI-SE, only *H. johnsonii* and *Halodule* are present. Total seagrass cover was slightly lower in 2017 than observed in 2012. There was a decline in *Halodule* and it was not observed in one quadrat during 2017 sampling (Figure 3.13b). *Halophila johnsonii* remained relatively stable with a peak in average cover in 2013 and 2014.

In Site 3, total seagrass cover did not change from 2012–2015, although *Syringodium* BBCA values remained low at average <5%, with a higher occurrence of *Halodule* and *H. johnsonii*, (Figure 3.13c). In 2016, there was an overall decline in total seagrass cover, after which only *Halodule* and *H. johnsonii* exhibited improvement in 2017.

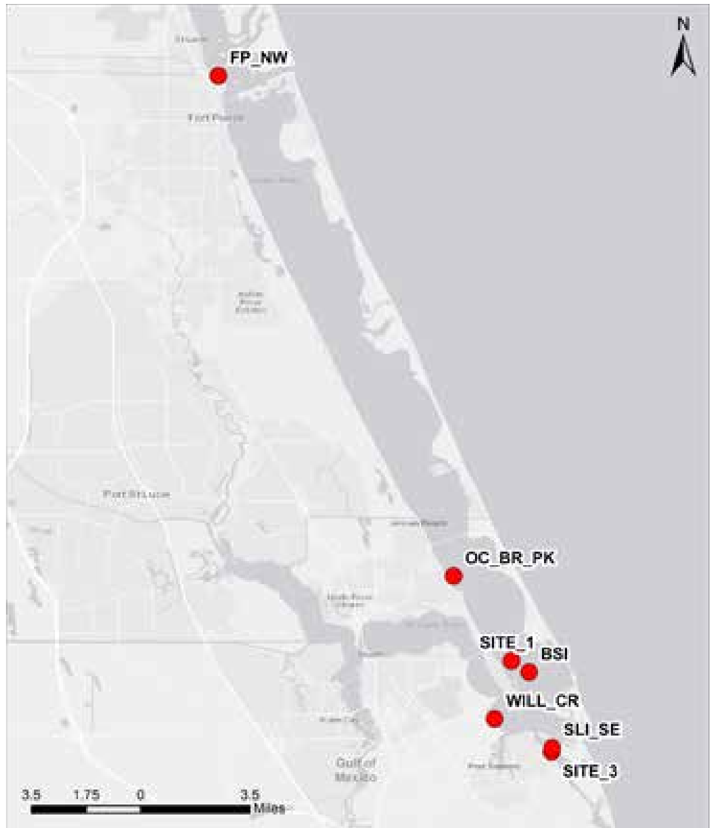


Figure 3.11. Map of seagrass monitoring sites in the SLE.

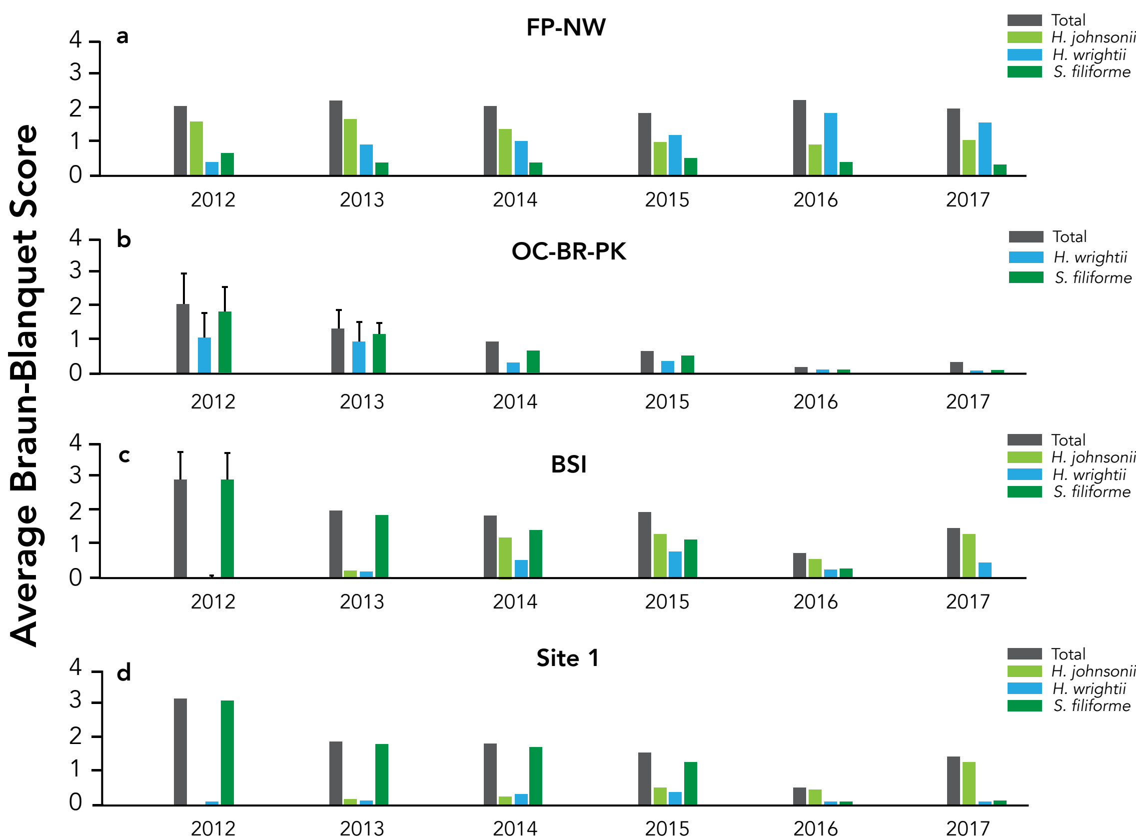


Figure 3.12. Average Braun-Blanquet cover and abundance score for the wet season (May–October) data for total seagrass and dominant species at (a) Ft. Pierce Northwest (FP-NW), (b) Ocean Breeze Park (OBP), (c) Boy Scout Island (BSI), and (d) Site 1 for 2012–2017.

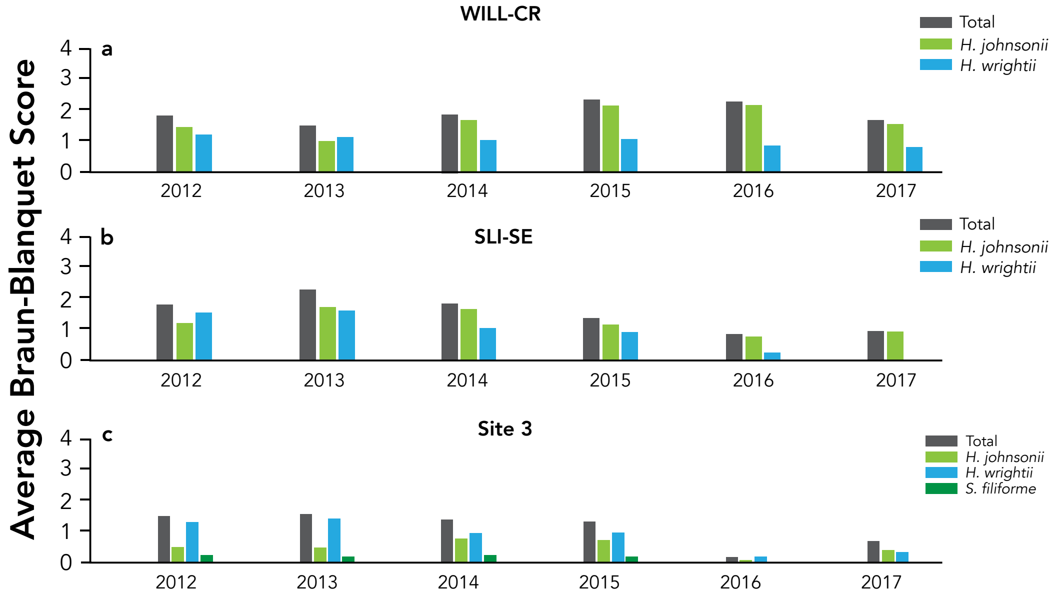


Figure 3.13. Average Braun-Blanquet cover and abundance score for the wet season (May–October) data for total seagrass and dominant species at (a) Willoughby Creek (WILL-CR), (b) St. Lucie Inlet Southeast (SLI-SE) and Site 3 (for 2012–2017).

Loxahatchee River and Estuary

In October 2007, the Loxahatchee River District (LRD) began collecting seagrass data at five sites in the Loxahatchee River Estuary (LRE). In 2013, an additional site (Inlet) was added, and in 2015 one site (Hobe Sound) was discontinued. Sites are positioned in a general upstream-downstream salinity gradient, with varying distances to the Jupiter inlet. From upstream to downstream the sites are Northwest Fork (NWF), Pennock Point (PP), North Bay (NB), Sand Bar (SB), Hobe Sound (HS), and Inlet (INL) (Figure 3.14). Monitoring at these sites did not include the freshwater species *Vallisneria americana*. The next System Status Report update will include metrics for a more robust monitoring program.

On average, total seagrass occurrence declined from 86% in 2008 to 52% in 2017 (Figure 3.15). Since 2008, the greatest decline in total seagrass have been at the 2 sites farthest upstream, including the NWF and PP (Figure 3.15). In the NWF, total seagrass declined from 74% in 2008 to ≤10% after 2014. In PP, there was a steady decline from 87% in 2008 to 54% in 2015. There was a 37% decline in seagrass from 2015–2016 at PP, but this site has been slowly increasing in total seagrass over the past 3 years (Figure 3.16).

In NB, total seagrass occurrence slightly increased from 2008–2012, with the highest recorded seagrass occurrence 89% in 2012, yet there has been an overall decline at NB from 76% in 2008 to 55% in 2017 (Figure 3.16). Despite the close proximity to NB, the SB site (Figure 3.14) has remained relatively consistent, with total seagrass occurrence remaining above 89% (Figure 3.16).

The HS site had 97% total seagrass occurrence in 2008, with gradual declines and increases until the 76% occurrence measured in 2015 when LRD discontinued monitoring. INL has shown a decline from 86% in 2013 to 72% in 2017 (Figure 3.16).

Figure 3.14. Map of seagrass monitoring sites in the LRE.

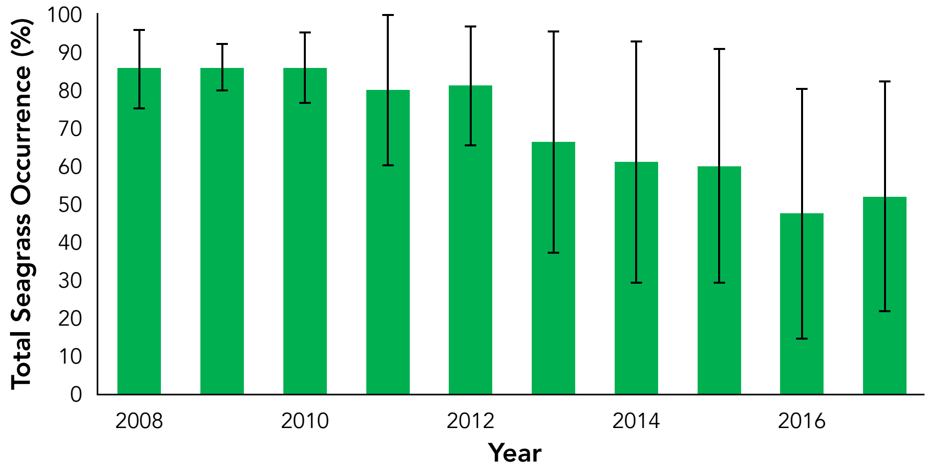


Figure 3.15. Average total seagrass occurrence from 2008–2017 across all sites. Annual Averages shown; error bars ± one standard deviation.

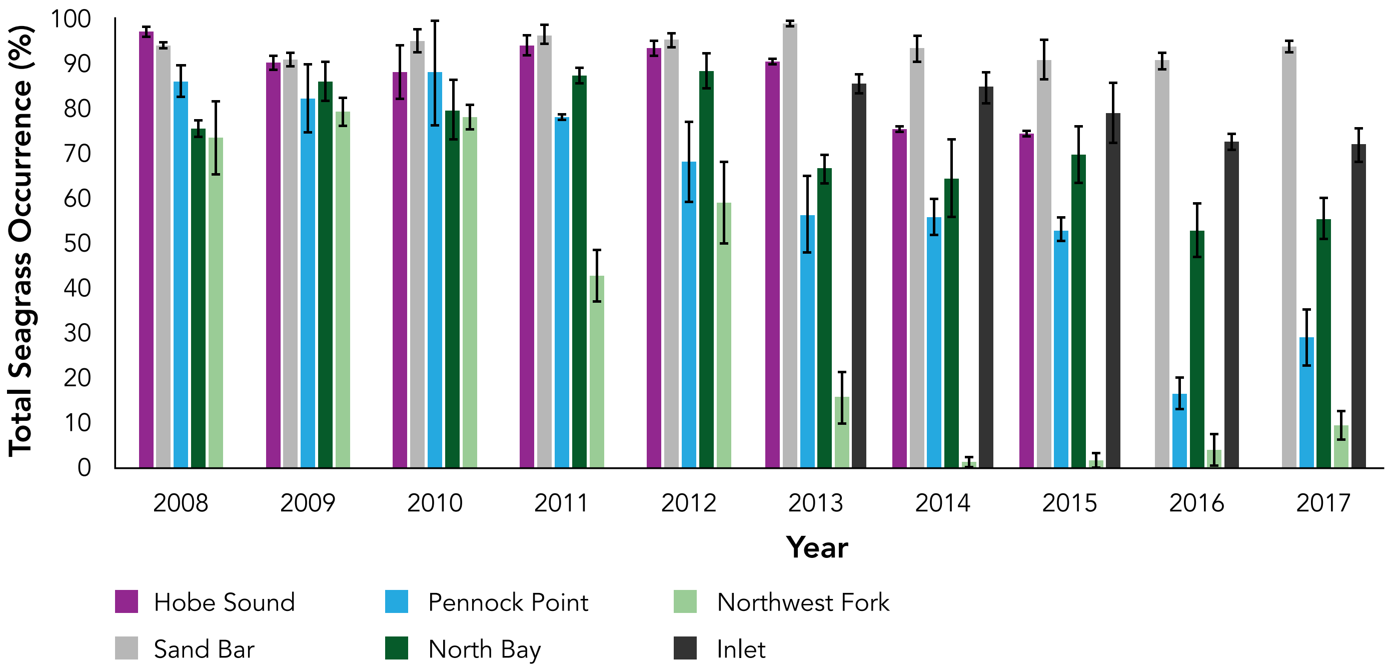


Figure 3.16. Average total seagrass occurrence from 2008-2017 by site; error bars ± one standard deviation.

Caloosahatchee River and Estuary

Methods of sampling and details of statistical analyses and results can be found in the RECOVER report by Kahn (2018). Results use Braun-Blanquet Cover and Abundance values (BBCA; Table 3.2).

SAV cover was assessed at 6 sites in the Caloosahatchee River Estuary (Figure 3.17). At CRE_2, total SAV cover varied (Figure 3.18). *Vallisneria americana* was the dominate species only during 2015, which was the year with the greatest (though sparse) coverage (>5% = 1 Braun-Blanquet score). *Ruppia maritima* was at this site in low quantities (BBCA scores 0–1) throughout the entire period of record. In October and December 2017, there was no presence of *V. americana* or *R. maritima*.

CRE_4 has been characterized by a monospecific *R. maritima* bed with a decreasing trend in BBCA abundance scores from 2012–2014 (2–0) and from 2015–2017 (1–0) (Figure 3.18).

CRE_5 and CRE_6 have monospecific *Halodule* beds. *Halodule* abundance at CRE_5 declined from 2012–2013 but showed little variability between 2013–2016 when it started to decline again, but steadied between 2016–2017 (Figure 3.18). CRE_6 BBCA scores increased slightly from 2012–2014 then started decreasing in 2015 before leveling out (Figure 3.19).

CRE _7 and CRE_8 have contained both *Halodule* and *T. testudinum*. At CRE_7 total seagrass abundance increased from 2012–2014, decreased from 2014–2016, and increased again in 2017. *Thalassia testudinum* was the dominant species except in 2014 when *Halodule* was more abundant (Figure 3.19). CRE_8 showed the same trend of increase/decrease as CRE_7, and *T. testudinum* was the dominate seagrass species (Figure 3.19).

The effects of flow and salinity on total seagrass BBCA were examined at the furthest upstream (CRE_2) and downstream stations (CRE_8). At CRE_2, *V. americana* was absent until 2014 when increased flows from S-79 and corresponding decreases in salinity resulted in modest increases in abundance (BBCA score 1 which is approximately 5%).

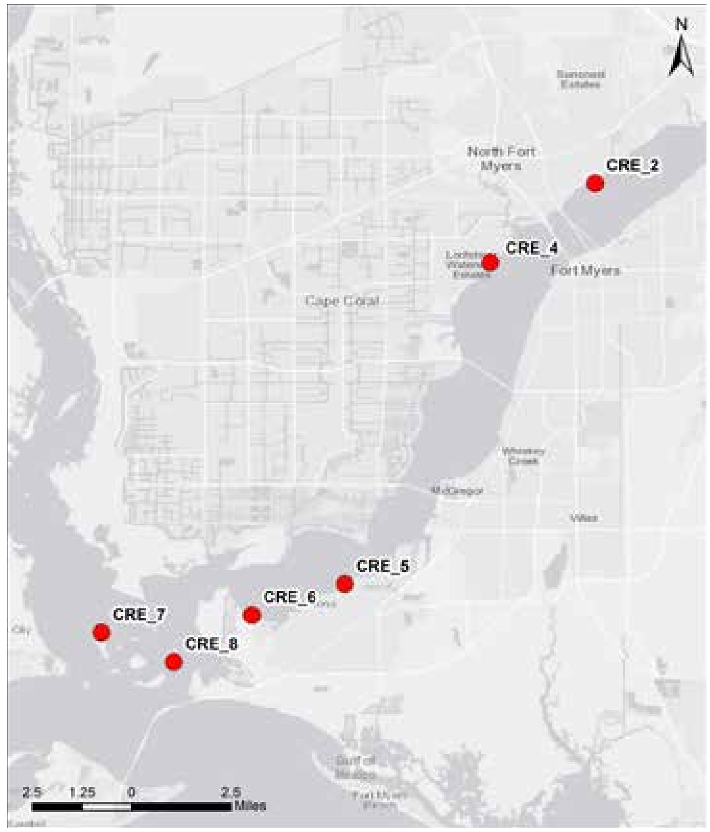


Figure 3.17. SAV sampling sites in the CRE.

Seagrasses at CRE_8 increased from a BBCA score of 3 to 5 (approximately 50–100 percent) from 2012–2014, then decreased to a BBCA score of 3 in 2015 and remained stable.

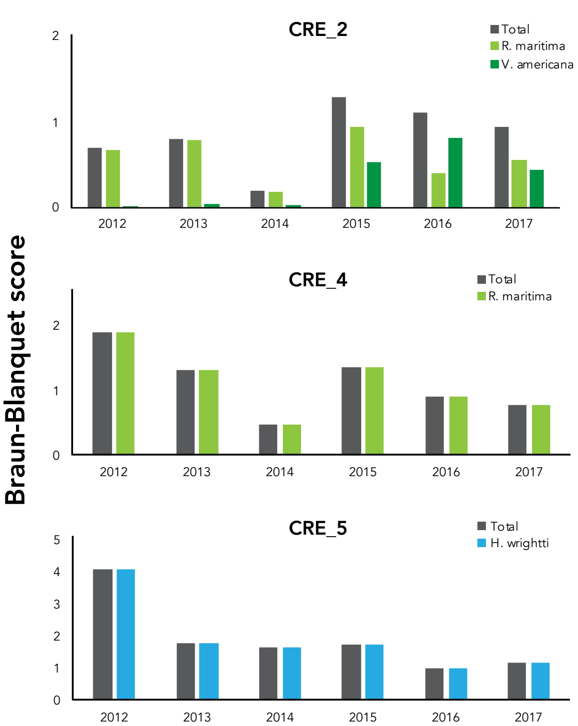


Figure 3.18. Average Braun-Blanquet cover and abundance score for wet season (May–September) data for total seagrass and dominant species at Old Bridge Road (CRE_2), Ft. Myers (CRE_4), and Peppertree (CRE_5) for 2012–2017.

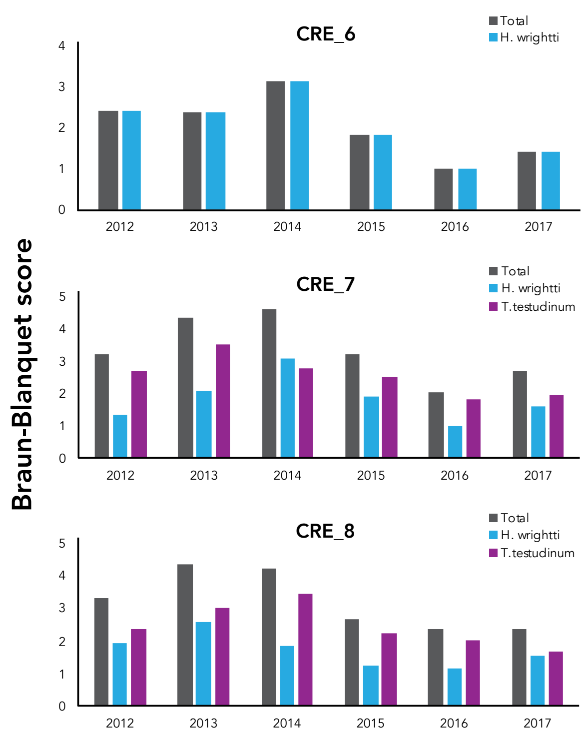


Figure 3.19. Average Braun-Blanquet cover and abundance score for wet season (May–September) data for total seagrass and dominant species at Iona Cove (CRE_6), Merwin Key (CRE_7), and Kitchel Key (CRE_8) for 2012–2017.

OYSTERS

The eastern oyster (*Crassostrea virginica*) is a natural component of estuaries in south Florida and can provide water quality benefits including reduction of nutrients and particulate matter, and the control of phytoplankton (Buzzelli et al. 2012). Oysters provide habitat and food for many estuarine species, and are an important commercial, recreational, and economic resource for coastal communities (Coen et al. 2007). Oyster reefs protect shorelines by attenuating wave action and other perturbations from recreational boating (Wall et al. 2005).

Principal environmental stressors on oysters include abrupt changes in salinity and temperature regimes. While adult oysters typically are found within a salinity range of 10–28 ppt (RECOVER 2007c), the optimal salinity range varies among oyster populations. Salinities >30 ppt are not alone detrimental to oysters, but can result in an increase of marine predators such as the oyster drill (*Urosalpinx* sp.) and higher prevalence and intensity in oyster disease via infection by the protozoan parasite Dermo (*Perkinsus marinus*). These effects are intensified when temperatures are high. Salinities <10 ppt are survivable for short durations by adults but have deleterious effects on earlier life stages. Targets for full CERP restoration implementation are 400 and 900 acres of suitable oyster habitat in the CRE and SLE, respectively, while the northwest fork of the LRE has targets based on salinity regimes suitable for all oyster life history stages (RECOVER 2007d).

The RECOVER oyster monitoring program includes density of settled oysters, reproductive development, juvenile recruitment, and prevalence and intensity of infection by the parasite Dermo. Monthly water quality sampling is conducted in conjunction with field sampling at each location. Methodology and sampling protocols are detailed in Parker and Radigan (2018).

St. Lucie Estuary and Southern-Indian River Lagoon

Settled Oyster Density

The density of live oysters in the SLE is an order of magnitude higher in the middle estuary than in the North and South forks of the estuary (Figure 3.20). In the forks, average densities rarely exceed 100 per square meter while those in the middle estuary generally range from 500 to 1000 oysters per square meter (Figure 3.21).

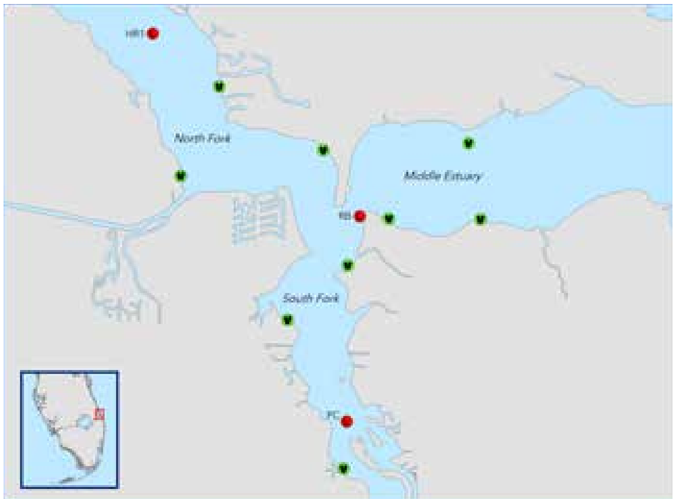


Figure 3.20. Oyster monitoring stations (green) and salinity data loggers (red) in the North Fork, South Fork, and Middle Estuary of the St. Lucie Estuary.

Densities of live oysters were relatively stable in the middle estuary in WY2013, but the occurrence of Hurricane Isaac in August 2012 and the subsequent drainage of the watershed and inland water releases kept salinities below the optimal range through October 2012. As a result, oyster densities measured during the spring 2013 survey showed decreases of 70% to 100% in the North and South Forks. There was a brief recovery period in early 2013, but salinities decreased sharply again in July and remained low through late October. The inundation of freshwater at the time caused an oyster die-off throughout the SLE and led to high levels of enteric bacteria and a cyanobacterial bloom, both of which prompted a health advisory for the area.

Salinity varied but remained relatively moderate during the remainder of WY2014, for all of WY2015, and during the first nine months of WY2016, allowing oysters to recover. However, increased rainfall from the 2015/2016 El Niño event led to prolonged freshwater releases into the SLE in early 2016. Although there was not a major associated die-off in the estuary, oyster densities were somewhat lower in spring 2016. Oyster densities stabilized, and increased in the middle estuary, in WY2017 despite a prolonged period of above optimal salinities during the second half of the WY.

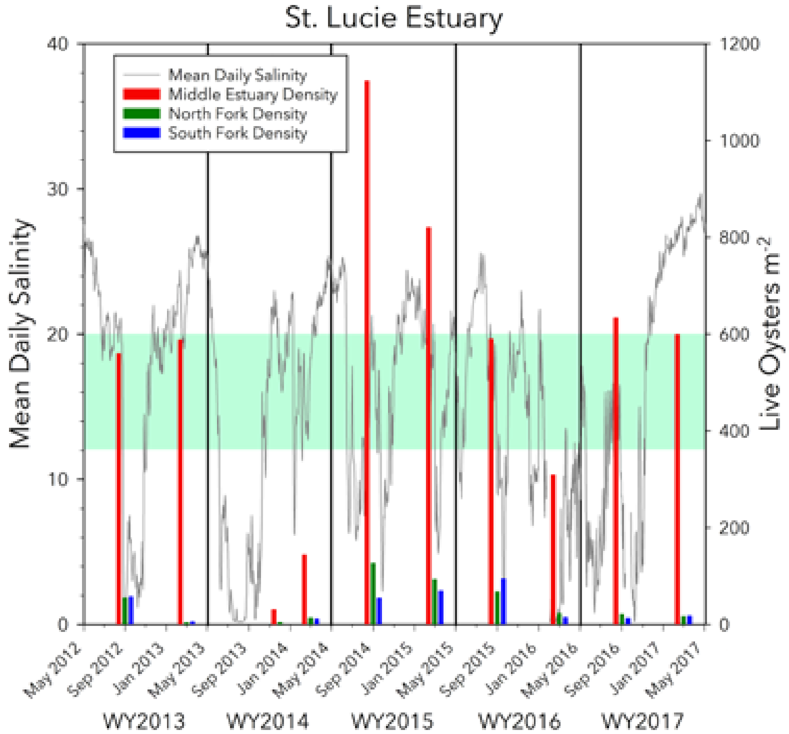


Figure 3.21. Mean number of live oysters in the middle estuary, North Fork and South Fork of the SLE during semi-annual surveys and mean daily salinity at the US-1 Roosevelt Bridge. The green band is the salinity range most favorable for oyster survival and health in the estuary.

Reproduction and Recruitment

The timing of reproductive development and larval recruitment in the SLE is similar among oysters in the forks and the middle estuary. Peak reproductive development and spawning activity typically occurs between April and September and is usually greater in the months during or after a period with moderate or higher salinities (Figure 3.22). Peak larval recruitment rates generally occurred in May of each year; however, there were smaller magnitude fall peaks in WY2015 and WY2016. Little to no larval recruitment was detected during periods when salinities were below the optimal range (WY2014 and WY2017). Analysis of reproductive development in adult oysters showed that most completed gametogenesis and spawned. This suggests that the newly spawned larvae either did not survive in the low salinity environment or were physically flushed downstream and out of the estuary.

Disease

Disease prevalence of Dermo was low to moderate ranging from 0 to 67% during the study period. More oysters (WY means 36% to 44%) were infected with the parasite during periods with moderate to high salinities that occurred in WY2013 and WY2016 (Figure 3.23). The lowest infection rates (WY mean 19%) occurred in WY2017 following the extended period of reduced salinities associated with the 2015/2016 El Niño event. No live oysters were present in the SLE for disease analyses from September–December 2013 due to die-offs associated with low salinity events.

Discussion

Oyster populations in the SLE continue to be negatively affected by the highly variable freshwater inflows that are a result of the altered local hydrology. Extended periods of high salinities result in gradual increases in disease infection rates that lead to compromised oyster health and survivorship. Periods of extremely low salinities, as occurred in WY2014, result in acute damage to oyster populations. The rapid transitions between high and low salinity regimes compound the effects of the salinity extremes by reducing the opportunity for acclimatization. The timing and duration of extreme low salinity events also affect the severity of the damage to oyster populations. In WY2014, the low salinity event began in the summer and concluded by October which allowed a small number of larvae to settle in the estuary before the end of the spawning season.

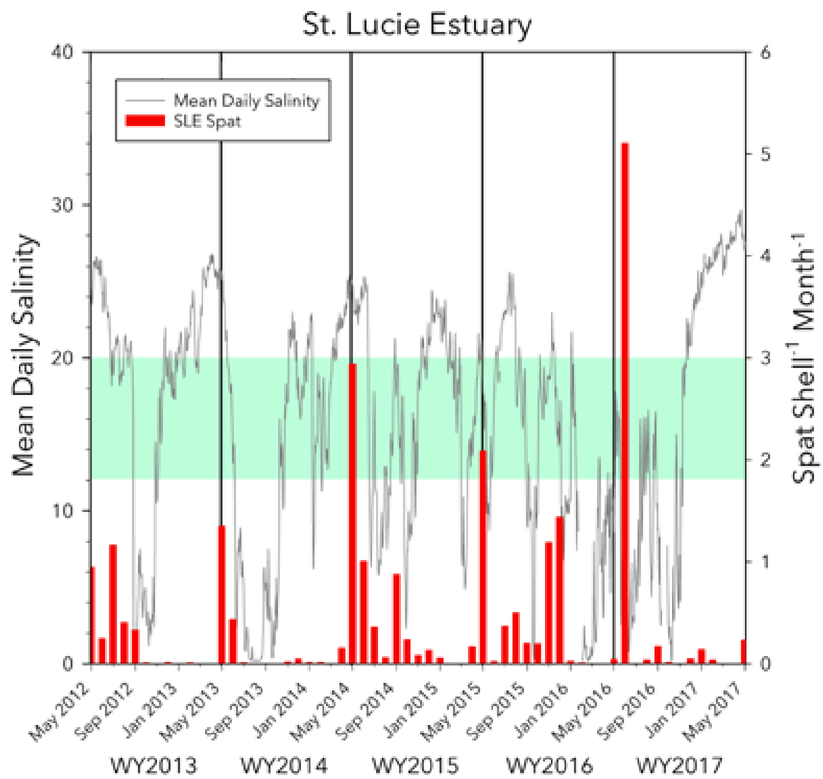


Figure 3.22. Mean number of oyster recruits (spat) per shell during monthly collections from the SLE and mean daily salinity at the US-1 Roosevelt Bridge. The green band represents the salinity range most favorable for oyster survival and health in the estuary.

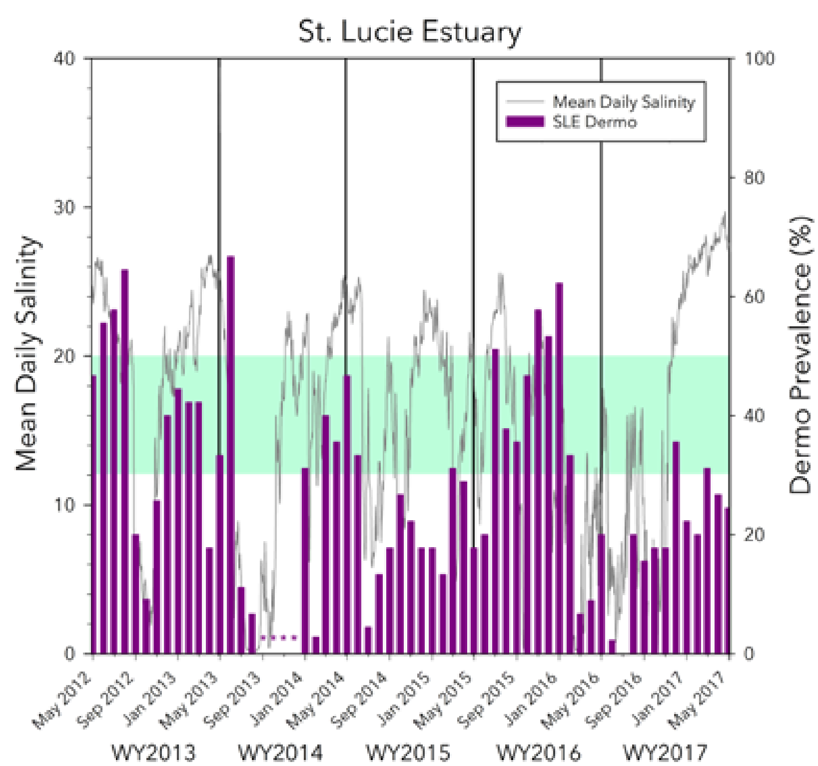


Figure 3.23. Percentage of oysters infected with Dermo during monthly collections from the SLE and mean daily salinity at the US-1 Roosevelt Bridge. The green band represents the salinity range deemed most favorable for oyster survival and health in the estuary. Asterisks denote months when no live oysters were available for collection and analysis.

Northern Estuaries

Loxahatchee River and Estuary

Settled Oyster Density

The density of live oysters is generally higher in the Northwest Fork than in the Southwest Fork of the LRE (Figure 3.24). Mean densities ranged from about 300 to 600 oysters per square meter in the Southwest Fork and from about 300 to 1200 oysters per square meter in the Northwest Fork (Figure 3.25). Densities of live oysters were similar among the forks in WY2013, and WY2014 but diverged beginning in WY2015 when Northwest Fork densities increased to almost twice those in the Southwest Fork. No substantial low salinity events occurred in the LRE from WY2013–WY2017, but there were more suboptimal salinity days in the Northwest Fork in WY2014. The overall mean WY salinity in the Northwest Fork decreased from values ranging from 18 to 20 ppt to a mean of 15 ppt in WY2014. That cumulative decrease likely reduced predation and disease pressures on resident oysters, ultimately resulting in the substantial increase in density. Despite the predominance of above optimal salinities in the Southwest Fork, densities of live oysters remained relatively stable from WY2013–WY2017.

Reproduction and Recruitment

The timing of reproductive development and larval recruitment in the LRE is similar among oysters in the two forks. Peak reproductive development and spawning activity typically occurred between May and October (Figure 3.26). Peak spring larval recruitment rates typically occurred in May of each year while peak fall rates occurred most commonly in October; however, there were moderate peaks in August of WY2016. One exception occurred in WY2014, when the spring peak was smaller and delayed until July. This was most likely due to the occurrence of several consecutive days of suboptimal salinities in the preceding two months. It's likely that the newly spawned larvae either did not survive in the low salinity environment or were physically flushed downstream and out of the estuary.

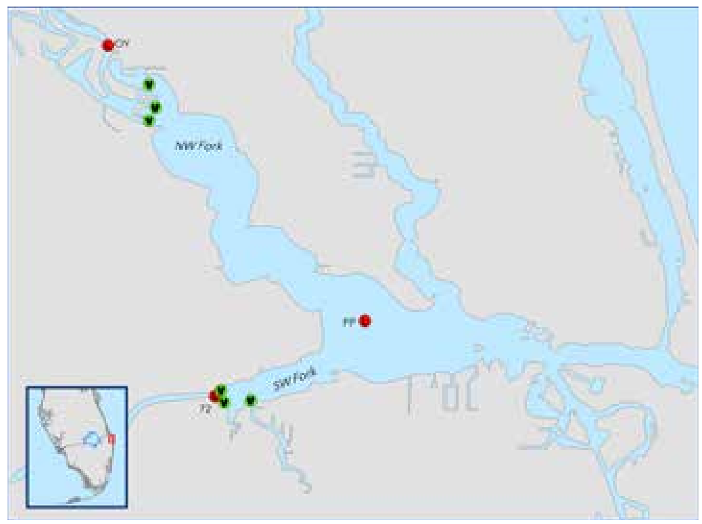


Figure 3.24. Oyster monitoring stations (green) and salinity data loggers (red) in the Northwest and Southwest Forks of the Loxahatchee River Estuary.

Disease

Disease prevalence of Dermo was moderate to high ranging from 30% to 97% in LRE oysters during the study period (Figure 3.27). These are substantially higher infection rates than seen in oysters from the SLE. The lowest infection rates (WY means near 60%) in oysters from the LRE were measured WY2014 during or following periods with reduced salinities. In other WYs, mean infection prevalence ranged from 63% to 81%. These high infection rates indicate that freshwater inflows into the estuary have generally not been of sufficient magnitude or duration to provide relief from disease pressure.

Discussion

Oyster populations in the LRE have been negatively impacted by the variable freshwater inflows that are a result of the altered local hydrology. Extended periods of high salinities result in gradual increases in disease infection rates that lead to compromised oyster health and survivorship. If salinities rapidly decrease to suboptimal levels, as occurred in WY2013, the opportunity for acclimatization to new conditions is reduced or eliminated and the local oysters more susceptible to predation and disease. High salinities are a persistent problem in the LRE but there is evidence that brief excursions to optimal salinities, or even suboptimal salinities, can substantially reduce disease rates and increase reproductive capacity. However, the timing of these low salinity events determines if there will be a positive or negative outcome. In WY2014, the low salinity events occurred just prior to and during the spawning season leading to substantially reduced larval recruitment rates.

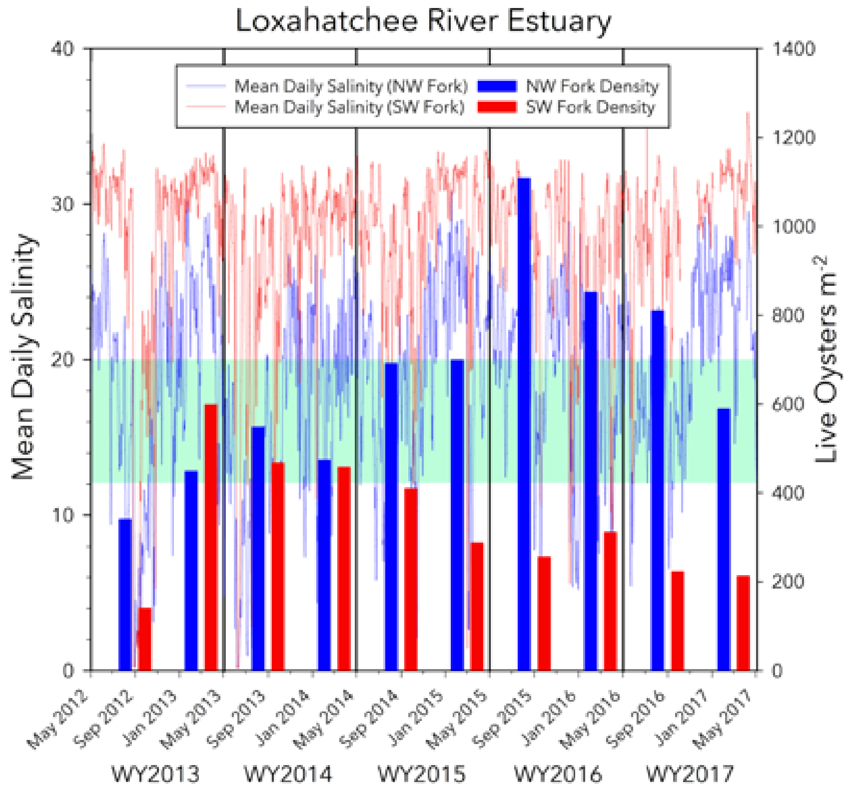


Figure 3.25. Mean number of live oysters in the Northwest Fork and Southwest Fork of the LRE during semi-annual surveys and mean daily salinity in the NW Fork and SW Fork. The green band represents the salinity range most favorable for oyster survival and health in the estuary.

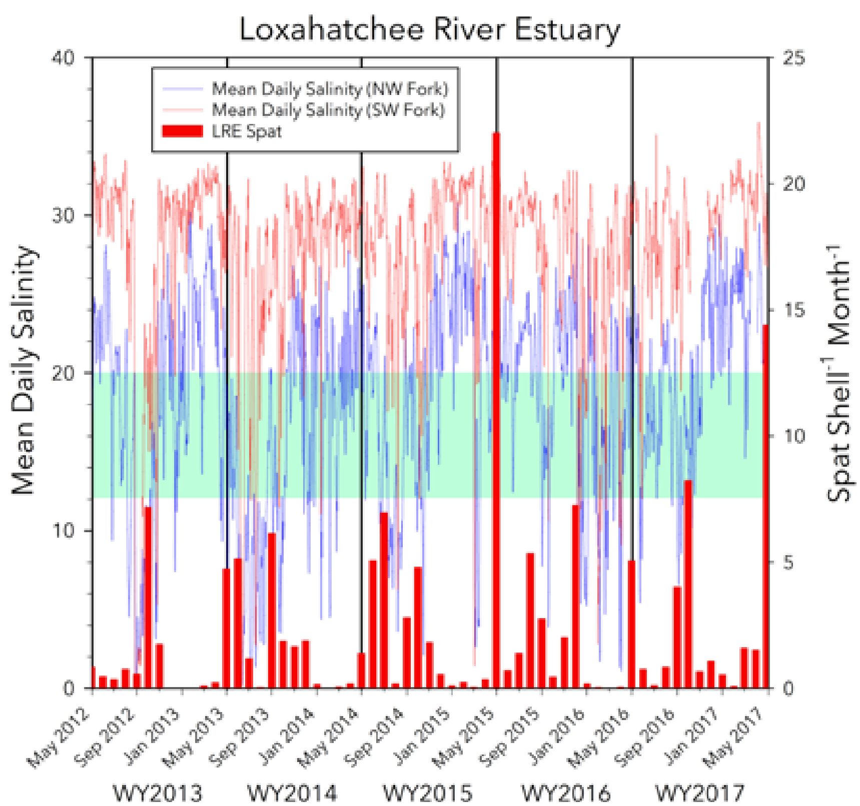


Figure 3.26. Mean number of oyster recruits (spat) per shell during monthly collections from the LRE and mean daily salinity in the NW Fork and SW Fork. The green band represents the salinity range most favorable for oyster survival and health in the estuary.

Northern Estuaries

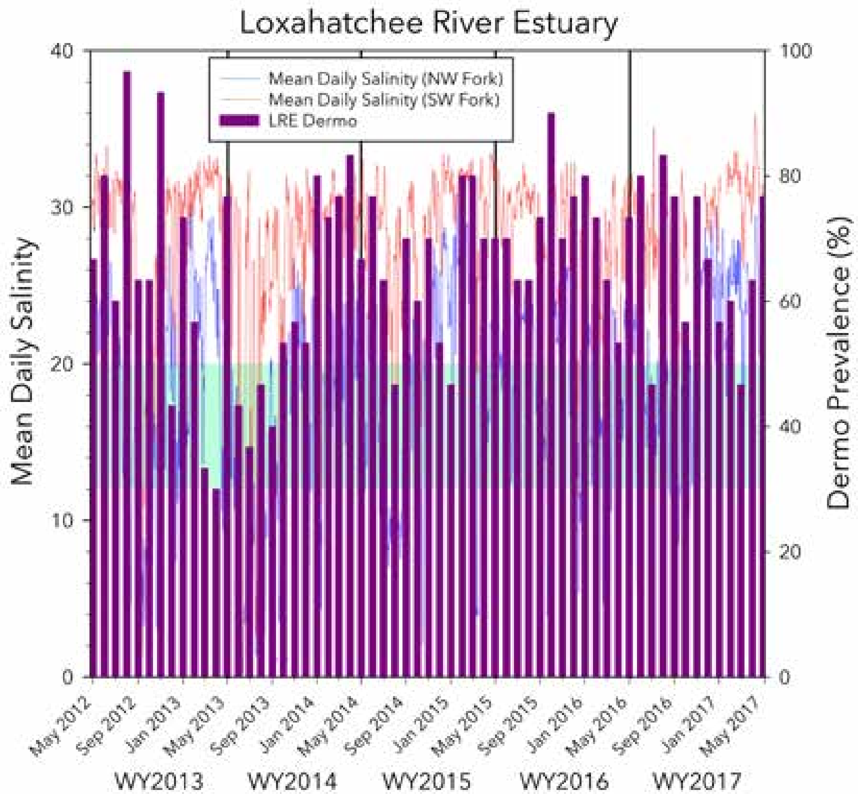


Figure 3.27. Percentage of oysters infected with Dermo during monthly collections from the LRE and mean daily salinity in the NW Fork and SW Fork. The green band represents the salinity range most favorable for oyster survival and health in the estuary.

Caloosahatchee River and Estuary

Settled Oyster Density

The density of live oysters is highly variable and influenced by freshwater inflows and the resultant salinity fluctuations along the upstream to downstream gradient (Figure 3.28). During most surveys, numbers were greatest at the Bird Island station where average densities ranged from about 1000 to 3000 oysters per square meter (Figure 3.29). The lowest densities of live oysters were most commonly found at the Kitchel Key station (100 to 500 oysters per square meter). Densities were greatest at the most upstream station (Iona Cove) during fall surveys in WY2013 when salinities were higher and the WY mean fell within the optimal range. At the opposite extreme, when freshwater inflows were high and salinities were near zero, as occurred in WY2014 and WY2017, oysters at the Iona Cove station disappeared or were present at very low densities.

Figure 3.28. Oyster monitoring stations (green circles) and salinity data loggers (red cylinders) in the Caloosahatchee River Estuary on the southwest coast of Florida.

Reproduction and Recruitment

Peak reproductive development and spawning activity typically occurred between April and November of each calendar year (Figure 3.30). Peak larval recruitment rates typically occurred in August or September of each year, however, there were earlier peaks in July of WY2015 and in April at the end of WY2016. Despite extended periods of suboptimal salinities in WY2014 and WY2016/2017, larval recruitment in the CRE continued, often at moderate to high rates.

Disease

Disease prevalence of Dermo was moderate to high ranging from 15% to 67% during the study period. More oysters were infected with the parasite (WY means 81% to 91%) during periods with moderate to high salinities such as those that occurred in WY2013 (Figure 3.31). These are much higher infection rates than seen in SLE or LRE oysters. The lowest infection rates (WY means of 55% and 34%) occurred in WY2017 following reduced salinities associated with the 2015/2016 El Niño event. These high infection rates indicate that freshwater inflows into the estuary have been insufficient in magnitude and/or duration to provide relief from disease pressure.

Discussion

Oyster populations in the CRE continue to be negatively affected by the highly variable freshwater inflows that are a result of the altered local hydrology. Extended periods of high salinities result in gradual increases in disease infection rates that lead to compromised oyster health and survivorship. Periods of extremely low salinities, as occurred in WY 2014, WY 2016, and WY2017, result in acute damage to oyster populations. The rapid transitions between high and low salinity regimes compound the effects of the salinity extremes by reducing the opportunity for acclimatization to new conditions. The timing and duration of extreme low salinity events also greatly affect the severity of the damage to oyster populations. Extended periods of above optimal or below optimal salinities are a persistent problem in the CRE but there is evidence that even brief periods of more moderate salinities can greatly enhance oyster density and reproductive output as well as reduce disease infection rates.

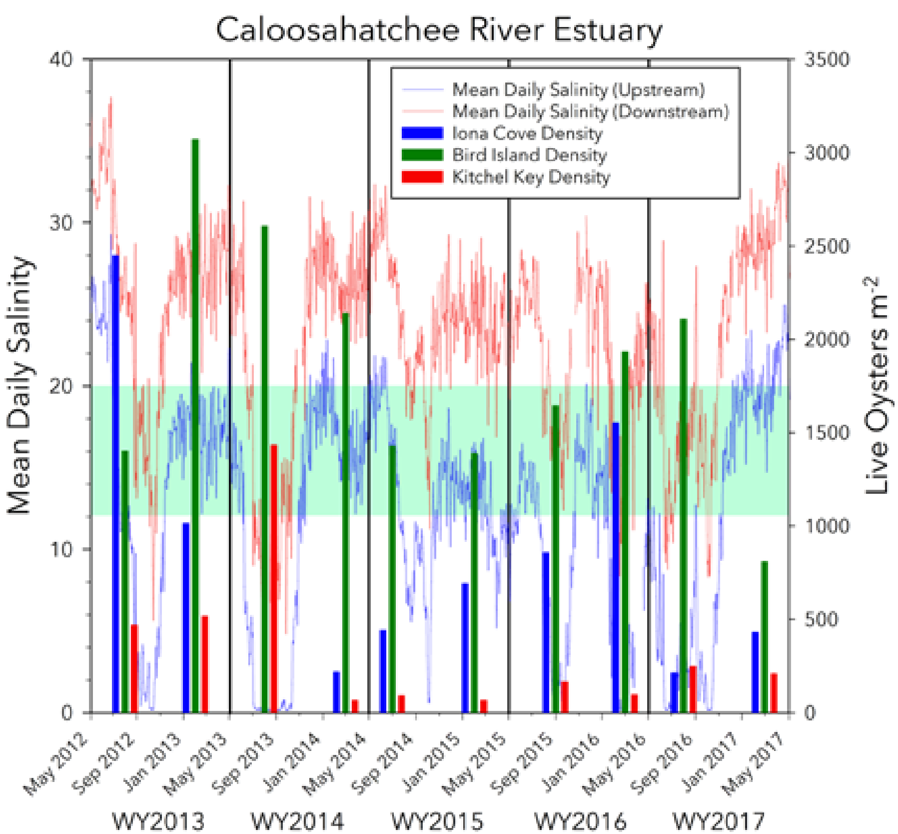


Figure 3.29. Mean number of live oysters at sampled stations in the CRE during semi-annual surveys and mean daily salinity at upstream and downstream locations. The green band represents the salinity range most favorable for oyster survival and health in the estuary.

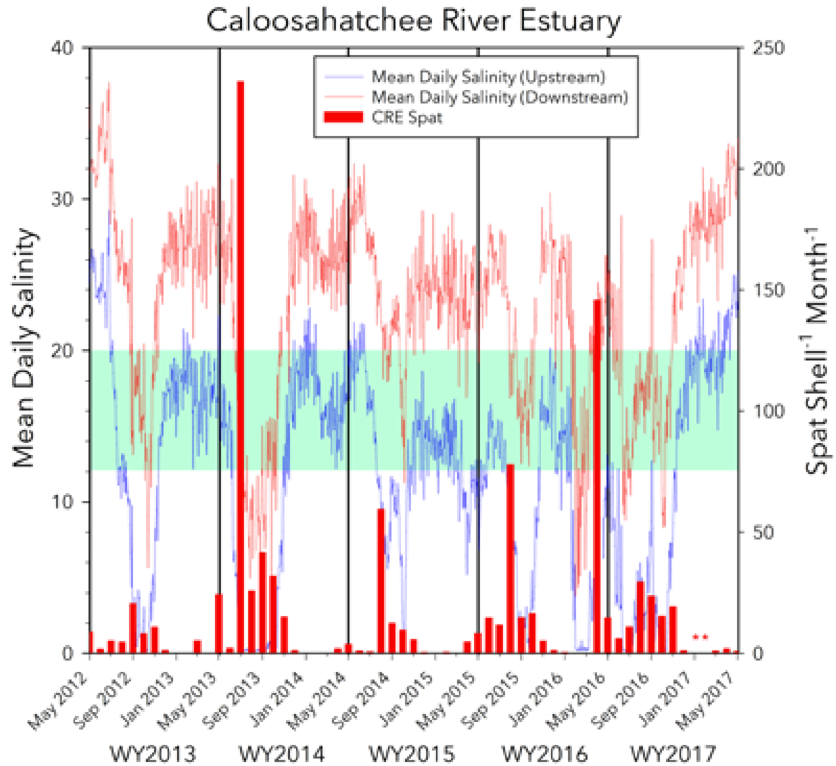


Figure 3.30. Mean number of oyster recruits (spat) per shell during monthly collections from the CRE and mean daily salinity at upstream and downstream locations. The green band represents the salinity range most favorable for oyster survival and health in the estuary. Asterisks denote months when sampling was not conducted.

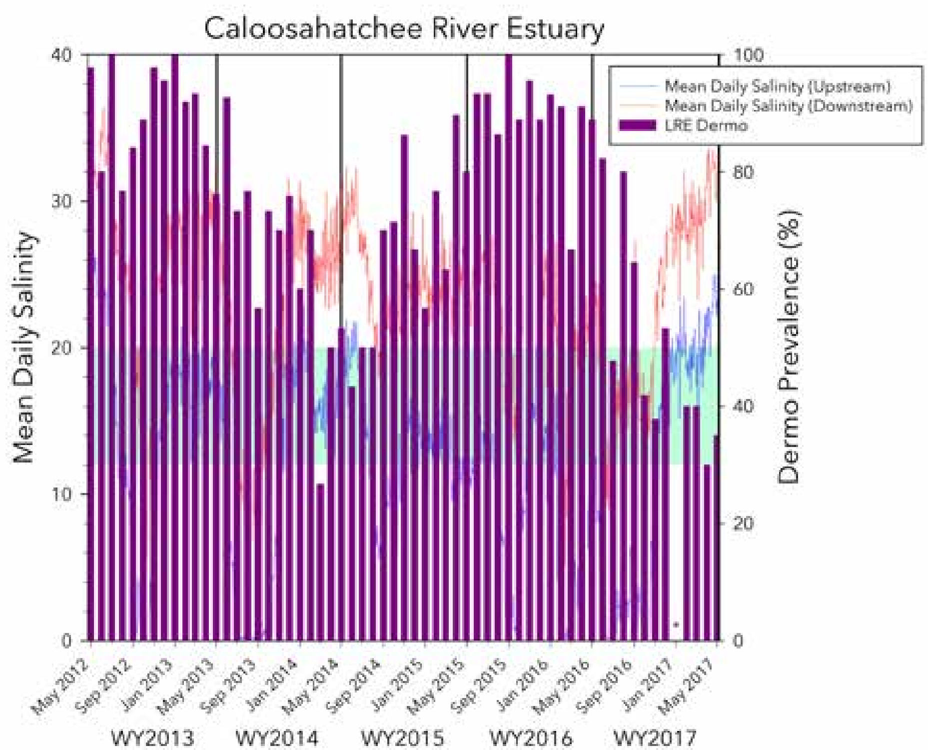


Figure 3.31. Percentage of oysters in the CRE infected with Dermo and mean daily salinity at upstream and downstream locations. The green band represents the salinity range most favorable for oyster survival and health in the estuary. Asterisks denote months when sampling was not conducted.

BENTHIC INFAUNA

Background

The benthos are a crucial component of the estuarine system. There are environmental and ecological processes that occur within the benthic environment, such as nutrient cycling and benthic-pelagic coupling, that are key to estuarine health and function. Benthic infauna, which are present in the sediment and include organisms such as burrowing worms, clams, and other invertebrates, are reliable indicators of habitat quality in aquatic environments. Changes in sediment composition, salinity, flow, and dissolved oxygen drive benthic infaunal community composition. Functional groups indicative of adaptations in a variety of benthic conditions (Gibson et al. 2001) can be used to detect changes in the benthic environment to natural or human stressors (RECOVER 2007e). Different species and functional groups are adapted to different sediment types, salinity, dissolved oxygen, etc., and will shift in response to changes in these variables at different spatial and temporal scales.

Methods and Results

From 2012–2017, Benthic infauna was only monitored in the St. Lucie Estuary (SLE) and southern Indian River Lagoon (SIRL). As part of the SIRL CERP project, muck dredging will occur due to the extensive quantity of soft sediments in the SLE that contain high levels of nutrients that can be easily resuspended into the water column. This monitoring will be used to quantify these harmful sediments before and after dredging as well as assist with the design of this restoration component. Fine-grained sediments are untenable habitat in Atlantic-coast estuarine systems (Sime 2005).

All sites are located in the St. Lucie River and IRL (Figure 3.32). Sites M14 and M15 were added in July 2007 in an attempt to more closely monitor the effects of C-44 reservoir and stormwater treatment area. Sites M2, M8, M10, M12, M13, and M15 were removed from processing in 2014 because of funding reductions. Therefore, only sites M1, M3, M4, M5, M6, M7, M9, M11, and M14 are included in the analyses. Additional samples are analyzed as funding becomes available.

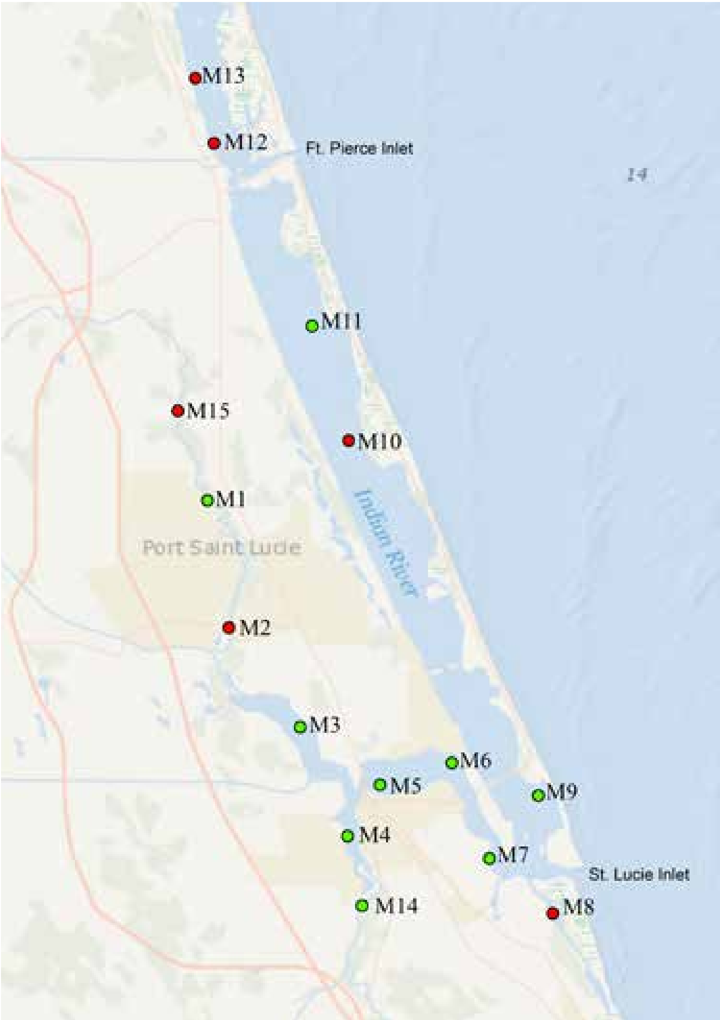


Figure 3.32. The 15 monitoring sites sampled quarterly in the SLE and IRL between 2005 and 2017. Sites marked in red are processed as funding allows.

There is a seasonal pattern of lower abundance in the winter and spring and higher abundance in the summer and fall. Some recovery in the estuary from an extremely wet 2016 is seen as spikes in abundance in the July samples for sites M3, M4, and M5. Any possible recovery or effect of 2016 on M7 is masked by the incredible abundance of *Cerapus sp*. from the October 2016 sample. Taxa follows the same pattern as the number of individuals, including site differences. A long-term decrease in average abundance and species richness is becoming apparent in the St. Lucie river sites (M3, M4, M5, M6, and M14). This decrease seems to correlate with the rate of inflow of water from the S80 structure (Figure 3.33).

Cluster analysis and multi-dimensional scaling of the biological data separates the sites into distinct classifications: river and lagoon. Sites M1, M3, M4, M5, and M14 group together within the river, while sites M6, M7, M9, M11 fall into a separate grouping. Further divisions in each category are determined by salinity regime. The main difference in species between the river and lagoon groups lies in their salinity tolerance. Relationships between biological and environmental data were explored, and the statistical model that best fit the data, which explains what is observed in samples, included percent water content of the sediment and salinity (correlation $R^2 = 0.615$).

Further analysis was done on the middle estuary sites (M3, M4, and M5) that grouped together in both the cluster and nMDS analysis at 40% similarity. Principle component analysis identified five main components explaining ~72% of the variation in samples, including 1) secchi depth, salinity, and water discharge (total outflow and total runoff); 2) temperature and oxygen, which are inversely related; 3) sediment characteristics (color, structure, and firmness); 4) depth, turbidity, and loss on ignition; and 5) sediment (color, type, and firmness).

Transect samples were taken in June 2016 to determine if sampling depth affected communities, as depth was not controlled for when sites were originally chosen. The grain size analysis indicated a change in sediment type with depth. Shallow samples were made of coarser sediments whereas deeper samples had a larger proportion of fine grain sizes, except at M14.

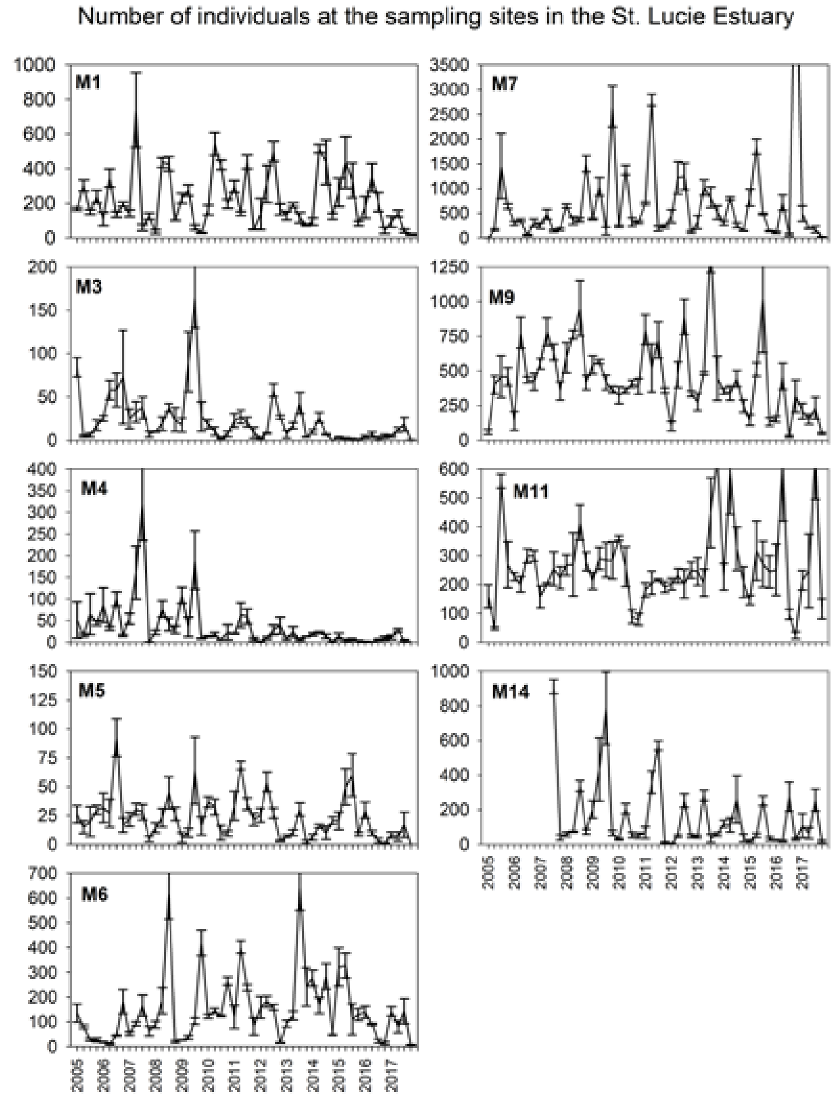


Figure 3.33. Average number of individuals per 0.02 m² at the 9 study sites between February 2005 and October 2017. The error bars represent standard error values. Note: Changes in y-axis values.

Species richness and abundance decreased with increasing depth in the mesohaline sites (Figure 3.33). Species richness increased with increasing depth at M14. However, this is also increasing species richness with decreasing proportion of silty (≤63 µm) sediments. The M7 biological data did not correlate with the sediment data. This could be explained by a high proportion of coarse (250 µm) sediments at the 0.5 m and 1.5 m depths. Two-way ANOSIM (a multivariate proxy for 2-way ANOVA) revealed differences among sites ($p = 0.001$) and depths ($p = 0.001$) in the biological data. Pairwise differences existed among all sites ($p = 0.04$). Pairwise differences also existed among depths.

Salinity is the predominant driver of macrobenthic community composition within the SLE and SIRL (SLE-SIRL). The positive relationship between salinity and diversity is well studied (Remane & Schlieper 1971, Attrill 2002, RECOVER 2014a). However, relating the biological data with the environmental data revealed that sediment characteristics are also a primary driver. Percent water content was the most important sediment characteristic in determining community composition. These sediments are characterized by high percentages of water, organic material, and fine grain size (Trefry et al. 1992). The two drivers cause the sites to cluster into three main groups (Figure 3.34). For simplicity, these groups are referred to in relation to their ostensible salinity regime: oligohaline, mesohaline, and euhaline. The oligohaline and mesohaline groups are within the SLE, while the euhaline sites are mostly within the SIRL, except for M6.

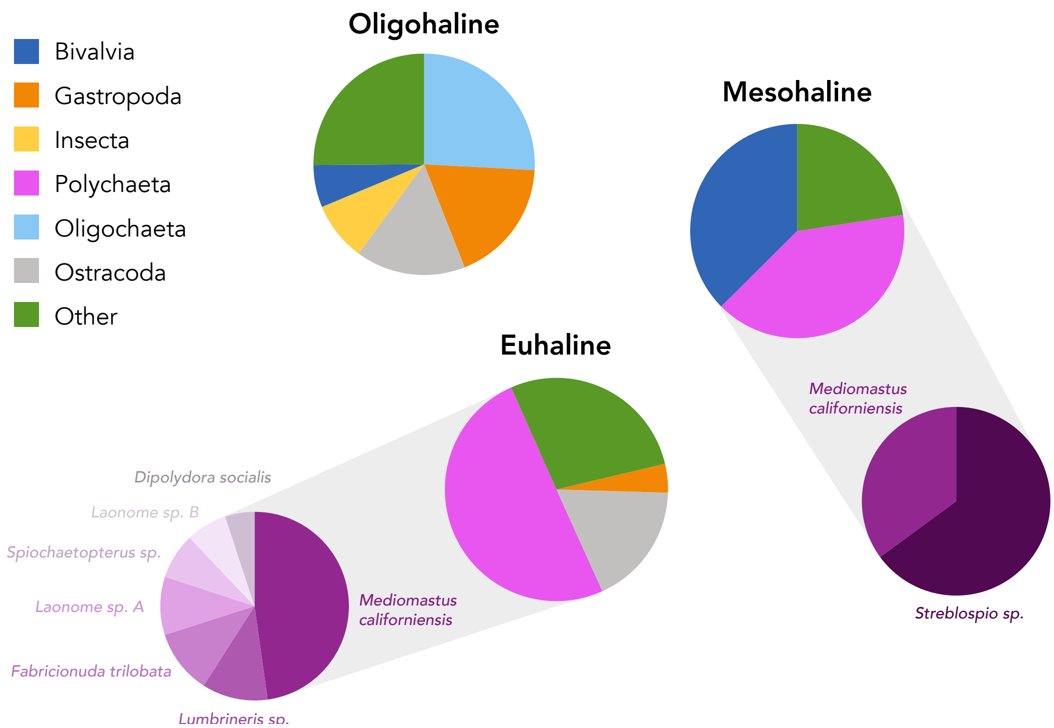


Figure 3.34. Charts representing the taxonomic diversity within the 3 regions. Call out charts demonstrate the difference in polychaete diversity in the mesohaline and euhaline regions.

The mesohaline sites are the most effected by freshwater inflow, as evidenced by lower diversity (Figure 3.35), dominance of tolerant taxa and fine grain, organic rich sediments with a high-water content. These sites are termed "mesohaline" but experience salinities ranging from 0–30 ppt.

Site M14 was added to the study to better track the effects of outflow from the C-44 canal. Despite experiencing salinities regularly over 10 ppt, and occasionally over 20 ppt the species assemblage of M14 is characterized by freshwater taxa. Additionally, the sediments at M14 are not what is expected from a degraded site. The sediments at M14 have a high percentage of organic matter, but larger grain sizes than those in the middle estuary. The sediments have a large amount of woody debris in them, attributable to the banks of this part of the river being dominated by mangrove forest, adjacent to a nature preserve. It appears the lack of fine grain, organic rich sediments with a high-water content is due to the high flow at M14 being fast enough to prevent the sedimentation of fine grain particles.

Conclusions

While reducing the pulses of freshwater to the SLE could improve the salinity regime, it may not improve diversity in the mesohaline sites. Mitigation of the fine grain, organic rich sediments with high-water content that have built up in the estuary, in addition to changes in the freshwater inflow, will likely be required to improve diversity in the mesohaline sites.

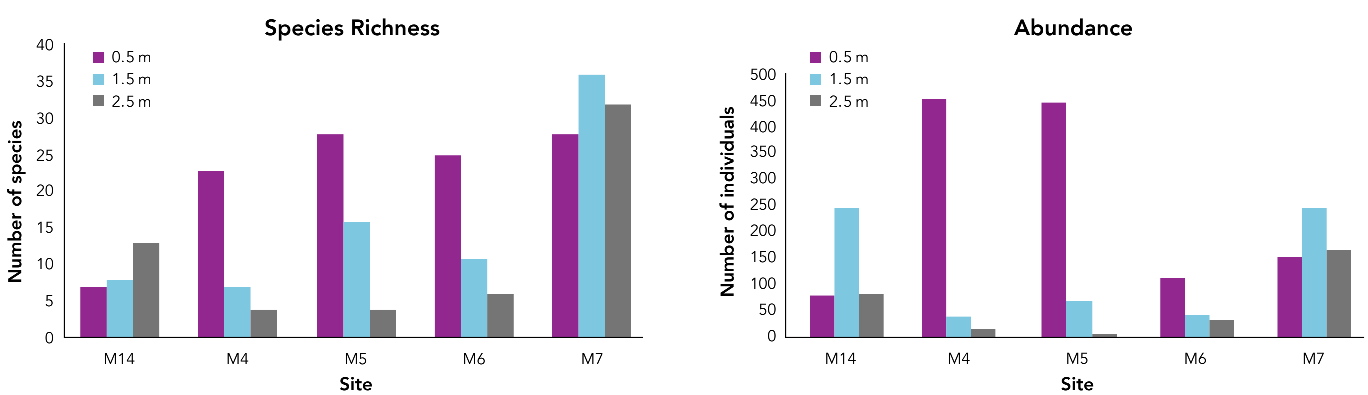


Figure 3.35. Species richness and abundance within transect samples. Presented by both site and depth.

FISHERIES

East coast estuaries

The southern Indian River Lagoon (SIRL) is a productive estuary that lies within a biogeographic transition zone with the greatest species diversity of any estuary in North America (Sime 2005). The distribution of temperate and subtropical fishes overlap in this area resulting in high species richness (Gilmore 1995). This richness is comprised of unique species relative to other estuaries in Florida, collectively referred to as tropical peripherals. Tropical peripherals include the river goby, bigmouth sleeper, opossum pipefish, and several species of snook, namely common snook, fat snook, swordspine snook, and tarpon snook.

The Indian River Lagoon and associated rivers are habitats at risk, because they support many fish species of particular concern and are in need of assessment, protection, and restoration (Musick et al. 2000). Opossum pipefish is an anadromous syngnathid that uses these habitats and is a National Marine Fisheries Service (NMFS) species of concern. Changes in environmental factors (temperature, salinity, turbidity), whether natural or anthropogenic, may have a pronounced effect on fish and invertebrate communities (Fraser 1997; Young et al. 1997; Paperno et al. 2006; Switzer et al. 2006) and these effects may be more apparent for species that have strict habitat requirements such as the opossum pipefish (Gilmore & Hastings 1983; Gilmore & Gilbert 1992), whose permanent breeding populations are believed to be limited to central coastal Florida (Gilmore & Gilbert 1992). The importance of the St. Lucie and Loxahatchee rivers and smaller tributaries to species of concern remains undetermined.

Another species of special concern is the goliath grouper. Large aggregations of goliath grouper occur just offshore between Jupiter and St. Lucie Inlets (Koenig et al. 2017). These aggregation sites represent one of the few places on the planet where dozens of groupers approaching 2 meters in length can be viewed by scuba divers. Juveniles of goliath grouper use river mouths and structured habitats within estuaries for their first 3 to 5 years of life before moving offshore (Koenig et al. 2007). The Indian River Lagoon and associated rivers provide juvenile habitat. Efforts are underway to determine the amount of estuarine area that is used by juvenile goliath grouper using acoustic telemetry. An array of acoustic receivers is maintained along the east coast of Florida including the southern Indian River Lagoon (SIRL) and associated rivers (see FACT array, http://secoora.org/fact; Figure 3.36). Juvenile goliath groupers have been tagged with acoustic transmitters (tag life exceeding 6 years) in the Indian River Lagoon and St. Lucie River and are being tracked as they move. Juveniles have shown responses to seasonal changes in freshwater inflows by moving downstream during wet periods. The goal is to quantify patterns of movement, use of specific habitat, and responses of these to varying freshwater inflows. Tagging additional species in the array of receivers could determine how large-bodied fish respond to changes in freshwater inflow and how they use restored habitats.

The SIRL and St. Lucie and Loxahatchee rivers have historically served as nursery habitat for the endangered smalltooth sawfish (Evermann and Bean 1898), which has been extirpated from many areas within its range due primarily to overfishing (Norton et al. 2012). Adult females can grow larger than 3.5 m in length and deliver 7–14 live young every other year in protected estuarine embayments and river mouths (Poulakis et al. 2011; unpubl. data). The young stay within the estuaries for at least 2 to 3 years (Scharer et al. 2012), after which they leave the nursery and are hypothesized to move into nearshore coastal habitats. With anticipated recovery of the smalltooth sawfish population in south Florida, the SIRL, St. Lucie, and Loxahatchee rivers may again support this species. If smalltooth sawfish are found to be using these nursery areas, a program to monitor habitat use could be implemented (NMFS 2009).

The most popular recreational fisheries in the SIRL target sheepshead, spotted seatrout, and common snook. Young sheepshead recruit to estuaries and support a recreational fishery before migrating to offshore habitat as adults (Winner et al. 2017). Structured habitats in the lower rivers, including oyster reefs, bridges, and mangrove shorelines, support sheepshead and are common locations for recreational anglers. The productive seagrasses of the SIRL are the primary habitats that support spotted seatrout, which spends its entire life in the estuary (Bortone 2003). Common snook also complete their entire life cycle within the estuary (Taylor et al. 1998). Adults aggregate at narrow ocean inlets (e.g., Sebastian, St. Lucie, Jupiter) during summer to spawn

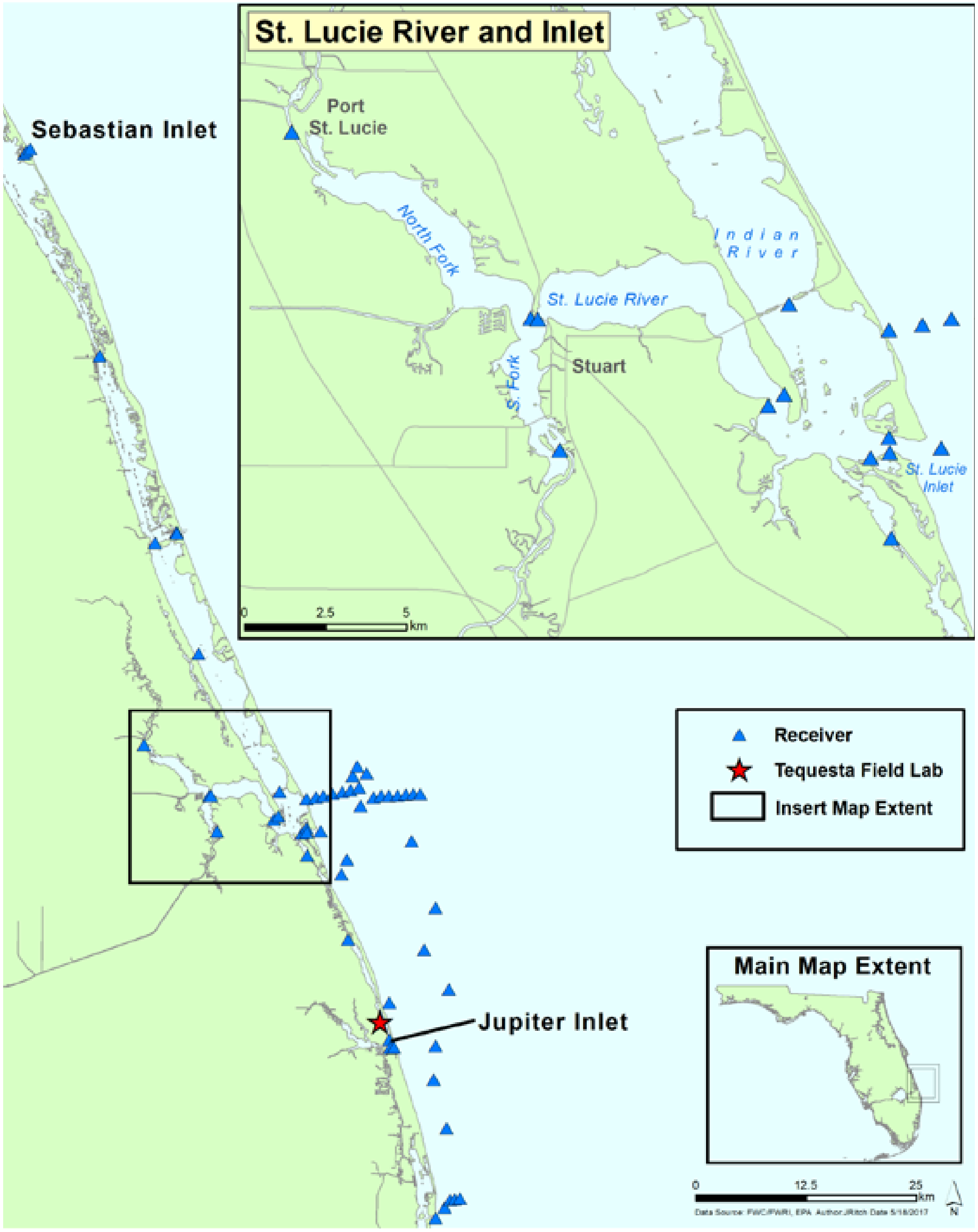


Figure 3.36. Map showing locations of Florida Fish and Wildlife Conservation Commission acoustic receivers in the southern Indian River Lagoon system. The acoustic receivers are part of a larger network that spans the coast of Florida and portions of the Caribbean.

(Young et al. 2016). Because of the propensity of common snook to aggregate, the large sizes they achieve in the Indian River Lagoon (larger than those of Florida's west coast), and accessibility of the fish (jetties), the SIRL is well known to snook anglers. Another popular recreational fishery in Florida targets red drum.

The St. Lucie and Loxahatchee rivers represent the core of juvenile habitat for estuarine fishes in the SIRL, largely because of coastal geomorphology and habitat loss elsewhere. The proximity of the rivers to ocean inlets allow larval and juvenile fishes easy access to the vegetated shorelines and lower salinity waters that offer protection from large predators. The braided channels of the river forks and the many backwater habitats are present despite alteration of the mainstem for water control and navigation. Elsewhere in the SIRL, habitat losses have been more severe. Nearly all the coastal wetlands of the Indian River Lagoon were impounded for mosquito control (Brockmeyer et al. 1997) though most have been reconnected (Rey et al. 2012), and many shoreline habitats along barrier islands have been lost to development. To preserve the unique fish communities of the SIRL, protecting and restoring shoreline vegetation and seagrass, and ensuring appropriate salinity regimes should be the highest priorities for conservation. Identifying specific, high-priority locations within the estuary to target for conservation or restoration is important.

Florida's fishery-independent monitoring (FIM) program operates in the SIRL. Sampling is jointly conducted by Florida Fish and Wildlife Conservation Commission's Melbourne and Tequesta field laboratories. This program is effective at tracking abundance of some species. For example, haul seine data was used to track recovery of common snook following a severe cold-kill event in 2010 (Stevens et al. 2016). Each year, FIM produces indices of abundance for spotted seatrout, common snook, and sheepshead among others (striped mullet, blue crabs) that are used in the management of these species both regionally in the Indian River Lagoon and state-wide. The FIM program also samples to identify nursery habitat, which can be used for permit (Adams & Blewett 2004), common snook (Stevens et al. 2007), blue crab (Flaherty & Guenther 2011), gray snapper (Flaherty et al. 2014), spotted seatrout (Flaherty-Walia et al. 2015), gag (Switzer et al. 2015), and red drum (Whaley et al. 2016). It is also useful for identifying important feeding habitats, particularly those associated with riverine floodplains and backwaters that are the subject of restoration efforts.

The Fisheries Ecology and Conservation Lab at FAU Harbor Branch conducts routine monitoring of elasmobranchs as apex predators in the Indian River Lagoon (IRL) (bull sharks and spotted eagle rays). For surveying, the mid/southern IRL is subdivided into five zones, including the St. Lucie River (mainstem and forks), and each zone is sampled quarterly. Blood and tissue samples are collected to establish physiological and epidemiological baselines which relate to ecosystem health. Since program inception in July 2016, two adult sawfish have been collected in the vicinity of the SLE (one just inshore of St. Lucie Inlet, one in the river mainstem). Ancillary catches of teleosts are also recorded in the dataset.

Dr. John Baldwin's lab at FAU Davie has been working closely with FWC-Tequesta to develop, analyze, and conduct further research on common snook responses to environmental conditions. FIM data has been used for body condition indices and population resilience following the 2010 cold event in the IRL. FWC acoustically-tagged common snook from 2008–2015, providing movement data on the east coast of Florida. Environmental parameters from open-source databases coinciding with the acoustic data are being used to model influences on snook movement within the St. Lucie Estuary.

West Coast Estuaries

The Caloosahatchee River estuary (CRE) supports over 250 species of fish (Poulakis et al. 2004), and is known for several fisheries that depend on estuaries. The most notable include a commercial blue crab fishery and recreational fisheries for common snook and red drum (Trotter et al. 2012; Lowerre-Barbieri et al. 2016; Stevens et al. 2016; Doering & Wan 2018). The CRE also serves as a well-known nursery for elasmobranchs, including cownose ray, bull shark, and the endangered smalltooth sawfish (Collins et al. 2008; Heupel and Simpfendorfer 2008; Poulakis et al. 2011, 2013). Seagrass beds in the lower estuary support gag, spotted seatrout, and baitfish such as scaled sardine that are used in recreational fisheries (DeAngelo et al. 2014).

The geomorphology of the river allows juvenile fish to respond to changes in freshwater inflow without moving upstream into narrow reaches, or moving out of the river, except under extreme conditions (Stevens et al. 2008). Species-specific analyses investigating the response of fishes (movement and abundance) to varying freshwater inflows revealed significant relationships. For example, red drum exhibited a strong relationship to freshwater flows. Under very high inflow conditions (>190 m^3/s), juvenile red drum were found on average about 8 km upriver in downtown Cape Coral, whereas at extreme low inflow conditions (~3 m^3/s), the mean position of juvenile red drum was about 35 km upriver in the narrow, channelized habitats.

Backwater areas found off the river's mainstem (mangrove coves and creeks) retain much of the form and natural vegetation that provide juvenile habitat for several economically-important fishes like common snook, red drum, and bluegill (Stevens et al. 2010a). Expected seasonal changes in fish assemblages of the main river channel are muted in the Caloosahatchee River, abundances of common estuarine species (sand seatrout, southern kingfish, and blue crab) are lower, and abundance of a resilient scavenger (Hardhead Catfish) is higher (Stevens et al. 2008; Olin et al. 2015). The ecology of the river is affected by disturbances (hurricanes, red tide, extreme cold event) and these effects are important to consider when analyzing trends in fish abundance (Stevens et al. 2006; Greenwood et al. 2006; Flaherty & Landsberg 2011; Stevens et al. 2016).

Physical alterations, changes in hydrology, and climate change can set the stage for the establishment of invasive species. Species that have been introduced in the Caloosahatchee River Estuary include African jewelfish, spotted tilapia, blue tilapia, brown hoplo, grass carps, Mayan Cichlid, and sailfin catfishes (Idelberger et al. 2011). Most of these species are found in freshwater and oligohaline reaches of the river. The potential for downstream expansion exists for the euryhaline tilapia (Blue and Spotted), Mayan cichlid, and African jewelfish (up to 50 ppt), which were collected in small numbers in the mesohaline zone (Idelberger et al. 2011). Introduced fishes affect native species directly by competing for food, space, or by predation. Indirect effects occur through the introduction of parasites and diseases, or through alteration of habitats from consumption of vegetation and detritus (cichlids), benthic nest-building (brown hoplo), and burrowing along banks (sailfin catfishes). Introduced fishes can provide benefits; the brown hoplo is a major diet item for common snook in the Caloosahatchee (Stevens et al. 2010b). For the Caloosahatchee River estuary, a number of introduced fishes could eventually enter the system including the Asian swamp eel, blackchin tilapia, and pike killifish. These species are established in Tampa Bay to the north and in the Everglades system to the south (Idelberger et al. 2011). Periodic sampling in the Caloosahatchee River estuary (2–3 years of sampling every decade) may help assess the status of exotic species and any overall changes in fish communities.

A notable feature of the lower estuary are seagrass shoals, which are farther from shore (>~100 m) and are commonly characterized by deeper water, steeper slopes, sandier bottoms, and greater seagrass coverage than seagrass beds along shorelines (DeAngelo et al. 2014). Fish assemblages of seagrass shoals differed from those of seagrasses along shorelines (DeAngelo et al. 2014). Species that were more abundant on seagrass shoals included gag, spotted seatrout, and scaled sardine, while other species such as common snook, sheepshead, and striped mullet were more abundant in shoreline seagrass beds. Despite the prevalence of seagrass shoals in Gulf Coast estuaries, studies documenting use of this habitat by fishes are few.

Currently, the only fish sampling effort in the Caloosahatchee River is targeted research on the endangered smalltooth sawfish. This project began in 2004 and is ongoing. Data have shown that sawfish use four nursery hotspots in the Caloosahatchee River during their residence in the river (at least 2–3 years old and 2.5 m in length; Scharer et al. 2012). During periods of low freshwater inflow (winter and spring), sawfish move upriver and associate with two nursery hotspots. During periods of high freshwater inflow (late summer and fall), sawfish move downriver to mangrove-lined embayments, a distance of about 20 km.

Storm-induced events, and regulatory releases from Lake Okeechobee, can exceed 200–300 m^3/s. Despite these flows, and the rapid changes in salinity that they cause, no sawfish mortalities have been observed following these events (sawfish public encounter database, Norton et al. 2012), and health issues associated with stress in fishes have been minimal in sawfish (Bakenhaster et al. 2018). Sawfish can move up and down the river to an even greater degree during dry-season releases in the CRE (Scharer et al. 2017). How dry-season releases might affect sawfish over the long-term is unknown. A preliminary analysis of sawfish growth rates during years of extreme freshwater inflow showed that growth rates did not differ from those of more typical years, and blood profiles of sawfish from the nursery may indicate chronic, metabolic stress compared to Everglades nurseries farther south (unpubl. data; Prohaska et al. in press).

Conservation, enhancement, and restoration of backwaters associated with the CRE can do a great deal to maintain current fish production in the river. In many tidal creeks associated with the CRE, homeowners have left native vegetation intact despite building docks for popular boating activities. Encouraging a culture that favors living shorelines in lieu of seawalls in backwater habitats helps conserve the coastal wetlands needed to support nurseries for sport fishes such as common snook.

Periodic seasonal and out-of-season water releases into the CRE provide a framework for improving understanding of the movement and habitat use patterns of large-bodied fishes. A relatively large network of acoustic telemetry receivers is already present in the CRE, and continued support of this technology can expand the ability to track responses of large-bodied fish to freshwater inflow and to determine habitat use by fishes in areas of interest. The fisheries-independent monitoring effort in the CRE could be revisited at appropriate time intervals (i.e., 2–3 years of monitoring each decade) to check on the status of the system. Such status checks can be used to identify any gross changes in fish communities that may occur during implementation of water management and restoration projects.

3.4 DISCUSSION

The Northern Estuaries region is complex as it includes three separate systems on either coast of peninsular Florida. The major drivers that influence their ecology are similar. There are variable salinity regimes due to altered hydrology and demands from flood control and water supply. Land-use practices and impacts from impervious surfaces, like nutrient loading, create a highly-altered system to which estuarine organisms must adapt. In coordination with the Southern Coastal Systems module, an updated, regional conceptual ecological model (CEM) was drafted which describes these natural and anthropogenic mechanisms (see RECOVER 2018 in prep). Additional CEMs based on each region's ecological indicators ("hypothesis cluster" CEMs) are currently under revision.

Several environmental events from WY2013–2018 have had significant impacts on the systems' ecology, including harmful algal blooms and hurricanes. More detail about these events and how they impacted each RECOVER region are described in Chapter 2 of this report, and their impacts are occasionally reflected in subsequent sections of Chapter 3 as they pertain to each of the Northern Estuaries indicators and their monitoring programs.

3.5 RESTORATION

A major goal of CERP is to reduce harmful releases and provide supplemental flows to the Northern Estuaries by providing additional storage and conveyance of water south toward the Everglades proper. Significant progress is expected over the next five years with the construction and planning of several key CERP projects expected to benefit the estuaries.

St. Lucie Estuary and Southern-Indian River Lagoon

A major component of CERP that will provide positive impacts to the St. Lucie and South Indian River Lagoon is the C-44 Reservoir and Stormwater Treatment Areas (STAs), the first component of the Indian River Lagoon-South (IRL-S) project. This project includes several components, each of which will provide future improvements in water quality for SAV, oysters, and benthic infauna in the estuary. These components include four STAs, restoration of ~92,100 acres of habitat upstream (mixed wetland and upland), and redirection of freshwater flows to the North Fork of the St. Lucie River from the C-23/C-24 basin. Additional components of the IRL-S focus specifically on improving and restoring the benthic habitat in the St. Lucie River Estuary for VECs such as SAV, oysters, and benthic infauna by removing untenable sediments. The St. Lucie River C-44 STA is set to be completed in one year and the reservoir set to be completed in approximately two years. Other restoration efforts are underway through the Indian River Lagoon National Estuary Program.

There are several long- and short-term strategies being implemented by multiple agencies in the region, with the goals of improving the water quality and better managing flows into the SLE by increasing water storage in the regional water management system. The long-term strategies include the St. Lucie River and Estuary Basin Management Action Plan (BMAP; FDEP et al. 2013), which is the blueprint to meet Florida Department of Environmental Protection (FDEP) Total Maximum Daily Loads (TMDLs; Palmer et al. 2008). Shorter-term strategies include a water storage reservoir in the Everglades Agricultural Area (EAA) to further reduce damaging releases and nutrient loads to the Northern Estuaries (SFWMD 2018).

Caloosahatchee River and Estuary

A major component of CERP that is set to provide positive impacts to the Caloosahatchee River and Estuary in the next five years is the C-43 Reservoir. This project is designed to capture excess C-43 Basin runoff and regulatory releases from Lake Okeechobee during the wet season and release water from the reservoir during the dry season. The project includes development of an aboveground reservoir with a total storage capacity of approximately 170,000 acre-feet (ac-ft). The project will reduce extreme salinity changes in the CRE by providing more consistent inflows of water into the estuary. The C-43 Reservoir is scheduled to be completed in 2023. Once completed, flows should be more consistent which should promote a more balanced and healthy salinity regime for the different valued ecosystem components of the river such as SAV and oysters.

Another major component of CERP that is set to provide positive impacts to the CRE over the next five years is the Lake Okeechobee Watershed Restoration Project (LOWRP). This project, which is in the planning phase, is expected to improve water levels in Lake Okeechobee, improve the quantity and timing of releases to the Caloosahatchee Estuary, restore degraded habitat for fish and wildlife, and increase the spatial extent and functionality of wetlands. Over the next five years, LOWRP is expected to be authorized, and when constructed it and other authorized projects will reduce the number and duration of undesirable Lake Okeechobee releases to the CRE. This reduction in flow volume will improve salinity conditions and improve habitat for oysters, SAV, and fish. Other restoration efforts are underway through the Charlotte Harper National Estuary Program.

Lake Okeechobee System Operations Manual (LOSOM)

Lake Okeechobee water management and lake levels are regulated by the 2008 Lake Okeechobee System Operations Manual (LOSOM). The LOSOM was developed to balance the performance of multiple project purposes while preserving public health and safety, not to optimize performance of any single project purpose at the expense of another. One of the primary goals of LOSOM is to maintain a lake level between 12.5 and 15.5 feet. LOSOM includes a seasonally-adjusted schedule to help guide water management decisions. Over the next five years, a new study on water management and lake levels that includes significant public involvement will be undertaken. The revision of LOSOM has the potential to improve Lake Okeechobee releases to the Northern Estuaries providing better salinity regimes for the SLE and CRE. RECOVER is looking to update the Northern Estuaries Salinity Envelope Performance Measure prior to the LOSOM study.

Lake Okeechobee. Photo by SFWMD.

Lake Okeechobee

4.1 introduction

Lake Okeechobee (LO) is the second largest natural freshwater lake contained entirely within the contiguous United States by area, and by far the largest water storage feature in south Florida. The Lake receives freshwater from local watersheds and tributaries from as far north as Orlando via the Kissimmee River, and distributes water south to the Greater Everglades and east and west to the Northern Estuaries. The Herbert Hoover Dike (HHD) construction began in the 1930s to provide flood protection to communities around the lake, but this caused peak inflows to the lake to greatly exceed the capacity to remove water. To protect the dike, engineers release large volumes of water into the St. Lucie and Caloosahatchee Estuaries when high lakes stage are anticipated. "Getting the water right" means increasing watershed storage and improving water quality so that lake water levels can be better managed to mimic historic hydrology, benefiting ecological conditions within the lake and reducing water releases to the Northern Estuaries, while at the same time moving more water south to the Greater Everglades. Progress has been made toward constructing a series of reservoirs and stormwater treatment areas, though more water storage will be needed to meet restoration targets.

Lake Okeechobee is shallow and eutrophic. Historic and background information, including its importance to the south Florida ecosystem and the impacts development has had on it can be found in the 2007 System Status Report (RECOVER 2007b). The natural shoreline, inflow, and outflow of LO was altered by the construction of the HHD and associated water control structures and watershed drainage features, while increased nutrient inputs have caused excessive eutrophication over many decades. As a result, water levels within LO fluctuate with increased frequency and amplitude, and vast quantities of nutrient-laden sediments have accumulated in deeper portions of the lake which are easily re-suspended by even moderate winds (Maceina & Soballe 1991). This has caused LO to become increasingly turbid and has exacerbated water-column nutrient concentrations upon their release from the sediment. Excessive nutrients and dramatic fluctuations in water levels favor invasive species, displacing large areas of marsh with nonnative or nuisance vegetation which lowers habitat quality and increases management costs.

Lake Okeechobee provides ecosystem services such as water supply, flood protection, and recreational activities including fishing, boating, and bird watching. The main threats to the health of LO are poor water quality, inappropriate or extreme water levels, and exotic species. LO has three sub-regions that

are functionally dissimilar and consequently may respond to changes in water level and/or water quality differently: a littoral marsh, a nearshore region, and an open water (pelagic) region (Figure 4.1). The effects of hydrologic modifications and eutrophication are somewhat related in terms of their impact on the different regions of the lake. For example, as lake stages increase, so too does horizontal mixing; i.e. the transport of nutrients and suspended material from the pelagic zone into the nearshore and littoral areas of the lake.

Lake levels are managed to improve and sustain the ecological health of the lake and also for flood control and water supply. For ecological benefits, a desired stage envelope (12.5 feet–15.5 feet National Geodetic Vertical Datum of 1929 [NGVD29]) was developed to maximize the extent of littoral wetlands within the levee, while also minimizing the transport of sediment and nutrients to the nearshore and littoral regions (RECOVER Lake Stage PM 2007).

Figure 4.1. Three distinct ecological zones of Lake Okeechobee.

To address concerns related to the hydrologic modifications and eutrophication of LO, Conceptual Ecological Models (CEMs) were developed to provide a science-based path toward restoration (SFWMD 2006). These models depict the relationships between lake stage, nutrient condition, and key flora and faunal communities that respond to or are affected by these stressors. These CEMs were used to select indicators of the overall ecological condition of the lake and are representative of the three sub-regions in LO. They include the important recreational sportfish species black crappie (*Pomoxis nigromaculatus*) and largemouth bass (*Micropterus salmoides*), wading birds, submerged and emergent vegetation communities, and a variety of water quality indicators; total phosphorus concentration and load, chlorophyll *a*, phytoplankton community (diatom and cyanobacteria ratios), and water clarity.

Each of these indicators is affected by changes related to lake stage, based on the relationship between stage and vertical/horizontal mixing of nutrient laden sediments. When pelagic sediments and associated nutrients are suspended in the water column and transported to the nearshore zone, light penetration decreases, vegetation coverage can decline, frequency or extent of algal blooms can increase, phytoplankton communities can change, and faunal indicator groups can decline. The desired condition for the lake is to have each of these indicators showing improvement from current conditions, either from reductions in peak stages that increase horizontal mixing, or from reductions in sediment resuspension through improvements in pelagic water quality. The latter, however, would be a long-term solution requiring substantial improvements in both watershed and in-lake nutrient conditions, and removal or capping of the fluid sediments responsible for internal loading of nutrients and turbidity. Therefore, maintaining lake stage within a general range of seasonally variable water levels is the most direct and impactful way to affect ecology within LO. This chapter reviews the status of several indicators affected by lake stage, as well as how stages themselves have varied over the five water-year period WY2013–WY2017.

4.2 KEY FINDINGS

The five-year period from WY2013–WY2017 (May 2012–April 2017) was marked by relatively stable water levels compared to the previous five water years. The WY2008–WY2012 period included four major droughts, resulting in record low lake stages and three separate years with stages below 10 feet NGVD (National Geodetic Vertical Datum). By comparison, the latter period was considerably wetter, with water levels going above the stage envelope in all five water years and failing to reach the seasonal low of the stage envelope in two water years. Evaluation of the indicators during this period suggest such water levels, despite comprising one of the more stable periods in decades, have not been favorable for overall ecological conditions on LO. This may be due to events where lake stages were higher during critical growing season periods, which may have had an outsized effect on vegetation and other indicators.

Indicators evaluated in Lake Okeechobee were fish, submerged aquatic vegetation (SAV), emergent aquatic vegetation (EAV), wading bird proportion (based on prey density), wading bird interval between exceptional nesting years, chlorophyll *a*, water clarity, and lake stage (Figure 4.2). Lake stages were close to desired targets, except for several high-water events during the peak of the summer growing season. These untimely exceedances may explain the difference between lake stage scores and those for flora and fauna. EAV and SAV were poor to fair, likely affecting fish and wading bird indicators; though the wading bird interval indicator scored well. Water clarity scores were very poor and chlorophyll *a* scores were poor, likely affecting SAV and fish indicators.

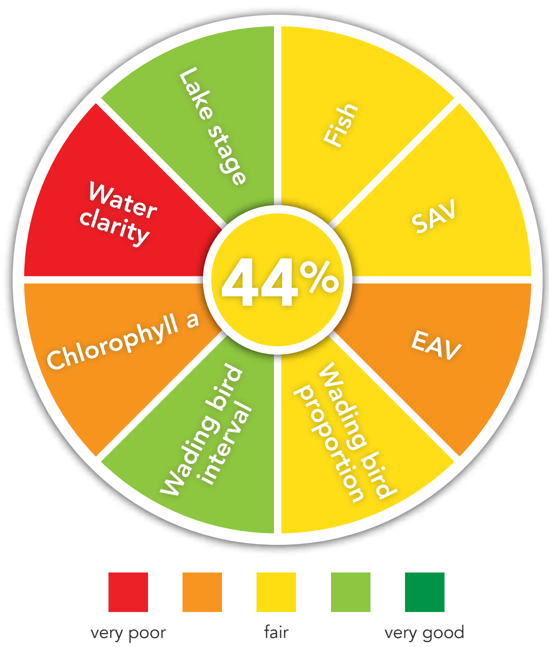


Figure 4.2. Lake Okeechobee indicator scores from the 2012–2017 Everglades Report Card.

Stage envelope: The lake stage was above the desired ecological envelope 33% of the period, with most of those exceedances occurring during the peak of the growing season (June–October); having a large effect on lake ecology.

Chlorophyll *a*: Mean chlorophyll *a* concentrations remained well above target levels and increased from the previous period. During WY2013–WY2017, algal bloom frequency averaged 9.1%, nearly double the target of <5%. When present, algal blooms were most often dominated by Cyanobacteria.

Water clarity: Concurrent with greater average water depths in the most recent five-year period, nearshore water clarity declined. It is possible that this caused decreased SAV acreage, see below.

Emergent Aquatic Vegetation (EAV): Effects from extreme low lake stages between WY2008–WY2012 were still evident from the abundance of woody species and torpedograss, while high lake stages between WY2013–WY2017 reduced coverage of desirable groups (bulrush and spikerush) and increased coverage of the floating leaf community in the interior marsh.

Submerged Aquatic Vegetation (SAV): Total SAV acreage decreased 33% between WY2013–WY2014 and by another 40% between WY2016–WY2017 due to large reductions in non-vascular species following elevated summer lake stages. Total acreage of vascular SAV species declined every year after WY2014, with WY2017 having the lowest coverage of both vascular and non-vascular species of the five-year period, and the lowest total since data collection began in 2001 (absent hurricane effects).

Black crappie: In WY2008–WY2012, recruitment and adult populations increased as habitat and food returned and turbidity declined. Since WY2013, recruitment has been steadily declining, likely due to the loss of vegetation in the nearshore zone, leading to a reduction in food and decreased survival in young fish. While the adult population has remained fair, further declines are expected if recruitment levels remain the same or continue to decline.

Largemouth bass: Similar to black crappie, populations increased in WY2008–WY2012 with the return of SAV and EAV. In WY2013–WY2017, loss of habitat due to high water may have contributed to the decrease in recruitment of bass, particularly in the past few years. In WY2013–WY2017, loss of habitat due to high water may have contributed to the decrease in recruitment of bass, particularly in the past few years. Adult populations have declined as well, but remain fair. However, vegetation levels at current or reduced levels will increase the loss of adult bass.

Wading birds: There was a decline in snowy egret and white ibis nesting from 2012–2017 and compared to the previous period (2006–2011). However, great egret nesting increased during this reporting period, particularly in the four wettest breeding seasons (2013–2016).

4.3 INDICATORS

Introduction and background

The status of Lake Okeechobee is generally described in regard to 1) lake stages, 2) phosphorus budgets, 3) phytoplankton dynamics, 4) SAV, 5) EAV, 6) fish, and 7) wading birds. Conceptual ecological models were developed to address how hydrologic and nutrient issues affect these attributes, and those efforts were used to select indicators of the overall ecological condition of the lake. These indicators are representative of the three ecological zones in LO and are affected by changes related to lake stage, i.e. the relationship between stage and vertical and horizontal mixing of nutrient laden sediments. They include a variety of water quality indicators, including; total phosphorus concentration and load, chlorophyll *a*, phytoplankton community (diatom and cyanobacteria ratios), and water clarity; and also, submerged and emergent vegetation communities; important recreational sportfish species black crappie (*Pomoxis nigromaculatus*) and largemouth bass (*Micropterus salmoides*); and wading birds. Additionally, because of the importance of lake stage to these indicators and overall ecological conditions of the lake, stages themselves are used as an indicator, as a measure of how well lake stages were maintained seasonally and annually within the ecologically beneficial stage envelope of 12.5–15.5 ft NGVD29 (RECOVER 2007f).

STAGE ENVELOPE

In April 2008, the Lake Okeechobee System Operations Manual (LOSOM) was implemented to lower lake stages while the U. S. Army Corps of Engineers (USACE) began repairing the aging dike. After several droughts in WYs 2008, 2009, 2010, and 2012, lake stages were relatively stable and within the ecological stage envelope 52% of the time for WYs 2013–2017 (Figure 4.3). There were only two periods where monthly averages dipped below the envelope; at the beginning of WY2013 and at the end of WY2017. These events, particularly when stages are above 11.0 ft NGVD, are considered less damaging to the lake ecology than when lake stages exceed the envelope. While the upper reaches of the marsh tend to be completely dried for months during droughts, lower water levels in the nearshore zone, coupled with decreased nearshore turbidity, promote vegetation and periphyton recovery; revitalizing the SAV, EAV, and periphyton communities at the deeper ends of the marsh. This leads to increased nutrient uptake, increased water clarity, and reductions in algal blooms, all of which constitute good habitat conditions for associated faunal communities. Conversely, exceedances above the stage envelope lead to declines in SAV, EAV, and periphyton abundance in the nearshore region and enable nutrient laden water to move farther into the interior marshes.

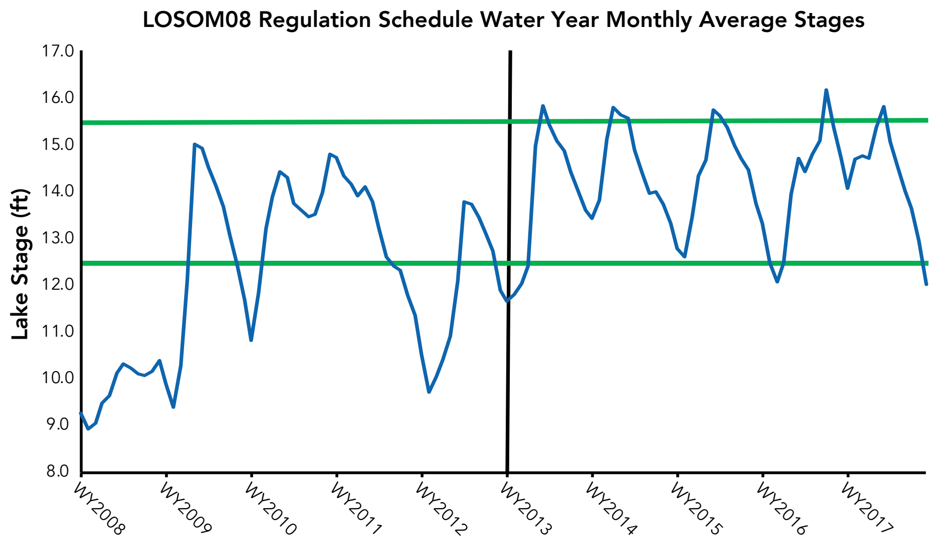


Figure 4.3. Lake Okeechobee monthly average stage hydrograph from water year (WY) 2008–2017, or May 1, 2007 to April 30, 2017. Green horizontal lines denote the lake stage envelope and the vertical line is where WY2013–2017 begins.

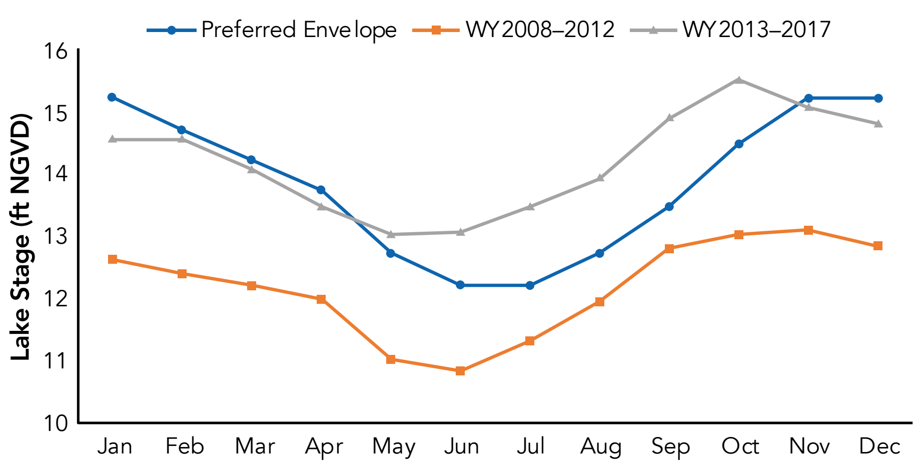


Figure 4.4. Average monthly lake stage for the preferred ecological envelope, and actual lake stage for WYs 2008–2012, and WYs 2013–2017.

While the five-year period between WY2013–WY2017 was relatively stable, lake stages exceeded the ecological envelope 33% of the time. Further, these exceedances were primarily during the peak of the growing season (June–October). Given that summer lake stages are critical for SAV, EAV, and periphyton communities in the nearshore region, and in predicting the prevalence of summer algal blooms, the 1.0–2.5-foot higher lake stages in WY2014 and WY2017 during these critical periods likely had a larger impact on lake ecology than the overall "envelope" performance would indicate (Figure 4.4).

WATER QUALITY

Several performance measures related to water quality were created to monitor progress in the Lake Okeechobee Protection Plan (SFWMD et al. 2004). These measures collectively describe the status of nutrients in the inflows (loads) and in the lake itself (concentrations), algal bloom conditions, water clarity, and total SAV. Targets were set for many of these indicators, providing important benchmarks to evaluate current conditions (Table 4.1). For more information on the development and relevance of these measures, see SFWMD (2005).

Table 4.1. Performance measures established for water quality and SAV attributes as part of Lake Okeechobee Protection Act. Water quality and SAV five-year averages and performance measure (PM) targets (SFWMD 2018b).

Variable	PM target	Five-year average (WY2008–WY2012)	Five-year average (WY2013–WY2017)
Total phosphorus (TP) load	140 mt/yr	387 mt/yr	531 mt/yr
Total nitrogen (TN) load	No target	4,788 mt/yr	6,302 mt/yr
Pelagic TP	40 µg/L	134 µg/L	129 µg/L
Pelagic TN	No target	1.52 ppm	1.41 ppm
Pelagic SRP	No target	42 µg/L	43 µg/L
Pelagic DIN	No target	191 µg/L	199 µg/L
Pelagic TN to TP	>22:1	11.3:1	10.6:1
Pelagic DIN to SRP	>10:1	4.5:1	4.7:1
Nearshore TP	Below 40 µg/L	76 µg/L	89 µg/L
Algal bloom frequency	<5% of pelagic chlorophyll *a* exceeding 40 µg/L	5.6%	9.1%
Diatom:Cyanobacteria ratio	>1.5:1	3.3:1 (Pelagic) 3.6:1 (Nearshore)	2.1:1 (Pelagic) 1.4:1 (Nearshore)
Nearshore[a] water clarity	Secchi disk visible on lake bottom at all nearshore SAV sampling locations from May to September (100%)	44%	32%
Nearshore SAV coverage	Total SAV ≥50,000 ac Vascular SAV ac = no current target	38,137 ac 17,388 ac	28,905 ac 22,032 ac

[a]Nearshore SAV sites were replaced with nearshore South Florida Water Management District (SFWMD) water quality sites in WY2012, so the five-year water clarity average values are not directly comparable. [Note: acres–ac; DIN–dissolved inorganic nitrogen; ft–feet; mt/yr–metric tons/year; N–nitrogen; P–phosphorus; ppm–parts per million; SAV–submerged aquatic vegetation; SRP–soluble reactive phosphorus; µg/L–micrograms per liter.]

Nutrients

The five-year averages for the total phosphorus (TP) and total nitrogen (TN) loads into the lake and most of the in-lake concentrations during the recent WY2013–2017 period were all higher than the previous five-year period, except for pelagic TP and pelagic TN (Table 4.1). The nutrient loads were higher mostly due to increased inflows during the overall wetter period, while the pelagic concentrations were similar or slightly lower due to overall higher water levels, which tend to reduce resuspension of nutrient laden sediments in the pelagic area, as well as dilute concentrations with higher lake volume. However, TP concentrations were substantially higher in the nearshore zone, likely due to increased horizontal mixing with the pelagic zone at higher lake stages. The average TP load of 531 mt/yr for the five-year period was over 3.5 times the target level of 140 mt/yr, while the average nearshore and pelagic TP concentrations were roughly 2 and 3 times their target values of 40 µg/L. Further, while the TN:TP and DIN:SRP ratios were similar between the two periods, they remained about half of the target ratios of >22:1 and >10:1, respectively. Overall, this suggests that phosphorus and nitrogen-related parameters were not improving in LO and remained far above target levels for the five-year period.

Chlorophyll *a*

Algal biomass, reported here as chlorophyll *a* concentration, was monitored across 10 nearshore and 9 pelagic stations monthly. Mean annual algal biomass was between 12 and 17 µg/l during WY2008–2012 and between 13 and 26 µg/l during WY2013–2017. Additionally, in eight of the past ten water years, the mean annual concentration was higher in the nearshore region. The overall mean chlorophyll *a* concentration increased from 15.2 µg/l during the previous five-year period to 20.5 µg/l during the recent five-year period with four of the five highest chlorophyll *a* concentrations recorded in WYs 2014 to 2017. The highest value of 278 µg/l was recorded at a pelagic site in WY2017.

Algal blooms are defined by the South Florida Water Management District (SFWMD) as equivalent to chlorophyll *a* concentration of ≥40 µg/l. During the recent five-year period, the WY with the highest frequency of algal blooms was WY2014 (31%), followed by WYs 2015 (17%) and 2017 (18%) (Figure 4.5). The lowest algal bloom frequency occurred during WY2013 (0%) and WY2016 (5%). Since WY2008, the performance measure target of <5% algal bloom frequency was met once in the nearshore region (though very close two other times) and four times in the pelagic region. Recently, the target has not been met in four of the past five water years in either region with blooms occurring most frequently from June through October.

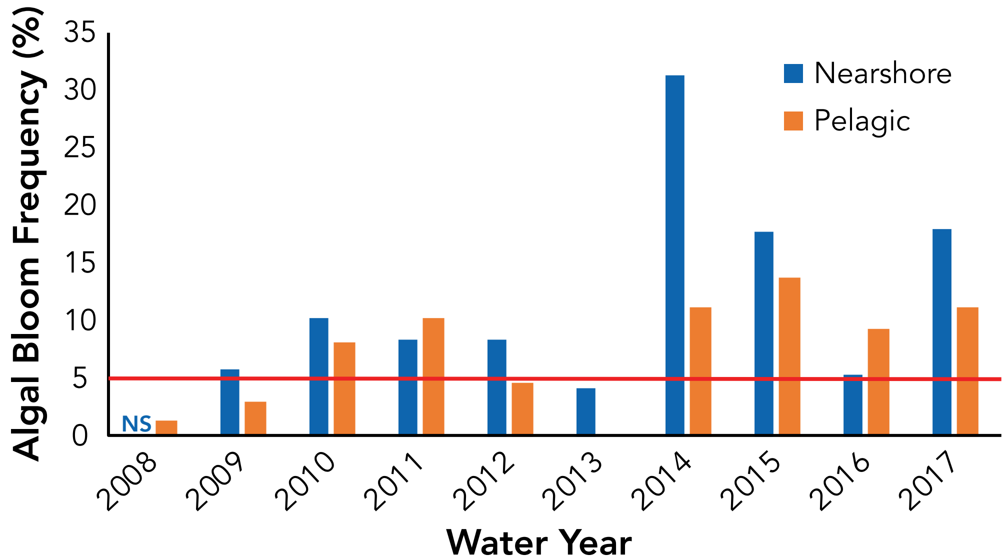


Figure 4.5. Percent frequency of algal blooms (as chlorophyll a ≥40 µg/l) at the nearshore and pelagic sites by water year. The red line is the performance measure target. (NS = Not Sampled due to drought).

Diatoms and cyanobacteria

Collectively, diatoms and cyanobacteria have dominated the phytoplankton community for the past ten years comprising over 75% of the algal biomass. The predominant taxa have been *Aulacoseira*, *Cylindrospermopsis*, *Dolichospermum* (*Anabaena*), *Merismopedia*, and *Planktolyngbya*. A diatom to cyanobacteria ratio (D:C) of >1.5:1 indicates the phytoplankton community is dominated by more desirable diatoms rather than noxious bloom-forming and potentially toxin forming cyanobacteria species. Since WY2008, the average annual D:C exceeded the target ratio of 1.5:1 in both the nearshore and pelagic zones in WYs 2010, 2011, 2016, and 2017 (Figure 4.6). During WY2011 to WY2015, the nearshore ratio was below the target four times while the pelagic ratio was below the target three times, indicating cyanobacteria dominance during that five-year period. An increase in the lake-wide ratio over the past two water years suggests a possible shift back to diatom dominance may be occurring. However, a continued decline in water column TN:TP ratio would favor cyanobacteria and an increase in N-fixing algal blooms would be expected.

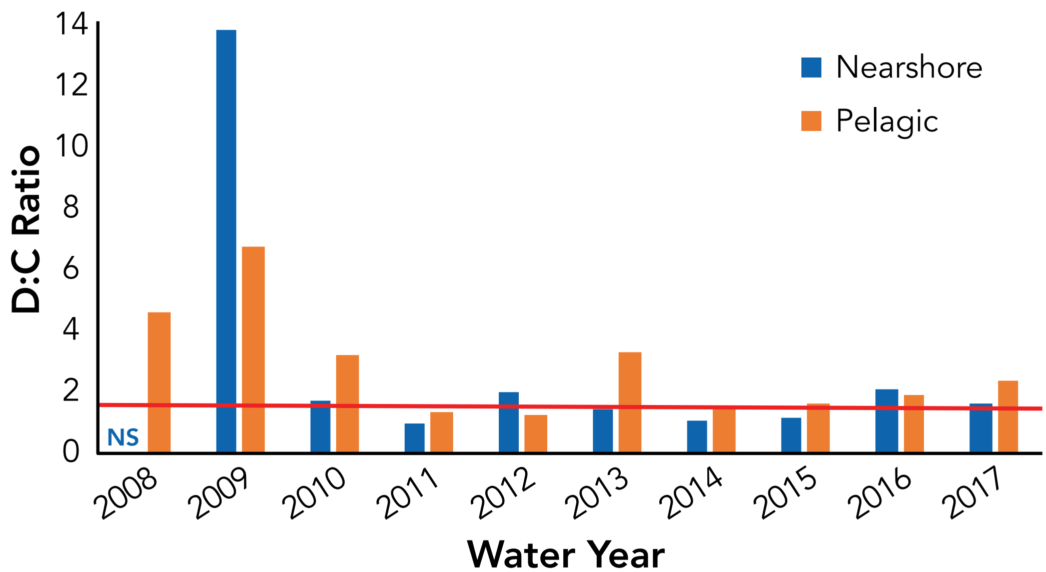


Figure 4.6. Mean annual diatom to cyanobacteria ratio (D:C) at nearshore and pelagic sites. The red line is the performance measure target (NS = Not Sampled due to drought).

Water clarity

Water clarity is used as an indicator in the nearshore zone because of its relevance to supporting vegetation growth in an area that becomes too turbid to support meaningful biomass during prolonged high lake stages. Additionally, because of the increased coupling of turbid pelagic water with nearshore water at higher lake stages, this metric also serves as an indicator of transport between these two regions.

Water clarity is monitored and evaluated annually by assessing the proportion of sampling locations that secchi depths, a general measure of light penetration, were the same as water column depth; i.e. what proportion of sampling locations visible light reached the sediment. While the established target is for 100% of the nearshore sample stations to have this 1 to 1 ratio, the values over the past five WYs averaged 32%, and ranged from a low of 3% in WY2017 (highest lake levels) to a high of 55% in WY2013 (lowest lake levels). This five-year average represents a 12% decline from the WY2008–2012 period, most likely because the most recent period was wetter, so sites had lower secchi to total depth ratios. However, increased depths lead to increased horizontal mixing and reduced water clarity as well, which further reduces the ratio.

Generally speaking, unless the pelagic pool of easily resuspended mud sediments is removed and nutrient levels of both inflows and in-lake water are dramatically reduced (limiting phytoplankton blooms), only low lake stage can effectively improve secchi to water depth ratios and reestablish robust SAV communities.

If expansive SAV and EAV communities moved into lower elevations in the nearshore, water clarity would increase through increased sedimentation rates, reduced resuspension rates, and direct competition with phytoplankton for nutrients. However, in the near term, improvements in water clarity in the nearshore zone appear entirely dependent on low lake stage conditions that persist long enough to allow germination and vegetative regrowth at lower elevations and slow enough ascension rates following establishment to allow those recovering communities to remain in optimal light range in the water column.

EMERGENT AQUATIC VEGETATION

The Lake Okeechobee littoral marsh consists of approximately 100,000 acres bounded by the Herbert Hoover Dike and the 10 ft NGVD bathymetric contour. The distribution and composition of plant communities within this area is primarily a function of water depth, species competition, and interactions between water depth and horizontal mixing of turbid, nutrient enriched water from the pelagic and nearshore zones. A RECOVER PM (RECOVER 2018) was established to quantify coverage targets, as well as interim goals of 50%–75% of targets, for many of the dominant plant communities found in the littoral marsh of LO. Based on years of monitoring and research, these targets represent good ecological conditions for fish and other wildlife in the littoral zone.

A complete mapping of the littoral marsh is attempted every three years, though annual assessments are done by evaluating coverage at a smaller scale; 50 individual 2.47-acre grids located at 24 representative sentinel sites distributed throughout the marsh. The areal coverage targets for the selected vegetation communities and percentage of the lake-wide and sentinel site targets met for each of the EAV indicators during three annual monitoring events are listed in Table 4.2.

During WY2016 and WY2017, the aerial plant coverage target was only met for the invasive exotics category, a group that did not include torpedograss. Torpedograss was within 26–50% of range, not meeting its target. Willow exceeded its target by 99 acres while cattail, woody species other than willow, and floating leaf plants exceeded their targets by 1,900 to 8,578 acres. Bulrush, sawgrass, and rushes were well below targets. Together, these results suggest extreme low lake stages during the WY2008–2012 period had lasting impacts on the expansion of woody-species and torpedograss communities, while more recent high lake stages have reduced coverage of bulrush and spikerush along the outer edge of the marsh and increased coverage of the floating leaf group along the outer edge and in interior regions of the marsh. More land management activities, including selective herbicide treatments and prescribed fire, could help to reduce cattail, torpedograss, and woody species coverage, but only lower lake stages can improve bulrush and spikerush communities along the outer edge of the marsh.

SUBMERGED AQUATIC VEGETATION

Nearshore SAV coverage is an important indicator for LO because it provides habitat for fish, macroinvertebrates, zooplankton and other aquatic taxa, substrate for epiphytes, and improves water quality. Both SAV and epiphytes compete with phytoplankton for water column nutrients and indirectly reduce phytoplankton biomass and potential bloom formations. Based on annual summer SAV mapping during 2001–2015, an updated SAV RECOVER PM was established (RECOVER 2018). The target is July/August vascular and/or non-vascular (which is almost exclusively *Chara* spp. [muskgrass]) covering a combined >50,000 acres, which is 50% of the nearshore region. The nearshore region is roughly defined as occurring between the 5.5 ft and 12 ft elevation contours (Figure 4.7). The potential nearshore SAV coverage extends offshore to the 5.5 ft contour since that is the lowest elevation SAV have been found previously. However, if lake stages stayed within the preferred envelope of 12.5–15.5 ft NGVD, water levels would be 7–10 ft deep in this region, so water clarity would have to be greatly improved for SAV to expand this far offshore. Therefore, the interim goal is 35,000 acres which is 35% of the nearshore region. The restoration target is based on

Table 4.2. The lake-wide (top) and sentinel (bottom) vegetation targets, interim goals, and scores for the nine littoral zone EAV species.

Lakewide vegetation target	Target (ha)	75% range (ha)	50% range (ha)	2003 (ha)	2007 (ha)	2015–2016 (ha)
Bulrush	>1,900	1,425–1,899	950–1,424	145	0	670
Beakrush/ Spikerush	>10,000	7,500–9,999	5,000–7,499	826	7,546	3,085
Sawgrass	>1,900	1,425–1,899	950–1,424	522	1,787	981
Cattail	<8,000	8,001–10,000	10,001–12,000	6,992	1,413	11,473
Willow	3,000–5,000	2,250–2,999 or 5,001–6,250	1,500–2,999 or 6,251–7,500	2,970	4,717	5,040
Floating leaf above 3.8 m	<1,500	1,501–1,875	1,876–2,250	3,203	238	2,283
Torpedograss	≤2,000	2,001–2,500	2,501–3,000	3,493	3,658	2,648
Other invasive exotics	<25	26–32	33–38	47	126	5
Woody, not willow	500–1,500	375–499 or 1,501–1,875	250–374 or 1,876–2,250	1,188	3,636	3,483

Sentinel vegetation target	Target (ha)	75% range (ha)	50% range (ha)	2003 (ha)	2007 (ha)	2015–2016 (ha)
Bulrush	>60	45–59	30–44	9	0	33
Beakrush/ Spikerush	>300	301–375	376–450	48	112	114
Sawgrass	>40	30–39	20–29	33	13	19
Cattail	<240	241–300	301–360	166	93	275
Willow	90–150	68–89 or 151–187	45–67 or 188–225	28	35	32
Floating leaf above 3.8 m	<45	56	68	188	3	226
Torpedograss	<60	61–75	76–90	242	87	32
Other invasive exotics	0	0	0	0	0	0
Woody, not willow	15–45	11–14 or 46–57	7–10 or 58–68	19	84	20

the largest amount of potential colonizable acres, which was mapped during WY2010 (52%), following record droughts that kept lake stage below 11 ft NGVD for all WY2008. The interim goal is based on the WY2002–WY2005 and WY2008–WY2016 (non-hurricane impact years) summer average nearshore coverage of 36%.

The average total SAV from WY2013–2017 increased slightly from the WY2008-2012 total, despite having an average stage nearly two feet higher (14.2 ft vs 12.2 ft NGVD). This is because SAV coverage was greatly reduced after hurricanes in WY2005–WY2006 uprooted thousands of acres of plants and greatly elevated water column turbidity for multiple years, resulting in just 494 ac of vascular SAV in WY2008. However, there was nearly 28,000 ac of *Chara* at low elevations due to prolonged low water levels throughout WY2008. Water levels remained low through much of WY2009 and total SAV coverage increased to a record high of 53,599 ac in WY2010. The coverage of SAV declined to 36,309 ac by WY2012. During a drought that year, SAV expanded and by WY2013 covered 44,707 ac. Tropical storm Isaac affected the lake after sampling in WY2013 (August), causing a rise in lake stage of nearly 3.5 ft in two months, though stages were back within the preferred envelope by November. Sampling in WY2014 showed a decline in total SAV coverage of 33% in WY2014, and another 40% decline in WY2017; both a result of large decreases in non-vascular coverage that coincided with lake stages well above the ecological envelopes in the summer of those years prior to sampling. Vascular SAV, a slower-responding indicator, declined every year since WY2014 (Figure 4.8). This highlights the importance of reaching low stages during the critical growing season to support a robust SAV community, as WY2017 total coverage was at the lowest level recorded (absent major hurricane effects) since monitoring began in 2001.

Vascular SAV was still higher in WY2017 than three other non-hurricane impact WYs, at over 14,000 acres, but was primarily limited to sheltered bays or areas behind emergent vegetation. Meeting the target of 50,000 combined ac of SAV may require frequent and prolonged periods of lake stage below the envelope to support SAV growth, or much improved light conditions in the nearshore region. The latter would require substantial improvement in the nearshore and pelagic region water quality, including reductions in sediment resuspension and transport.

Figure 4.7. The 100,000-acre nearshore region (green color) and potential area for vascular and non-vascular SAV to grow.

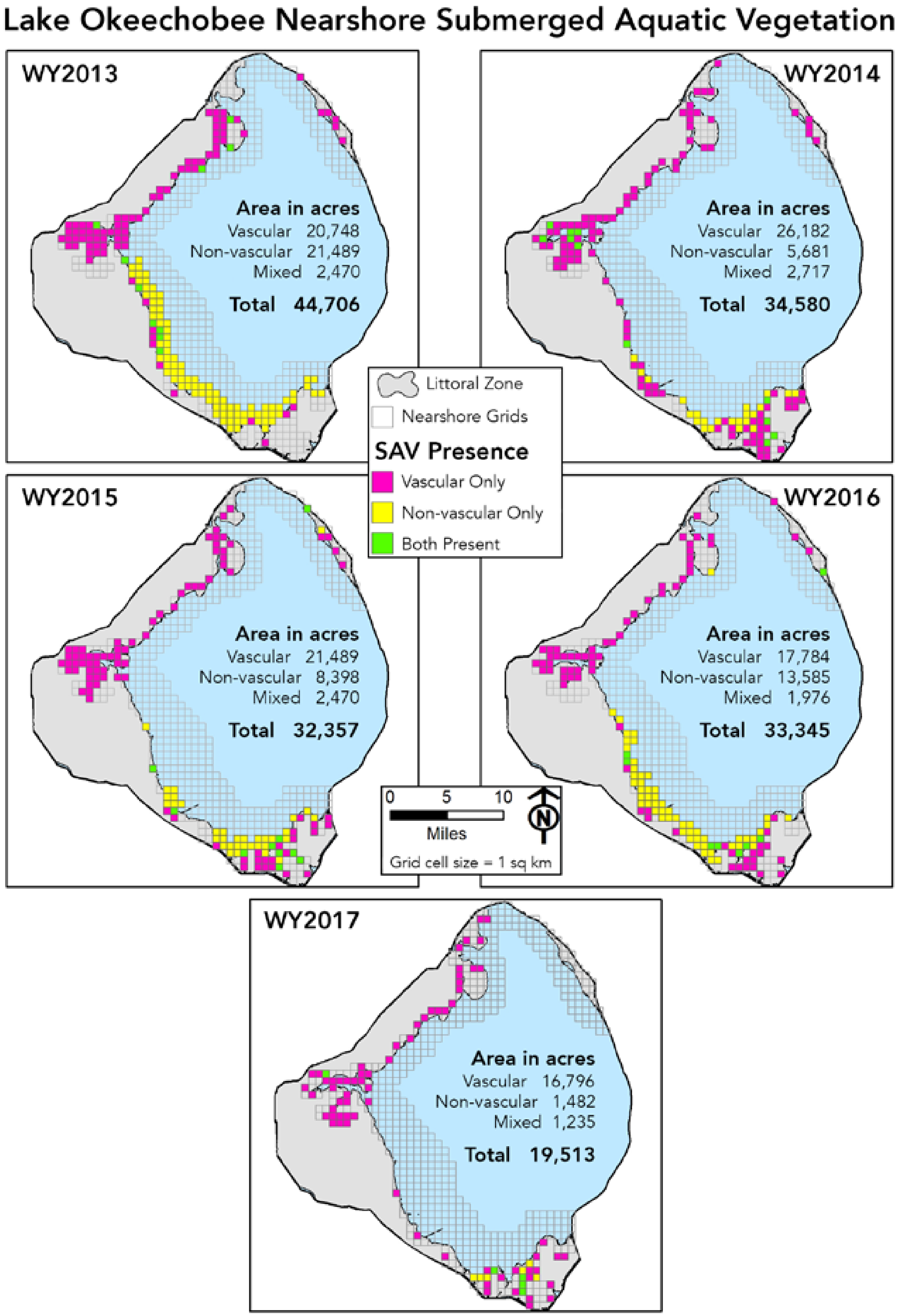


Figure 4.8. The nearshore vascular, non-vascular, and total SAV coverage during the summers of WY2013–WY2017. For additional details, visit www.sfwmd.gov or contact Therese East at 561.682.6706.

BLACK CRAPPIE

Black crappie (BLCR) are one of the most popular sport fisheries on Lake Okeechobee and provide important economic value to the region. They are sensitive to changes in vegetation and food; eutrophication negatively impacts this community by shifting larval and juvenile macroinvertebrate prey-base from preferred taxa such as chironomids (non-biting midges) to one dominated by less preferred oligochaeta (annelid worm) taxa. Threadfin shad (*Dorosoma petenense*) are the preferred food for adult BLCR which are also dependent on various macroinvertebrate species for food. BLCR are monitored annually in January, using the same trawl methods since 1973 (Bull et al. 1995). Catch rate (catch per unit effort or CPUE) is measured in fish per minute. For the purpose of analysis, BLCR were grouped into two categories; age-1 fish, which represent the previous year's spawn; and fish that are 10 inches and larger, which coincides with minimum harvest size and the age at which they have likely spawned at least once. Results are presented as CPUE.

Age-1 Black crappie

Following high waters and hurricanes in the early 2000's, the BLCR population was at an all-time low catch rate of 0.02 fish/minute in 2005. Severe droughts from WY2007–WY2009 resulted in an increase in SAV coverage but kept BLCR away from most of the new vegetation, resulting in poor recruitment for several years. When water levels rapidly increased due to Tropical Storm Fay in WY2009, fish were able to move back into these newly restored marsh habitats, which began the recovery of the BLCR population several years after hurricane impacts. The CPUE increased from 0.32 fish/minute in WY2009 to 1.13 fish/minute a year later, as water levels remained optimal for recruitment (Figure 4.9). Another drought in WY2012 pushed lake levels below 10 feet and likely slowed recruitment since much of the marsh was unavailable for spawning, resulting in a CPUE of 0.92 fish/minute. The lower water levels again increased SAV in the nearshore region, resulting in the highest recruitment since 2003, with an age-1 CPUE of over 2 fish/minute. Catch rates were similar to WY2010–WY2011 in WY2014–WY2015. Recruitment began to dip in WY2016, coinciding with high lake stages during El Niño conditions, coupled with gradually declining levels of total SAV; reaching a nine-year low CPUE of 0.18 fish/minute by WY2017. Overall, the five-year period from WY2008–2012 was marked by a dramatic recovery in BLCR spawning, apparently triggered by droughts and recovering SAV communities. However, catch rates of age-1 BLCR declined throughout the WY2013–WY2017 period, concurrent with declines in SAV coverage.

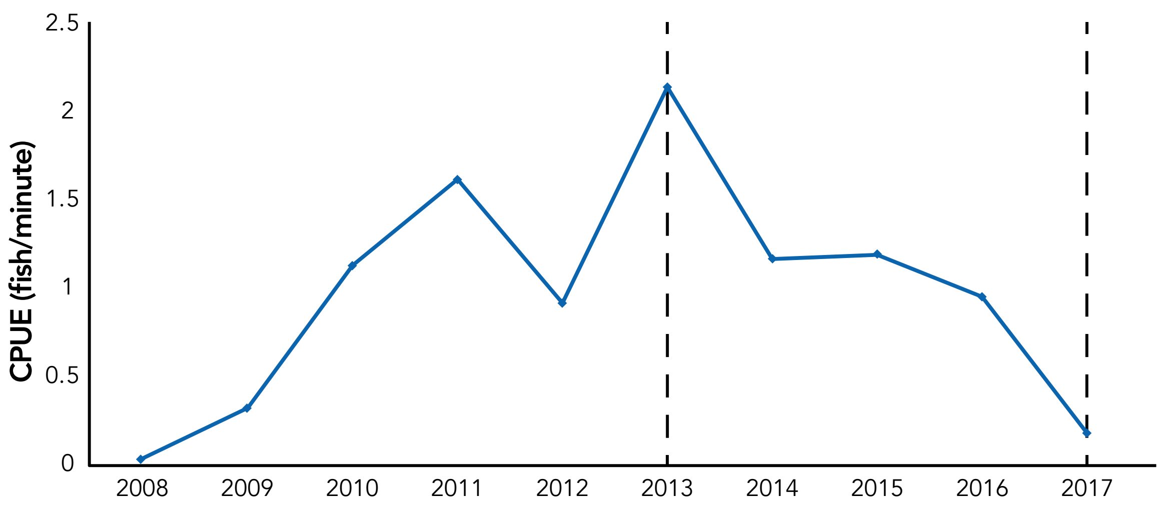


Figure 4.9. Age-1 black crappie CPUE between January 2008 and 2018. Vertical dashed lines indicate period of review, WY2013–WY2017.

Black crappie ≥10 inches

Similar to the age-1 results, WY2008 had the lowest recorded CPUE (0.03 fish per minute) for BLCR ≥10 inches for the 11-year period of record. This record low CPUE was proceeded by multiple years of low recruitment and low numbers of threadfin shad following hurricane impacts in WYs 2005–2006 (Figure 4.10). The adult BLCR CPUE showed the same trends as above for WYs 2009–2012, with a peak CPUE in WY2011 of 1.13 fish/minute. These increases were likely due to the increased recruitment in previous years and an increase in threadfin shad in 2008 and 2010 (SFWMD 2014). The 2006 (age-1 fish in 2007) year class was the first decent spawn (age-3 fish in 2009) to be protected by the newly implemented 10-inch minimum harvest regulation in 2008, allowing more fish to reach adult size. The CPUE of larger fish in WYs 2012–2013 likely decreased due to many of the 2006 year class beginning to die of old age (many BLCR do not live past age 6, rarely past 7 or 8) with few other older fish to support the population. There was also a decrease in growth rates; a majority of the fish caught in the WY2012 trawl were age-2 BLCR, which in previous years were >10 inches but were <10 inches in this sample; therefore, were not counted for this metric. The average size of two-year-old crappie in WY2012 was 8.75 inches compared to 10.5 inches in WY2008. Growth rates in fish may increase when populations are low due to lack of competition, often leading to the population recovering faster due to reaching sexual maturity at a lower age and size (Miller et al. 1990). When populations begin to stabilize, growth rates often return to more normal levels. While this is good for the population overall, it may result in smaller fish compared to earlier-post hurricane recovery years.

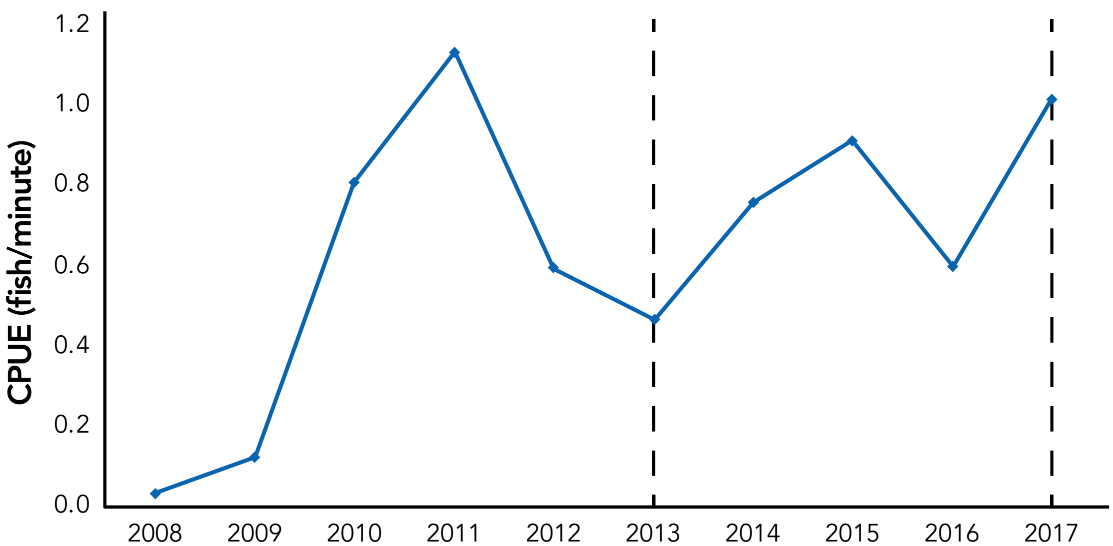


Figure 4.10. Black crappie CPUE for fish ≥10 inches between January 2008 and 2018. Vertical dashed lines indicate period of review, WY2013–WY2017.

Water years 2014, 2015, and 2017 showed continued signs of improvement in terms of large BLCR, possibly due to an increase in threadfin shad between 2012 and 2016 (SFWMD 2018b). While WY2016 showed a decrease in large BLCR, the overall population actually increased, so this is likely due to the change in growth rates. Growth rates continue to slow with many age-4 and age-5 fish (spawned 2014 and 2013) below 10 inches in length. In general, since WY2008, growth rates have decreased each year, leading to increasingly older fish needed to be of harvestable size. Overall, the 5-year period from WY2008–2012 was marked by a dramatic recovery in larger crappie, while the latter period appears to represent a fairly stable, but slower growing population.

Discussion

While the WY2017 catch rate for BLCR ≥10 inches appears fair, the data for the WY2016 and 2017 recruitment suggests a different story. Typically, having two poor recruitment years is manageable for a population, but with catch rates for both age-1 fish and ≥10 inch mostly fair or poor for the past few years, the fishery may not have much resilience to continued poor conditions. The last time there was a crash in the population (WY2005–2008), the fishery was much more robust leading up to that event. The low recruitment of the past few years has likely been due to loss of vegetation in the nearshore zone and/or increased turbidity, and if vegetation levels remain the same or continue to decline, recruitment is likely to continue the same trend. Fish recruited after Hurricane Irma in September 2017 were too small to be collected in the January 2018 trawl. However, Hurricane Irma heavily impacted the amount of vegetation available for spawning. Recruitment is likely to be low in 2018, resulting in a lower age-1 catch rate for 2019. The adult population may remain stable for a year or two, but there is a high chance of a population crash within the next few years if there is not a strong recruitment, as older fish will begin to die out. The fishery would benefit from multiple months of low water levels to allow nearshore SAV and EAV to recover, allowing the population to have successful spawns and recover from the high water levels of the past few years.

LARGEMOUTH BASS

Largemouth bass (LMB) are the most popular sport fish on Lake Okeechobee, providing enormous economic benefits to the region. Four key factors have been found to influence the recruitment of bass into the adult population: availability of favorable spawning substrate; protection of nests from wind; availability of epiphytic invertebrates, forage fish, and other food resources; and protection from predators. These aspects are all directly related to the presence of a structurally complex vegetative community as fish habitat (Hoyer & Canfield 1996, Havens et al. 2005). As with BLCR, continuous excessive nutrient loading and prolonged periods of deep water flooding may negatively impact the fish communities by causing a decrease in the biomass and spatial extent of EAV and SAV.

LMB data were collected during annual lake-wide electrofishing samples conducted in October, which have used the same standardized methods since 1999 as described in Havens et al. (2005). For analysis, LMB were grouped into two categories; age-1 fish, which represent the previous year's spawn; and fish that are >12 inches, which generally coincides with LMB that are age-2 or older and are considered adult fish. No samples were collected in WY2008 due to low water levels.

Age-1 largemouth bass

Following hurricanes in WYs 2005 and 2006, extensive damage to the lake's plant community and water quality resulted in a WY2009 age-1 catch rate of 0.005 fish/minute, tying the lowest recorded on the lake. Similar to BLCR results, recovering SAV communities from droughts in WY2008–2009 led to a drastic increase in age-1 LMB recruitment, with a catch rate of 0.122 fish/minute in WY2010 and 0.256 fish/minute in WY2011 (Figure 4.11). LMB typically respond more quickly to improving habitat conditions than BLCR. Lake levels below 10 feet NGVD in the summer of WY2012 drove recruitment down which resulted in lower catch rates in WY2012–WY2014. Relatively stable water levels and stages within the ecologically beneficial envelope during the latter part of WY2014 and into WY2015 resulted in increased CPUEs in WY2015–2016. However, high water levels from El Niño in the latter part of WY2016 resulted in turbid conditions throughout the lake and a loss of SAV in the nearshore, which had a detrimental effect on spawning. This was reflected in the WY2017 age-1 fish where recruitment dropped to 0.044 fish/minute, the lowest since the fishery began recovery in WY2009. Overall, LMB recruitment through the two five-year periods were similar to the BLCR; a dramatic recovery following the hurricanes in the first period, followed by a general decline coinciding with reductions in coverage of SAV.

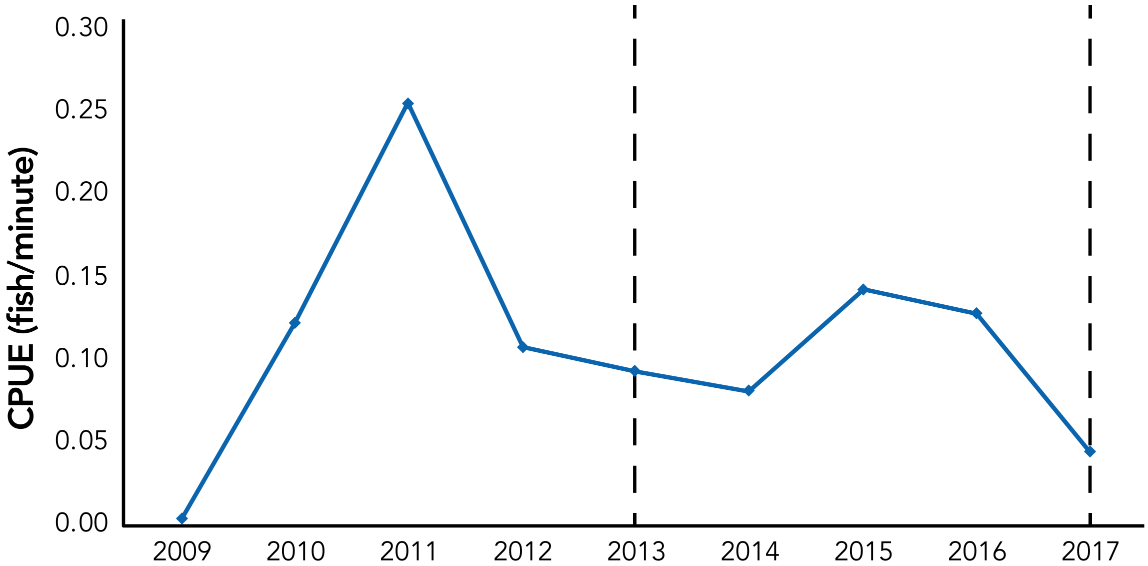


Figure 4.11. Age-1 largemouth bass CPUE between October 2008 and 2017. Vertical dashed lines indicate period of review, WY2013–WY2017.

Largemouth bass ≥12 inches

Similar to BLCR, vegetation losses and poor water quality after hurricanes resulted in a record low catch rate of adult LMB (≥12 inches) in WY2009, at just 0.032 fish/minute (Figure 4.12). In WY2010 the population began improving, showing a positive response to the recovery in vegetation and the resulting increase in LMB spawn in the years following the WY2008–2009 droughts. By WY2013, the highest CPUE of the monitoring period for bass ≥12 inches was recorded (0.306 fish/minute). Through WY2016, adult LMB CPUEs remained good, supported by increased spawning and age-1 bass recruitment in prior years. However, CPUEs in WY2017 dropped to a 5-year low. This was presumably due to high-water impacts on nearshore SAV during the El Niño events in the spring of WY2016.

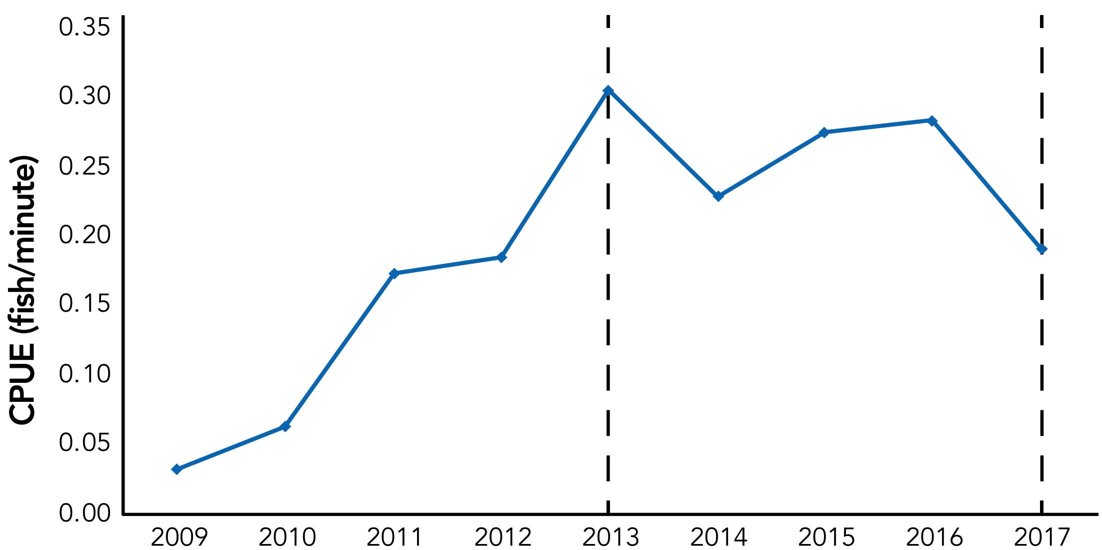


Figure 4.12. Largemouth bass CPUE for fish ≥12 inches between October 2008–2017. Vertical dashed lines indicate period of review, WY2013–WY2017.

Discussion

The WY2017 CPUEs for age-1 and ≥12 inches LMB show reductions compared to the previous four WYs. Further, age-1 bass CPUEs in the future will likely have decreased due to extreme high-water levels and a loss of SAV and EAV after Hurricane Irma in September 2017. Similarly, adult LMB can be expected to plateau or increase only slightly since there was a large decrease in age-1 bass in WY2017, and there will not have been enough recruitment into the adult population since then. If vegetation loss continues in the lake, recruitment of new fish into the LMB population will also decline. The low CPUEs of age-1 bass since WY2016 suggest that there has not been sufficient spawn to sustain a thriving adult population in the coming years. Recovery of the plant community through prolonged low water levels will provide improved habitat complexity that is optimal for spawning bass and critical for improving the LMB fingerling and adult fish populations.

WADING BIRDS

Wading birds have foraging and nesting requirements that make them intrinsically tied to the nutrients and hydrology of LO and these aspects of their life history make them a significant indicator of LO's health. Long-term hydrologic patterns and nutrient impairment affect the distribution and composition of vegetation used for foraging and nesting, while short-term hydrology affects prey densities and predator access to colonies. The status of wading bird nesting on LO was gauged using two performance measures (PMs), as described below. Due to the fact nesting seasons may overlap two water years (which begin in May of the previous calendar year), these measures were analyzed by calendar year. For simplicity sake, since most of each nesting season (January–April) occurs in the same water year as calendar year, the terms can be thought of as generally interchangeable throughout this section.

Focal species for performance measures are the great egret (*Ardea alba*; GREG), snowy egret (*Egretta thula*; SNEG), and white ibis (*Eudocimus albus*; WHIB). These species are selected because they are white birds, making them more conspicuous on aerial surveys, their ecological requirements are fairly well known, and their nest abundance is linked to hydrologic conditions. The first PM is the mean interval between exceptional nesting years (MIEN), which was based on a Greater Everglades Ecosystem performance measure that monitors the interval between exceptional nesting events for white ibis (Frederick et al. 2009). Exceptional years are defined as the 70th percentile of all nest abundance estimates in the period of record. The target value for MIEN is any interval at least one standard error below the overall MIEN prior to the current reporting period. The second performance measure is the mean percentage of maximum nest abundance observed during the current reporting period (PMNA). PMNA is calculated by dividing the mean 5-yr running average of nest abundance during the reporting period by the average of the 5 highest nest abundances during the period of record. This calculation reduces the effect of years with extremely low or high nest abundance on the performance measure score. The target value for PMNA is 100% of maximum nest abundance and the score is presented as a percentage between 0% and 100%. A percent score for wading bird performance at Lake Okeechobee can be calculated by assigning equal weight to the MIEN and PMNA performance measures, across all species, and averaging the individual performance measure scores.

The mean interval between exceptional nesting (mean ± SE) from 1977 to 2011, the period of record preceding the current reporting period, was 3.2 ± 0.6, 3.3 ± 0.7, and 2.8 ± 0.7 years for GREG, SNEG, and WHIB, respectively (Figure 4.13). The target interval is ≥ 1 standard error below the mean interval for the period of record equating to target intervals of <2.6, <2.7, and <2.13 years for GREG, SNEG, and WHIB, respectively. Mean interval between exceptional nesting during the reporting period (2012–2017) was 1.2 ± 1.0, 0.5 ± 0.2, and 2.0 ± 0.6 years for GREG, SNEG, and WHIB, respectively (Figure 4.14). Thus, the target for exceptional nesting events was met for all species, resulting in a score of 100% for all species for the first performance measure.

Maximum nest abundance (mean of 5 highest nest abundance estimates) for GREG, SNEG, and WHIB were 2329, 2580, and 5750 nests, respectively. The PMNA (mean ± SE) for GREG, SNEG, and WHIB was 40 ± 6, 70 ± 8, and 24 ± 2 percent during the period of reporting (Figure 4.15). Nest numbers were considerably short of the target for all focal species; however, SNEG nest abundance was relatively high throughout the reporting period, producing a modest PMNA of 70%. Averaging the scores for both performance measures across species results in a percent score of 72% for wading birds at Lake Okeechobee.

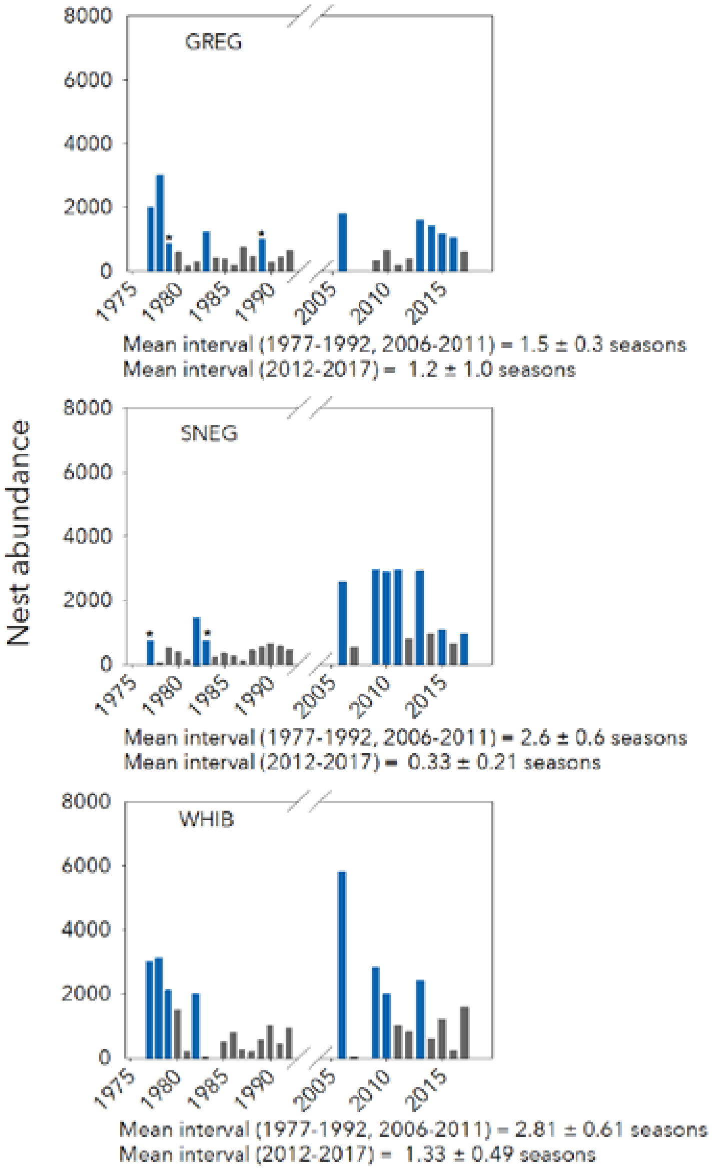


Figure 4.13. Estimates of nest abundance for great egrets (GREG), snowy egrets, (SNEG), and white ibis (WHIB). Exceptional nesting years (>70th percentile nest abundance) are in bold and the interval between years with exceptional nest abundance are in parentheses. Nest abundance estimates with an asterisk are those that fell below the 70th percentile once the reporting period was included. Nest abundance estimates during the reporting period are shaded in gray. The target interval for the reporting period was set at one standard error below the mean interval between exceptional nesting years from 1977–2011; the target was met for all species.

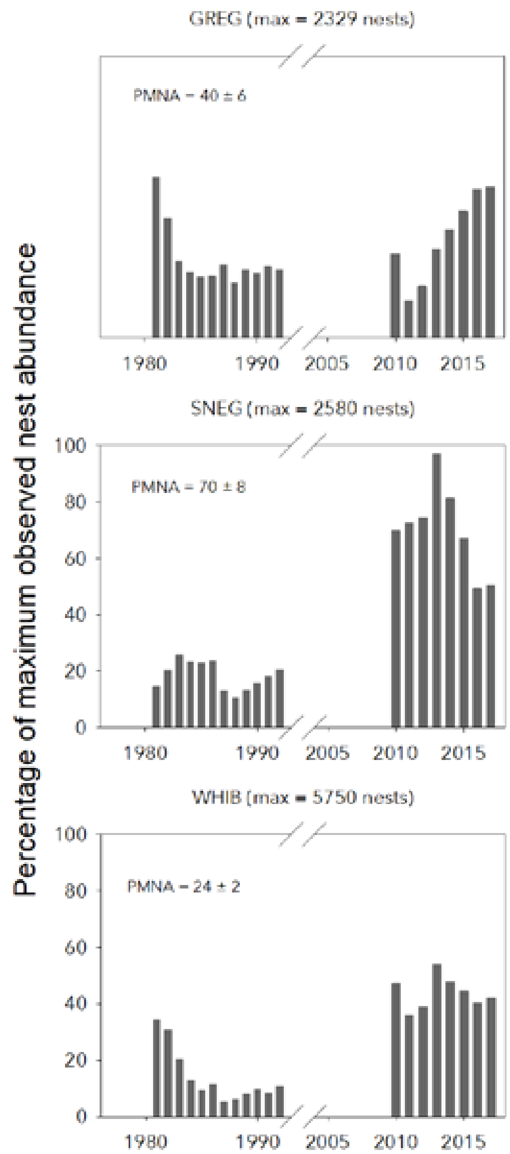


Figure 4.14. Percentage of the maximum nest abundance (PMNA) observed at Lake Okeechobee since 1977 for GREG, SNEG and WHIB. Maximum nest abundance is the mean of the five highest nest abundance estimates from all years for which data are available (36 season since 1957), but data are only presented for years in which monthly systematic aerial surveys were performed. Each bar represents the PMNA of the 5-year running average of nest abundance.

Lake Okeechobee

Trends

Low water levels preceding the 2012 breeding season likely resulted in low prey densities (Chastant et al. 2016), and severe storms during the nesting season exacerbated the effects of low prey density resulting in low nest abundance. Water levels ranged between 12–15 ft in the 2013, 2014, and 2015 breeding seasons (Table 4.3). Nest abundance was supernormal in 2013 (defined as nest abundance >1 standard deviation above the mean), and near average in 2014 and 2015. High water levels (>15 ft), which are necessary for increased prey production, preceded all three seasons, and in all three breeding seasons water levels fell within the ecologically desirable range (~12–15 ft). Supernormal nesting events occur more frequently in the one or two years following severe drought in the Everglades and LO (David 1994; Frederick & Ogden 2001), so it is possible that the severe drought in 2011 is related to higher nest numbers in 2013 than in 2014 and 2015, despite similar hydrologic conditions in each year. Water levels were extremely high in the 2016 breeding season, starting at 16.3 ft and drying to 13.6 ft. High water levels during the breeding season resulted in low prey densities and habitat availability. Nest abundance in 2016 was lower than any other year in the reporting period. Water levels were low (11.0–14.2 ft) in 2017 and there was a prolonged, uninterrupted dry down. There were high prey densities, but available habitat was restricted to long hydroperiod sites at the edge of the littoral zone. Nest abundance in 2017 was near average for all focal species.

Table 4.3. Lake Okeechobee hydrologic conditions and wading bird nesting, 2012–2017. Pre-breeding period is defined as July–December and breeding season is defined as January–June, since great egrets begin nesting in January and white ibis nest through June in most seasons.

Year	Pre-nesting lake stage	Breeding-season lake stage	Nest effort
2012	Low (max. = 13.9 ft)	Low (13.7–11.5 ft)	2,004
2013	High (max. = 15.9 ft)	Moderate (15.0–13.3 ft)	6,903
2014	High (max. = 16.1 ft)	Moderate (14.2–12.3 ft)	2,943
2015	High (max. = 16.0 ft)	Moderate (15.2–12.2 ft)	3,434
2016	Moderate (max. = 14.8 ft)	High (16.3–13.6 ft)	1,923
2017	High (max. = 16.1 ft)	Low (14.2–11.0 ft)	3,124

There has been an overall increase in wading bird nest abundance at LO compared to the 1980's and early 1990's, though trends differed among species (Figure 4.15). Higher nest abundance is likely the result of an ecologically desirable water management regime which maintains lower water levels, particularly during the dry season (SFWMD 2015). Nest abundance remained relatively high in the current reporting period (2012–2017), although there was a noticeable decline in SNEG and WHIB nesting compared to the previous five years (2006–2011; Table 4.3 and Figure 4.15). Nest abundance exceeded 4,000 in four breeding seasons from 2005–2011, but only once from 2012–2017 (in 2013). This appears to be, in part, driven by differences in drought frequency from 2005-2011 versus 2012–2017, since all of the seasons in which nest abundance exceeded 4,000, with the exception of 2006, were preceded by exceptionally dry conditions in the previous one or two years. Previous studies at LO have posited that higher nest abundance in years subsequent to drought was related to increased willow recruitment in dry years (Chastant et al. 2016; David 1994), however evidence for this is indirect. Furthermore, WHIB nest abundance also increases subsequent to drought in the Everglades, where nest substrate is not considered to be limited (Frederick & Ogden 2001; Kushlan 1986). GREG nesting increased during the reporting period, particularly in the four wettest breeding seasons (2013–2016), which is corroborated by recent models that predict peak GREG nest abundance should occur when water levels are moderately high early in the breeding season at LO (Gawlik et al. 2018).

Lake Okeechobee is a valuable part of the greater Everglades wading bird habitat. Nesting numbers for SNEG and tricolored herons (*Egretta tricolor*; TRHE), have been consistently below restoration targets in the Everglades Protection Area since 1986. Since 2009, LO has supported on average 57% of SNEG nests in the Greater Everglades, with a maximum contribution of 82% in 2013. The mean percentage of TRHE nests supported by Lake Okeechobee is less certain but could be up to 72% of the Greater Everglades nests on average since 2009. This highlights the importance of suitable water levels on LO considering concerns about areas failing to support nesting targets for these species.

Discussion

Targets set for MIEN were met since exceptional nesting years occurred more frequently. This is likely the result of water management that allows for infrequent extreme dry downs and prevents prolonged periods of extremely high water levels. Target values set for PMNA were not met for any species, suggesting that there are still factors limiting nest abundance. The five-year running average of SNEG and WHIB nest abundance declined from 2012–2017 compared to 2006–2011 (Figure 4.15), coinciding with an increase in GREG nest numbers. This suggests a shift in wading bird species composition in which species that do not require high prey densities (e.g., GREG) increased while species that require high prey density declined (Gawlik 2002). The amount of seasonal foraging habitat due to water levels and the degree to which levels decline during the dry season are key factors affecting wading bird nest abundance at LO (Chastant et al. 2016, Gawlik et al. 2018).

There have been several recent attempts to link lake levels with wading bird nest abundance using statistical models (Botta 2014; Chastant et al. 2016; Gawlik et al. 2018). These models test hypotheses based on the assumption that habitat availability, prey availability, and nest substrate availability can each potentially limit wading bird populations at LO. These models treat habitat availability as a nonlinear function of lake stage, and prey availability as a function of prey production preceding the breeding season and recession rate during the breeding season. Chastant et al. (2016) and Gawlik et al. (2018) each include a willow availability

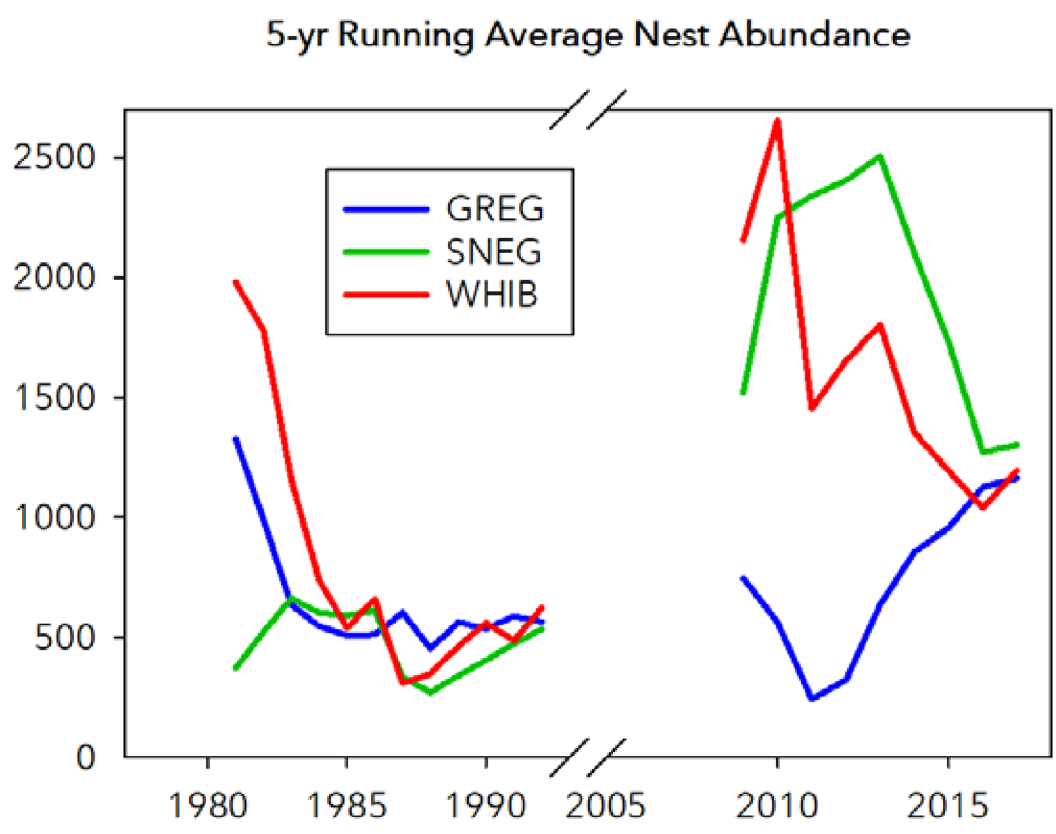


Figure 4.15. Numbers of nests (5-yr running average) at Lake Okeechobee by great egret (GREG), snowy egret (SNEG), and white ibis (WHIB), 1981–2017. The break indicates years in which the aerial survey was discontinued.

parameter to account for increased availability of nest substrate following one or two years of extremely low water levels. Chastant et al. (2016) showed that a willow availability index was the most important parameter in predicting combined wading bird nest abundance. The index in Gawlik et al. (2018) categorizes willow availability on a scale of 0 to 3, 0 being the lowest and 3 the highest availability. During the reporting period, willow availability ranged from 0 in 2017, the year with lowest nest abundance, to 3 in 2013, the year with highest nest abundance. While the willow availability index seems to be useful in predicting whether overall wading bird nest abundance will be exceptionally low or high, species-specific models show that this trend does not necessarily apply for all of the focal species (Gawlik et al. 2018). Willow availability index score was an important parameter for predicting SNEG nest abundance, but not GREG or WHIB nest abundance. Lake stage was the most important parameter for explaining variation in GREG nest abundance, which was predicted to be lowest when lake stage is low during the peak nesting month (March). GREG nest abundance ranged between 407 and 1592 during the current reporting period and was relatively high in all years except those in which average March lake stage fell below 13 ft (2012 and 2017; Figure 4.13). None of the variables examined were important in explaining variation in WHIB nest abundance, however, an examination of the data suggests that WHIB nest abundance is consistently high one or two years subsequent to exceptionally low lake levels. It is possible that this trend is not revealed in models because exceptionally dry conditions occur relatively infrequently, so the influence of extreme dry downs on WHIB nest abundance is infrequent in the data set. Furthermore, there are years in which WHIB nest abundance was high following years without extreme drought (e.g. 2006), which could dampen the positive effect of infrequent drought in the model.

4.4 DISCUSSION

Trends

Water quality and SAV indicators for the period WY2013–WY2017 suggested poor conditions on LO, with nearly all elements showing worse conditions relative to the previous five-year reporting period. Nutrient loading (TP and TN) increased by greater than 30%, the concentration of nearshore TP increased 17%, the frequency of algal blooms increased, and water clarity and SAV coverage declined. Pelagic phosphorus and nitrogen concentrations were the only indicators that improved, which was likely due to increased lake volume (dilution) and less pelagic resuspension during the considerably wetter period. Sport fish populations, wading bird nesting, and EAV suggested moderate conditions but, with recent declines in spawning numbers, declining nesting activity of wading birds dependent on high prey density, and few vegetation coverage targets met in either the low or high elevations of the marsh, ecological indicators were not trending in a favorable direction.

Together, the status of indicators is poor given how closely lake stages stayed within the preferred stage envelope, at least relative to the high (15.5 ft) and low (12.5 ft) stages in general. However, the seasonality of the water levels varied considerably from desired ranges, particularly during the growing season. From roughly June–October, lake stages exceeded the envelope by 1.0–2.5 ft in WY2014 and WY2017, at a critical period for plant growth and algal bloom formations. These deviations likely played an important role in the status of the indicators reviewed here, having an asymmetrical impact due to the timing of high water levels.

Performance measure updates

Three of the six ecological Performance Measures (PMs) approved by RECOVER in 2017 for use in evaluating lake ecology were described in the 2014 System Status Report Lake Okeechobee chapter. The other three ecological PMs were developed after the 2014 SSR was released, including *Chara* (muskgrass, a non-vascular SAV), and two periphyton PMs (epiphytes, and epipelon). The scoring method for the vascular SAV PM was also updated. These are all described below.

Chara performance measure

Macro algae SAV (almost exclusively *Chara* spp.) can constitute a large portion of total SAV coverage on LO during some years, particularly those after lower lake stages. This species tends to grow in the peat-substrate areas of the lake, primarily the southern end, and because it is an alga, responds more quickly to optimal growing conditions than the vascular species. Therefore, a performance measure was developed to evaluate conditions for *Chara* coverage on the lake. Analyses showed that the annual July–August nearshore coverage (when the data is collected) was significantly, negatively correlated with July average lake stage. Therefore, the following criteria were developed to score conditions for *Chara* coverage:

- When lake stage is greater than 15.5 feet NGVD in July, conditions are poor for *Chara* coverage, so these conditions score 0 points.
- When lake stage is between 12 and 15.5 feet NGVD in July, conditions are intermediate for *Chara* coverage, so this condition scores one point.
- When lake stage is less than 12 ft NGVD in July, conditions are optimal for *Chara* coverage, so this condition scores two points.

The results indicate how the summer areal coverage varies based on average July lake stages and related light penetration into the water column, especially since *Chara* stem height is typically small on the lake (<20 cm).

Epiphyte performance measure

Epiphyte abundance is used in the lake as an indicator of water quality in the nearshore region, as higher light penetration can lead to better growth conditions for epiphytes, which in turn reduce nutrient concentrations in the water and support a suite of faunal species. Abundance of epiphytes on EAV and SAV during the spring (March, April) and fall (September, October) was used for this analysis, which revealed epiphyte biovolume was significantly and negatively correlated with average monthly lake stage in the month prior to collection. Therefore, the following criteria were developed to score conditions for epiphyte abundance:

- When lake stage is greater than 15 ft NGVD in the month prior to the spring and fall sampling periods, conditions are poor for epiphyte abundance on aquatic vegetation, so these conditions score 0 points.
- When lake stage is between 14 and 15 ft NGVD in the month prior to the spring and fall sampling periods, conditions are intermediate for epiphyte abundance on aquatic vegetation, so this condition scores one point.
- When lake stage is less than 14 ft NGVD in the month prior to the spring and fall sampling periods, conditions are optimal for epiphyte abundance on aquatic vegetation, so this condition scores two points.

The nearshore epiphyte biovolume abundances during the 2008–2012 sampling period were substantially higher than the previous sampling period (2002–2005). This is likely related to greater light penetration during the second period, when the spring prior month average lake stages were between 10 and 14 ft NGVD as compared to 14 and 16 ft NGVD in the earlier period. Similarly, the fall prior month average lake stages were between 10 and 15 ft NGVD compared to 15 and 17 ft NGVD in the earlier period.

Epipelon performance measure

Similar to epiphytes, algal communities on the sediment (epipelon) require light penetration through the water column, and robust epipelic communities can be an indicator of good conditions in the nearshore region of the lake. Abundance of epipelon during the spring (March, April) and fall (September, October) was found to have a significant and negative correlation with the average monthly lake stage one year prior. Therefore, the following criteria were developed to score conditions for epipelon abundance:

- When lake stage is greater than 15 ft NGVD in the month one year prior to the spring and fall sampling periods, conditions are poor for epipelon abundance on the bottom sediments, so these conditions score 0 points.

- When lake stage is between 12 and 15 ft NGVD in the month one year prior to the spring and fall sampling periods, conditions are intermediate for epipelon abundance on the bottom sediments, so this condition scores one point.
- When lake stage is less than 12 ft NGVD in the month one year prior to the spring and fall sampling periods, conditions are optimal for epipelon abundance on the bottom sediments, so this condition scores two points.

Epipelon biovolume in the nearshore region during the 2007–2010 sample period was substantially higher than the previous period (2002–2005) and is likely related to the extended period of largely increased water column light penetration during the 2007–2008 drought. The spring prior year average monthly lake stages for the later sampling period were between 10 and 15 ft NGVD, compared to 14 and 16 ft NGVD in the earlier period. Similarly, the fall prior year average monthly lake stages for the second sampling period were between 9 and 16 ft NGVD compared to 15 and 17 ft NGVD for the earlier period.

Submerged aquatic vegetation performance measure
There was a minor change in the way lake stages were scored for the vascular SAV PM, going from a 0–1 point score to a 0–2 point score. The current PM scores a zero for summer (July–August) vascular SAV coverage when average July lake stage is <10.0 ft NGVD or >18.0 ft NGVD and scores 1 point when average July lake stage is between 15.5–17.9 ft NGVD or between 10–11.9 ft NGVD. The optimal score of 2 points is when average July lake stage is between 12.0–15.5 ft NGVD. However, this PM may be too broad to assess hydrologic effects on a scale likely to occur from CERP. For example, the same optimal score for SAV is applied over a 3.5-foot range of July lake stages. Similarly, an average July lake stage would almost never exceed 18 ft NGVD (0 points) and is more likely to be below 12 ft NGVD (1 point) versus above 15.5 ft NGVD (also 1 point) in the early portion of the wet season. Therefore, the PM likely penalizes lower lake stages more than higher lake stages, despite proven benefits of lower water levels to SAV communities in the nearshore zone (Havens et al. 2004). This and other PMs are currently going through a reevaluation process, partly due to several years of additional data collected since their development, and partly to meet the need for more sensitive measures of evaluation in the future.

4.5 RESTORATION

Goals and actions

Many of the indicators described above are difficult to manage the status of in the short- or even long-term in a system the size of LO. Water quality is in part affected by a legacy pool of sediment that is continuously resuspended in the water column, decreasing light penetration and increasing TP levels. While nutrients in the watershed have been the focus of many restoration and management efforts over the past several decades, nutrient inflows have not been reduced despite projected improvements from a suite of agricultural and urban best management practices (BMPs). Previous studies have investigated dredging or chemical treatment of the sediment to address internal loading and turbidity issues, though newer technologies may warrant further research in these areas; particularly long-term dredging projects that leverage current lake-circulation models. Similarly, faunal groups like sportfish and wading birds are indicators of a complex suite of habitat and prey interactions, and little can be done in the short-term to affect low or declining populations. SAV and EAV marsh communities can be manipulated to some extent through mechanical or chemical management, but only to reduce or alter distributions and compositions, not to expand those communities' downslope.

Lake stage is the one tool that can affect all the indicators, through direct and indirect effects on depths, hydroperiods, water column nutrient concentrations, and vertical/horizontal mixing of pelagic nutrients and turbidity. The largest restoration effort focuses on keeping lake stage within the ecological stage envelope more frequently through increased watershed storage.

Besides lake stage, there are ongoing management efforts that focus on habitat quality. For example, a combination of herbicide treatments and prescribed fires have been used over the past several years on invasive species to dramatically improve habitats in thousands of acres of marsh, supporting some of the largest concentrations of wading birds and endangered snail kites (*Rostrhamus sociabilis*) ever recorded on the lake. Similarly, cooperative efforts among multiple agencies, including the Florida Forest Service (FFS), Florida Fish and Wildlife Conservation Commission (FFWCC), and the SFWMD have significantly increased prescribed burning activities in the upper marsh, helping to restore natural fire patterns and reduce organic loads and vegetation density in some of the areas least affected by cultural eutrophication. Together, these efforts maintain habitat complexity and diversity throughout expansive littoral marshes of the lake, offsetting some of the impacts from extreme fluctuations in lake stage.

Projects

The Lake Okeechobee Watershed Restoration Project is a planning effort being conducted by the USACE and the SFWMD to identify opportunities to improve the quantity, timing and distribution of flows into LO. The project area, where placement of potential features is being considered, covers a large portion of the Lake Okeechobee Watershed north of the lake. One of the goals for the project is to increase water storage capacity in the watershed, resulting in improved LO water levels.

During an earlier phase of the project in 2007, 273,000 acre-feet of water storage north of the lake was identified as the most cost-effective reservoir storage option by the USACE and SFWMD but was ultimately shelved due to a variety of issues. The purpose of the Lake Okeechobee Watershed Restoration Project (LOWRP), which was re-initiated in 2016, is to increase water storage capacity in the watershed, resulting in improved Lake Okeechobee water levels, improved quantity, timing, and distribution of water to the Northern Estuaries, increased accessibility of water supply for existing legal Lake Okeechobee Service Area users, and to restore wetlands within the project area. The Recommended Plan would achieve these goals and objectives by reducing the large pulses of regulatory flood control releases sent from Lake Okeechobee by redirecting these flows to an above-ground wetland attenuation feature (WAF) and aquifer storage and recovery (ASR) wells. Additionally, the Recommended Plan restores approximately 4,779 acres of wetlands along the historic Kissimmee River channel.

Five year look ahead

Improved conditions in the next five years for LO will likely depend on achieving desired low stages for consecutive years, the likelihood of which would be increased with below-average rainfall. SAV and nearshore EAV is in poor condition after high water levels in WYs 2016 and 2017, and from the winds and turbidity from Hurricane Irma. The black crappie and largemouth bass fisheries indicate likely declines in the next year or two after multiple years of reduced or poor spawns because of habitat conditions. Water quality, including recurring cyanobacterial blooms, may remain degraded from Hurricane Irma for several years, if the hurricanes in WYs 2005 and 2006 are any indication. All of the indicators mentioned above were in very poor condition after those hurricanes, and even with subsequent droughts in WYs 2008–2009, it still took several years for them to recover. While conditions appear more favorable in the months following Hurricane Irma than they did in WY2007, dramatically lower lake stages (e.g. <11.0 ft NGVD for at least three months during the growing season) are likely needed to jumpstart the recovery of nearshore SAV and the cascade of beneficial effects that follows. Without low lake stages, conditions will likely remain poor throughout several of the next five years.

Everglades ridge and slough landscape. Photo credit: National Park Service.

Greater Everglades

5.1 INTRODUCTION

The Greater Everglades (GE) region is a dynamic, fire-adapted system that experiences annual water level fluctuations as a result of wet and dry season rainfall patterns over the course of the year. It includes a mosaic of inter-connected freshwater wetlands differentiated by elevation, soils, hydrology, and vegetation (Figure 5.1). A ridge and slough system of patterned, freshwater peatlands extends throughout the Water Conservation Areas (WCAs) and into Shark River Slough (SRS), and drains into tidal rivers that flow through mangrove estuaries and into the Gulf of Mexico. Higher-elevation marshes, characterized by marl substrates and exposed limestone bedrock, flank either side of SRS. Marl marshes east of SRS form the drainage basin for Taylor Slough, which flows through an estuary of dwarf mangrove forests and empties into northeastern Florida Bay. To the west of WCA-3 and Everglades National Park (ENP), the Everglades marshes merge with the forested wetlands of Big Cypress National Preserve.

Figure 5.1. Map of the Greater Everglades region.

The Greater Everglades provides many ecosystem services such as recreation, tourism, water supply, and flood protection. Defining characteristics of the pre-altered GE region included a unique combination of sheet flow, water depth patterns, oligotrophy, salinity distributions (in coastal estuaries), landscape patterns, and an abundance of wildlife, particularly

wading birds (Ogden et al. 2005). Today, the geographic extent of the region has been reduced by roughly 50%, the spatial and temporal patterns of hydrology, fire, and nutrient supply have been altered, landscape-scale structure of the ridge-slough mosaic has been lost, and wildlife populations have declined (Davis & Ogden 1994). Restoration goals for the GE are based on the defining characteristics, and they identify a minimum set of criteria that must be achieved for the Comprehensive Everglades Restoration Plan (CERP) to be successful.

There are a number of key questions, or uncertainties, regarding restoration from a quantity, quality, timing and distribution objective (Ogden 2005; Ogden et al. 2005; Davis et al. 2005a, 2005b; Duever 2005). These key questions are being addressed through continued monitoring that captures climate variability and the real-world effects of adhering to currently established water management regimes (e.g., regulation schedule for WCA-3A) on the system (RECOVER 2009).

Large numbers of wading birds were one of the defining phenomena of the historic Everglades. They had important roles in the redistribution of nutrients and demographic effects on fish and invertebrate populations (Ogden et al. 2005; Frederick & Powell 1994; Frederick & Spalding 1994; Kushlan 1974, 1976, 1977; Gawlik 2002). Currently, wading birds are nesting in greatly reduced numbers, and at different locations than recorded prior to 20th century modifications of the ecosystem (Ogden et al. 2003). The collapse of nesting colonies in the southern Everglades is attributed to declines in the population densities of aquatic prey (Frederick & Spalding 1994; Gawlik 2002).

Alligators are an iconic species of the GE and are critical in the food web as top predators, influencing abundance and composition of prey (Mazzotti & Brandt 1994), and as ecosystem engineers, creating refugia for plants and animals (Kushlan & Kushlan 1980; Campbell & Mazzotti 2004; Palmer & Mazzotti 2004). Loss of flow and altered water depth patterns have adversely affected crocodilians causing shifts in distribution and reducing body condition.

The extent of invasion by non-indigenous species has presented serious threats to the structure and function of the GE ecosystem (Ferriter et al. 2008; Rodgers et al. 2017). South Florida is particularly susceptible to nonnative invasions because of its climate, island-like geography, major ports of entry, and pet trade. Nonnative plant species, such as Melaleuca (*Melaleuca quinquenervia*) and Old World climbing fern (*Lygodium japonicum* and/or *Lygodium microphyllum*), which currently pose a threat and are the focus of ongoing eradication programs. Nonnative wildlife, including species of pythons and tegu lizards, can impact native species through competition and predation (Enge et al. 2004), and some invasive aquatic species have already been recognized as a potential barrier to successful restoration (National Research Council 2005; South Florida Ecosystem Restoration Task Force 2015). Without successful management of nonnative, invasive species, it is uncertain that restoration goals can be achieved.

5.2 KEY FINDINGS

In the Greater Everglades region conditions varied throughout the five-year reporting period, with indicator scores ranging from good to poor (Figure 5.2). Conditions for periphyton were good despite a shift in periphyton community structure. Tree islands were also in the good range due to resilience of the islands in conservation areas. Although nonnative fish had a good score overall, the score ranged from good to fair, with more nonnatives in recent years. Invasive reptiles also continue to increase in number and expand their range, scoring poor overall. Multiple years of wet conditions impacted prey availability, and as a result, most wading bird targets were not met. Prey abundance and alligator indicators remain impaired. Marl prairie and ridge and slough habitat remain degraded; however some areas of marl prairie habitat have shown improvement.

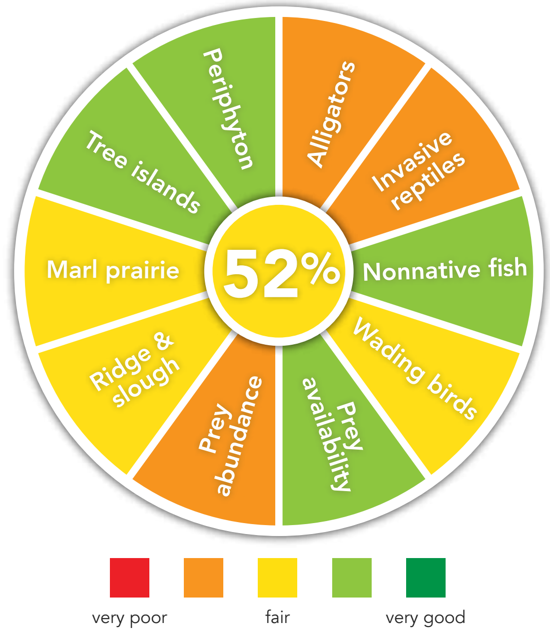


Figure 5.2. Greater Everglades indicator scores from the 2012–2017 Everglades Report Card.

Periphyton: Everglades periphyton continue to expose legacy sources of phosphorus, especially along the boundaries of WCA-3A and Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR).

Aquatic fauna: Better hydrological conditions in Shark River Slough have resulted in slight improvements since 2015. Improvements can be linked to a combination of operations and projects, including the Everglades Restoration Plan (ERTP), the MWD Project, and C-111 South Dade Project.

Wading birds: For the past five years, the 5-year running interval between large ibis nesting has been well within restoration range.

Marl Prairie: In recent years, portions of marl prairie habitat near the ENP boundary have shown signs of improvement. Improvements may be attributable to rainfall and water management activities, including seepage control measures in excessively dry areas and strategic regulation of water deliveries in excessively wet areas.

Alligators: An analysis of data from 2000–2014 showed that alligator body condition was highest in the early 2000's and declined in 2014. For areas where there are recent data, body condition has been stable for the past three years.

Dry Season Prey: A first quantitative attempt to develop a wading bird food availability performance measure suggests that although system-wide prey densities in foraging pools are related to wading bird nesting, so is the total amount of foraging habitat that becomes available.

Nonnative fish invasions and changing diets of wood storks: A recent diet study indicated wood storks, have switched from consuming primarily native annual fish to consuming mostly native sunfish (*Lepomis* sp) and nonnative African Jewelfish (*Hemichromis letourneuxi*).

5.3 INDICATORS

PERIPHYTON

Approach: Periphyton is a key metric of the oligotrophic nutrient status in the Everglades. When marshes receive phosphorus at concentrations exceeding background levels, microbes (algae, bacteria, fungi) comprising periphyton mats of the Everglades remove the added phosphorus from the water. A series of ecological changes ensues, beginning with a change in species comprising the periphyton (Figure 5.3). Mat-forming blue-green algae and diatoms that are only found in the Everglades and other similar Caribbean wetlands (endemic species) are replaced by "weedy" species that occur in phosphorus-enriched environments all over the world. When the endemic species are replaced, the mats disintegrate, resulting in a loss of calcareous periphyton mat biomass that provides habitat and food for aquatic animals. Ultimately, a cascade of changes occurs that result in a transition to a cattail-dominated marsh. Because all of these ecosystem transitions resulting in a degraded state can occur without a change in water phosphorus concentration, periphyton serves as an important early-warning indicator of water quality degradation (Gaiser 2009).

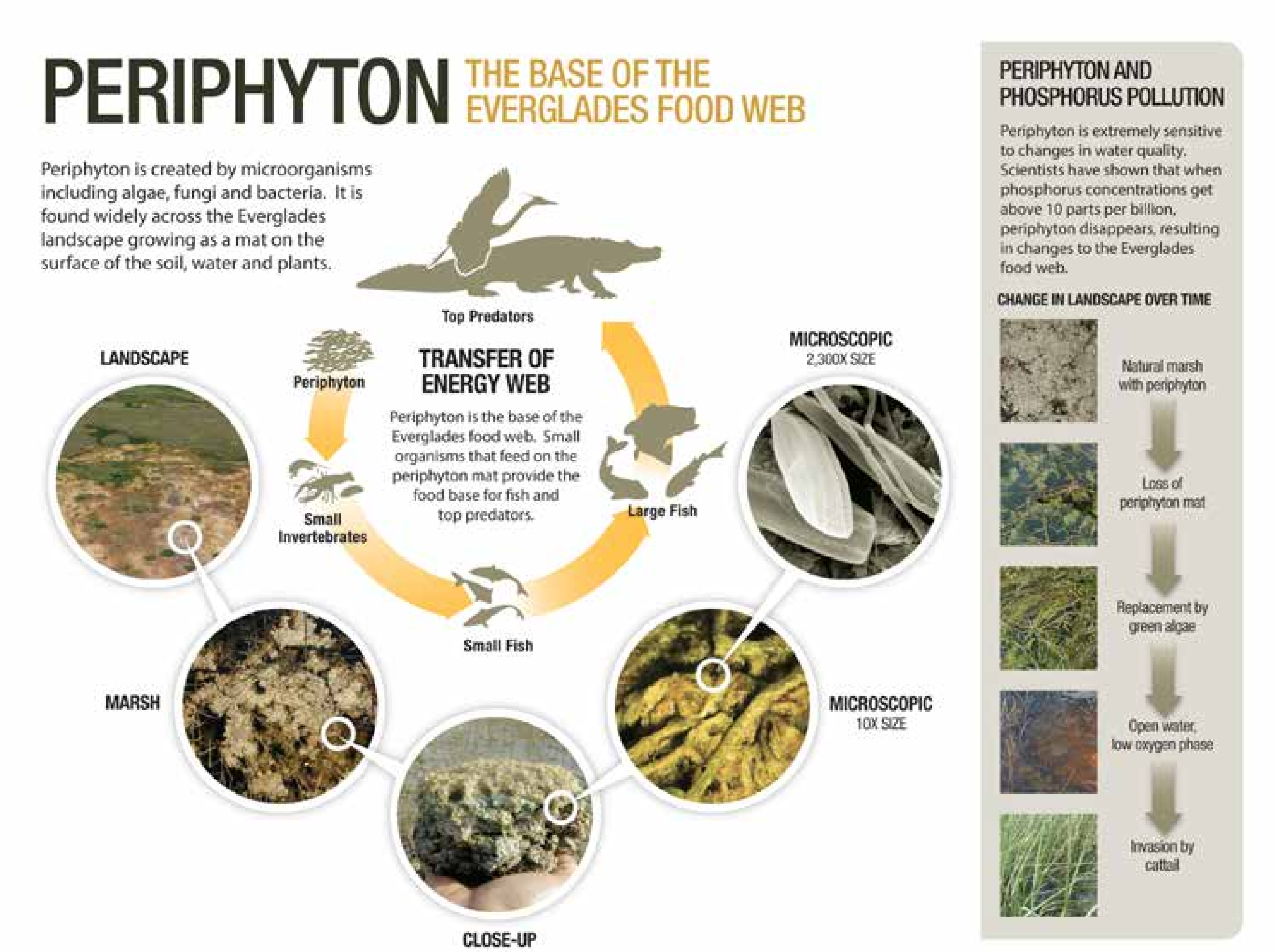


Figure 5.3. This infographic shows the cascade of changes occurring within periphyton mats (center) and at the ecosystem scale (right) in response to above-background phosphorus exposure. [Infographic developed in collaboration with H2H Graphics, Everglades Foundation].

Assessments for periphyton are based on a multi-metric approach using the concentration of total phosphorus (TP) in the periphyton, total biomass, and the percent of the diatom community comprised of endemic (versus cosmopolitan) species, developed from multi-scalar experiments and long-term observations. These three indicators together can detect a history of low to high phosphorus exposure with 30 and 95 % accuracy, respectively (Gaiser et al. 2015).

Methods: Using data from the Periphyton and Aquatic Fauna sampling for the Comprehensive Everglades Restoration Plan Monitoring and Assessment Program, each of 150 Probabilistic Sampling Units (PSU) across the greater Everglades region were scored as impaired, cautionary, or baseline relative to regionally-expected values for total phosphorus, biomass, and endemic diatoms (according to Gaiser 2009), and assigned a value of 0, 50 or 100%, respectively. An average "multi-metric" value for each PSU based on the three metrics and these values was averaged across wetland regions (Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR), Shark River Slough (SRS), Taylor Slough (TS), Water Conservation Area 2A (WCA-2A) and Water Conservation Area 3A (WCA-3A) for each water year (Figure 5.4).

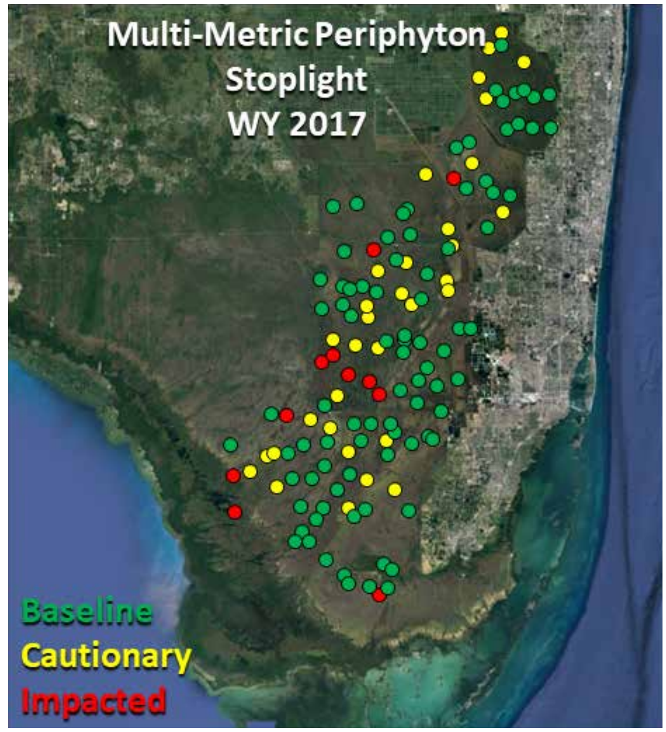


Figure 5.4. The multi-metric periphyton stoplight for water year 2017.

Spatial Patterns: The distribution of baseline, cautionary, and impacted locations in WY2017 was similar to prior years of record (Figure 5.5). Significant deviations from expected composition of diatom communities was evident especially in the northwestern edge of LNWR and the central WCA-3A drainage. Periphyton TP concentrations had been high in these areas in WY2016, perhaps due to above-ambient phosphorus delivery from input structures and resulting in persistent compositional alterations. Periphyton biomass was lower than expected in WCA-3A in WY2017, particularly along the southern boundary. However, lower than expected biomass levels were also evident in TS and SRS but without elevated phosphorus or altered species composition, most likely due to elevated water levels relative to prior years, that lower periphyton biomass. Elevated periphyton phosphorus, low biomass, and altered diatom communities are expected in the SRS and TS ecotone where they receive natural supplies of phosphorus from the Gulf of Mexico.

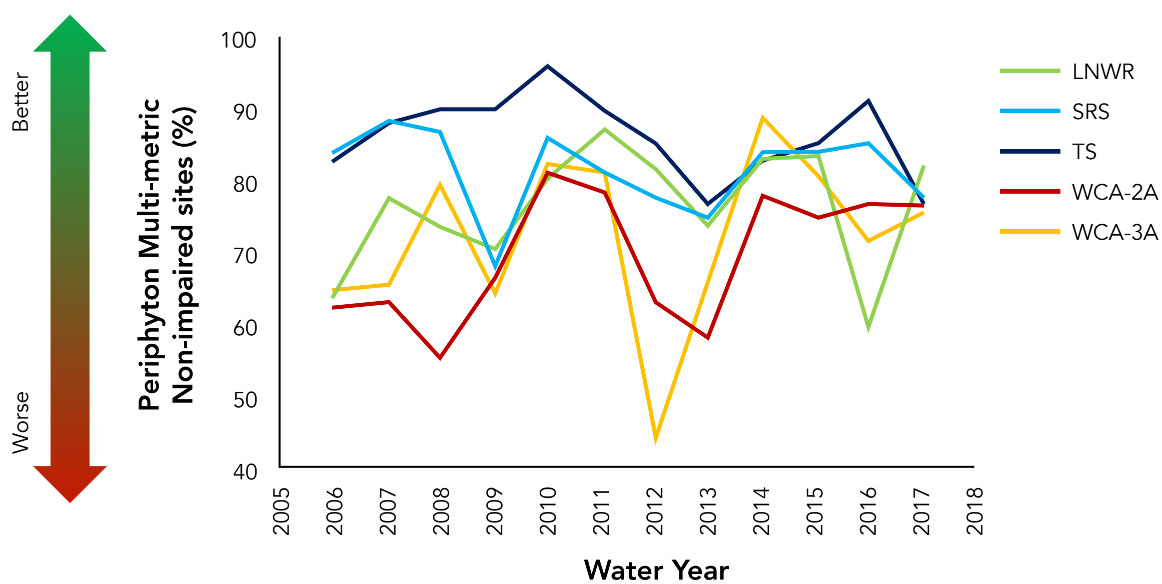


Figure 5.5. Periphyton conditions vary in different regions over time.

Temporal Trends: The periphyton multi-metric suggests that TS and SRS are consistently the least impacted regions, while LOX, WCA-2A, and WCA-3A show signs of impairment. The years with the greatest number of impacted sites were 2008, 2009, 2012, 2013, and 2016, which also experienced the highest water levels and hydroperiods preceding the sampling period. It is likely that in these years, periphyton mats in the water conservation areas are receiving above-ambient loads of phosphorus, reflected in periphyton total phosphorus content, biomass, and species composition (Figure 5.5).

Summary: Everglades periphyton continue to expose legacy sources of phosphorus, especially along the boundaries of WCA-3A and LNWR. The multi-metric approach helps discern effects of increased water loading from exposure to excess phosphorus above background levels. Related work shows concerning expansion of impacted areas within 100 m of the eastern boundary of TS (Gaiser et al. 2015). Continued studies are assessing changes along the SRS and TS boundaries associated with modified water delivery projects.

RIDGE AND SLOUGH LANDSCAPE

Background: Ridge and slough (R&S) landscape includes distinct linear sawgrass-dominated ridges that are oriented in the direction of predominant water flow and separated by a network of similarly oriented sloughs with sparse emergent, submerged, and floating-leaved plant species. In the pre-drainage Everglades, the R&S landscape had ridges ≥ 30 cm higher in elevation than the sloughs (McVoy et al. 2011). Thus, a healthy R&S system is characterized by distinctness in vegetation composition, bimodality in elevation, and directionality in landform orientation. A deviation from vegetation distinctness, elevation bimodality, and loss of directionality represents degraded landscape. The degradation process might include the simultaneous decline in both topographic variation and vegetation distinctness, or degradation in one may be the leading indicator of future degradation in the other.

Approach: For better understanding of the mechanisms involved in formation, maintenance, and degradation of patterned R&S landscape, a detailed system-wide assessment of the spatiotemporal patterns in R&S was initiated as a pilot in 2009 and a full study in 2010. The sampling design was based on the Generalized Random-Tesselation Stratified (GRTS) approach (Stevens & Olsen 2003) and included 80, 2 km x 5 km cells, called Probabilistic Sampling Units (PSUs) (Philippi 2007). In the first two years, the study included a fine-grained topographic and vegetation survey in 32 PSUs. However, owing to the reduced budget since FY 2012, the number of PSUs and the number of sites sampled every year were adjusted. Some PSUs were dropped, and the target number of plots was reduced from 240 to 135. In years 3 and 4, sampling efforts included additional PSUs, but in modified form to monitor the DECOMP Physical Model, and downstream of 1- and 2.6 mile bridges along Tamiami Trail (Section 2.6) (Ross et al. 2016).

Methods: In the first five years (2010–2015), 62 PSUs distributed in different water conservation areas (WCAs) and Everglades National Park (ENP) were visited. Within each PSU, water depth and plant species cover were measured in 1-m^2 plots at 135–240 randomly selected locations. In 2016 and 2017, 22 PSUs from the study years 1 and 2 were re-visited, and the measurements were repeated in subset of previously sampled locations. The two topographic condition metrics were: the standard deviation of elevation (microtopography variability) and difference in elevation between two modes of bimodality distribution curve (elevation mode difference). The two vegetation condition metrics were: vegetation community distinctness (the distance between two vegetation clusters) and vegetation-elevation association (as measured by Mantel r [Ross et al. 2016]).

Results: In 62 PSUs sampled from 2010–2015, the microtopography showed high levels of variation with standard deviation of elevation ranging from 2.3 to 26.3 cm. Ground elevation showed bimodal distribution within 30 PSUs. Difference in elevation between two modes ranged from 9 to 23.4 cm with highest differences generally in central portion of WCA-3A South (Figure 5.6). Vegetation cluster analysis identified two dominant clusters: ridges dominated by sawgrass, and communities including both wet prairies and sloughs. The close correspondence between global (all PSUs together) and local (individual PSUs) k-means clusters suggested that cluster distance for individual PSUs was an effective proxy for plant community distinctness. Community

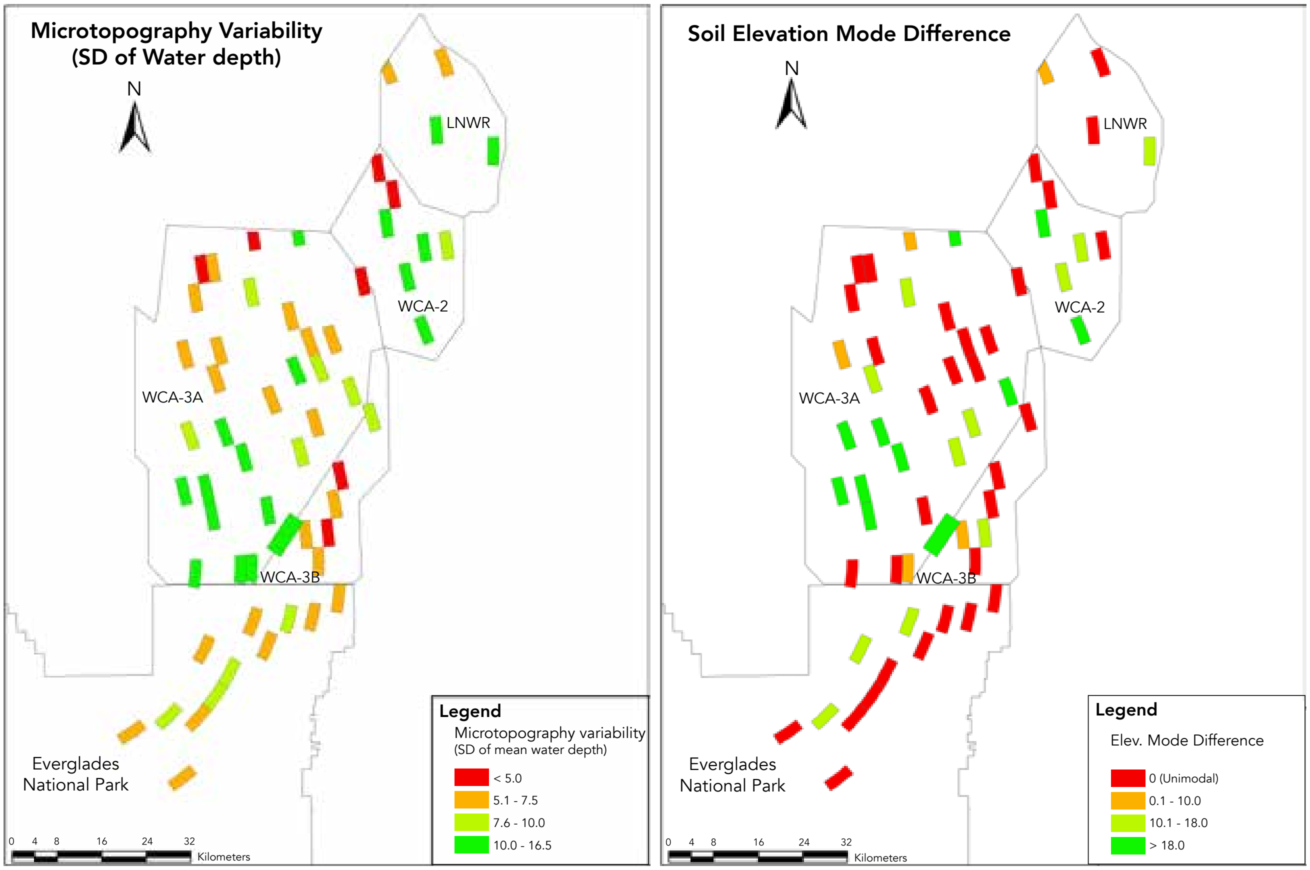


Figure 5.6. Microtopography variability and soil elevation mode difference in PSUs sampled over five years.

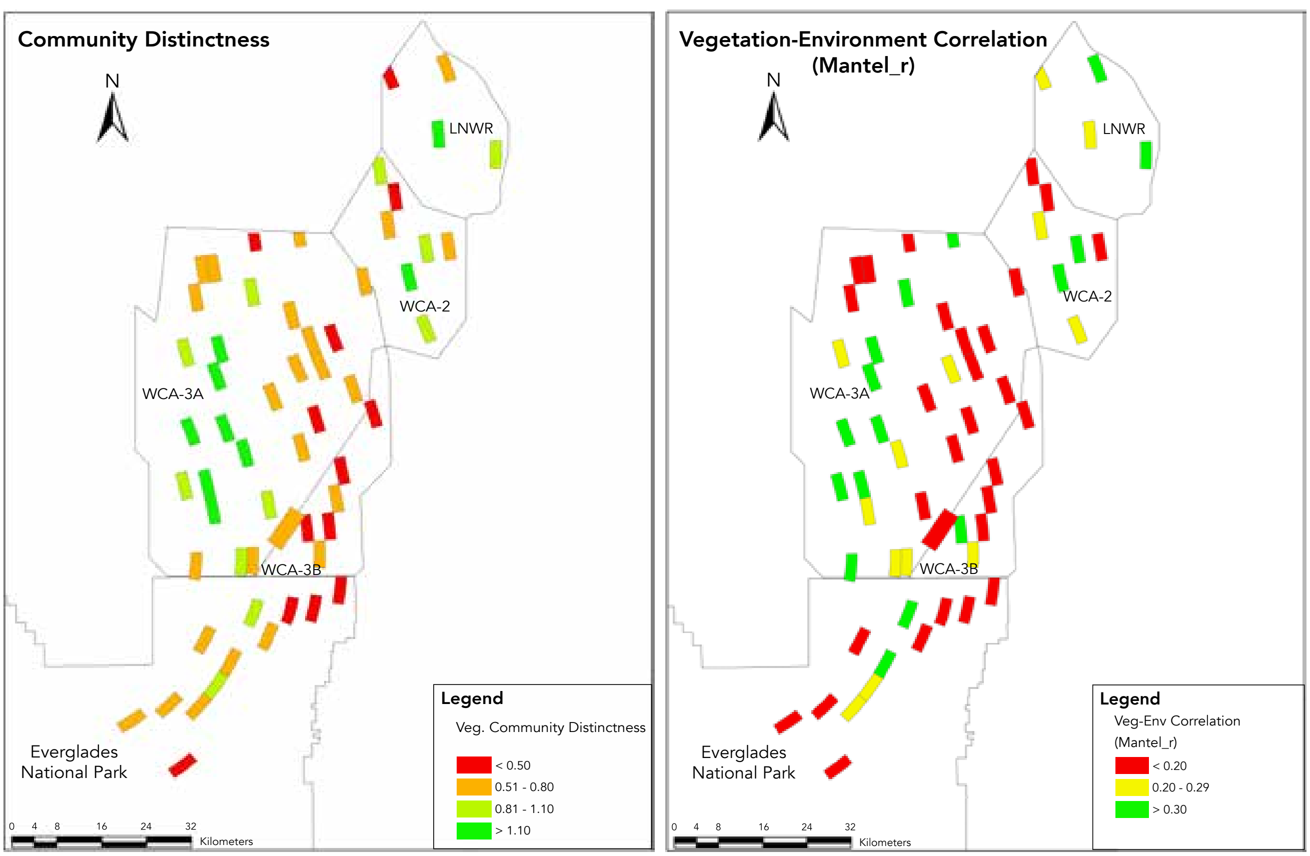


Figure 5.7. Vegetation distinctness and vegetation-environment relationship (Mantel r) in PSUs sampled over five years.

distinctness was also relatively high in PSUs within central WCA-3A South. Sections of ENP, WCA-3B, WCA-3A North, and to a lesser extent WCA-2 and LNWR, are in a more degraded state as defined by the community distinctness (Figure 5.7). PSUs with high distinctness also had stronger vegetation-elevation association.

The microtopography variability was highest in the PSUs with long-term mean water depths between 25 and 51 cm. Outside this hydrologic range, elevation distributions were unimodal and exhibited low variance. While the preservation of microtopographic differentiation of R&S is best maintained by long-term mean water depths between 40 and 50 cm, microtopographic structure sometimes resists degradation at water levels as low as 25 cm. Similarly, maximal community distinctness generally occurred within PSUs with long-term mean water depths between 20 and 50 cm. However, the drier end of this range (20 to 35 cm) also included PSUs with indistinct vegetation pattern, indicative of degraded conditions. Across PSUs, microtopographic variability, community distinctness, and their associated indicators followed similar geographic patterns (Figures 5.6 and 5.7). Only a small fraction of the historic R&S landscape, primarily within central WCA-3A South is in a relatively conserved condition. All PSUs in WCA-3B were characterized by degraded conditions by majority of indicators, whereas PSUs within ENP, LNWR, and WCA-2 largely exhibited less topographic variability and reduced community distinctness suggesting various degree of degradation.

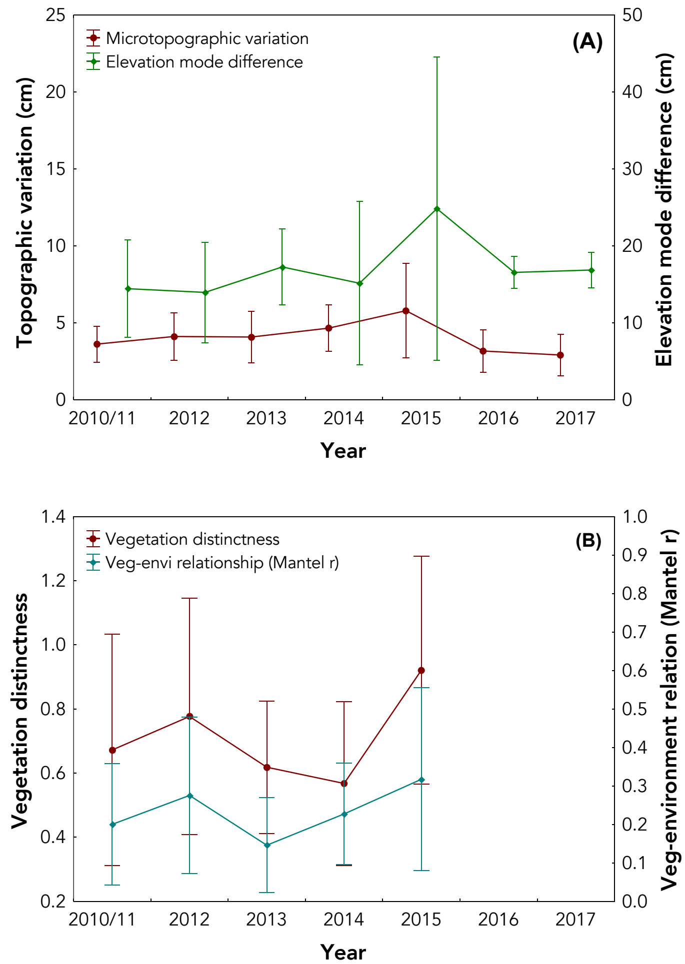


Figure 5.8. Annual mean (±1 SD) values of (A) topographic variability and soil elevation mode difference, and (B) Vegetation distinctness and veg-environment relationship (Mantel r). The PSUs targeted to be sampled in the first year of cycle 1 were sampled over a two-year period (2010–2011).

Annual variability in four major indicators between 2011 and 2017 (Figure 5.8) is largely due to different PSU locations sampled each year. However, PSUs sampled in 2016 and 2017 were the same as presented in 2011 and 2012. Among those PSUs, while fewer exhibited significant bi-modality during the cycle 2 sampling than was observed during the cycle 1 sampling, all PSUs that showed bi-modality during cycle 2 also had conserved topography in cycle 1. Few PSUs, in which bi-modality was detected during cycle 1 but not cycle 2 sampling, had smaller mode elevation differences (10–12 cm) during cycle 1. The shift from detection of bi-modal soil elevations to their non-detection does not necessarily indicate ongoing degradation in ENP and WCA-3B, but could be due to reduction in sampling intensity between cycles. Wetter hydrologic conditions during cycle 2 sampling than cycle 1 may have influenced estimates of soil elevation distributions. The uncertainty in soil elevation estimates contributes to uncertainty surrounding the presence of multiple soil elevation modes.

Conclusions: While substantial portions of the R&S landscape are severely degraded, patterns of co-variation between topographic variance and vegetation community distinctness indicate that ground elevation changes often precede vegetation change during critical transitions from patterned to degraded landscape states especially in the drained landscapes. In contrast, vegetation change (reduced in vegetation distinctiveness) may serve as a leading indicator of landscape degradation in impounded conditions. Successful Everglades restoration will need to maintain a spatially-averaged long-term mean annual water depth of 35 to 50 cm in the areas where a healthy ridge and slough structure is an important objective.

TREE ISLANDS

Background: Tree islands are an integral component of the Everglades, but they have undergone extensive damage from extreme flooding, drought, fire, tropical storms, and invasive species, (Sklar & van der Valk 2002). These islands are also sensitive to ongoing small to large-scale restoration activities of the CERP. Changes in hydrologic regimes due to restoration projects, including construction of Tamiami Bridges and other Central Everglades Planning Project (CEPP) components, are likely to alter the impact of drivers and stressors on tree islands. While such alterations in the impact of these stressors at the broader scale influence the spatial distribution pattern of tree islands within the landscape, the hydrologic alterations also affect the plant community structure and function on individual tree islands.

Methods: The four tree islands annually monitored from 2012–2017 were the subset of a network of 16 tree islands that were studied for varying periods within both the ridge and slough (R&S) and marl prairies (MP) landscapes in the Everglades National Park (Ross & Jones 2004; Ruiz et al. 2011; Sah et al. 2018). Three islands (Black Hammock, Gumbo Limbo Hammock, and Satinleaf), are in Shark River Slough (SRS), and have been monitored since 2001 (Ross & Jones 2004). The fourth island, SS-81, monitored since 2007, is within the Northeast Shark River Slough (Figure 5.1) (NESRS), downstream of the 1-mile bridge that has been built along the Tamiami Trail. The monitoring plots ranged from 300 m^2 to 625 m^2 (Table 5.1). Mean elevation of tree island heads in SRS varies between 1.190 ± 0.094 m and 2.663 ± 0.191 m (Ruiz et al. 2011). Plot elevations within individual islands were highly variable. Among four islands, SS-81 had higher within-plot variability than other islands, with low spots frequently occupied by swamp forest trees. From 2012–2017, the mean annual relative water level (RWL) across all islands was approximately 66 cm below the ground surface.

Table 5.1: Tree island topographic data (mean, minimum, and maximum), and mean relative water level (RWL) of four islands annually monitored during 2012-2017.

Tree island	Plot size (m^2)	Mean (± 1 S.D.) Plot Elevation (m NAVD 88)	Minimum Plot Elevation (m NAVD 88)	Maximum Plot Elevation (m NAVD 88)	Mean Annual Relative Water Level (m)
Black Hammock	400	2.330 ± 0.166	1.988	2.584	-0.80
Gumbo Limbo Hammock	625	2.059 ± 0.071	1.916	2.24	-0.63
Satinleaf	625	2.221 ± 0.076	2.082	2.368	-0.64
SS-81	300	2.168 ± 0.304	1.592	2.649	-0.55

Results: Tree density and basal area are functions of tree mortality and in-growths, two important indicators of woody vegetation dynamics on tree islands. During 2007–2010, mean annual tree mortality on 16 tree islands was 3.6%, and both NESRS and R&S islands had higher mortality than MP islands (Figure 5.9). During these years, mean tree in-growth was significantly higher (paired t-test, $P < 0.001$) than mean tree mortality. In subsequent years (2011–2017), when hammocks on only four islands were annually monitored, the mean tree in-growth showed little variation. But tree mortality noticeably increased, resulting in significantly reduced regeneration (in-growths minus mortality) on these four islands (Figure 5.10). Between 2012 and 2017, mean mortality was 4.67%, and tree regeneration decreased from -0.18% in 2012 to -9.2% in 2017. On these four islands, tree mortality was positively related to RWL. The mean tree mortality was the highest when the mean water level was less than 60 cm below the ground during the preceding year. Similar to the trend in tree mortality and in-growths, tree basal area on the islands also showed a decreasing trend. A sharp decrease in tree basal area occurred between 2016 and 2017, when mean tree mortality was the highest (Figure 5.11).

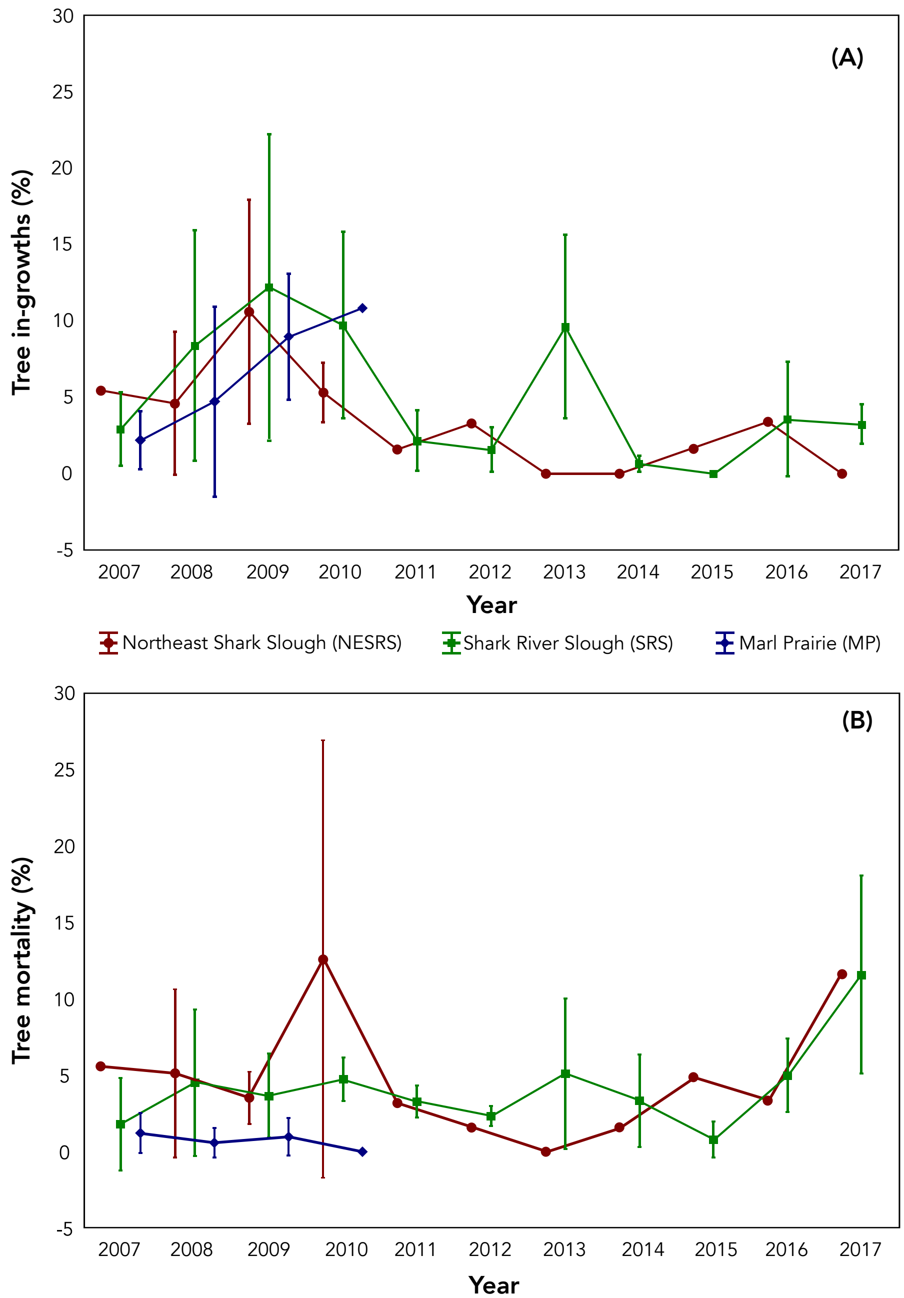


Figure 5.9. Annual mean (±) tree in-growths and mortality on the 16 tree islands monitored within the Everglades National Park between 2007 and 2017.

Conclusions: Hydrology is the major driver of differences in species composition among various plant communities arranged along topographic gradient within a tree island. However, in the rarely flooded hardwood hammocks where mean annual water table is often below 40 cm, tree species composition is probably the legacy of long-term interaction between hydrology and other physical processes, including disturbances. The short-term trend of vegetation dynamics observed in the hardwood hammocks is mostly in tandem with variation in hydrologic condition. Hardwood hammocks are characterized by flood-intolerant species which cannot survive water levels above or near the ground surface (Stoffella et al. 2010).

Decline in tree in-growths and increase in mortality in 2017 was, to some extent, probably due to unusually high water conditions in the dry season of the preceding year. In the hardwood hammock of four tree islands within the Park, while 5-year (WY2012/13–2016/17) mean dry season water level was more than 52 cm below ground, during the 2016 dry season, water level in the Park was very close (<40 cm) to the ground surface for an extended period. This probably caused an increase in mortality of flood-intolerant species, such as gumbo limbo (*Bursera simaruba*) and sugarberry (*Celtis lavaegata*) in the SRS and NESRS tree islands, respectively. While the annual RWL within SRS tree islands remains well below the soil surface, fluctuations in the water level within these areas play a major role in plant community dynamics. Slight increases in marsh hydroperiod or water depth are likely to have little impact on tropical hardwood hammock communities, but an incremental upward shift in the RWL could potentially cause a significant shift in species composition and productivity, ultimately changing the health of tree islands.

Tree island vegetation dynamics might also be influenced by natural disturbances. In the hardwood hammocks, major disturbances include wildfires, hurricanes, and tropical storms. In several R&S hardwood hammocks, high mortality was observed for 3–4 years after Hurricane Wilma in 2005 (Ruiz et al. 2011). In 2017, several tree islands were hit hard by Hurricane Irma. A preliminary analysis of tree data collected on eight tree islands in ENP suggests high tree damage. When trees stressed by the hurricane experience drought or high water conditions in next few years, tree island vegetation is likely to be adversely affected.

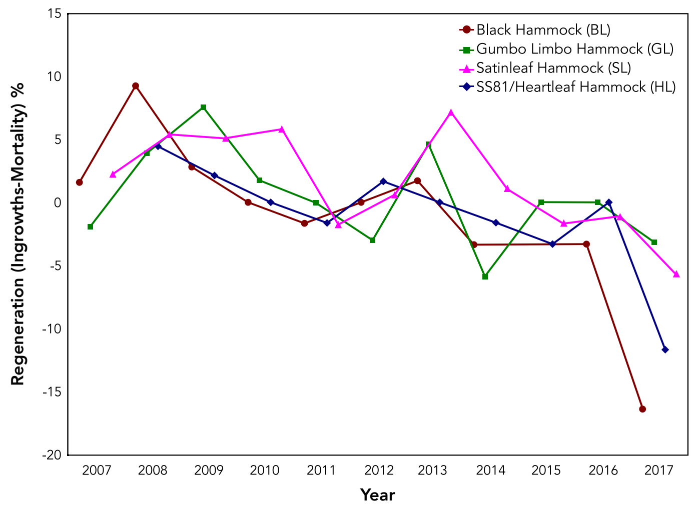


Figure 5.10. Annual mean tree regeneration (in-growths minus mortality) on four tree islands monitored within the ENP between 2007 and 2017.

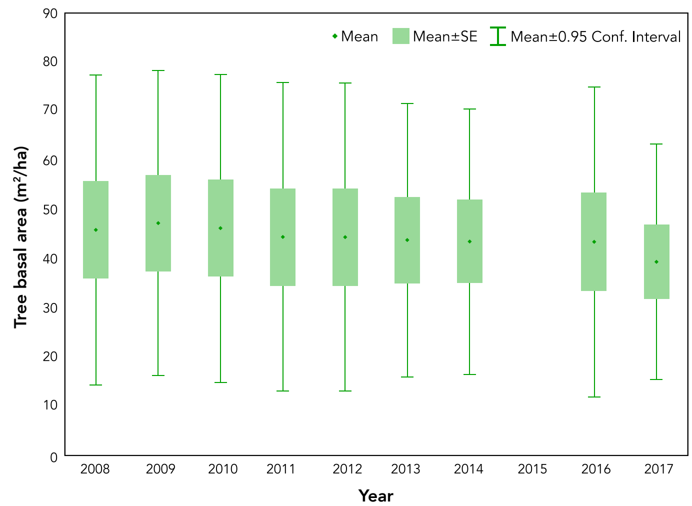


Figure 5.11. The trend in tree basal area on four tree islands monitored within the ENP between 2007 and 2017. In 2015, only three tree islands were sampled, and thus is not included.

MARL PRAIRIE

Background: In the Everglades, both Shark River Slough (SRS) and Taylor Slough (TS) are flanked by short hydroperiod (3–8 months) marl prairies, habitat of the endangered Cape Sable seaside sparrow (CSSS). In the marl prairie landscape, a normal dry season is essential for its characteristic vegetation and habitat quality. Since 2002, water management activities in the Everglades have been directed to improve sparrow habitat. Conditions of marl prairies within the habitat of all six sub-populations (A–F) of the sparrow were regularly monitored from 2003–2010 (Ross et al. 2006; Sah et al. 2011). After 2010, monitoring focused mainly on habitat change along marl prairie-slough gradient transects, within C-111 Spreader Canal Project area (sub-population D), and recently burned areas. In 2016, monitoring of sparrow habitat partly resumed and additional monitoring sites were added in the northeastern portion of sub-population A, the western portion of sub-population E, and between sub-populations E and F.

Methods: Evaluation of marl prairie conditions includes an analysis of EDEN data-derived hydrologic metrics (USFWS 2006) and an assessment of the change in vegetation-inferred hydroperiod (Armentano et al. 2006). Analyzing relative changes in vegetation-inferred hydroperiod between successive sampling years tests the hypothesis that vegetation in the CSSS habitat has changed in response to short-term hydrological changes over the same period. Desirable hydrologic regimes for optimal CSSS habitat include discontinuous hydroperiod to be in the range of 90 to 210 days (Ross et al. 2006; Beerens et al. 2016; USFWS 2006). Concurrently, marl prairie areas with 90–210 days of vegetation-inferred hydroperiod were considered optimal habitat, and they received relative score of 80 to 100. Sites in marl prairie with <90 days vegetation-inferred hydroperiod were considered as too dry, 211–240 days as wet, and >240 days as too wet. Those sites received relative scores of 80–0, 80–60 and 60–0, respectively.

Results: The hydrologic conditions of CSSS habitat within marl prairies varied with space and time. In sub-population A, EDEN-based mean 4-year discontinuous hydroperiod was greater than 210 for all water years since 1995, including the period of 2012–2017 (sofia.usgs.gov/eden/). However, in the areas where model results have shown that habitat condition would improve, mean hydroperiod was in the optimum range for most of the years, and in 4 out of 5 years between 2012 and 2017. The hydrologic condition was optimum in sub-populations B, C, and F, but the sub-populations D and E were wetter (hydroperiod >210 days) in recent five years (2012–2017) than previous 10 years. Marl prairie vegetation composition closely tracked with the hydrologic metrics. From 2003–2017, annual mean vegetation-inferred hydroperiod ranged from 218 to 262 days, whereas in the most recent five years, it varied from 226 to 262 days (Figure 5.12). Vegetation-inferred hydroperiod varied annually. Differences among years was due to annual variation in hydrologic conditions and disparity in sampling sites and area.

Habitat condition also varied among different portions of the marl prairie landscape. Annual mean vegetation-inferred hydroperiod was the highest in sub-population A and the lowest in F (Figure 5.13). Most years mean inferred hydroperiod was >240 days in sub-population A, >225 days in D, and <180 days in C and F. The values were about 210 days in sub-populations B and E. When inferred-hydroperiod values of recent years (2012–2017) were compared with the previous nine-year period (2003–2011), vegetation showed noticeable change and the direction of change differed between east and west.

In sub-population A, mean inferred-hydroperiod from 2012–2017 was 18 days shorter than the previous nine-year period (Figure 5.13). This decrease caused western prairie vegetation to shift to a drier type. The drying trend was prominent in the northeastern portion of the sub-population. The direction of vegetation change in the eastern prairies showed a mixed pattern. Areas near the Park boundary within sub-population F exhibited an increase in mean inferred-hydroperiod, suggesting that species composition at these sites recently shifted to a wetter type. Similarities were seen in sub-populations B and E, especially the southern portion of B and sites close to SRS in E have become much wetter during the 2012–2017 period. In contrast, marl prairie within sub-population D is relatively dry in recent years, though the trend is gradually reversing since 2012, after the implementation of C-111 Spreader Canal Western Project (Sah et al. 2018). Outside the existing CSSS habitat, hydrologic conditions between sub-populations E and F, and transition sites along the marl prairie-slough gradient varied over the study period (2006–2017). In recent years, prairies between sub-populations E and F and within NESRS were relatively wet, whereas those in transition zone west of SRS were drier (Figure 5.14).

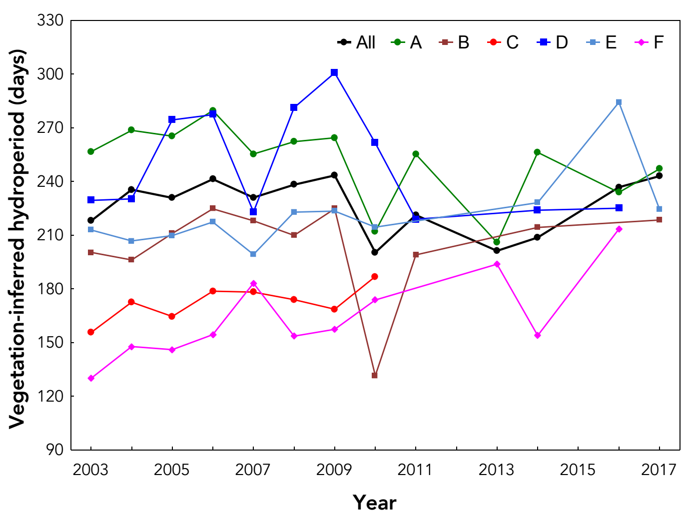


Figure 5.12. Annual trend in mean vegetation-inferred hydroperiods based on vegetation composition sampled within the habitat of Cape Sable seaside sparrow (CSSS). The number of sites sampled within each sub-population varied among years.

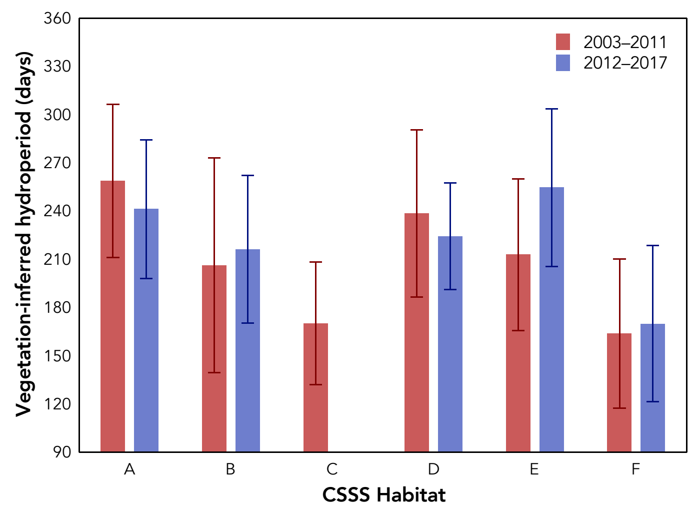


Figure 5.13. Mean (±1 SD) vegetation-inferred hydroperiods for two periods, 2003-2011 and 2012-2017, in each sub-population of Cape Sable seaside sparrow (CSSS).

Conclusions: The trend of vegetation change in marl prairie landscape is influenced by year-to-year variation in water conditions, caused by both rainfall and water management activities. In the southern Everglades, recent water management efforts have been directed toward ameliorating the adverse effects caused by previous water management activities. A series of water detention ponds are in operation along the eastern boundary of the Park to mitigate water loss from the rocky glades to the canal that resulted in excessive dryness in the area. Marl prairie indicators show that such measures have helped control seepage back to the canal and protect nearby sparrow habitat from further deterioration. Vegetation adjacent to the canal shows signs of shifting to a more mesic type (Sah et al. 2011, 2017), possibly improving habitat conditions for CSSS.

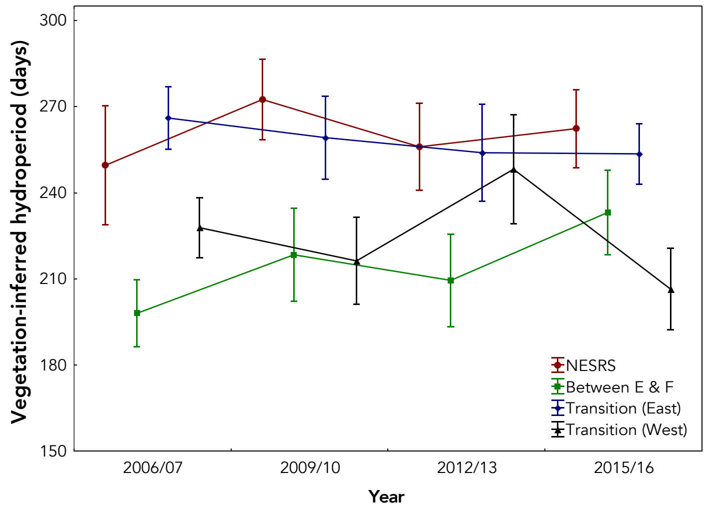


Figure 5.14. Mean (±1 SD) vegetation-inferred hydroperiods based on vegetation composition sampled at sites in Northeast Shark River Slough (NESRS), between sub-population E & F, and transition zones along the marl prairie-slough gradient.

Marl prairie habitat in the northeastern and eastern portions of sub-population A is showing improvement. This trend is expected to continue, and could result in new habitat when restoration activities, envisioned in CEPP, of moving water through NESRS, are fully implemented. In contrast, the southern portions in sub-population B and western areas in both B and E are expected to get wetter, mostly due to sea level rise (SLR) and increased water flow in SRS, respectively. The intensity of the effects of natural events and management activities on marl prairies depends on the rate of SLR and the volume and timing of water deliveries to the Park and water flow in both SRS and Taylor Slough.

PREY ABUNDANCE

Approach: The abundance of small fish and crustaceans is a key metric of Everglades food webs because they feed iconic apex predators including wading birds and alligators. Diminished production and availability of fish and crustaceans during the critical nesting season has been linked to diminished nesting success of these key predators. Abundance of prey species is closely tied to hydrological variation and periphyton quantity and quality, which are sensitive to management actions affecting timing and quantity of water delivery and water quality. Small fish and crustaceans have short generation times, a year or less, and their abundance responds to hydrological management at an annual time scale, recovering from marsh drying events over three to seven years. Sampling methods of small fish and crustaceans are well evaluated and use of a 1-m^2 throw trap provides readily interpretable information; substantial historic data gathered using this approach is available.

Methods: Targets for the aquatic fauna metric are dynamic based on observed rainfall and resulting hydrological fluctuation observed in the mid-1990's when high rainfall and management in the southern Everglades generated water stages like those predicted for the pre-management ecosystem. In years with low rainfall, the target is lower abundance of fish and crustaceans than in periods of greater rainfall. Dynamic targets avoid assigning a low performance score for years when little rainfall made it impossible for managers to support production of high prey biomass. The data used for this assessment come from 21 sites (Figure 5.15) continuously sampled five times per year since 1996. This provides a robust basis for development of statistical models during the pre-2000 baseline period. Deviation from targets are scored based on the magnitude of overlap of observed and target values and accompanying measures of uncertainty for both estimates. Relative abundance of nonnative fishes is also assessed, and their impacts are evaluated by comparing the observed abundance of native taxa to expected abundance derived from times before nonnative fishes were present.

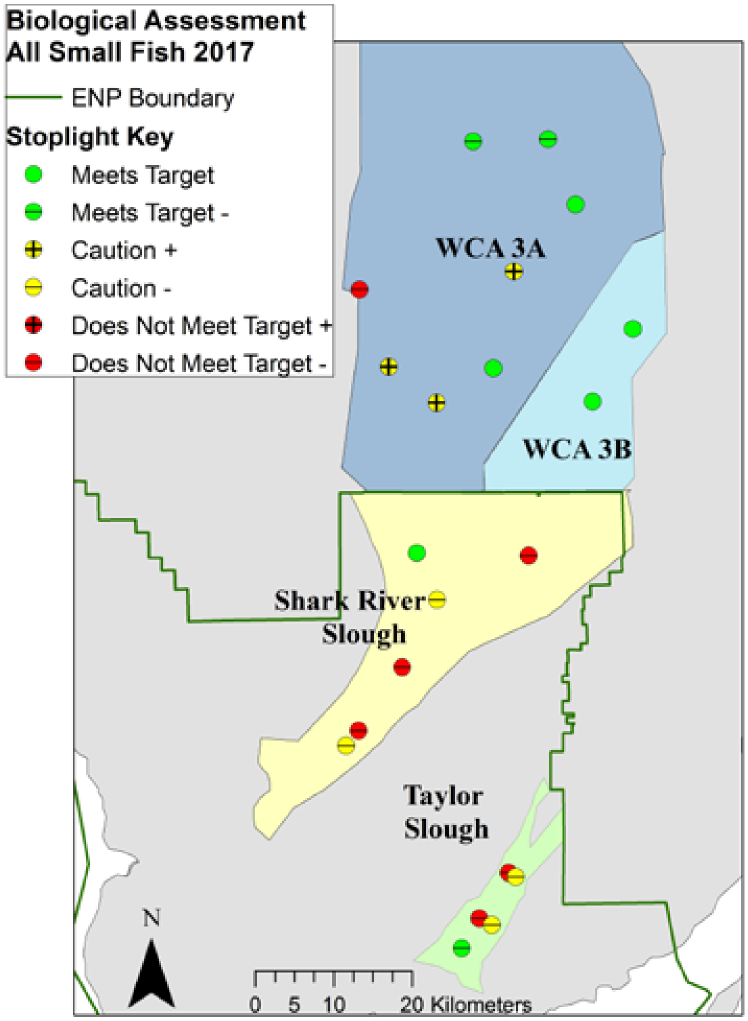


Figure 5.15. Site locations and indicator colors (red is worst, green is best) for small fish metric at long-term study sites in WCA-3A, 3B, and Everglades National Park.

Spatial Patterns: Fewer fish than expected were collected at several sites in Shark River Slough and Taylor Slough during the 2017 water year, but most sites met targets in WCA-3A and WCA-3B (Figure 5.15). The sites in Shark River Slough with too few fish also had high relative abundance of the nonnative predatory fish, African Jewelfish (*Hemichromis letourneuxi*). Before 2014, Shark River Slough was often below the target fish abundance because of more frequent drying. The decline in fish abundance at several sites in Shark River Slough is due to a dramatic drop in abundance of Eastern Mosquitofish (*Gambusia holbrooki*) and Least Killifish (*Heterandria formosa*). Too few fish were also collected in Taylor Slough, but this did not seem to be linked to invasive species.

Temporal Trends: Since 2003, Shark River Slough has consistently had fewer fish than the target, though some improvement was noted since 2015 (Figure 5.16). That improvement appears to have come from better hydrological conditions relative to targets for areas other than Northeast Shark River Slough, which was too dry. In January 2010, an extreme cold event decreased the abundance of nonnative fishes in the southern freshwater Everglades, Shark River, and Taylor Sloughs, but by 2014 their numbers and relative abundance had re-bounded and surpassed previous values (Figure 5.17). Since 2015, several sites in Shark River Slough, including the one in Northeast Shark River Slough, have been below targets, possibly because of impacts by African Jewelfish that increased dramatically in abundance from 2012–2017. Taylor Slough has had intermediate scores since 2015 because of fewer fish than expected (Figure 5.16). This area has been drier and has experienced an increase in predatory nonnative fishes, Mayan Cichlids (*Cichlasoma* (*Mayaheros*) *urophthalmus*) and Asian Swamp Eels (*Monopterus albus*). Water Conservation Area 3A has consistently earned intermediate scores because of several areas that have not dried at times predicted to do so, resulting in more fish than the target. Water Conservation Area 3B had some sites with mixed values meeting and below the target because of modest deviations from hydrological predictions. Marshes of the Water Conservation Areas currently have low relative abundance of nonnative fishes.

Summary: Shark River Slough and Taylor Slough continue to have a poor match to targets because they receive less water at critical times in the dry season than desired. Recent rapid increases in nonnative fishes, notably African Jewelfish, are causing native fish abundance to be below targets, resulting in low scores. The fish and crustacean metric is an index of food-web functions that support iconic apex predators. Nonnative fish invasions are a new threat to this function, in addition to the challenges of hydrological management. Ongoing research is evaluating how invasive species function in the food web (do they sustain similar abundance and biomass as native taxa) and as prey for apex predators (are they as readily captured and used as food) compared to the native community to better delineate the implications of these new challenges for Everglades restoration.

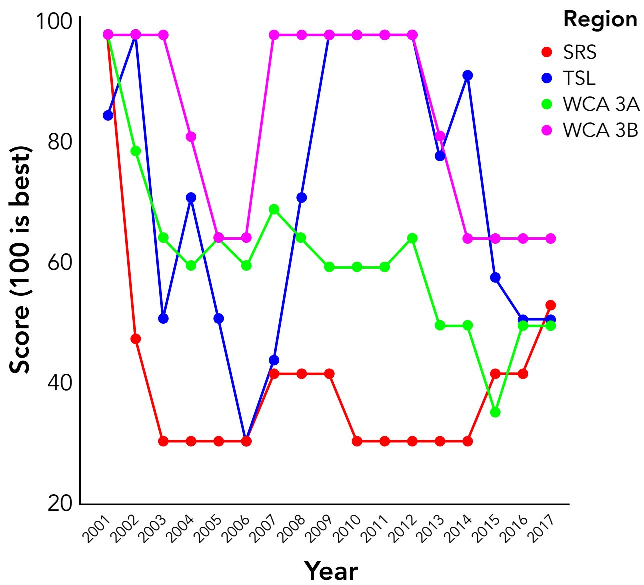


Figure 5.16. Assessment score (100 best; 30 worst) from water years 2001–2017.

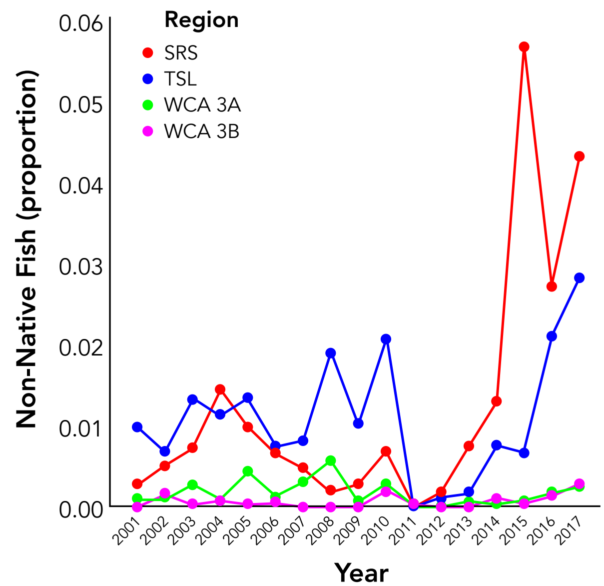


Figure 5.17. Proportion of fishes that were nonnative species from water years 2001–2017.

PREY AVAILABILITY

Approach: The dry season prey concentrations project monitors the spatial patterns of aquatic fauna densities across the Everglades landscape. Of particular interest, are the inter-annual variation and correlations with local site characteristics, hydrologic patterns, wet season fauna production, and ultimately, predatory wading bird nesting numbers. This monitoring is based on the framework of the trophic hypothesis, which states that wading bird population size is limited by the availability of aquatic fauna that are, in turn, affected by hydrologic patterns and conditions.

Methods: Since 2005, prey concentrations have been monitored via 1-m^2 throw traps during the dry season (approximately January–May). Sampling sites are located across the Everglades landscape using a multi-stage sampling design with strata of landscape units, primary sampling units, sites, and throw traps. Landscape units were delineated based on hydroperiod (number of days inundated with water) and vegetative characteristics. Each landscape unit contained at least seven 500 m x 500 m randomly placed primary sampling units. Each primary sampling unit contained two randomly placed sites. In each site, aquatic fauna were sampled from two randomly placed throw traps cleared with bar seines. Microtopography was characterized by water depth measurements taken every meter along a 100 m transect, centered on the first throw trap, at each site. Additional water measurements were derived from the EDEN. From 2012–2017, dry-season prey concentrations were characterized with 685 throw trap samples: 105 traps in 2012, 119 traps in 2013, 174 traps in 2014, 4 traps in 2015, 114 traps in 2016, and 169 traps in 2017.

Annual trends

2012: The 2012 dry season was characterized by low water levels and normal recession rates at the start of the season. However, several rain events in late April caused water levels to rise about 6 weeks earlier than previous years (Figure 5.18). These increased water levels decreased suitable foraging habitat system-wide. Due to these water patterns, prey production was likely hindered, and wading bird nesting was low in 2012.

2013: Water levels were relatively low at the start of the 2013 dry season. Recession rates were normal, but periodic rain events increased water levels and prevented an extensive dry-down of the landscape (Figure

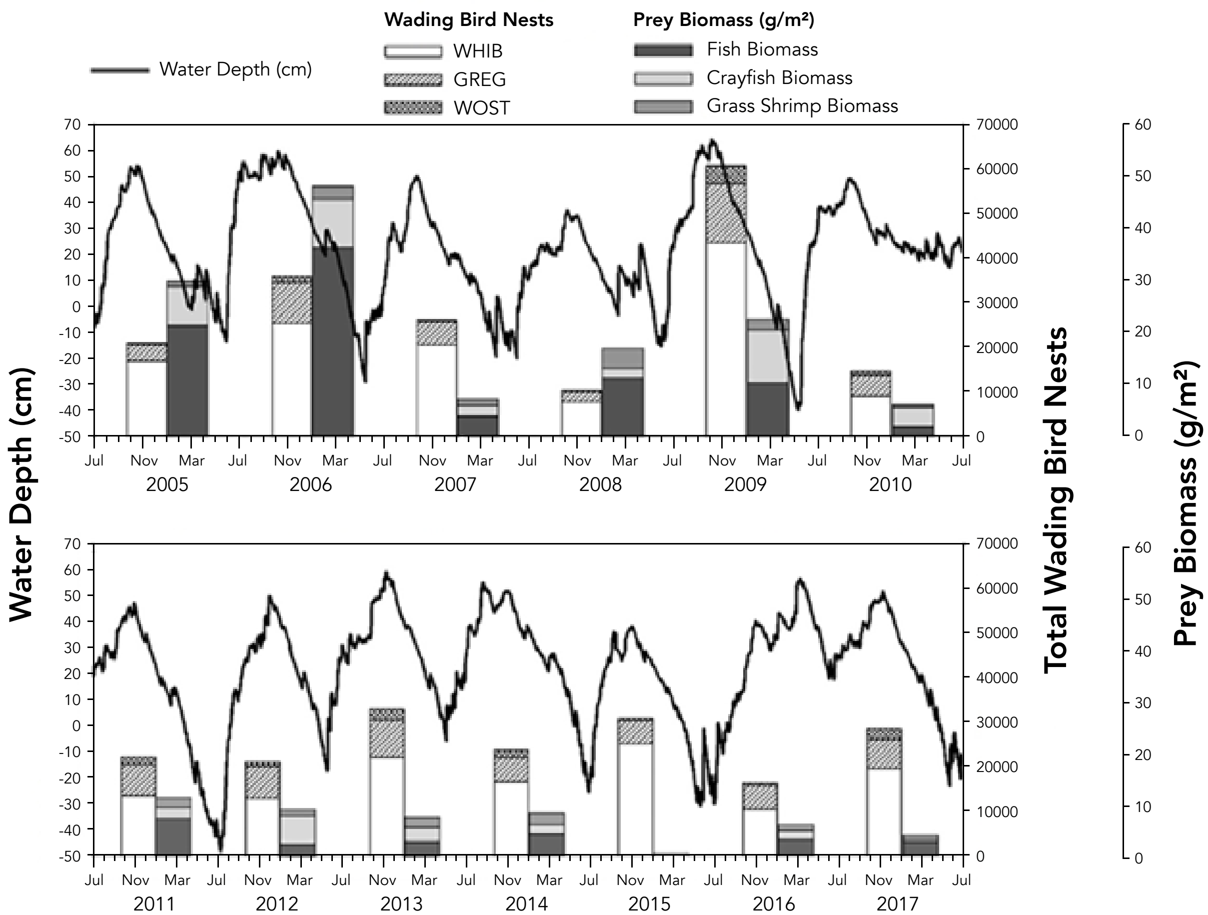


Figure 5.18. Mean rainfall, mean water depth, number of wading bird nests and wet and dry season prey biomass throughout the Florida Everglades from June 2005 to July 2017. Depth values represent the mean of 46,818 EDEN grid cells throughout most of the freshwater portion of the Everglades.

Table 5.2. Mean prey density (g/m^2) and biomass (g) found within 1-m^2 throw trap random sites throughout the Florida Everglades and wading bird nest numbers during the 2012–2017 dry seasons (Note: 2015 prey density and biomass reflects only one day of data collection).

Dry season	Mean prey density	Mean prey biomass	Habitat availability[a]	Nest abundance[b]
2012	32.69 ± 8.24	9.58 ± 2.33	4602	23200
2013	45.13 ± 12.23	8.53 ± 2.20	3773	33629
2014	64.15 ± 22.31	9.83 ± 2.74	4958	24663
2015	45.75 ± 65.17	2.88 ± 5.16	4265	31253
2016	40.06 ± 10.71	7.98 ± 2.57	2709	17425
2017	32.32 ± 7.74	4.36 ± 1.05	6037	29568

[a]The total area (km^2) of wading bird foraging habitat that became available during each dry season calculated from the number of Everglades Depth Estimation Network (EDEN) cells that became available.
[b]Nest abundance numbers are a combination of great egrets, white ibises, wood storks, snowy egret, tricolored heron, and little blue heron.

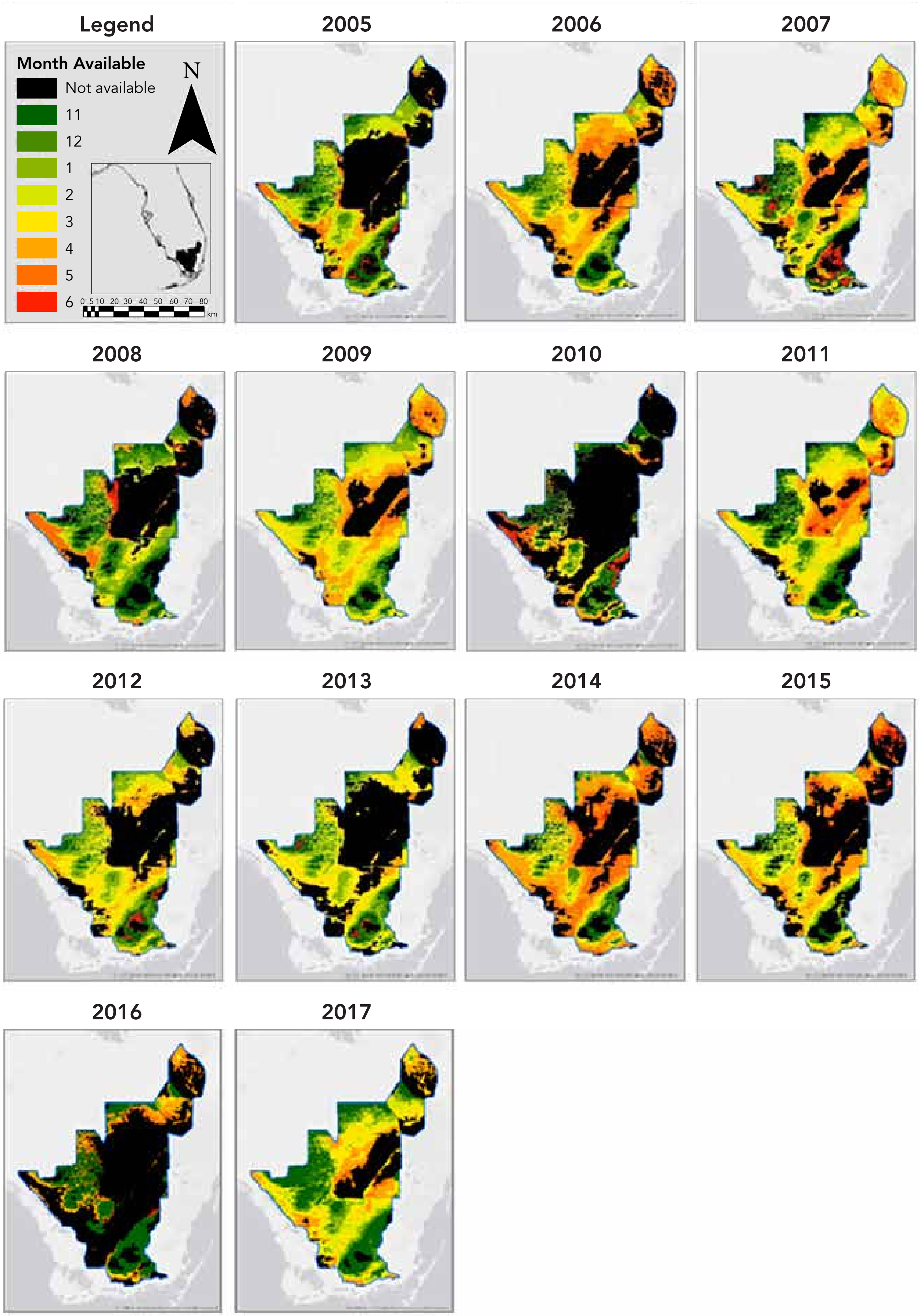


Figure 5.19. Monthly available habitat. Colors indicate the month when habitat became available for wading bird foraging. Black indicates that habitat did not become available. November and December in each map represent previous calendar year.

5.18; Figure 5.19). 2013 had moderate levels of available habitat, prey, and wading bird nesting numbers (Table 5.2).

2014: The 2014 dry season started with relatively high-water levels. Water receded slowly and was interrupted by reversals during much of the dry season (Figure 5.18). Although about 60% of the landscape became available for wading bird foraging, the timing of habitat availability was much later, especially in short hydroperiod regions (Figure 5.19).

2015: Water levels receded slowly in the 2015 dry season and were interrupted by reversals during late April and May (Figure 5.18). Although 57% of the landscape became available for wading bird foraging (Figure 5.19), the timing of habitat availability was later again.

2016: Water levels were exceptionally high during the 2016 dry season. Record breaking amounts of rainfall occurred from November through April averaging nearly 1 foot above average over the entire Everglades system (Figure 5.18). Only 36% of the landscape became available for wading bird foraging, and the timing of habitat availability was earlier but was halted by heavy rainfall in January (Figure 5.19).

2017: Water levels at the start of the 2017 dry season were relatively low, followed by extreme rainfall events from June to July (Figure 5.18). Prey densities were low, however by March 81% of the landscape was available as suitable foraging habitat (Figure 5.19), hence higher wading bird nest abundance (Table 5.2).

Performance Measures: Two dry season prey measures are used to evaluate dry season prey availability for nesting wading birds in the Everglades, the interval between exceptional prey density years and the interval between exceptional densities of large prey (>2 mm; Klassen et al. 2016). These measures are based on the trophic hypothesis where fishes and crustaceans link the hydrologic drivers to wading bird nesting abundance (Trexler & Gross 2009). Wading bird nest abundance in the Everglades is characterized by high interannual variability ranging from years with little nesting to years defined as supranormal nesting (Frederick & Ogden 2001). These supranormal nesting years are facilitated through exceptional availability of dry season aquatic prey (Frederick & Ogden 2001; Gawlik 2002).

To determine if exceptionally high prey density years are occurring at the same frequency as exceptional wading bird nesting years, the interval between years of exceptional nesting for the period of record (1985–2017) was calculated. Exceptional nesting years are based on combined nest counts of great egrets (*Ardea alba*), white ibises (*Eudocimus albus*), wood storks (*Mycteria americana*), snowy egret (*Egretta thula*), tricolored heron (*Egretta tricolor*), and little blue heron (*Egretta caerulea*). Years are categorized as exceptional nesting years if they are in the top 70th percentile of the mean for the period of record (1985–2017; Frederick et al. 2009). To determine if exceptionally high prey density years are occurring at the same frequency as exceptional wading bird nesting years, the interval between years of exceptional prey density for the period of dry season prey on record (2005–2017) was calculated. Exceptional prey densities are calculated by the density of fishes, crayfish, and grass shrimp in 1-m^2 throwtrap samples for the period of record (2005–2017). Years are considered as exceptional when density of these species is 1 standard deviation above the mean for the period of record (2005–2017). This determines if prey densities and high wading bird nesting events are associated.

Results: The mean interval between exceptional nesting events for wading birds over the period of record (1985–2017) is 4.12 ± 0.82. The target interval for exceptional prey density is ≥ 1 standard error below the mean interval for the period of record for nesting events, which is 3.30. The mean interval between exceptional nesting wading bird nesting during the reporting period (2012–2017) was 5.5 ± 0.84 for all prey and 5.5 ± 0.84 for large prey. The score for the performance measures over the reporting period was 60% and thus targets for exceptional prey densities were not met. However, there were only two exceptional nesting years. Prey densities prior to the reporting period (2005–2011) had mean intervals between exceptional prey densities of 0.57. It was during the period where three of the five nesting years were exceptional.

Discussion: Targets set for dry season prey availability were not met as exceptional prey densities were not occurring at the same frequency as exceptional nesting years. This is likely the result of lower initial water levels along with restricted dry-downs in most years. The number of exceptional prey densities declined from

2012–2017 compared to 2005–2011, coinciding with a decrease in exceptional wading bird nest abundance. However, high prey densities are not the only mechanism that increases wading bird nest numbers (Klassen et al. 2016). High initial water levels at the start of the dry season coupled with optimal water level recession rates across a large spatial area may increase the amount of marsh area that becomes available to foraging (Botson et al. 2016; Petersen 2017) and offset poor prey production, thus increasing wading bird nest numbers. The relationship regarding nesting wading birds, aquatic prey densities, and habitat availability differs among years. During the reporting period (2012–2017) habitat availability rather than prey densities had a greater effect on the number of wading bird nests (Figure 5.20). This shifted from 2005–2011 where prey densities rather than habitat availability resulted in great numbers of wading bird nests (Figure 5.20). Klassen et al. (2016) demonstrated that these effects are species specific. Wading birds capable of foraging in larger areas (great egrets, white ibises, and wood storks) benefit from high foraging habitat availability across the landscape versus those that forage locally (little blue herons, snowy egrets, and tricolored herons).

This first quantitative attempt to develop a wading bird food availability performance measure suggests that although system-wide prey densities in foraging pools are related to wading bird nesting, so is the total amount of foraging habitat that becomes available to birds. Results from the model selection analysis shows that timing of high prey concentrations in Everglades National Park occurring later in the breeding season coupled with system-wide foraging habitat availability are important contributors of wading bird nest abundance.

Management Implications: The amount and quality of dry-season prey concentrations, and the spatial and temporal pattern of prey availability across the landscape all can influence wading bird nesting, with the relative contribution of each varying yearly based on hydrologic conditions. Although the highest prey availability occurs when high wet season water levels that promote production are followed by a prolonged recession that generates high concentrations, it is not possible to dry a large portion of the landscape every year and retain large wet areas for long periods of time. It is critical to manage for a large spatial extent with diverse hydropatterns, where long-hydroperiod regions dry-down intermittently. Managing for high water levels at the start of the dry season maximizes the amount of the landscape that is inundated, increasing the spatial extent of foraging habitat that becomes available for breeding wading birds as water levels recede across the landscape.

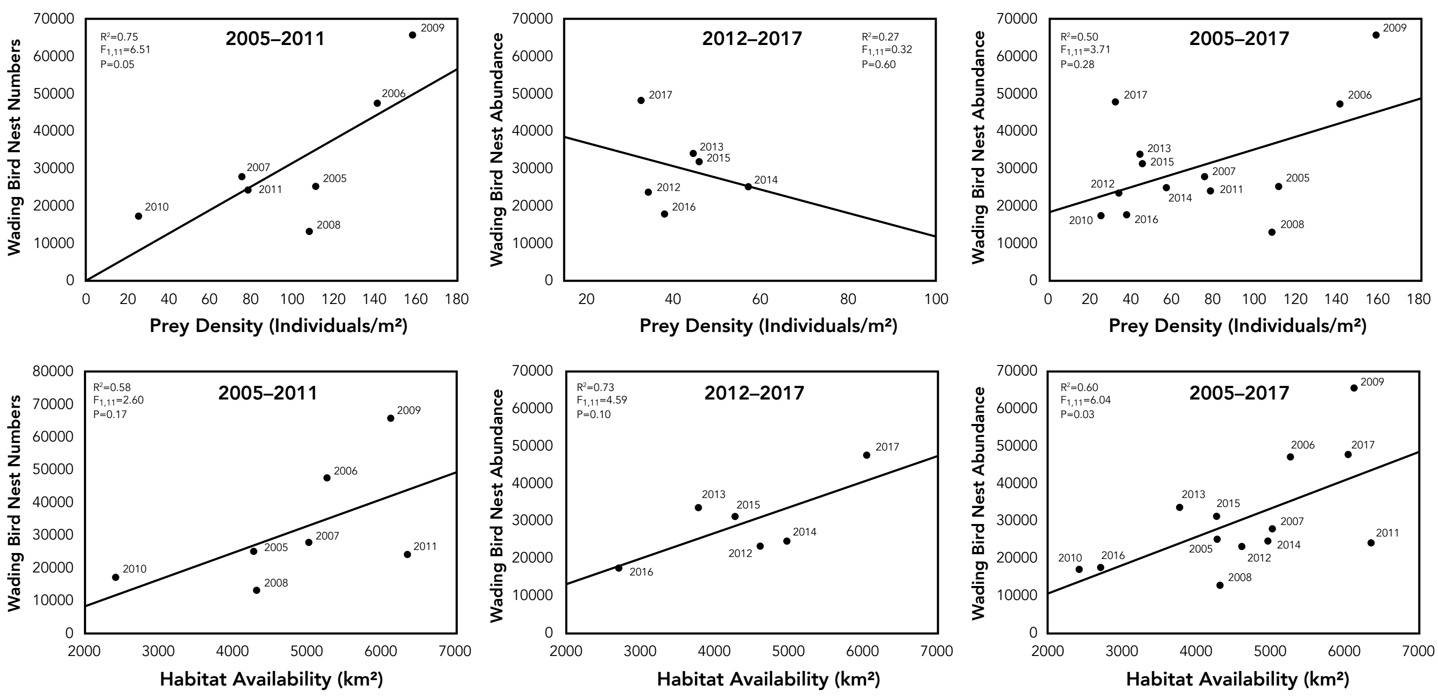


Figure 5.20. Regression plots between (A) mean dry season prey densities and wading bird nest abundance (great egrets, little blue herons, snowy egrets, tricolored herons, white ibis, and wood storks) and (B) available foraging habitat within a nesting year and wading bird nest abundance (great egrets, little blue herons, snowy egrets, tricolored herons, white ibis, and wood storks) within the Everglades, 2005-2017.

NONNATIVE FISH AND WOOD STORK DIETS

The wood stork (*Mycteria americana*) is a high management priority by government agencies throughout the southeastern U.S. and Florida, in particular because of its listed status. In 2014, the wood stork was down-listed to Threatened because its total breeding population size increased. However, this population growth came mostly from an expansion of the birds' breeding range outside Florida (USFWS 2015). Though the Everglades was once the core of U.S. wood stork nesting, the breeding population has not increased to benchmark recovery levels since the 1984 listing (USFWS 2014). The wood stork is also a priority species because it is a key biological indicator in Everglades restoration (Crozier & Gawlik 2003; Frederick et al. 2009).

Wood storks are an apex predator in the Everglades, and their unique feeding-habitat requirements make them sensitive to water levels and changes in their prey populations. Storks require high densities of fish to be produced in the wet season, followed by specific rates of receding water levels during the dry season to distribute prey fishes into shallow pools where the storks can effectively capture them (RECOVER 2005; Frederick et al. 2009). These ecological relationships are documented (Kahl 1964; Kushlan et al. 1975; Ogden et al. 1976; Kushlan 1989; Gawlik 2002) and have been formalized through the development of predictive models that quantify the relationships among hydrological conditions, fish and crayfish that form the prey base, and stork nesting and foraging responses (Beerens et al. 2015; Botson et al. 2016; Petersen 2017). Stork models serve as an evaluation tool for Everglades restoration scenarios and for assessing the ecosystem condition on a real-time basis (Beerens et al. 2015).

As these predictive models were being developed, the south Florida landscape was being invaded by exotic fishes (Kline et al. 2014; Schofield & Loftus 2015). Marshes of the Shark River Slough and Taylor Slough in the southern Everglades are increasingly home to high relative abundance of nonnative fishes (Figure 5.21). At some sites in Everglades National Park, exotic fish species now comprise over 60% of all fish (Kline et al. 2014; unpublished data) and the aerial extent of invasion may be increasing (Figure 5.22). Overlain on this dramatic anthropogenically-driven shift in the aquatic community of south Florida has been a stagnant stork population that is not showing the growth of populations seen in more northern regions, suggesting the possibility that changes to the prey community are limiting the stork population in this region.

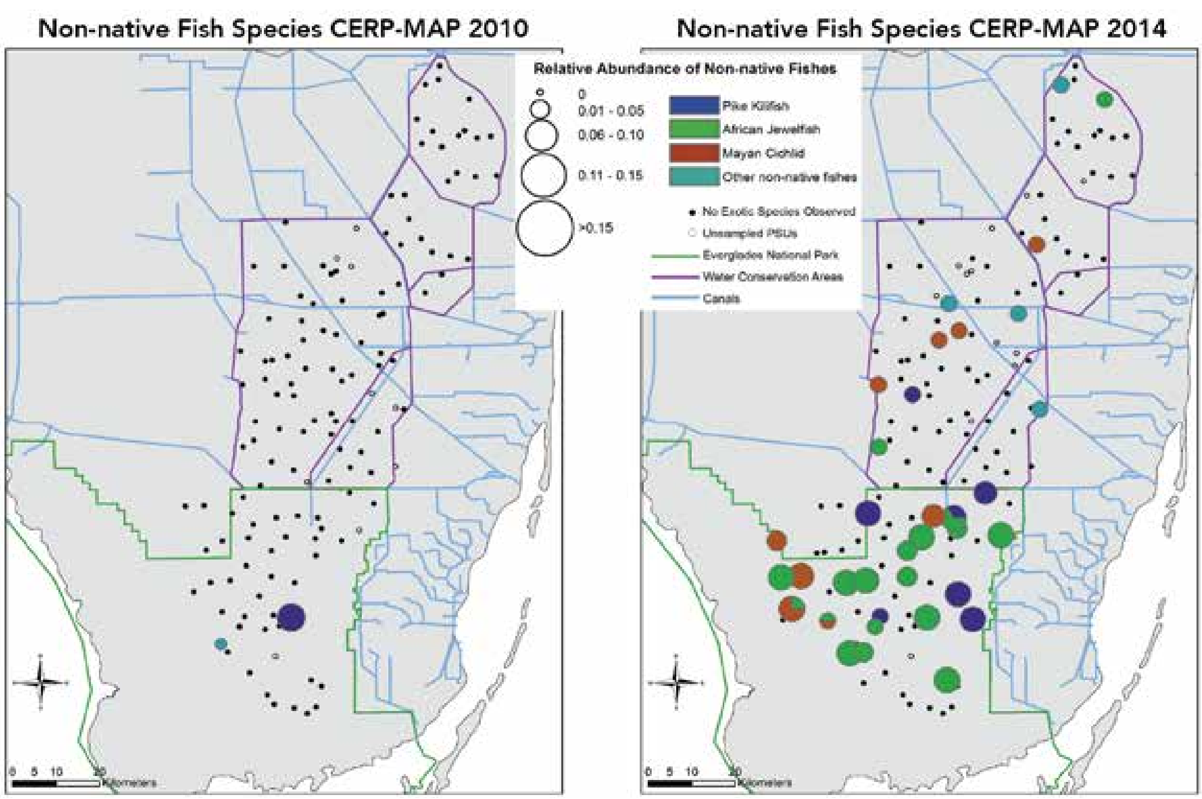


Figure 5.21. Distribution of nonnative fishes in Everglades marshes sampled with throw traps in the wet season of 2010 and 2014.

A three-year study of wood stork diets in the Everglades conducted from 2014–2016 (Evans et al. 2017; Klassen & Gawlik in press) indicated that storks, but not small herons, have switched from consuming primarily native fish in the 1970s (Ogden et al. 1976) to consuming mostly native sunfish (*Lepomis* sp.) and nonnative African Jewelfish (*Hemichromis letourneuxi*) (Figure 5.23). Finding an increasing frequency of nonnative fish in the diet of wood storks was unexpected because nonnative fish are <1% of the fish community in the drying pools in which wading birds forage (Gawlik et al. 2016). In stark contrast, the biomass of marsh fishes in drying pools is a good predictor of small heron nest numbers (Klassen et al. 2016), suggesting that wood storks are responding more quickly than other wading birds to changing aquatic communities of the southern Everglades marsh.

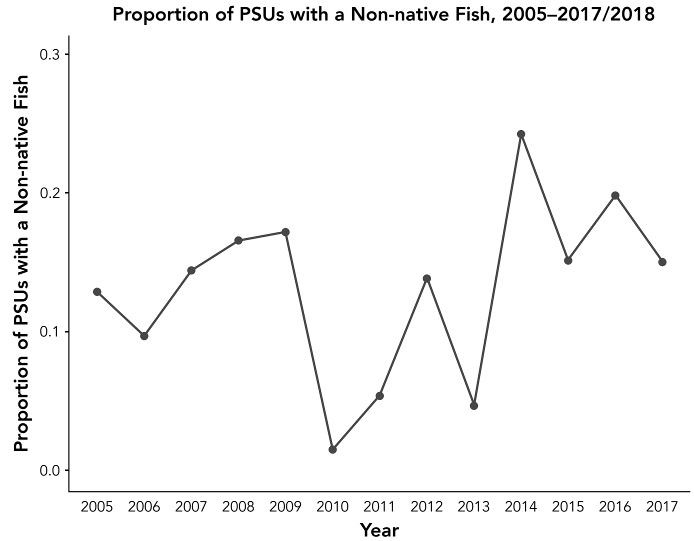


Figure 5.22. Proportion of primary sampling units (PSUs) where nonnative fishes were collected in wet-season samples from 2005 through 2017.

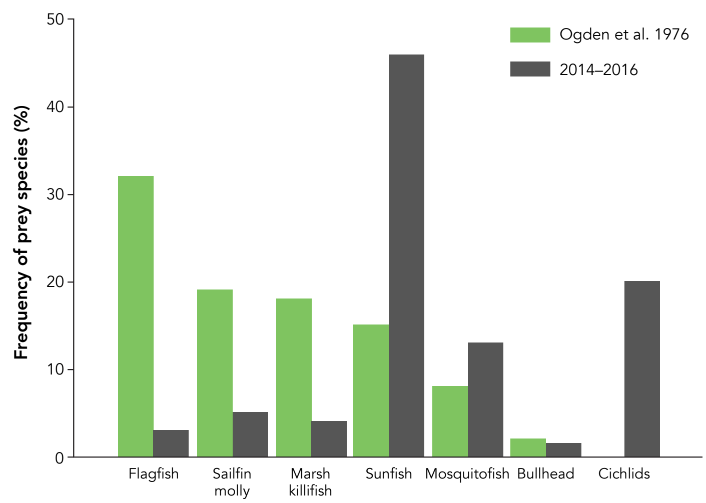


Figure 5.23. Species composition in the diet of wood storks in south Florida from Ogden et al. (1976) and an unpublished study (Evans et al. 2017) from 2014–2016 (n=545).

The reasons for the difference between wood stork and small Heron diets are not known but may have important management consequences. Stork chicks take weeks longer to fledge than small heron chicks, which must occur before the onset of the rainy season when water levels rise (Klassen et al. 2016). Storks overcome this timing constraint by using energetically efficient non-flapping flight to forage over large areas, potentially bringing them into contact with nonnative fish in novel anthropogenic habitats (canals and retention ponds) outside the Everglades marsh. Several new studies show that these anthropogenic habitats are dominated by nonnative cichlids that are more similar to the fish in the diets of storks than are marsh fishes (Klassen 2016; Evans et al. 2017). It is possible that storks have shifted their foraging locations from Everglades' marshes to anthropogenic habitats such as created wetlands, road-way ditches, and retention ponds, but small herons have not.

There is strong evidence that Everglades' wading bird populations are driven by hydrologic conditions that produce, then concentrate, small marsh fishes into drying pools (Gawlik 2002; Botson et al. 2016). But, there is some evidence that cichlids and sunfish may move away from drying pools into deeper refuges before the water is shallow enough to trap them (Trexler 2000; Rehage et al. 2014). Such behavior could also lead to differences in the abundance of native and nonnative fishes between drying sloughs and deeper water microhabitats. If storks were preferentially foraging in or near deeper water microhabitats within the Everglades marsh, it could also lead to an increase in the prevalence of nonnative fish in their diets.

All expectations for food-web response to hydrological restoration assume that the native annual fishes and crustacean communities link basal productivity to iconic apex predators. Stork models have served as an evaluation tool for Everglades restoration scenarios (Beerens et al. 2015) and for assessing the condition of ecosystem health on a real-time basis. Current fish and wading bird predictive models are powerful, but their performance may deteriorate if the historic ecological relationship between annual fishes and wood storks is replaced. On-going monitoring and research on food web ecology linking hydrological management and iconic apex predators must continue to explore these new ecological relationships to assure adaptive management actions guide restoration of the Everglades and to minimize undesirable ecological surprises.

WADING BIRDS

The sustainability of healthy wading bird populations is a primary goal of CERP and other Everglades restoration programs in south Florida, rooted in the Trophic Restoration Hypothesis cluster. Four indicators have been used to gauge progress toward restoration of wading bird populations (Frederick et al. 2009).

Colony Location: It is estimated that more than 90% of the nesting of the indicator species occurred in the southern ecotone region during the pre-drainage period (1930s and early 1940s), in all likelihood because this was the most productive area due to freshwater flows. Movement of birds away from the coast coincided with major flow reductions, and a reversal of this trend is seen as critical evidence of estuarine restoration. The proportion of all nesting birds in the Everglades that are in coastal colonies has shown considerable improvement since the lows of the mid-1990s and early 2000's (2–10%), and since WY2012 has ranged between 12–22% (very poor to poor).

Ratio of visual to tactile foragers: This measure recognizes that the breeding wading bird community has shifted from being numerically dominated by tactile foragers (storks and ibises) during the pre-drainage period to one in which visual foragers such as great egrets are numerically dominant. Short hydroperiod, over-drained marshes tend to support prey species and foraging conditions that favor visual forager species like great egrets. While this measure has shown some improvement since the mid-1990s (movement from 0.66 to 3.5%), the ratio is still an order of magnitude less than the full restoration target (32%). During 2012–2017, the 5-year running average for this measure was 3.31% (very poor).

Timing of Nesting: This parameter applies to the initiation of nesting for wood storks, which has shifted from November–December (1930s–1960s) to January–March (1980s–present). Later nesting increases the risk of mortality of nestlings that have not fledged prior to the onset of the wet season and can make the difference between the south Florida stork population being a source or sink population. While there has been some general movement in the direction of earlier nesting since the consistent February start dates of the 1990s, the five-year running average of this measure was only slight, moving from poor to fair condition.

Exceptionally large ibis aggregations: Occasional exceptionally large breeding aggregations of ibises (>70th percentile in period of record) were characteristic of the pre-drainage system, and are thought to be indicators of the ability of the system to produce large pulses of prey resulting from typical cycles of drought and flood. The 5-year running interval between large ibis nestings has matched or exceeded restoration targets for every year since 2005, and for the past five years was well within restoration range (very good condition).

Discussion: These measures of wading bird nesting suggest that while there have been improvements in several of the measures during the past one or two decades, several key measures are stalled and are not showing further improvement. One measure has been met regularly (interval between exceptional ibis nesting years) and there has been hopeful movement on the proportion of nesting in the coastal zone. However, most measures are not improving or are so far from restoration targets that they remain in poor or very poor conditions. There is little evidence that the timing of nesting for storks is improving on average, and the ratio of tactile to visual foragers remains an order of magnitude below the restoration target. This picture illustrates that ibises are more regularly attracted to nest in large numbers in south Florida. While that shows ecological carrying capacity, it may also be that ibises are simply shifting away from less favorable conditions in other states. The other measures suggest that the system is still not functioning to support restored nesting. While this illustrates an apparent stasis, it should be remembered that full restoration of wading bird populations is predicted only as a result of full restoration of key historical hydropatterns, which has not yet occurred.

ALLIGATORS

In WY17, the value for the current condition of the alligator performance measure relative abundance met the target of >1.70 non-hatchling alligators/km (Hart et al. 2012) in three areas (Water Conservation Area 3A North 41 (WCA3A-N41), WCA3A Holiday Park (WCA3A-HD), and Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR; Figure 5.24). These three areas generally have longer hydroperiods than other areas. The current value of the body condition performance measure (Fulton's K, calculated using snout-vent length and mass) was below the restoration target of 2.27 in all areas (Figure 5.25).

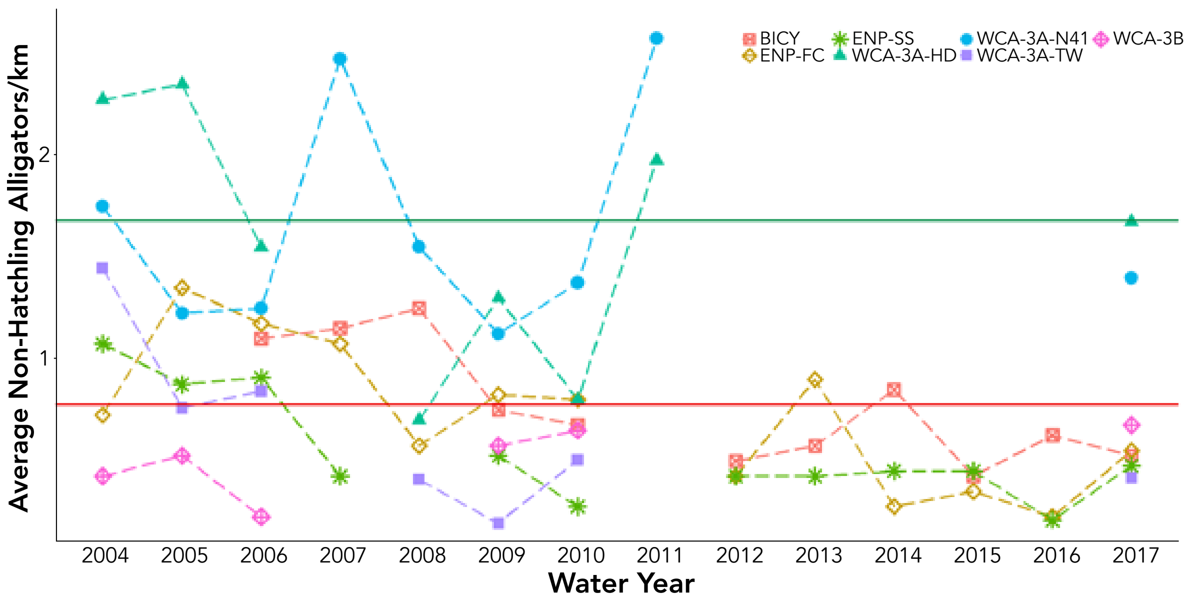


Figure 5.24. Average non-hatchling alligators/km of two spring surveys by water year for areas where alligators are monitored. Top green line indicates restoration target. Bottom red line indicates conditions well below the restoration target. LNWR is not included on the graph because densities are much higher than the other areas (ranging from yearly averages of 3.75–14.95 alligators/km). WCA-3A and 3B were not sampled WY2012–2016 due to lack of funding. Surveys in 2011 were not conducted in the spring because of dry conditions.

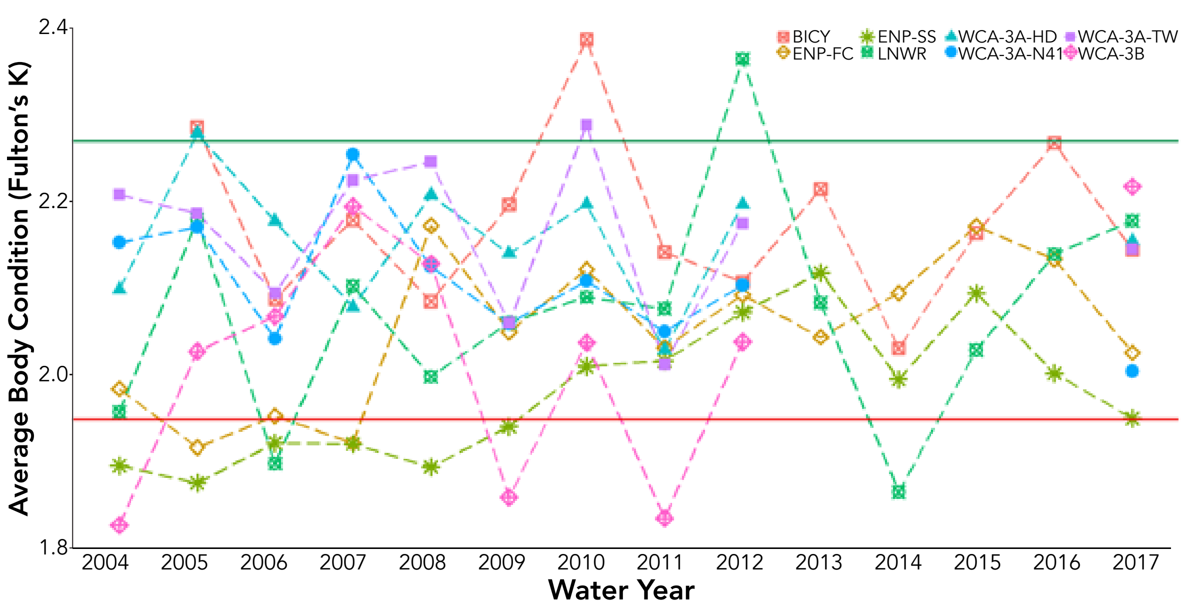


Figure 5.25. Average alligator body condition (Fulton's K) in areas where alligators are monitored. Sampling occurs in Spring and Fall. Top green line indicates restoration target. Bottom red line indicates conditions well below the restoration target. The four sites in WCA3A&B were not sampled WY2012–2016 due to lack of funding.

Relative abundance (past 5 years) and body condition (past 3 years) trends for areas where there are recent data (LNWR, Big Cypress National Preserve (BICY), Everglades National Park Frog City (ENP-FC), ENP Shark River Slough [ENP-SS]) were stable. Trends are a part of the performance measure and the target is to have a stable (if abundance exceeds 1.70 alligators/km or body condition exceeds 2.27 Fulton's K) or increasing trend (Mazzotti et al. 2009; RECOVER 2014b).

An analysis of data from 2000–2014 showed that across seven areas alligator body condition was highest in the early 2000's (Fulton's K 2.20) and was 5-10% lower in 2014 (Brandt et al. 2016). Body condition was positively correlated with range in water depth and fall water depth suggesting that restoring a greater range in annual water depths is important for improvement of alligator body condition.

Mazzotti et al. (2009) hypothesized that alligators will respond to restored hydrological patterns by increasing in size (body condition), number (relative abundance), or both, and that while ecological response may begin quickly it may take about three to five years to become evident. These hypotheses are supported by field studies of alligators in the Everglades. Waddle et al. (2015) found that abundance of alligators decreased in dry years in Arthur R. Marshall Loxahatchee National Wildlife Refuge, and Brandt et al. (2016) found that fluctuations in water level and fall water depth were positively correlated with body condition. Prolonged drought also affects fish abundance in Shark River Slough (Trexler 2012) and this decrease in aquatic productivity corresponded to areas where there was a decrease in alligator body condition in Shark River Slough (Brandt et al. 2016). Alligator body condition and relative abundance should respond positively (increase) in areas where restoration projects restore multi-year hydroperiods and more natural fluctuations in water depths.

INVASIVE REPTILES

Burmese pythons (*Python bivittatus*), northern African pythons (*Python sebae*), Argentine black and white tegus (*Salvator merianae*), Nile monitors (*Varanus niloticus*), and spectacled caiman (*Caiman crocodilus*) were selected as performance measures (PMs) for invasive reptiles in the Greater Everglades based on presence in the Greater Everglades ecosystem, relevance as targets of interagency management efforts, and existence of adequate information for scoring. Each PM was scored based on three metrics: abundance, spread, and impacts. The primary data source was EDDMapS (https://www.eddmaps.org/florida/Species/) data on distribution and occurrence, supplemented with data from the Everglades Invasive Reptile and Amphibian Monitoring Program, the Florida Fish and Wildlife Conservation Commission, and professional judgment. Scores for each PM were totaled and assigned a stoplight color and grade. PM scores were summed into a Greater Everglades score. Water Years were used for analysis. The desired condition for each metric is as follows: decreasing abundance and spread leading to absence, and minimal to no impacts.

PMs for invasive reptiles did not meet desired conditions for WY17 (Table 5.3). Three of the PMs (Burmese pythons, Nile monitors, and spectacled caiman) were scored as increasing and four of the PMs (Burmese pythons, Nile monitors, Argentine black and white tegus, and spectacled caiman) were scored as expanding. Impacts have been established for 2 PMs (Burmese pythons and Argentine black and white tegus).

PMs for invasive reptiles have not met desired conditions for any year going back to WY12 (Table 5.3). Failing scores for Burmese pythons and Argentine black and white tegus along with poor scores for Nile monitors were largely responsible for failure to meet desired conditions (Table 5.3).

Burmese pythons continue to increase in number and expand in area occupied. Recent efforts by the Florida Fish and Wildlife Conservation Commission and the South Florida Water Management District to compensate skilled python catchers has resulted in an increased rate of removal of Burmese pythons, but there is no evidence that this increased rate of removal is impacting numbers or spread of pythons.

Northern African pythons are infrequently sighted and appear to be confined to the Bird Drive basin. No northern African pythons have been sighted during deliberate search efforts by humans, detector dogs, or through the placement of refuges. Sign of their presence such as tracks and dog alerts have occurred.

Argentine black and white tegus may be showing a response to interagency management efforts. After five years of increasing number removed from their core area in southern Miami-Dade County, fewer and smaller Argentine black and white tegus were captured in WY17. Trapping continues in the core area.

Nile monitor removals from the C-51 basin have been increasing concomitant with an increase in effort to remove them. Removals have also expanded from the C-51 canal to the adjacent E-2 canal. Nile monitors also continue to be reported from Broward and Miami-Dade counties.

Spectacled caiman removal has continued to increase as well as locations where caimans have been observed and removed. Most caimans are located in southeastern Miami-Dade County near the Biscayne Bay Coastal Wetlands project area. New locations for caimans include western Miami-Dade County near Northeast Shark River Slough in Everglades National Park and Holiday Park in Broward County.

CERP projects are neither designed nor managed to affect any species of invasive wildlife, including invasive reptiles. This contrasts with invasive plants where CERP projects are managed to limit their occurrence and spread. Management efforts for invasive reptiles are ad hoc responding to individual species and specific locations. Management efforts that are proactive, deliberate, and systematic may affect invasive reptiles. Making invasive reptile management part of CERP projects would help address this issue.

Invasive reptiles' PMs focus on species that are already present in the Greater Everglades and with limited opportunities for extirpation. New invasive reptile species also pose a threat and provide an opportunity for eradication if detected early and responded to rapidly while their presence is small and localized (SFERTF 2015). Making early detection and rapid response (EDRR) part of invasive reptile management plans will help address this issue. Presence of new species will become a PM in the next iteration of the SSR. Prognosis for invasive reptiles in the Greater Everglades is uncertain. However, without EDRR and proactive management efforts for invasive reptiles as part of individual CERP projects, the prognosis is not encouraging.

Table 5.3. Water Year (WY) scores for invasive reptile performance measures in the Greater Everglades (color/score). Lower scores mean higher amounts of invasive reptiles. Yellow indicates a moderate score. Red indicates a poor score. BP = Burmese python, NAP = northern African python, ABWT = Argentine black and white tegu, NM = Nile monitor, and SC = spectacled caiman. Species scores are summed into a regional score (GE).

Species	WY12	WY13	WY14	WY15	WY16	WY17
BP						
NAP						
ABWT						
NM						
SC						
GE						

5.4 DISCUSSION

The Greater Everglades encompasses a mosaic of inter-connected freshwater wetlands located south of Lake Okeechobee. These wetlands play a critical role in the regional hydrology of collecting and storing water from Lake Okeechobee and rainfall, and channeling this water into the coastal estuarine ecosystems, cities, and towns along Florida's southern coasts. However, a century of drainage for urban and agricultural development has reduced the extent of these wetlands by about half. The reduced capacity to store rainfall makes the entire region more vulnerable to the hydrologic extremes of flood and drought. Getting the water right means restoring historic flow patterns by removing artificial barriers that subdivide the wetlands and increasing the flow of water south from the Everglades Agricultural Area and into Florida Bay and the southwest coast. Some progress has been made. The 1-mile Tamiami Trail Bridge and the C-111 Spreader Canal Western Project distribute water more naturally, as sheet flow in the Shark River and Taylor Sloughs, improving hydrological conditions in Everglades National Park.

Landscape patterns

Spatial patterning and topographic relief of ridges and sloughs are directly related to the volume, timing, and distribution of sheet flow and related water depth patterns, which drive processes of sediment accretion and loss. Water depth patterns have altered vegetation communities causing ridges to invade marsh areas (SCT 2003; Ogden 2005), sloughs to be usurped by wet prairie and ridge (Davis & Ogden 1994; Olmsted & Armentano 1997; Richards et al. 2011), and loss of tree islands (Sklar et al. 2004; Ogden 2005). Remaining ridges have lost rigidity, structure, directionality (Wu et al. 2006; Larsen et al. 2007; Watts et al. 2010), and elevation (Watts et al. 2010; McVoy et al. 2011). The mechanisms of ridge and slough maintenance are not fully understood, but the processes are likely complex with several mechanisms operating together (RECOVER 2014a).

The importance of oligotrophy to all aspects of Everglades ecology emphasizes the need to restore and maintain low nutrient conditions. Nutrient enrichment, by phosphorus in particular, has had a large impact on the GE and has led to the dramatic expansion of *Typha* species (Davis & Ogden 1994). Periphyton communities respond very rapidly to hydrology and water quality and can expose ecological ramifications of restorative or deconstructive changes associated with nutrient concentrations, hydroperiod and water depth patterns (Gaiser 2009). Periphyton communities dominate primary production in the GE and therefore contribute to soil production, ecosystem metabolism, and secondary production as well as the composition of dependent communities (Gaiser 2009).

Hydrologic patterns

The annual rainfall amounts and distributions leading to mean annual depths in the three Water Conservation Areas (WCAs) and Everglades National Park (ENP) during WY12-17 were average, with only WY15 and WY17 below the historic average amount, 89% and 93% respectively. When comparing precipitation amounts among basins, the WCAs generally received a higher percentage of the annual totals compared to the long-term average than ENP. Over this period of record, the WCAs received 103% of the historic average amount while ENP received 93% (SFER 13-18).

Hydropatterns over the past five and a half water years are related to historic averages, flooding tolerances for tree islands, and drought tolerances for wetland peat. Tree island inundation tolerances are considered exceeded when depths on the islands are above 2.0 or 2.5 feet, depending on the height of the tree islands, for longer than 120 days (Wu & Sklar 2002). The ground elevations denoted as red dashed lines in the figures indicate the threshold for peat conservation. When water levels are more than one foot below ground for more than 30 days, the drought tolerance of peat is considered exceeded according to the criterion for the Everglades MFL (SFWMD 2014), but peat may be lost at shallower water levels.

Water Conservation Area 1: Arthur R. Marshall Loxahatchee National Wildlife Refuge
Water depths in WCA-1 are routinely deeper than the historic median, and in four of the water years the depths exceeded the stage threshold that indicates stress to tree islands. However, depths rarely approached the low levels that elicit concern for peat soil development (Figure 5.26).

Water Conservation Areas 2A and 2B
Average water stages in WCA-2A during WY12-17 were generally lower than the historical average, with only WY14 exceeding the historical average. The few remaining tree islands within WCA-2A routinely experience flooding stress and the depth threshold indicating stress was exceeded in WYs 12-17. Depths rarely fell to the level of concern for over-drying of the peat soils. During WY15 stages dropped low enough to elicit concern for peat soil conservation (Figure 5.27).

Water Conservation Area 3A
Water levels in northeastern WCA-3A (Gage 63) exceeded the threshold indicating stress to tree islands during WY12-17 in each of the wet seasons and fell below levels that are a concern for peat conservation three times. The hydrologic pattern in central WCA-3A (Gage 64) was generally the same, except stages were closer to the historic average and exceeded the threshold for tree island flooding four times, while not falling to levels that threaten peat conservation (Figure 5.28).

Water Conservation Area 3B
The WY12-17 average stages in WCA-3B generally followed the historical average, only exceeding the tree island flooding threshold in WY18, and did not fall below the lower tolerance for protecting peat soils (Figure 5.29).

Tree islands

Restoration of degraded tree islands and protection of intact islands are among the goals for restoration of the central Everglades. Current restoration plans of the CEPP predict changes in water depth over extensive portions of the Everglades where large numbers of tree islands are embedded in the ridge and slough landscape. The primary objective of the tree island program is to evaluate the topographic differences across a broad spectrum of tree islands in the Central Everglades and to link these differences with current as well as potential future hydrologic scenarios in order to assess the feasibility of predicting the effects of proposed hydrologic changes on tree island spatial extent. A secondary objective is to determine how these changes may impact plant species composition on tree islands in the future.

Extensive and prolonged flooding of tree islands is observed in areas where surface water flow is impeded by levees, and prolonged dry-downs occurred frequently in areas that have been cut off from surface water flow. Current water management practices tend to cause pooling at the southern boundary of both WCA-3A and 3B. If the amount of standing water increases in either of these areas, the southernmost tree islands, which have the lowest heights within the region, may suffer adverse effects from flooding. Therefore, increasing water inflow to the WCA's will have to be accompanied by a concomitant increase in downstream outflow. To accomplish this, future restoration activities must include removal of the constructed barriers to flow that create the potential for ponding within both WCA-3A and WCA-3B.

5.5 RESTORATION

GOALS AND ACTIONS

Overarching restoration goals for the Everglades include improving the volume, quality, timing, and distribution of water throughout south Florida. This section summarizes current CERP projects and water control operations in the GE, and it provides an account of future projects and operations and the ecological benefits anticipated.

Broward County water preserve areas

The Broward County Water Preserve Areas project was authorized by Congress in the 2014 Water Resources Reform and Development Act. It aims to (1) reduce seepage loss from WCA-3 to the C-9 and C-11 basins and (2) capture, store, and distribute surface water runoff from the Western C-11 Basin. Capturing surface water from these basins will reduce discharges into WCA-3, reducing nutrient loading into the natural system. Additional project functions include maintaining the existing level of service for flood mitigation, groundwater

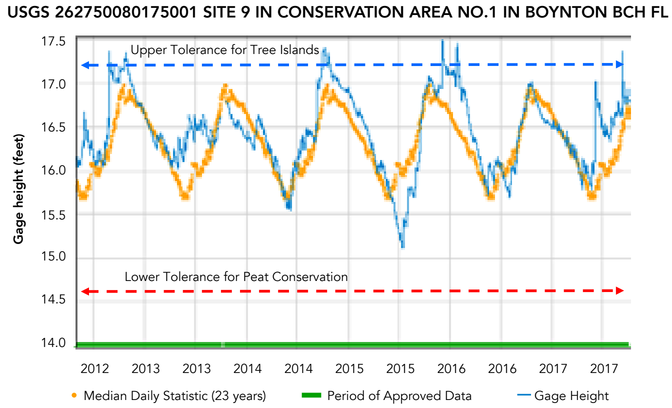
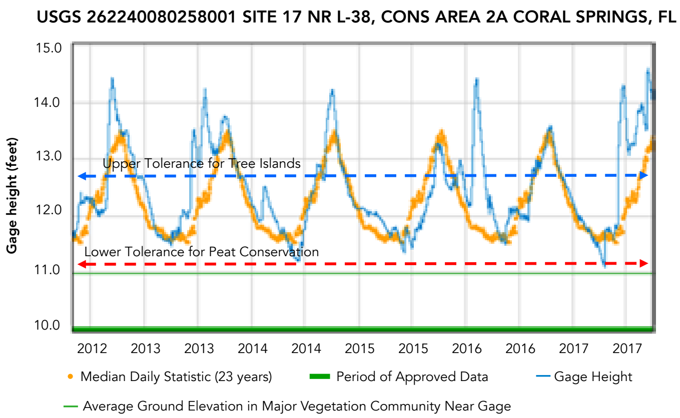


Figure 5.26. Hydropatterns for a site representative of WCA-1.



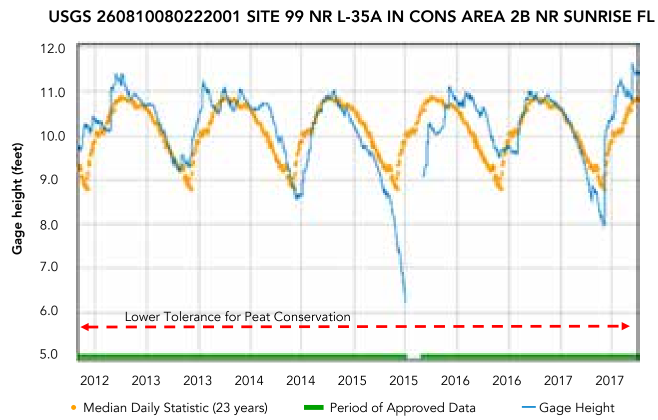
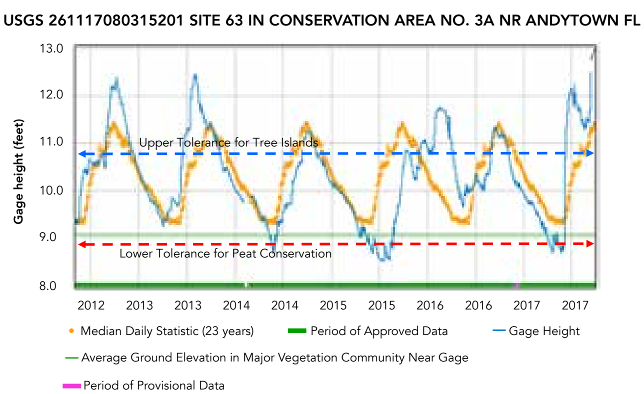


Figure 5.27. Hydropatterns for sites representative of WCA-2A (left) and WCA-2B (right).



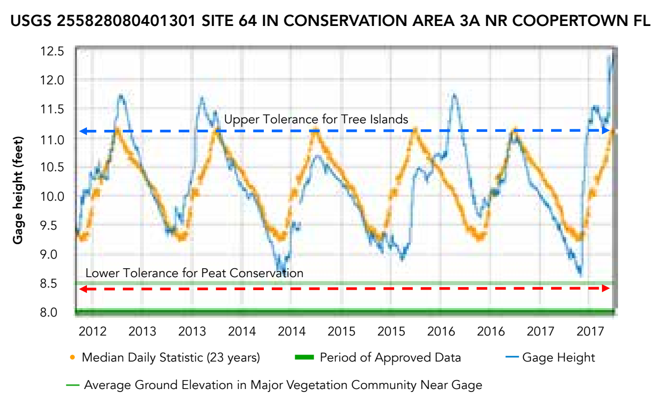


Figure 5.28. Hydropatterns for Gages 63 (left) and 64 (right) in WCA-3A.

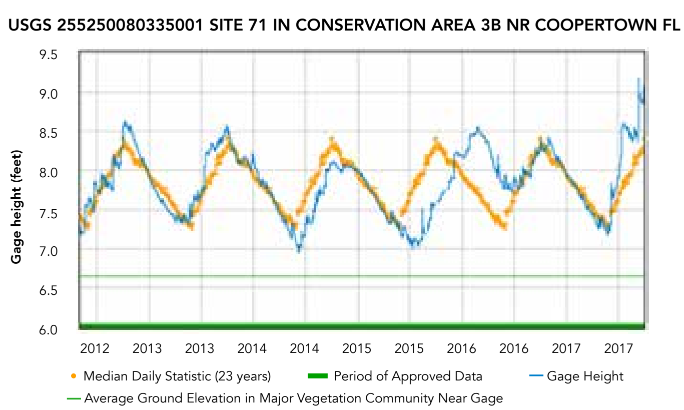


Figure 5.29. Hydropatterns for a site representative of WCA-3B.

recharge, increasing the spatial extent of wetlands, and improving hydroperiods and hydropatterns in WCA-3A/3B (Figure 5.30, USACE 2012).

The initial construction contract for the Northern Mitigation Area A Berm of the C-11 impoundment component was awarded in September 2017. Ecological benefits are expected to be realized once the remaining components are constructed and operating. Construction of the remaining components are pending congressional funding.

Figure 5.30. Map of the Broward County Water Preserve Areas project.

Everglades Restoration Transition Plan

The Everglades Restoration Transition Plan (ERTP) was implemented in October 2012 through the Water Control Plan for WCA-3A, ENP, and the South Dade Conveyance System. ERTP is a modification of the Interim Operational Plan (IOP) and includes operational flexibilities to provide further hydrological improvements amenable to multiple listed species. The ERTP integrates new information consisting of current climatological, hydrological and species conditions, performance measures, and ecological targets, along with closure periods on the S12A-B structures to maintain nesting conditions for the Cape Sable Seaside Sparrow.

The completion of restoration projects, such as the Modified Water Deliveries and C-111 South Dade projects, will enable operations to be refined further as part of the Combined Operational Plan (COP) (USACE 2010, USACE 2011). See Figure 2.18 for map of the ERTP project area.

OTHER PLANS AND PROJECTS

Combined Operational Plan

The Combined Operational Plan (COP) is expected to be implemented in May 2020. It will provide the optimal balance between restoration and operational benefits for the southern Everglades by defining operations for the constructed features of the Modified Water Deliveries and Canal-111 South Dade projects, while maintaining the Congressionally-authorized multiple purposes of the Central and Southern Florida Project (C&SF). The COP objectives include:

- Improve water deliveries (timing, location, volume) into ENP and restore natural hydrologic conditions in ENP given current and future (to the extent practicable) C&SF infrastructure.
- Maximize progress toward restoring historic hydrologic conditions in SRS, Taylor Slough, the Rocky Glades, and the eastern panhandle of ENP.
- Protect the intrinsic ecological values associated with WCA-3A, SRS, and ENP.
- Minimize the damaging freshwater flows to Manatee Bay/Barnes Sound through the S197 structure and increase flows through Taylor Slough and coastal creeks (USACE 2016a, USACE 2016b, USACE 2017b).

Central Everglades Planning Project (CEPP)—Planning Partnership Agreement South

The CEPP Planning Partnership Agreement South (PPA South) is composed of several projects in the CEPP that include those south of Alligator Alley/I-75. The USACE and the SFWMD will be kicking off further planning and design of these features over the summer 2018. PPA South is intended to remove barriers to sheetflow in the southern part of the greater Everglades and enhance the ability to rehydrate NE Shark River Slough in Everglades National Park. Construction of the project's components is to be staggered from 2022 through 2030. One element of the project, removal of Old Tamiami Trail, is slated for "deconstruction" in the fall 2018. Removal of approximately 5.5 miles of old roadway, which acts as a barrier to sheetflow, will eliminate point source discharges into the western side of Shark River Slough and allow flow to return to the marsh more naturally.


Sunset on the waves in Everglades City. Photo credit: John Getchel.

Southern Coastal Systems

6.1 INTRODUCTION

The Southern Coastal Systems encompasses a large ecologically and economically important area along the coasts of south Florida. The loss of freshwater wetlands upstream and increasing control over the regional hydrology for flood protection and societal water supply have decreased the inflow of freshwater into the Southern Coastal Systems. This has altered salinity in the shallow coastal waters and degraded habitat for valuable estuarine fish and wildlife. "Getting the water right" means restoring freshwater flows into coastal wetlands and downstream estuarine and coastal waters. Reestablishing more natural flows is important for building resilience in the face of climate change and accelerating sea level rise. Progress has been made by projects such as the C-111 Spreader Canal Western Project, the Biscayne Bay Coastal Wetlands Project, and the Picayune Strand Restoration Project which provide measurable benefits in wetlands upstream from the coast. However, critical components of these projects, and implementation of the Central Everglades Planning Project, remain to be completed before the full benefits to estuarine areas can be realized.

The Southern Coastal Systems (SCS) region of CERP is a contiguous network of coastal wetlands and estuaries that wraps around the southern end of the Florida peninsula from Biscayne Bay on the southeastern coast to the Ten Thousand Islands area on the Upper Southwest Coast, and includes Florida Bay and the Lower Southwest Coast (Figure 6.1). The SCS is one of the most ecologically and economically important regions in the state of Florida. Over the past century, water management practices and agriculture/urban development have disrupted the availability, timing, and distribution of fresh water to the SCS, which has significantly altered the structure and function of these ecosystems. An objective of restoration is to restore and sustain the highly productive estuaries and adjacent coastal wetlands of the SCS via the restoration of freshwater flows to the extent practical. Reestablishing more natural flows will restore estuarine salinity conditions, resulting in improved habitat for fish and wildlife resources. An abbreviated background of SCS key features, threats, stressors, desired conditions, and indicators are provided below. For more complete background information, see the 2009 and 2014 System Status Reports (RECOVER 2010, RECOVER 2014a).

The estuaries of the SCS are generally shallow and well-mixed; however, there are distinct geomorphological differences between the four SCS sub-regions. Biscayne Bay is a coastal lagoon with its southern and northern regions isolated from the open Atlantic waters by a series of barrier islands. Circulation within the bay is mainly wind-driven and relatively uninhibited by topographic features except for two banks in the southern

part of the bay. Florida Bay, located at the southern tip of the Florida peninsula, is characterized by a mosaic of mostly submerged mud banks, basins, and small islands. Circulation is complex with tidal influences significantly dampened in the interior of the bay by the Florida Keys and the Bay's internal mud banks. These features isolate this interior region from the Gulf of Mexico and Atlantic Ocean. The Lower Southwest Coast sub-region extends from Cape Sable to Lostman's River and it is more riverine in nature, with major rivers and sloughs conveying freshwater from the Everglades to the relatively unprotected coast. The Upper Southwest Coast, extending from Lostman's River north through the Ten Thousand Islands, is characterized by a smaller system of rivers and creeks that convey freshwater from upstream to a coastal area dotted with thousands of islands and embayments, resulting in a more complex estuarine circulation than the Lower Southwest Coast.

The ecological resources of the SCS are rich and diverse. Vast seagrass meadows are found in Biscayne Bay and Florida Bay, and various sponge species contribute significantly to Florida Bay's benthic habitat. The seagrass and sponge habitats support fish and wildlife including commercially important spiny lobsters, stone crabs, and juvenile pink shrimp. They also provide important habitat for recreationally important finfish species, such as spotted seatrout, gray snapper, and common snook. The upper and lower southwest coastal sub-regions are known more for their oyster reefs, which provide habitat for invertebrate and fish communities. The coastal wetlands in the SCS include the largest spatial extent of mangrove forests in the United States, and large expanses of graminoid marsh. These vegetation communities provide vital nursery and forage habitat for fish and wading birds. All four sub-regions support numerous imperiled species including the West Indian manatee, American crocodile, roseate spoonbill, and several species of sea turtles.

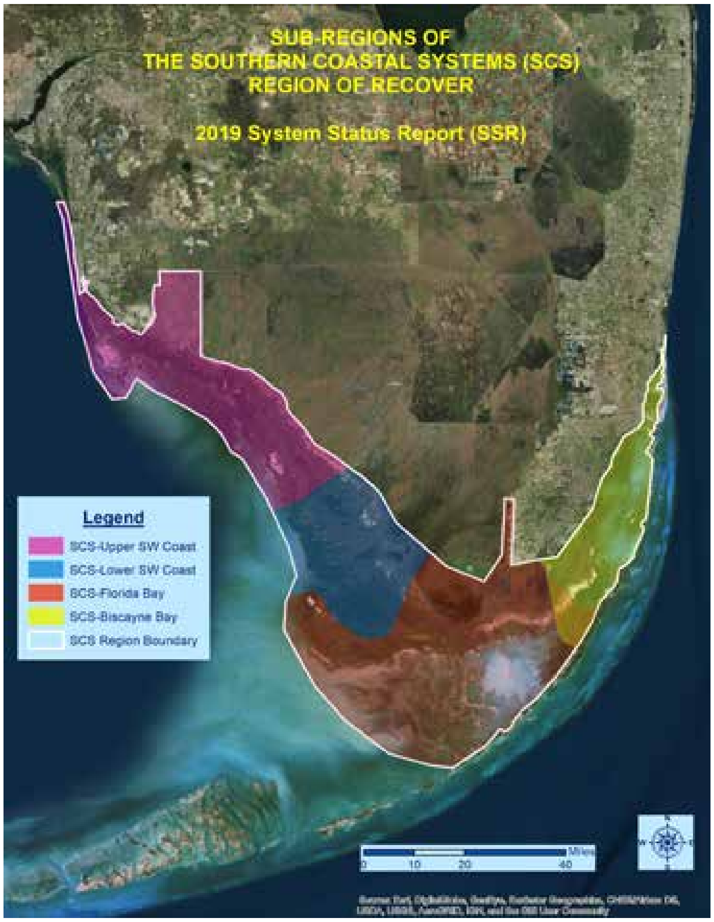


Figure 6.1. Map of Southern Coastal Systems showing the approximate delineations of its 4 sub-regions.

Beginning around the early 20th century, the hydrology of south Florida was dramatically changed as the result of agricultural and urban development and enhanced flood protection. In Biscayne Bay, the result is reduced spatial extent of coastal graminoid marshes and mesohaline conditions along the western shore, which has decreased the diversity and abundance of native flora and fauna. In Florida Bay, seagrass die-offs and phytoplankton blooms since the 1980s have been attributed to long-term changes in the salinity regime driven by water management and nutrient loading. Large-scale sponge die-offs and reduced abundance of gamefish such as spotted seatrout are attributed to reduced freshwater flow to Florida Bay. Along the upper southwest coast, reduced flows to the coast have affected the health, density, and distribution of eastern oysters and their associated communities. Point source discharges from conveyance canals to the estuaries also cause rapid, high-frequency fluctuations in salinity that is harmful to the benthos. This is especially apparent in Biscayne Bay, but also occurs in Florida Bay and the upper southwest coast. Lastly, climate change and sea level rise are affecting the SCS and those impacts will likely accelerate in the future. Sea level rise (SLR) is of particular concern and studies have tied SLR to expansion of mangrove territories 3.3 km inland since the 1940s. The effects of SLR may also prevent restoration efforts to reduce salinity in nearshore areas.

To assess the current and recent status of the SCS, a variety of ecological indicators are used. Salinity is perhaps the most important indicator as it is the primary physical parameter affected by CERP in the estuaries of the SCS. Most other indicators, such as the mangrove fish community, epifauna, seagrass, prey fish, American crocodiles, and roseate spoonbills are closely linked to salinity. The current salinity regime in the SCS creates significant stress on its inhabitants via hypersaline events, changes in salinity regimes in areas with reduced freshwater discharge, and rapid reductions in salinity due to pulsed freshwater flows from canals. As a result, the current nearshore biotic communities differ from historic communities.

One of the primary restoration goals for the SCS is to reestablish an estuarine salinity gradient from nearshore to offshore by returning to a diffuse and more natural runoff pattern. The restored system should eliminate the extreme variability of freshwater surface flows to the coast, reestablish a more natural groundwater flow, and provide more stable and persistent mesohaline salinity in nearshore waters. Accomplishing these salinity goals is expected to allow biota to return to a more natural species composition, distribution, and abundance. Moreover, decreasing the intensity, duration, frequency, and spatial extent of high salinity events should allow for a more productive upper trophic level biotic community. Alleviating harmful high salinity events should increase the abundance of important species like spotted seatrout.

6.2 KEY FINDINGS

The Southern Coastal Systems is one of the most ecologically and economically important regions in the state of Florida. Over the past century, water management practices and agriculture/urban development have disrupted the availability, timing, and distribution of fresh water to the SCS. This significantly altered the structure and function of these ecosystems. During this reporting period (2012–2017), the continued inconsistent delivery of freshwater combined with periods of significant drought, hurricanes and sea level rise, have continued to impact the ecological indicators of the SCS.

Overall, the Southern Coastal Systems regions are in poor to fair condition (Figure 6.2). Reduced freshwater flow combined with sea level rise has resulted in increased salinity throughout the region. Elevated salinity, due to a local drought in 2014 and 2015, negatively impacted crocodiles, gulf pipefish, and submerged aquatic vegetation (SAV) in Biscayne Bay and Florida Bay. Spoonbill nesting, prey community, and

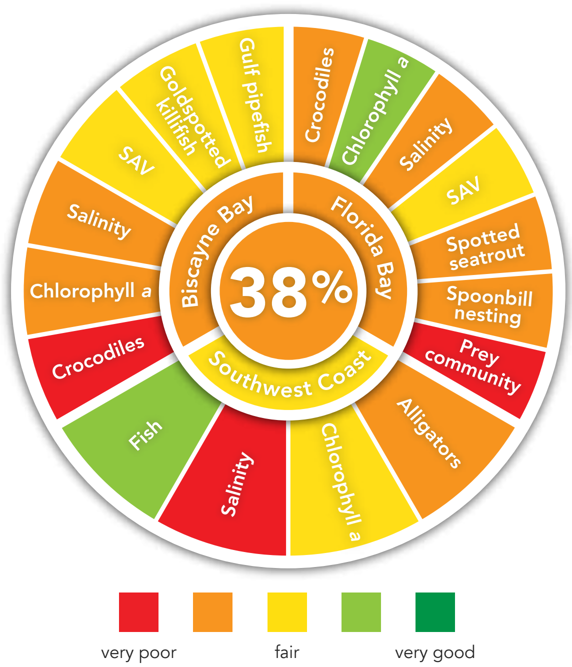


Figure 6.2. Scores from the 2012–2017 Everglades Report Card.

spotted seatrout are in poor to very poor condition, due to a prey base shift from high salinities. Gold spotted killifish, gulf pipefish, and fish in the Southwest Coast region were in fair to good condition because of the channelization of water flow and pulsed discharges. To improve the ecological processes and overall health of the Southern Coastal Systems region, restoration of freshwater flow will need to continue in the years to come.

- Salinity throughout Florida Bay continues to remain high regardless of season. The lack of freshwater flow to Florida Bay, combined with sea level rise, has resulted in a prey base shift composed of fewer freshwater species.
- Salinity in the Upper Southwest Coast sub-region remains spatially variable due to the channelization of water flow in the region resulting in continued pulse discharges.
- Submerged aquatic vegetation (SAV) loss combined with increased levels of chlorophyll *a*, total phosphorus, and total nitrogen suggest SAV recovery will be limited and could decline in northern Biscayne Bay, Barnes Sound, and Manatee Bay.
- Coincident with high rainfall amounts, eight years of low spotted seatrout population numbers in Florida Bay were broken in 2016 and 2017.
- Roseate spoonbill nesting effort ranged from 21% to 27% of target effort in Florida Bay with the number of nests producing a minimum of one chick declining between WY2013 and WY2017.
- Due to increasing salinity in nearshore and estuarine areas, American crocodiles have been observed further upstream in the Shark River Estuary and alligator health is declining along the southwest coast of the SCS. Both are likely due to abnormally high salinities from a lack of freshwater flow.

6.3 INDICATORS

All indicators used in the SCS region are provided in Table 6.1. Included in the table are the data type used in the analysis and the sub-regions to which the indicator applies.

Table 6.1. Indicators used in the SCS.

Indicator	Data type	Relevant sub-region
Salinity	Concentration (PPT)	All sub-regions
Epifauna (gulf pipefish)	Abundance, frequency of occurrence, density	Biscayne Bay
Mangrove fish (gold-spotted killifish, yellowfun majorra, gray snapper)	Frequency of occurrence, density	Biscayne Bay
Submerged aquatic vegetation (SAV)	Species occurrence, cover, density	Biscayne Bay, Florida Bay
Algae bloom/Chlorophyll *a*/Algae blooms	Concentration (µg/L)	All sub-regions
American crocodiles	Juvenile growth and survival	Biscayne Bay, Florida Bay
Creek and river flow	Volume (acre-feet)	Florida Bay, Southwest Coast
Sportfish (spotted seatrout)	Frequency of occurrence, density	Florida Bay
Roseate spoonbills	Number of nests, location of nests, nest production and success, prey fish community	Florida Bay
Fish	Catch per unit effort	Southwest Coast
American alligators	Relative density and body condition	Southwest Coast

BISCAYNE BAY

INTEGRATED BISCAYNE BAY ECOLOGICAL ASSESSMENT AND MANAGEMENT INDICATORS

The project IBBEAM (Integrated Biscayne Bay Ecological Assessment and Management) is located along coastal wetlands on the downstream shoreline of the Biscayne Bay Coastal Wetlands Project (BBCW). The BBCW plan is for a series of culverts, pumps, and associated wetlands to redirect, into the wetlands, part of the fresh water that would ordinarily enter the bay through canals. Water directed to wetlands will flow into the bay and reestablish the connection of the wetlands to the bay. Some BBCW components are already built. A stated regional and project-level objective of CERP and BBCW is to establish a mesohaline community of fish and invertebrates in Biscayne Bay's nearshore waters adjacent to the rehydrated wetlands.

IBBEAM is part of the monitoring and assessment network of RECOVER and was designed to assess effects on the nearshore Biscayne Bay of both region-wide CERP and its bayside component. IBBEAM is presently focused on salinity, the main environmental indicator that can be influenced by CERP, and biological indicators that can be influenced by salinity representing SAV, the epifauna community, and the mangrove fish community. IBBEAM includes continuous monitoring (every 15 min) of salinity, temperature, and conductivity at 17 sites and sampling epifauna and mangrove fish twice annually at 47 or more locations (Figure 6.3).

Salinity

Salinity is among the most important abiotic variables and substantial effort is devoted to its measurement, monitoring, and analysis. In Biscayne Bay, the main emphasis is on 17 nearshore sampling stations (Figure 6.3), each equipped with multi-probe water quality instruments that log salinity every 15 minutes. These data have been analyzed to yield a suite of "salinity regime metrics" that are indicative of the ecological status and trajectory of the Bay's southwestern shoreline and adjacent habitats. An important focus is the quantity and duration of salinity observations that are "mesohaline" (between 5 to 18 ppt). Several lines of evidence suggest that mesohaline conditions prevailed along the focal shoreline historically (Pitts et al. 2017); therefore, realizing a measurable increase in the frequency and persistence of mesohaline conditions is considered a positive step toward restoration.

Overall, mesohaline conditions continue to be insufficient to drive and maintain an estuarine biological community shift along Biscayne Bay's southwestern shoreline. This is evident from both the magnitude and trajectory of the mesohaline indices [computed for the wet (May–October) and dry (November–April) seasons of each year] as compared to the same index values calculated for a nearby reference site that possesses a more desirable (mesohaline) salinity regime. Considering the 2007–2017 period (Figure 6.4), the proportion of mesohaline salinities during the wet season oscillated both above and below the restoration target (0.26). However, the proportion of mesohaline observations during each dry season were well short of the dry season target (0.69), except for the 2016 dry season (0.64), which experienced over twice the rainfall of any previous dry season in the 10-year time series. The deficit in nearshore mesohaline salinity conditions is especially clear when considering variation in the mesohaline persistence index values. The maximum duration of uninterrupted mesohaline conditions ranged from 3 to 20 days for the wet season (target: 34 days) and 5 to 36 days for the dry (target: 78 days).

In summary, salinity measurements over the past decade indicate that freshwater flows to Biscayne Bay's southwestern perimeter are lacking in both volume and duration to prompt a significant change in the biological communities that reside along the shoreline and in its vicinity. The salinity regime indicators are expected to show changes over the next five years. However, those changes will be driven by forces other

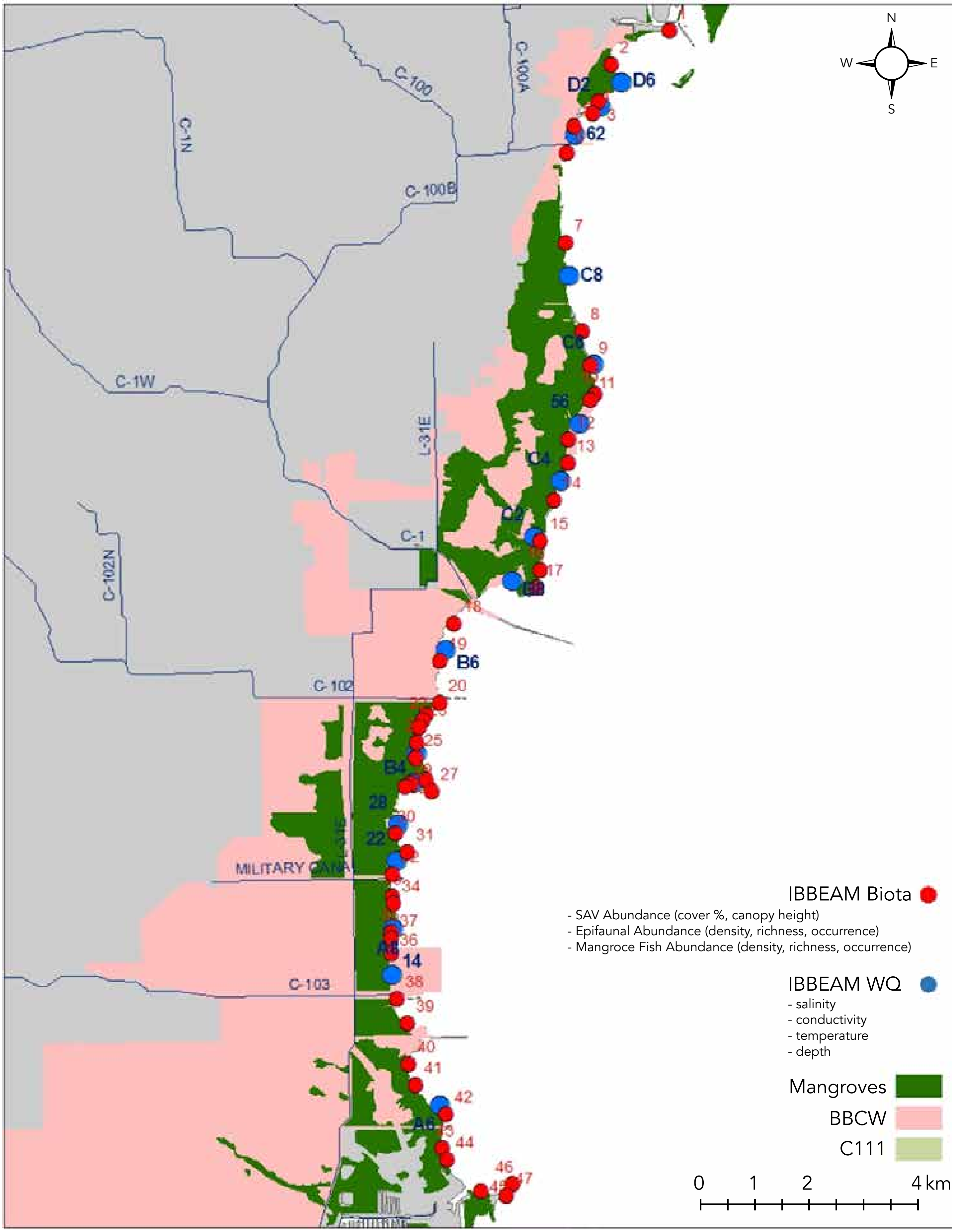


Figure 6.3. The IBBEAM nearshore study area along the shoreline showing water quality and biological sampling sites in Biscayne Bay and footprints of CERP projects BBCW and C-111 in the coastal wetlands.

than freshwater management, unless a concerted effort is made to deliver greater volumes of fresh water to the focal area and projects are completed that expand the distribution of these higher volumes in both time and space.

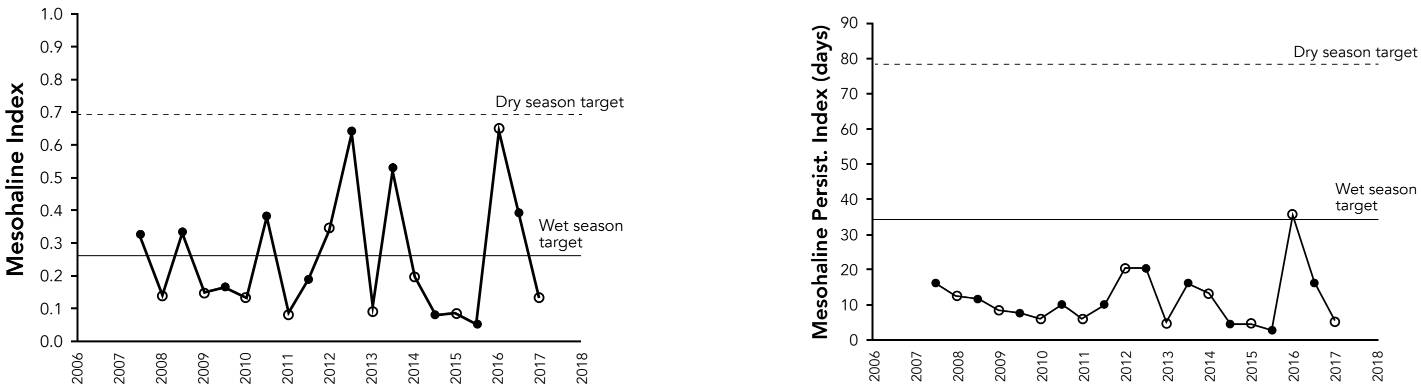


Figure 6.4. Temporal trajectory of two salinity regime metrics for Biscayne Bay's nearshore habitats: mesohaline index (left) and the mesohaline persistence index (right). Values for wet and dry seasons are represented with filled and open symbols, respectively. Horizontal lines indicate seasonal restoration target values (based on conditions at a reference site), with solid lines indicating wet season targets, and dashed lines indicating dry season targets.

Shoreline Seagrass Community

Halodule wrightii and *Thalassia testudinum* are the main components of the nearshore (<100 m from shore) seagrass communities of western Biscayne Bay from Matheson Hammock to Turkey Point, with only minor contributions from *Syringodium filiforme* (Figure 6.5). *Halodule* is the dominant species in terms of occurrence (found, on average, at 87% of sites), compared to *Thalassia*, which was found at 69% of nearshore sites on average over the period of record. The co-occurrence of *Halodule* and *Thalassia* at the same sites (a desired goal of CERP) was observed, on average, at 58% of sites. The increases in occurrence of *Halodule* from 2015–2017 reversed a declining trend that started in 2012. *Thalassia* occurrence, which was on a general increasing trend since 2013, started declining in the 2016 wet season. The occurrence of *Halodule* and *Thalassia* is high, but the benthic cover of these species is low. The average cover was 17.1% for *Halodule*, 9.1% for *Thalassia*, and only 0.2% for *Syringodium* from 2008–2017.

Even when inter-annual fluctuations were recorded, seagrass abundance over the period of record has been fairly resistant and resilient to climatic extremes (2010 cold water anomaly), hypersalinity events, algal blooms, and Hurricane Irma. The fluctuating abundance of *Halodule* nearshore is consistent with its life history as a species that thrives in environments with low and variable salinity and increased nutrient inputs. *Halodule* has a slight declining trend in cover since 2014. *Thalassia* has shown lower variability between years and more pronounced longer-term trends; generally increasing since 2013. *Halodule* and *Thalassia* abundance shows large seasonal swings (peaks generally in the wet season), with *Thalassia* cover fluctuating >10% and cover of *Halodule* fluctuating >15% between seasons. *Halodule* has responded rapidly to favorable salinity conditions in nearshore habitats of Biscayne Bay and is considered a robust and consistent indicator of nearshore salinity.

In summary, patterns of seagrass abundance over the past 10 years in western Biscayne Bay have shown high seasonal fluctuations but fairly stable long-term trends largely unaffected by large-scale disturbances. This is in contrast with the large-scale seagrass losses reported for Florida Bay (2015) and the Julia Tuttle Basin in northern Biscayne Bay. While seagrass occurrence is high, average seagrass cover is low in the study region and may increase over the next five years if mesohaline conditions are maintained, fostering the co-occurrence of *Halodule* and *Thalassia*.

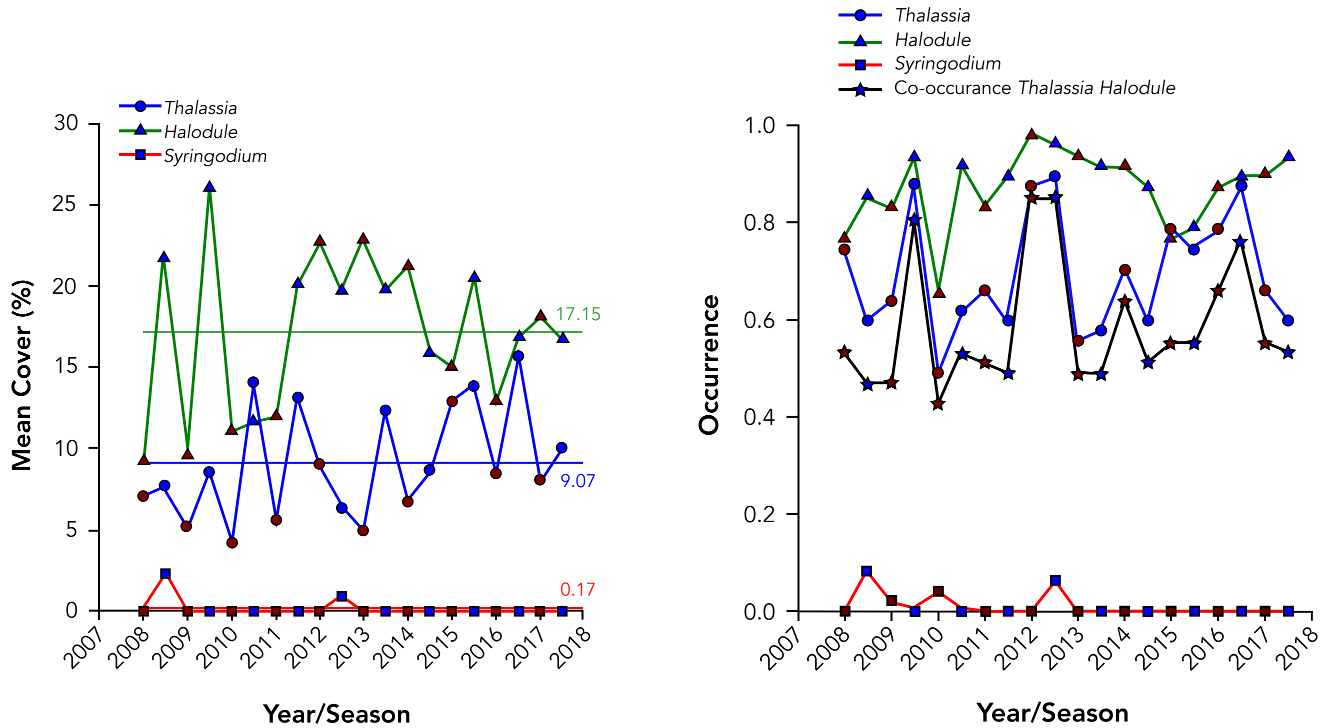


Figure 6.5. Percent cover of the three dominant seagrass species in nearshore western Biscayne Bay since 2008. Black symbols indicate dry season, blue symbols indicate wet season. The data presented were collected from nearshore (<100 m from shore, left) and offshore (100–500 m from shore, right) habitats during the wet season between Matheson Hammock and Turkey Point.

Epifauna Community

Methods. The IBBEAM Epifauna Project is designed to monitor and assess progress toward a more mesohaline nearshore community of shrimp, crabs, and small fish. Integral to this assessment is finding and following ecological indicators representative of this community that are sensitive to salinity. Epifaunal samples and water quality data (salinity, temperature, dissolved oxygen, pH, and water depth) are co-collected twice a year (dry season and wet season) at 47 sites along the shoreline between Shoal Point and Turkey Point (Figure 6.3). A 1-m^2 throw trap is used to collect three subsamples at each site, which are merged to form a 3 m^2 sample for the site and collection period. Abundances of potential indicator epifauna taxa are measured by density and occurrence. These abundance metrics are followed temporally and spatially to determine patterns and trends and are examined in relation to salinity and other environmental factors. They are also examined in relation to extreme events. There are four epifauna indicator taxa: goldspotted killifish (*Floridichthys carpio*), gulf pipefish (*Syngnathes scovelli*), shrimp of the genus *Farfantepenaeus* (pink shrimp and both identified and unidentified related taxa), and grass shrimp species (*Palaemonetes* spp.). Pink shrimp is a commercial species in the bay and elsewhere, and the other three taxa are relatively common in the bay western shoreline area.

Results. Analyses to determine relationships of species abundances with salinity have consistently yielded a similar statistically significant relationship for each indicator taxa when new data were added each year. These analyses, which also had percent cover of the seagrass, *Halodule*, as an explaining factor, suggested that goldspotted killifish, gulf pipefish, and *Farfantepenaeid* shrimps had salinity optima within the salinity range of the data (a parabolic relationship), and the grass shrimps were more abundant at the lower end of the data's salinity range, decreasing linearly as salinity increased. Salinity optima indicated by equations based on data through the Dry Calendar Year (CY) 2017 were 22 (4.87 fish/m^2), 24 (0.67 fish/m^2), and 22 (7.45 shrimp/m^2) for goldspotted killifish, gulf pipefish, and *Farfantepenaeid* shrimp, respectively. According to the equation, *Palaemonetes* shrimp had a density of 2.97 at 0 salinity, 2 at a salinity of 20, and 1.05 at salinity of 48. Three of the four epifaunal taxa—gulf pipefish, *Palaenometes* shrimp and *Farfantepenaeid* shrimp—were significantly more abundant in the dry season than in the wet season (Figure 6.6).

Abundances of the four epifauna indicator species did not differ significantly between the 5-yr period from Wet CY2007 to Dry CY2012 and the 5-yr period from Wet CY2012 to Dry CY2017. Variances between the two periods did not differ significantly either.

Seventy-six fish taxa were identified in Biscayne Bay epifauna collections from the 1-m^2 throw trap over the period of Water Years 2008 through 2017. Thirty-two taxa were found only in the WYs 2008–2012 period, 17 taxa were found only in the WYs 2013–2017 period, and 27 were common to both 5-yr periods. The main distinction in species community between the first and second 5-yr periods was that 6 species associated with low euhaline habitat were found only in the first 5-yr period and 4 species associated with mesohaline habitat were collected only in the second 5-yr period. Associations were assigned by median salinity of occurrence of individuals in the taxon. Haline categories were adapted from the Venice system and are mesohaline: 5–18 ppt, low polyhaline: 18–24, high polyhaline: 24–30 ppt, and low euhaline: 30–35 ppt. Since restoration of a mesohaline faunal community in the Biscayne Bay nearshore area is an objective of CERP and BBCW, the number of mesohaline taxa appearing in samples from one 5-yr period to the next may be an appropriate indicator of progress toward successful restoration.

Future Work. IBBEAM Epifauna sampling has collected many epifauna taxa in addition to the four mentioned here. The more abundant of these will be examined for their potential sensitivity and consistency as indicator species and a community-level index will be developed that includes all the epifauna taxa collected. Computer code is being developed to describe the salinity range and frequency distribution of salinity (with 5, 25, 50, 75, and 95 percentiles) where found, weighted by the number of individuals found at each salinity, for each species in the database to help classify taxa by halohabitat and follow changes over time in the types of communities dominating.

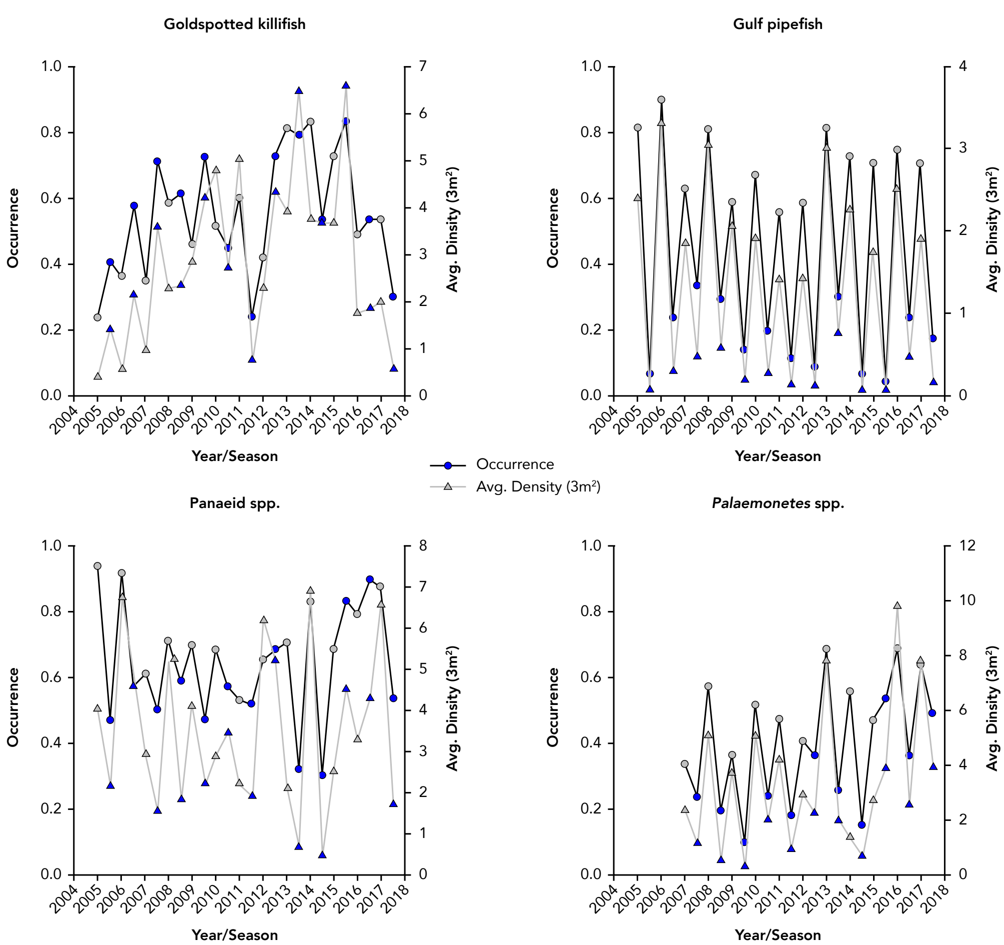


Figure 6.6. Occurrence (circle) and mean density (triangle) of epifaunal (SAV-associated) (A) goldspotted killifish, (B) gulf pipefish, (C) Penaeid *shrimp* spp.*, and (D)* Palaemonetes spp. *by year and season (open symbols indicate dry season, closed symbols indicate wet season). Density is number per 3 m^2.*

Mangrove Fish Community

Methods. From 1998 to 2018, mangrove shoreline fish assemblages have been characterized and quantified using a visual "belt-transect" method (Serafy et al. 2003; Serafy et al. 2007). While over 100 species have been observed, emphasis focuses on three species that either show abundance increases in response to lower salinity conditions: goldspotted killifish (*Floridichthys carpio*) and yellowfin mojarra (*Gerres cinereus*) or have fisheries value: gray snapper (*Lutjanus griseus*). Two abundance metrics per species are considered: fish density and frequency of occurrence. The former is expressed per 60 m^2, which is belt-transect survey area, and the latter is the proportion of total belt-transect surveys that were positive for the species.

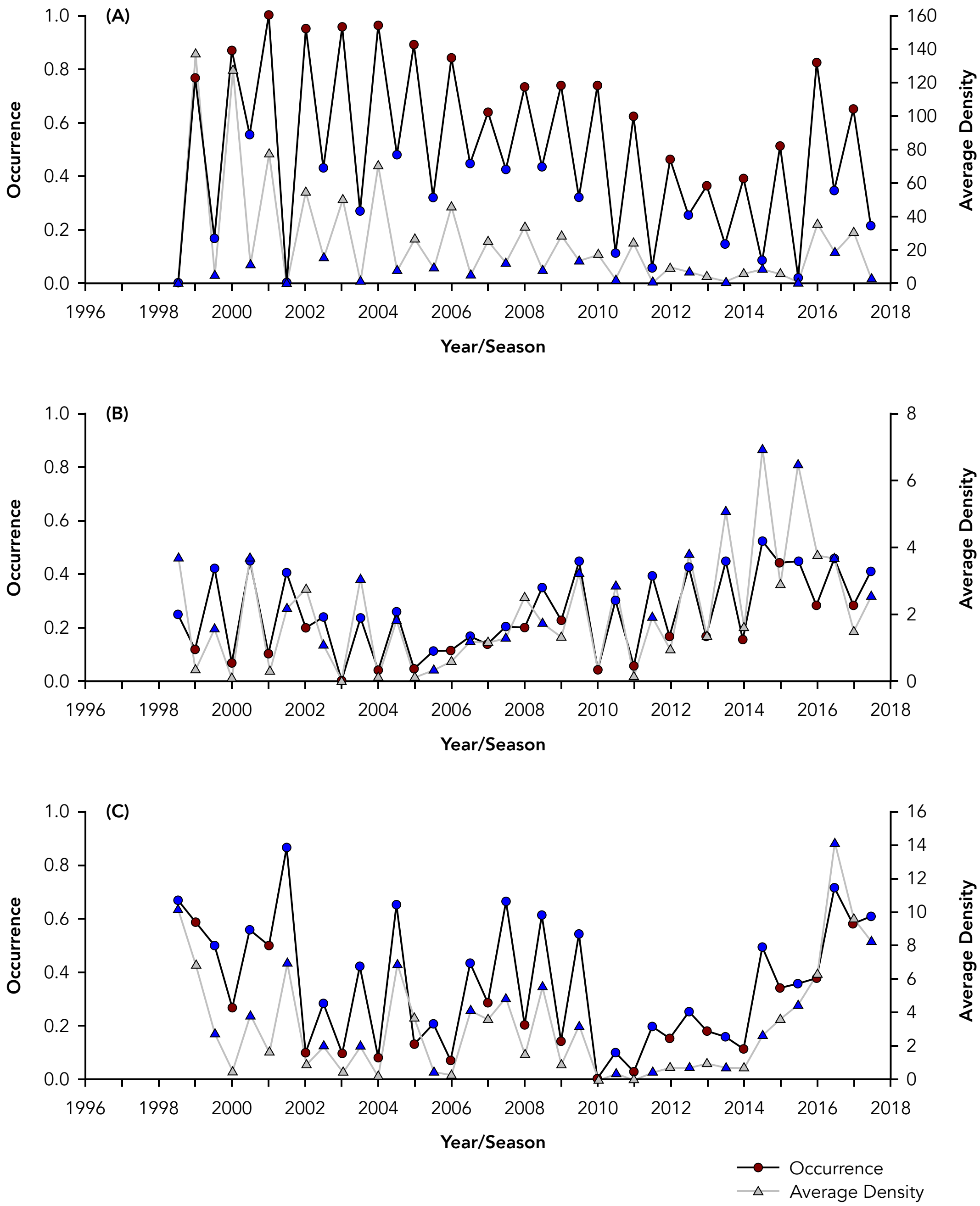


Figure 6.7. Occurrence and mean density of mangrove-associated (A) goldspotted killifish, (B) gray snapper, and (C) yellowfin mojarra by year and season (blue symbols indicate wet season, grey and red symbols indicate dry season). Density per 60 m^2.

Southern Coastal Systems

Results. Goldspotted killifish continue to occur most frequently during the dry season, and their occurrence-salinity relationship continues to follow a parabolic pattern, peaking at about 22 ppt (McManus et al. 2014). From 2007 to 2015 (Figure 6.7), a general decline in goldspotted killifish occurrence and density was evident, with particularly low values during seasons with hypersaline conditions. However, goldspotted killifish abundance metrics increased during the 2016 dry season, when salinities were remarkably low due to unusually high rainfall. The following year, the same abundance metrics were intermediate in magnitude.

Gray snapper abundance metrics tend to be highest in the wet season versus the dry, and abundance metrics are positively correlated with salinity. From 2007 through 2009, gray snapper occurrence and density metrics were relatively high until the 2010 dry season when temperatures were at record low levels. Over the next four years, gray snapper abundance metrics generally climbed and appear to have leveled-off by 2017 at relatively high values (Figure 6.7).

Yellowfin mojarra occurrence and density tend to be highest during the wet season. Both abundance metrics are negatively correlated with salinity, which is in contrast to those of gray snapper. From 2007 through 2009, yellowfin mojarra occurrence and density was relatively high, but fell to zero soon after the 2010 cold event. Since then yellowfin mojarra abundance metrics have increased steadily and the most recent values are among the highest observed since the IBBEAM project's inception.

Conclusions. Of the three mangrove-fish species examined in this report, it is the abundance metrics of goldspotted killifish that appear to be the most consistent and responsive to the naturally-driven fluctuations in salinity observed to date. However, likely because nearshore salinity regimes have not changed appreciably over the long term, goldspotted killifish density and occurrence were similar upon comparison of the two, 5-year time periods (wet season 2007–dry season 2012 vs wet season 2012–dry season 2017). Higher occurrence and density of both gray snapper and yellowfin mojarra were apparent for the second 5-years compared to the first. This result is best explained by the latter two species' greater sensitivity to the 2010 cold snap, from which both species appeared to slowly recover during the wet season 2012–dry season 2017 time period. Therefore, it is important to account for temperature effects (or events) when examining for impacts of future changes in salinity due to CERP implementation.

OTHER INDICATORS

Submerged Aquatic Vegetation

Miami-Dade County DERM has monitored seagrass and water quality in Biscayne Bay for over thirty years. Established in 1985, the benthic community monitoring program showed largely stable seagrass throughout the Bay, with only one seagrass loss event documented prior to 2005 and no significant phytoplankton or macroalgal blooms occurred until then. Since 2005, there has been a succession of algal blooms and seagrass losses, with two significant phytoplankton blooms, and a macroalgal bloom. Although two of those blooms were associated with large areas of seagrass loss, a recent decline of seagrass in northern Biscayne Bay was observed and may have contributed to relatively high chlorophyll *a*.

Seagrass extent

In chronological order, the earliest seagrass losses documented by this program occurred in northern Biscayne Bay in the late 90's. A fixed monitoring transect that was dominated by *Syringodium filiforme*, since monitoring was established in 1985, died off in 1998. The station and surrounding area has not recovered seagrass since. In 2005, following a two-year period of hypersalinity, a combination of mangrove removal and road construction practices coupled with Hurricane Katrina's freshwater and nutrient discharges resulted in seagrass losses and a multi-year phytoplankton bloom in the southern Biscayne Bay basins, Barnes Sound, and Manatee Bay (Rudnick et. al. 2012). About the same time in 2005, an *Anadyomene* spp. macroalgal bloom became apparent in the Northern-Central Inshore region of the Bay. This bloom rapidly developed and peaked in 2010–2012, resulting in a major loss of seagrass in the region (Collado-Vides et al. 2013). Most recently, losses of a dense area of *S. filiforme* in northern Biscayne Bay have accelerated. This event is being studied and no specific causal factors have been identified. Cumulatively the area of seagrass lost since 2005 in Biscayne Bay is estimated to be 56.4 km^2, calculated by stratified random sampling Braun-Blanquet divided by percent coverage of seagrasses (Table 6.2 and Figure 6.8).

The significant loss of habitat and the increasing frequency of these events make it apparent that Biscayne Bay is responding to nutrient inputs in an unprecedented manner. Short-term evaluations indicated increases in chlorophyll *a* and limited seagrass recovery following a loss of seagrass event (Millette et al. 2018). Additionally, long-term evaluations have shown increasing trends in chlorophyll *a*, total phosphorus, and total nitrogen.

Looking ahead, the future of Biscayne Bay's SAV appears bleak. Given the large areas that have been impacted by seagrass losses, with limited to no recovery and the shift to increased chlorophyll *a* that follows those losses, coupled with the long-term increasing trends in nutrients and chlorophyll *a*, it is likely that seagrass recovery will remain limited and the Bay is at risk of further declines in the SAV community.

Table 6.2. Quantified estimates of seagrass loss area by event in Biscayne Bay since 2005.

Event	Before event	Present	Lost area	Percent decrease
Anadyomene Bloom Area	51.2 km^2 (2000–2003)	12.1 km^2 (2014–2016)	39.1 km^2	76.40%
Julia Tuttle Area	12.0 km^2 (2002–2008)	6.6 km^2 (2016)	5.4 km^2	45.00%
Barnes Sound/ Manatee Bay	24.5 km^2 (2005)	12.6 km^2 (2014–2016)	11.9 km^2	48.60%
Total	87.7 km^2	31.3 km^2	56.4 km^2	64.31%

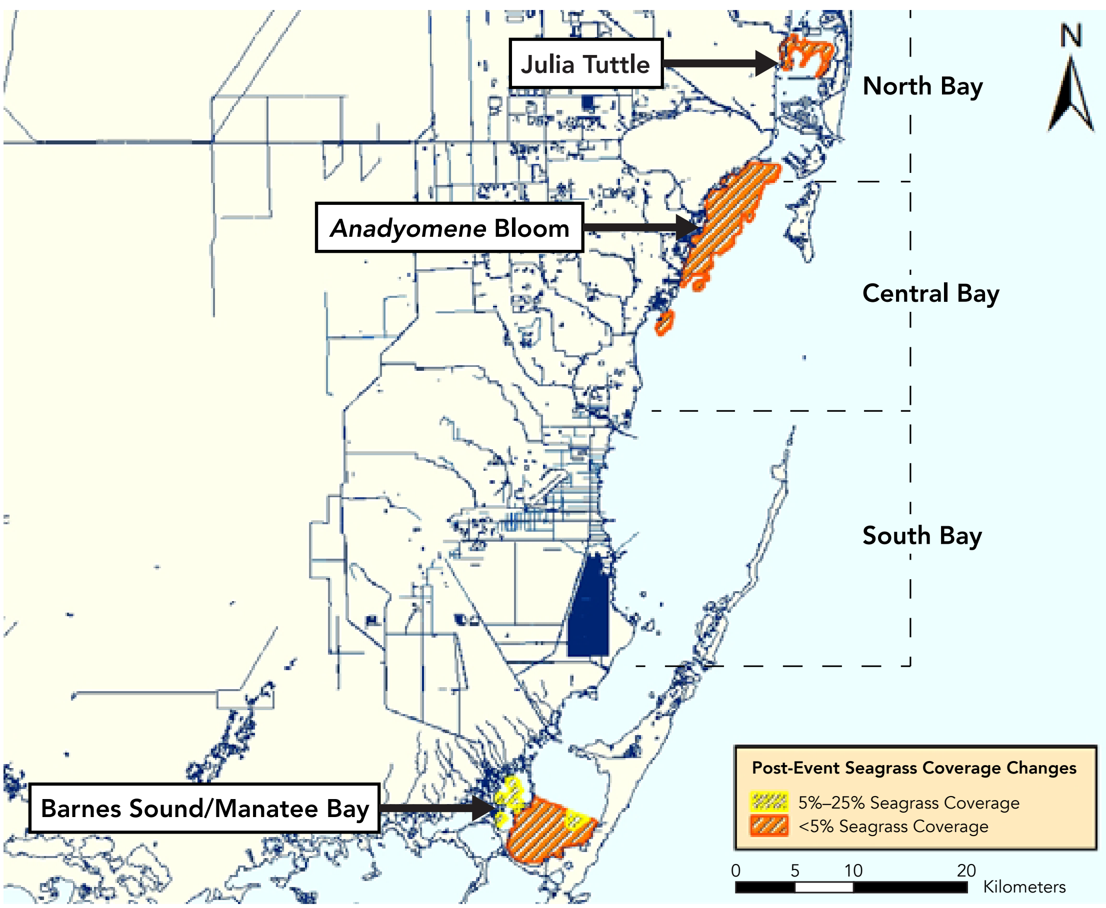


Figure 6.8. Map showing areas of seagrass decline in Biscayne Bay since 2005.

Southern Coastal Systems

Chlorophyll a

Background. Biscayne Bay water quality monitoring is conducted by the Miami-Dade Department of Environmental Management (DERM) and the South Florida Water Management District. Extensive ecological change has been evident in much of Biscayne Bay over the past decade. This includes seagrass die-offs and macroalgae blooms. In the southern bay, there has been a shift toward higher chlorophyll *a* (chla) concentrations after the occurrence of an intense, multi-year phytoplankton bloom that began in WY2006, after Hurricanes Katrina, Rita, and Wilma (Millette et al. 2018; Rudnick et al. 2007).

Results. The phytoplankton bloom stoplight indicator scores for all three Biscayne Bay regions (Table 6.3) show that for the past 13 years, all of the regions' scores have been yellow or red, meaning that annual median scores in the bay have shifted to a higher chla state than occurred during the reference period (calendar years 1993 or 1996 to 2006). This is consistent with conclusions of a rigorous statistical analysis of the southern Biscayne Bay (SBB region) by Millette et al. (2018). The most notable shift appears to be in the central and northern bay, with seven of eight stoplight scores being red in the past four years, following a nine-year period when only one of 18 scores was red.

Table 6.3. Biscayne Bay algal bloom indicator stoplight scores, based on Boyer et al. 2009. Green results are good, yellow are fair, and red are poor. Results are derived from chlorophyll a concentrations measured by SFWMD, Miami-Dade DERM, and NOAA monitoring programs. The number of stations and frequency of sampling per region were not constant. Regions shown are: southern Biscayne Bay (SBB); central Biscayne Bay (CBB); and northern Biscayne Bay (NBB).

	Water year												
Sub-region	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
NBB													
CBB													
SBB													

Conclusions. The absolute chla concentrations over the past five years would not be considered extraordinarily high in most estuaries, especially estuaries adjacent to large urban areas. The maximum annual median was 2.04 micrograms/L in WY2014. However, the indicator is providing a clear warning that ecological conditions in much of the bay have degraded. It is also important to note that this indicator only considers phytoplankton in the water column and not microalgae or macroalgae that grow on the bay bottom. As with phytoplankton, increases in macroalgae have been observed over the past decade (SSR, SCS, SAV-Biscayne Bay text; Collado-Vides et al. 2013) and increases elsewhere typically are driven by increased nutrient availability. In Biscayne Bay, changing nutrient inputs may be associated with changing surface water or groundwater inputs.

Crocodilians

At the end of WY17, current condition for the crocodile performance measure of growth in Biscayne Bay Complex (from Matheson Hammock park to US-1 including Card and Barnes Sounds and Crocodile Lake National Wildlife Refuge) was 0.072 cm/day and was below restoration target of >0.15 cm/day. For the crocodile survival performance measure, current condition was 0.62 and well below restoration targets of >0.85 (Mazzotti et al. 2009; RECOVER 2015b).

The three-year trend in growth is stable. As of this report, long-term (10–30 years) trend analysis has not been performed on growth within Biscayne Bay area.

The five-year trend in mean monthly fall survival calculated using minimum known alive, is stable. Briggs-Gonzalez et al. (2017b) described calculating age-specific survival rates from capture-recapture of known-aged and marked individuals, rather than using the minimum known alive method. This analysis will be incorporated to update crocodile survival targets. Using this new analysis with data from 1978–2015, crocodile hatchling survival was estimated to be 22% in south Florida (ENP and Biscayne Bay area, not including Turkey Point; Briggs-Gonzalez 2017c). In Biscayne Bay area (north of Card Sound, not including Turkey Point) one-year survival rate was estimated at 48%. Crocodile Lake National Wildlife Refuge (69%) and Flamingo/Cape Sable area (53%) had higher survival estimates (Briggs-Gonzalez et al. 2017c).

Targets are being developed for the crocodile performance measure of body condition (Fulton's K, calculated using snout-vent-length and mass). Analysis of body condition for captures made 1978–2015 showed that body condition varied by area. Crocodiles in Biscayne Bay area (2.08) had body condition similar to crocodiles in NE Florida Bay (2.03) but was higher in West Lake area (2.18) and highest for crocodiles in Flamingo/Cape Sable area (2.26), who were in best body condition (Briggs-Gonzalez et al. 2017b).

Additional targets are being developed for the crocodile performance measure of crocodile relative density or encounter rate (number of crocodiles observed/km of shoreline surveyed). Data from nocturnal spotlight surveys currently performed three times a year have yet to be analyzed. From 1996–2005 encounter rates increased 13% annually for both sub-adult and adult crocodiles, with the rate for hatchlings and juveniles not changing over this time period (Figure 6.9). Barnes and Card Sounds had the most crocodile observations (377, Figure 6.8; Cherkiss et al. 2011).

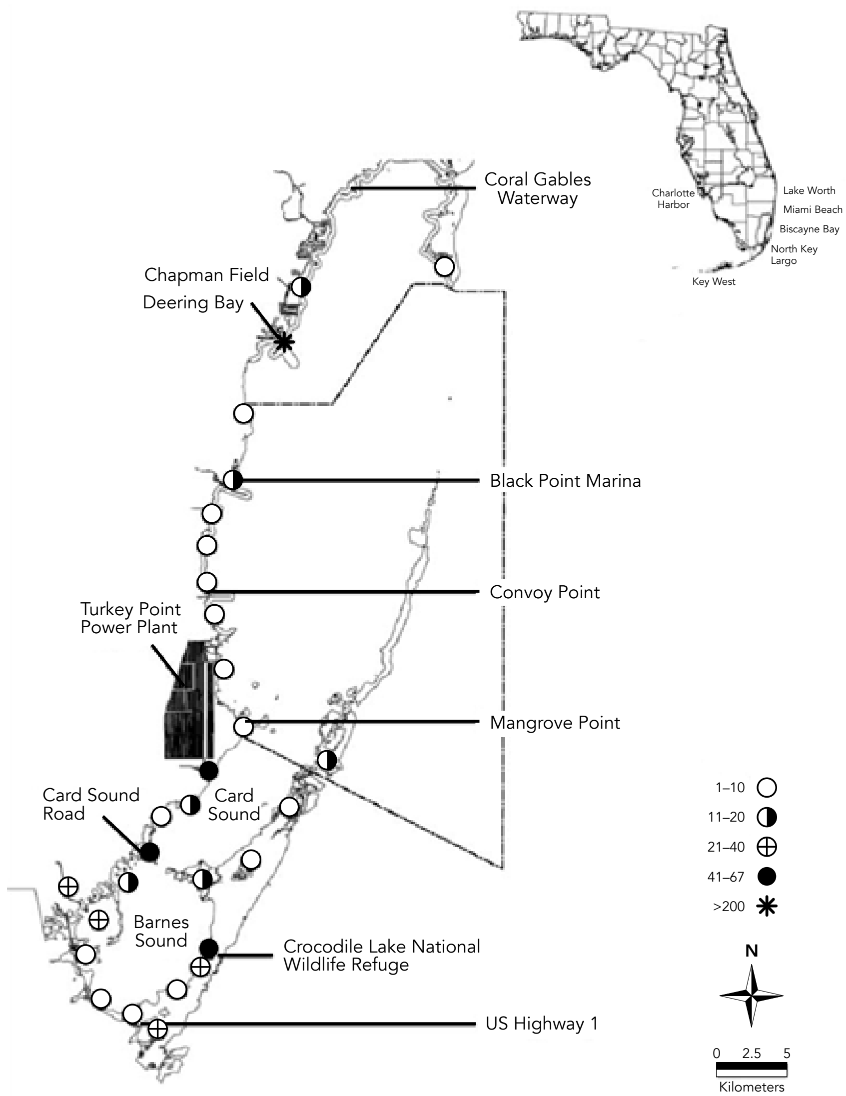


Figure 6.9. Distribution of American crocodile (Crocodylus acutus) observations from spotlight surveys conducted in Biscayne Bay Complex between 1996–2005.

Crocodiles will benefit from restoration of freshwater flows into their estuarine habitat (Mazzotti et al. 2007). Crocodile growth and survival is expected to increase over the next five years with the Biscayne Bay Coastal Wetlands (BBCW) and C-111 Spreader Canal projects as water is redistributed via wetlands rather than through canals. Increased encounter rates of crocodiles and improved body condition are expected over the next five years as quantity, quality, and timing of freshwater entering the bay are improved.

FLORIDA BAY

Flow

Eight creeks and rivers (West Highway Creek, Stillwater Creek, Trout Creek, Mud Creek, East Creek, Taylor River, McCormick Creek, and Alligator Creek) were monitored to describe the total flow volume to Florida Bay. Total annual flow volumes were determined for WY1997 through WY2017 (Figure 6.10). During the monitoring period, three water operational periods were implemented: pre-Interim Operational Period (pre-IOP, WY1997–1999), Interim Operational Period (IOP, WY2000–2012), and the Everglades Restoration Transition Plan (ERTP, WY2013–2017). Annual flow volumes were compared during the three operational periods and also compared to the historical annual mean flow for the SWC of ENP and Florida Bay, respectively.

The total annual flow volumes during the ERTP ranged from a minimum of 122,309 ac-ft in WY2015 to a maximum of 438,920 ac-ft in WY2013. During the ERTP, the total annual flow was at or above the period of record (POR) mean annual flow (305,013 ac-ft) in WY2013–2014 and in WY2016, but was below the mean in WY2015 and WY2017. The lowest monitored total annual flow to Florida Bay for the POR coincided with hypersaline conditions (>40 ppt) at all USGS sites along the coastline of Florida Bay in WY2015. A seagrass die-off was observed in central Florida Bay in WY2015.

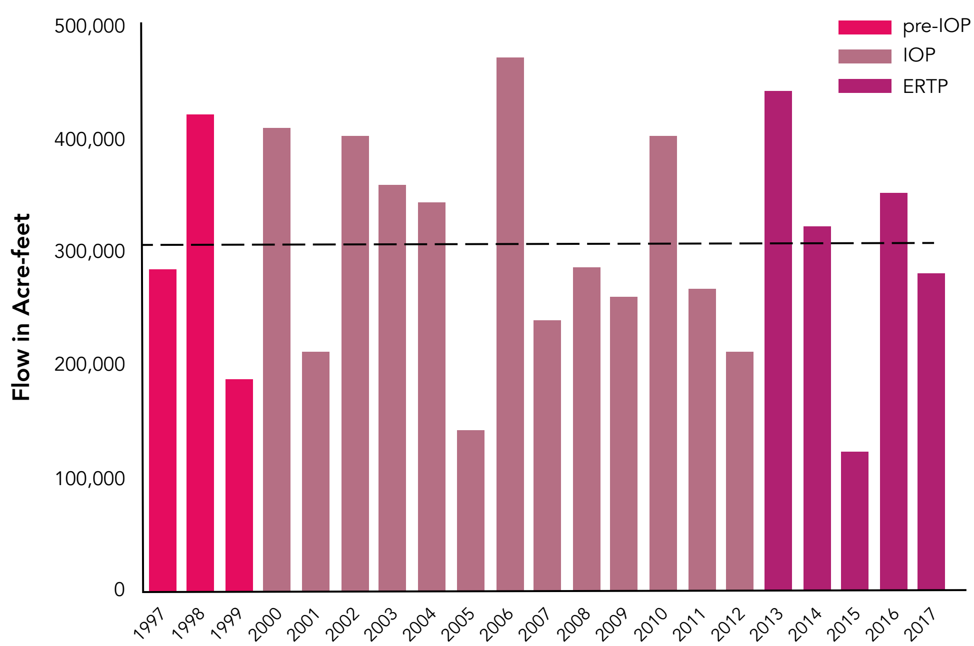


Figure 6.10. Total annual flows in acre-feet for the flow monitoring stations at the coastline of Florida Bay. Dashed line represents the mean annual flow (305,013 ac-ft) for the period of record (WY1997 to WY2012).

Summary statistics of flow to Florida Bay representing conditions during the pre-IOP, IOP, and ERTP were compared (Table 6.4). The total mean flow during the ERTP was slightly lower than the total mean flow during the pre-IOP and the IOP. Although the total annual mean flows varied among water years, the mean flows for each operational period varied from 10,095 ac-ft to 1,097 ac-ft when compared to the POR mean.

The distribution of flow to Florida Bay was evaluated using the five original creek sites assessed in the pre-IOP, IOP, and ERTP. Use of these sites ensures that results are not influenced by the addition or removal of sites during the past 20 years. The total annual flow from the five creeks was summarized to reflect the contribution from the upstream basins such as Taylor Slough to the west and the C-111 Drainage Complex to the east for each operational period (Table 6.5). Flow from Taylor Slough to Florida Bay is represented by the total annual flows from McCormick Creek (MCC), Taylor River Mouth (TR), and Mud Creek (MC). Flow to Trout Creek originates from Joe Bay which receives flow from Taylor Slough and the C-111 Drainage Complex. Flow from the C-111 Drainage Complex to Long Sound are represented by the total annual flow from West Highway Creek. The percentage of flow contributed from Taylor Slough to Florida Bay via MCC, TR, and MC increased from 20% during the pre-IOP to 27% during the ERTP. Trout Creek has been the largest contributor of flow to Florida Bay, representing roughly 60% of the total monitored flow. The percentage of monitored flow at West Highway Creek has decreased from 17% during the pre-IOP to 10% during the ERTP.

Table 6.4. Summary statistics of flow to Florida Bay representing conditions during pre-IOP/S332i, IOP/S332D, and ERTP water operations.

Operational periods	Flow, in acre-feet				
	Minimum	Maximum	Mean	Median	Standard deviation
WY1997–1999 (pre-IOP)	186,902	421,880	297,254	282,980	118,138
WY2002–2012 (IOP)	139,350	470,823	306,110	283,660	97,538
WY2013–2017 (ERTP)	122300	438,920	294,918	320,150	114,793

Table 6.5. The percentage of flow from Taylor Slough and the C-111 Drainage Complex to Florida Bay during the pre-IOP/S332i, IOP/S-332D, and ERTP water operations. The mean flow includes only the 5 creek sites.

Basin	WY1997–1999	WY2000–2012	WY2013–2017
Taylor Slough	20	29	27
Trout Creek	62	59	62
West Highway Creek	17	13	10
Mean Flow	236,497	248,718	258,205

Salinity

Background. Salinity is an important abiotic variable for the health and ecological diversity of the estuarine system throughout Florida Bay. Florida Bay is a complex, heterogeneous coastal environment that, prior to human intervention, varied due to natural factors including hurricanes, climatic variation, and changing sea level (Nuttle 2004). The landscape and hydrological systems of south Florida have been altered due to water management practices primarily implemented to increase water supply and reduce the risk of flooding.

In order to assess the status of salinity in Florida Bay, the Florida Bay Salinity Performance measure was developed and finalized in June 2012. This performance measure evaluates salinity conditions in "six zones of similarity" as described by Boyer and Briceño (2010) (Figure 6.11, Table 6.6). Using 17 stations in the Everglades National Park Marine Monitoring Network, a stoplight methodology categorizes salinity during the wet season (May through November) and dry season (December through April) for the following metrics: regime overlap (distribution of salinities in the paleo-adjusted NSM record (target) compared to the observed or predicted distribution of results between the 25th and 75th percentiles (mid-range)); high salinity (number of days of exceedence above the high salinity threshold (90th percentile value) in observed data, divided into the target exceedence); mean offset (measure of the magnitude that observed data or predicted output may deviate from the target); and aggregated metrics scoring (RECOVER 2012).

Results. Reduction of freshwater flow has altered the salinity throughout Florida Bay impacting the ecology and historic natural paradigm. Generally, salinity conditions during the wet season (May 1st through November 30th) have been worse throughout all Florida Bay Zones of Similarity (Table 6.6). The overlap and high salinity metrics have index scores from 0–1, with 1 matching estimated pre-drainage salinity, while the mean offset score is an absolute salinity unit (PPT) difference between the target and recent observed salinity.

Three data sets (2000–2008, 2009–2013, and 2013–2017), for both wet and dry seasons, are used for trend analysis (Table 6.7). Analysis is based on Aggregated Metric Scores (AMS), by converting the category (color) of the scoring metrics to a value (Green = 0.825, Yellow = 0.5, Red = 0.165), then averaging the values together for the season and/or years to be grouped. The AMS is a calculation that normalizes the three salinity performance metrics and averages them together to give a single value that reflects the overall match between the observed salinity and the salinity target for each station and zone in the bay. Salinity conditions during the wet season dropped to "unsatisfactory" (red) for 2009–2013 for all regions compared to 2000–2008 (Table 6.7). During the same time period, AMS scores for the dry season remained "cautionary" (yellow) or dropped to "unsatisfactory" (red) in the 2009–2013 data set compared to 2000–2008.

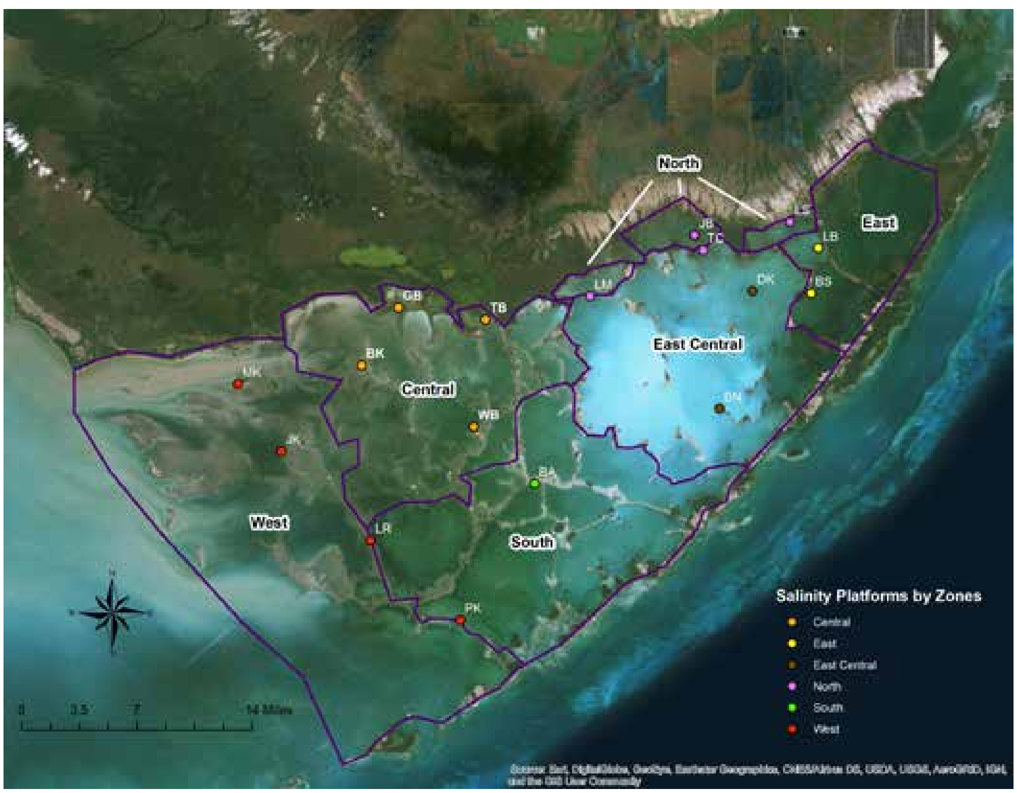


Figure 6.11. Everglades National Park marine monitoring stations and salinity zones of similarity in Florida Bay.

Table 6.6. Florida Bay Salinity Performance Measure Metric Calculations (green: satisfactory, yellow: cautionary, red: unsatisfactory).

Overlap Metric												
Basin (Monitoring Station)	2012 Wet	2012 Dry	2013 Wet	2013 Dry	2014 Wet	2014 Dry	2015 Wet	2015 Dry	2016 Wet	2016 Dry	2017 Wet	2017 Dry
Joe Bay (JB)	0.23	0.13	0.23	0.00	0.25	0.15	0.00	0.00	0.00	0.46	NULL	NULL
Little Madeira Bay (LM)	0.00	0.00	0.22	0.00	0.53	0.00	0.00	0.00	0.00	0.49	0.14	0.00
Long Sound (LS)	0.00	0.00	0.41	0.00	0.35	0.00	0.00	0.00	0.00	0.07	0.01	0.00
Trout Cove (TC)	0.17	0.00	0.21	0.00	0.25	0.00	0.00	0.00	0.00	0.41	0.25	0.04
North Bay Average	0.10	0.03	0.27	0.00	0.35	0.04	0.00	0.00	0.00	0.36	0.13	0.01
Blackwater Sound (BS)	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.89	0.20	0.00
Little Blackwater Sound (LB)	0.00	0.00	0.41	0.00	0.09	0.00	0.00	0.00	0.00	0.74	0.06	0.00
East Average	0.00	0.00	0.52	0.00	0.05	0.00	0.00	0.00	0.00	0.82	0.13	0.00
Butternut Key (BN)	0.00	0.00	0.96	0.63	0.18	0.05	0.00	0.00	0.00	0.59	0.09	0.00
Duck Key (DK)	0.00	0.00	0.64	0.00	0.10	0.00	0.00	0.00	0.00	0.53	0.14	0.00
East-Central Average	0.00	0.00	0.80	0.32	0.14	0.03	0.00	0.00	0.00	0.56	0.12	0.00
Buoy Key (Bk)	0.00	0.00	0.26	0.00	0.39	0.00	0.00	0.00	0.00	0.16	0.10	0.00
Garfield Bight (GB)	0.01	0.00	0.52	0.00	0.17	0.35	0.00	0.00	0.05	0.12	0.00	0.00
Terrapin Bay (TB)	0.00	0.00	0.57	0.00	0.40	0.35	0.00	0.00	0.00	0.33	0.08	0.00
Whipray Basin (WB)	0.00	0.34	0.57	0.50	0.55	0.59	0.00	0.00	0.00	0.38	0.14	0.04
Central Average	0.00	0.09	0.48	0.13	0.38	0.32	0.00	0.00	0.01	0.25	0.08	0.01
Bob Allen Key (BA)	0.00	0.00	0.74	0.85	0.32	0.39	0.00	0.00	0.00	0.59	0.00	0.00
South Average	0.00	0.00	0.74	0.85	0.32	0.39	0.00	0.00	0.00	0.59	0.00	0.00
Johnson Key (JK)	0.00	0.00	0.24	0.01	0.03	0.00	0.00	0.00	0.00	0.59	0.06	0.00
Little Rabbit Key (LR)	0.01	0.00	0.36	0.04	0.27	0.13	0.00	0.00	0.00	0.54	0.24	0.00
Murray Key (MK)	0.07	0.00	0.31	0.34	0.27	0.43	0.00	0.00	0.00	0.58	0.21	0.00
Peterson Key (PK)	0.00	0.00	0.40	0.01	0.28	0.15	0.00	0.00	0.00	0.47	0.00	0.00
West Average	0.02	0.00	0.33	0.10	0.21	0.18	0.00	0.00	0.00	0.55	0.13	0.00

Mean Offset												
Basin (Monitoring Station)	2012 Wet	2012 Dry	2013 Wet	2013 Dry	2014 Wet	2014 Dry	2015 Wet	2015 Dry	2016 Wet	2016 Dry	2017 Wet	2017 Dry
Joe Bay (JB)	12.89	11.32	4.65	9.31	6.08	5.39	12.63	16.46	21.45	1.90	NULL	NULL
Little Madeira Bay (LM)	13.82	8.59	4.48	4.55	3.15	5.78	14.91	14.95	22.09	2.84	5.39	8.75
Long Sound (LS)	15.99	13.81	5.17	15.11	8.41	13.23	18.77	19.99	23.76	4.52	8.16	16.03
Trout Cove (TC)	13.49	13.32	5.75	11.51	6.19	9.36	16.14	19.59	22.99	2.79	5.71	13.71
North Bay Average	14.05	11.76	5.01	10.12	5.96	8.44	15.61	17.75	22.57	3.01	6.42	12.83
Blackwater Sound (BS)	9.90	4.00	1.97	5.04	5.52	6.13	11.02	10.22	14.54	1.28	4.27	6.50
Little Blackwater Sound (LB)	12.71	8.36	3.71	9.65	6.97	10.35	15.09	14.60	19.44	1.45	7.13	10.70
East Average	11.31	6.18	2.84	7.35	6.25	8.24	13.06	12.41	16.99	1.37	5.70	8.60
Butternut Key (BN)	9.90	3.53	0.78	1.01	4.33	3.35	11.32	9.90	14.17	3.03	6.79	4.74
Duck Key (DK)	11.33	5.65	1.74	3.63	5.32	5.45	12.76	11.79	17.44	2.71	7.05	7.75
East-Central Average	10.62	4.59	1.26	2.32	4.83	4.40	12.04	10.85	15.81	2.87	6.92	6.00
Buoy Key (Bk)	7.86	6.52	4.74	5.85	4.05	4.88	9.72	7.20	14.17	3.71	6.68	6.35
Garfield Bight (GB)	16.74	14.00	4.23	12.06	8.13	6.58	15.92	16.19	21.62	7.26	10.72	11.69
Terrapin Bay (TB)	18.29	10.95	4.46	6.95	5.20	4.66	16.37	19.00	24.66	5.72	8.40	10.17
Whipray Basin (WB)	9.44	2.62	1.75	1.78	2.02	2.04	10.66	10.97	14.66	2.89	6.45	5.20
Central Average	13.08	8.52	3.80	6.66	4.85	4.54	13.17	13.34	18.92	4.90	8.06	8.35
Bob Allen Key (BA)	9.49	2.98	1.10	0.94	2.78	1.96	10.62	9.83	12.16	1.43	6.40	4.10
South Average	9.49	2.98	1.10	0.94	2.78	1.96	10.62	9.83	12.16	1.43	6.40	4.10
Johnson Key (JK)	4.93	4.11	3.19	3.07	4.62	2.64	6.68	4.41	8.42	2.30	4.36	4.84
Little Rabbit Key (LR)	5.47	4.31	3.14	2.93	3.89	2.79	7.14	4.40	9.98	2.24	4.41	4.68
Murray Key (MK)	4.98	3.53	2.46	1.78	2.16	1.11	6.80	3.28	8.33	1.68	3.88	3.19
Peterson Key (PK)	4.31	2.97	1.46	1.82	1.96	1.58	5.89	4.66	5.63	0.97	4.00	2.96
West Average	4.92	3.73	2.56	2.40	3.16	2.03	6.63	4.19	8.09	1.80	4.16	3.92

High Salinity												
Basin (Monitoring Station)	2012 Wet	2012 Dry	2013 Wet	2013 Dry	2014 Wet	2014 Dry	2015 Wet	2015 Dry	2016 Wet	2016 Dry	2017 Wet	2017 Dry
Joe Bay (JB)	0.97	0.63	1.00	1.00	0.86	1.00	0.86	0.43	0.60	0.80	NULL	NULL
Little Madeira Bay (LM)	0.73	0.67	1.00	1.00	1.00	1.00	0.59	0.41	0.59	0.80	1.00	0.69
Long Sound (LS)	0.59	0.41	0.71	0.71	0.71	0.41	0.59	0.42	0.59	0.80	0.71	0.41
Trout Cove (TC)	0.62	0.41	0.71	0.43	0.69	0.50	0.61	0.41	0.59	0.65	0.71	0.42
North Bay Average	0.73	0.53	0.86	0.66	0.82	0.73	0.66	0.42	0.59	0.76	0.81	0.51
Blackwater Sound (BS)	0.73	1.00	1.00	0.85	0.86	0.43	0.59	0.41	0.59	0.80	1.00	0.64
Little Blackwater Sound (LB)	0.73	0.61	1.00	0.42	0.71	0.41	0.59	0.46	0.59	0.80	0.86	0.41
East Average	0.73	0.81	1.00	0.64	0.79	0.42	0.59	0.44	0.59	0.80	0.93	0.53
Butternut Key (BN)	0.73	1.00	1.00	1.00	0.86	1.00	0.59	0.41	0.59	0.80	0.73	1.00
Duck Key (DK)	0.73	0.98	1.00	1.00	0.65	0.68	0.59	0.41	0.59	0.70	0.73	0.58
East-Central Average	0.73	0.99	1.00	1.00	0.76	0.84	0.59	0.41	0.59	0.75	0.73	0.79
Buoy Key (Bk)	0.75	0.98	0.77	0.69	0.71	1.00	0.59	0.70	0.61	0.66	0.74	0.83
Garfield Bight (GB)	0.73	0.43	1.00	0.82	1.00	1.00	0.59	0.45	0.71	0.80	0.86	0.85
Terrapin Bay (TB)	0.73	0.71	1.00	1.00	1.00	1.00	0.59	0.43	0.60	0.80	0.86	0.92
Whipray Basin (WB)	0.76	1.00	1.00	1.00	1.00	1.00	0.59	0.41	0.59	0.80	0.74	0.95
Central Average	0.74	0.78	0.94	0.88	0.93	1.00	0.59	0.50	0.63	0.77	0.80	0.89
Bob Allen Key (BA)	0.73	1.00	1.00	1.00	1.00	1.00	0.59	0.41	0.59	0.80	0.73	1.00
South Average	0.73	1.00	1.00	1.00	1.00	1.00	0.59	0.41	0.59	0.80	0.73	1.00
Johnson Key (JK)	0.74	0.95	0.78	1.00	0.60	1.00	0.59	0.95	0.59	0.63	0.74	0.80
Little Rabbit Key (LR)	0.75	0.95	0.86	0.97	0.67	0.80	0.59	0.95	0.60	0.64	0.76	0.86
Murray Key (MK)	0.75	0.83	0.84	1.00	0.86	1.00	0.59	0.80	0.59	0.67	0.73	0.98
Peterson Key (PK)	0.73	0.63	0.86	0.96	0.71	0.80	0.59	0.41	0.59	0.80	0.73	0.50
West Average	0.74	0.84	0.84	0.98	0.71	0.90	0.59	0.78	0.59	0.69	0.74	0.79

Despite a significant drought in 2014–2015, salinity AMS scores for the 2013–2017 data set improved for both wet and dry seasons compared to the 2009–2013 data set (Table 6.7). Salinity conditions dropped to unsatisfactory scores across the three performance metrics used to assess salinity throughout Florida Bay (Table 6.7): overlap (regime) metric, mean offset metric, and high salinity metric (RECOVER 2012). Despite the 2014–2015 drought, salinity conditions improved during the past 5 years throughout Florida Bay compared to the previous five year period. However, salinity conditions remain poor (generally cautionary [yellow]) (Table 6.7).

Conclusions. Florida Bay suffers from the lack of freshwater flowing from Taylor Slough, Shark River Slough, and numerous creeks and rivers. Future CERP restoration projects, such as the C-111 Projects and the Central Everglades Planning Project (CEPP), should improve the amount and timing of freshwater flows to Florida Bay. Until those projects are implemented, hypersaline conditions will dominate the Florida Bay landscape, and may increase as sea level continues to rise bringing saline water further into the bay and surrounding wetlands.

Table 6.7. Florida Bay Salinity Performance Measure Aggregate Metric Scores (AMS) for three separate data sets. Green results are satisfactory, yellow are cautionary, and red are unsatisfactory.

	WY2000–WY2008		WY2009–WY2013		WY2013–WY2017	
	Aggregate		Aggregate		Aggregate	
Basin (Monitoring Station)	Wet	Dry	Wet	Dry	Wet	Dry
Joe Bay (JB)	0.50	0.17	0.50	0.39	0.39	0.50
Little Madeira Bay (LM)	0.39	0.39	0.28	0.39	0.39	0.50
Long Sound (LS)	0.61	0.17	0.28	0.17	0.28	0.28
Trout Cove (TC)	0.39	0.17	0.28	0.17	0.28	0.28
North Bay Average	0.50	0.28	0.28	0.17	0.39	0.28
Blackwater Sound (BS)	0.39	0.39	0.28	0.39	0.50	0.39
Little Blackwater Sound (LB)	0.50	0.39	0.28	0.28	0.39	0.39
East Average	0.39	0.39	0.28	0.28	0.50	0.39
Butternut Key (BN)	0.28	0.39	0.28	0.39	0.50	0.61
Duck Key (DK)	0.28	0.39	0.28	0.39	0.50	0.50
East-Central Average	0.28	0.39	0.28	0.39	0.50	0.50
Buoy Key (Bk)	0.39	0.39	0.17	0.39	0.50	0.50
Garfield Bight (GB)	0.39	0.39	0.39	0.39	0.39	0.39
Terrapin Bay (TB)	0.39	0.39	0.39	0.39	0.39	0.50
Whipray Basin (WB)	0.39	0.39	0.28	0.50	0.50	0.61
Central Average	0.39	0.39	0.28	0.39	0.50	0.50
Bob Allen Key (BA)	0.28	0.39	0.28	0.50	0.50	0.72
South Average	0.28	0.39	0.28	0.50	0.50	0.72
Johnson Key (JK)	0.28	0.39	0.17	0.39	0.39	0.61
Little Rabbit Key (LR)	0.28	0.39	0.17	0.39	0.50	0.61
Murray Key (MK)	0.39	0.39	0.17	0.39	0.61	0.61
Peterson Key (PK)	0.28	0.39	0.28	0.39	0.61	0.61
West Average	0.28	0.39	0.17	0.39	0.61	0.61

Salinity in streams flowing to Florida Bay

Background. Salinity gradients in coastal Everglades National Park (ENP) are primarily determined by freshwater sheet flow in the streams composing Shark River Slough (SRS) and Taylor Slough (TS), the two principal flow paths within ENP. SRS flows into the Gulf of Mexico at the southwest coast of ENP, whereas TS, Trout Creek, and West Highway Creek account for the majority of flow into Florida Bay. The primary source waters for SRS are the S-12 structures and the outlets from Tamiami Canal; the main water source for TS is Canal 111 (C-111) at S-18C and Taylor Slough Bridge (TSB). Trout Creek receives water from TS and the C-111 Drainage Complex, and West Highway Creek receives flow from the C-111 Drainage Complex.

For the current reporting period, salinity data include the stations at the outlets of the principal streams flowing into Florida Bay. McCormick Creek, Taylor River (at the mouth), and Mud Creek were monitored for salinity, and salinity was monitored at the outlets of Trout Creek and West Highway Creek.

Results. The mean annual salinity for the current reporting period was higher at all Florida Bay monitoring sites when compared to the past mean annual salinity (Table 6.8). Salinities increased from 22.4 ppt to 25.0 ppt at McCormick Creek, from 14.9 ppt to 18.7 ppt at the mouth of Taylor River, from 17.3 ppt to 19.7 ppt at Mud Creek, from 18.7 ppt to 22.1 ppt at Trout Creek, and from 15.7 ppt to 22.8 ppt at West Highway Creek. During the current period, the mean annual salinity ranged from a minimum of 11.8 ppt at the mouth of Taylor River to a maximum of 32.8 ppt at McCormick Creek, which was the highest annual mean salinity recorded. The highest mean annual salinity for the period of record (34.5 ppt) also occurred at McCormick Creek in WY2005 (Figure 6.12).

Table 6.8. Mean annual salinity for the current period (WY2014–2017) and the period of record (WY1997–2017).

Site	Current period	Period of record
McCormick Creek	25.0	22.5
Mud Creek	19.7	17.3
Taylor River	18.7	14.9
Trout Creek	22.1	18.7
West Highway Creek	22.8	15.7

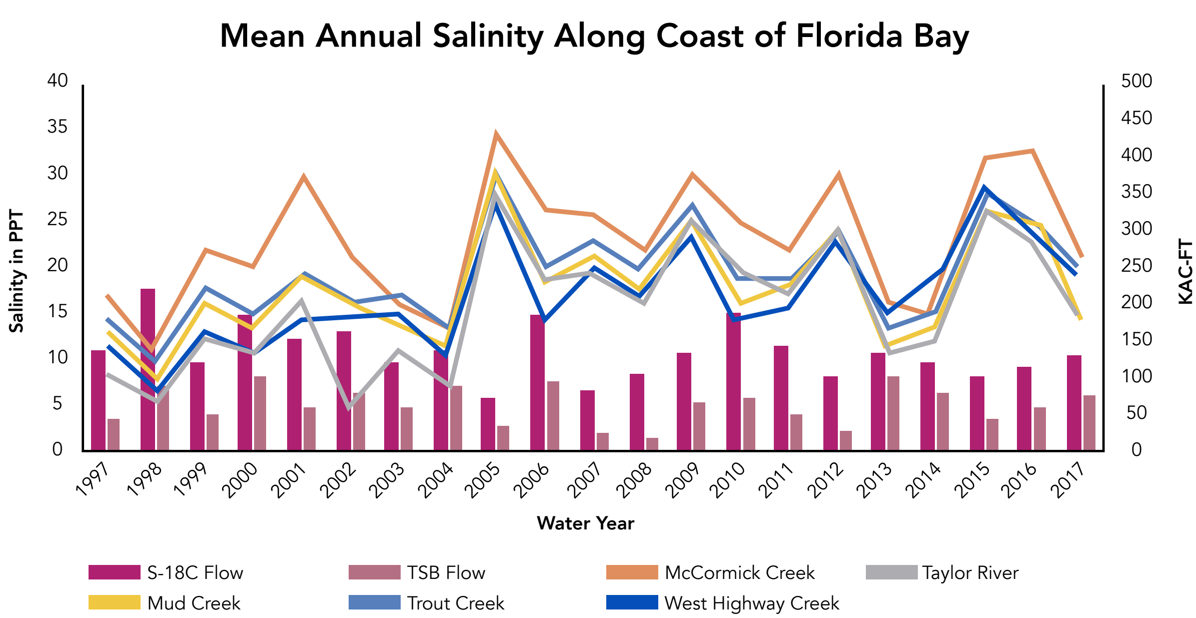


Figure 6.12. Annual mean salinity, in parts per thousand (ppt), along coastal Florida Bay at McCormick Creek, the mouth of Taylor River, Trout Creek, Mud Creek, and West Highway Creek, and annual mean flows, in 1,000 ac-ft (kac-ft), at S-18C and TSB from WY1997–WY2017.

Inflows from C-111 at S-18C and TSB are inversely related to salinity at the outlet stations that flow into Florida Bay. During the current reporting period, mean annual flow was lower at S-18C (-17.8%) and TSB (-6.6 %) than mean annual flow during the period of record at S-18C (140,533 ac-ft) and TSB (61,739 ac-ft). In WY2015, when outflows into Florida Bay were about 60% below the mean for the period of record, salinity was substantially higher at all outflow monitoring stations, and a seagrass die-off and algal blooms occurred.

The maximum daily mean salinity for the current reporting period was 59.4 ppt at McCormick Creek in WY2016, the highest daily mean salinity recorded for the period of record at all sites. The preceding WY2015 had the lowest measured annual mean flow to Florida Bay (122,309 ac-ft) for the current reporting period. The minimum daily mean salinity during the current reporting period (0.5 ppt) occurred at West Highway Creek in WY2014; the minimum daily mean salinity for the period of record was 0.2 ppt at West Highway Creek (WY1997 and WY1998), at Trout Creek (WY1997), and at the mouth of Taylor River (WY2004).

Conclusions. Water management modifications and restoration efforts are designed to decrease salinities along the coast of ENP and Florida Bay, and to improve the quality, quantity, timing, and distribution of flow into ENP. Optimizing water management operations in the upper TS watershed and the C-111 Drainage Complex is expected to reduce salinity in Florida Bay by increasing freshwater flows. Allowing additional flows from the Tamiami Canal outlets, such as the 1-Mile Bridge and the soon to be completed 2.6-Mile Bridge, and optimized water management operations, could directly benefit Shark River Slough and ultimately Florida Bay.

Chlorophyll a

Florida Bay has a history of dramatic changes in ecological state, most prominently with the occurrence of large-scale seagrass die-off events, which most recently occurred in 2015 (see Florida Bay SAV). Phytoplankton blooms may be a cause and/or an effect of die-off events and blooms were evident in years following the late 1980s die-off event. Such blooms are of ecological concern because they can sustain a cycle of seagrass die-off and also impact sponge populations (Rudnick et al. 2005; Butler et al. 1995; Stevely et al. 2010).

Results from the phytoplankton bloom stoplight indicator scores for Florida Bay's regions (WFB, SFB, NCFB, and the eastern boundary BMB; Table 6.9) show differing patterns among regions, but overall had annual median chla concentrations similar to the indicators' reference period, such that 39 of 70 stoplights (56%) were green since 2005, compared to a statistical expectation of 50% with no change. However, at a region specific level, this inference of similarity breaks down. Most striking are the long successions of years with green stoplights in western and north-central bay regions, from WY2005 through 2016 in the former and WY2008 through 2015 in the latter. Good (green) years ended following the seagrass die-off of the summer and fall of WY2016, which occurred only in these two regions. The time series of chla concentrations within these years, with elevated concentrations after the die-off, is consistent with the die-off being a cause of phytoplankton blooms in these regions (Kelly 2018).

Storm events also strongly influence phytoplankton blooms in Florida Bay, with blooms occurring after several hurricanes, including Hurricane Irene in 1999, and Hurricanes Katrina, Rita, and Wilma in 2005. Though Hurricane Irma occurred outside the reporting period in 2017, preliminary observations can be made about the storm's impact in the region. Phytoplankton blooms appeared to be immediately and strongly stimulated by Irma's disturbance, with chla concentrations hitting record high values at almost all north-central and western bay sampling sites. Irma appeared to stimulate phytoplankton in other regions of the bay to a variable extent, with relatively strong influence in the northeastern bay and weak influence in the southern bay. These patterns are consistent with storm influence being driven by increased watershed stages and flow increasing the export of wetland nutrients to the bay, and the mobilization of nutrients already within the bay.

Table 6.9. Florida Bay algal bloom indicator stoplight scores, based on Boyer et al. 2009. Green results are good, yellow are fair, and red are poor. Results are derived from chla concentrations. Sub-regions shown are: western Florida Bay (WFB); southern Florida Bay (SFB), north-central Florida Bay (NCFB); northeastern Florida Bay (NEFB); and Barnes Sound, Manatee Bay, and Blackwater Sound (BMB).

Water year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
WFB	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow
SFB	Green	Yellow	Yellow	Red	Green	Yellow	Green	Green	Green	Green	Yellow	Yellow	Green
NCFB	Green	Yellow	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow
NEFB	Green	Red	Yellow	Yellow	Green	Green	Yellow	Yellow	Red	Yellow	Green	Green	Green
BMB	Green	Red	Red	Red	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green

Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) status in Florida Bay was scored per water year using a subset of the indicator established for the stoplight indicator reporting (Madden et al. 2009). The score is a composite referred to as seagrass abundance Index A in Madden et al. (2009) and includes spatial extent (percent of all sampling locations where seagrass was present) and abundance (average density of seagrass cover where seagrass was present). Sampling and scoring was performed in 19 individual basins within Florida Bay (Figure 6.13). Since Index A is a stoplight indicator with 3 levels (Red, Yellow, and Green), these were converted to 0, 50, and 100, respectively, for each basin and water year and then averaged across regional zones to produce scores on the scale of 0 to 100 for this report. Each zone contains at least 2 individual basins (Table 6.10). SAV sampling for each water year was performed in May, and thus, represents the condition when the water year started and does not include effects of events that happen within that water year. For example, the seagrass die-off that occurred during the summer of 2015 (WY2016) is not reflected in the score until WY2017 since it occurred after the May 2015 sampling.

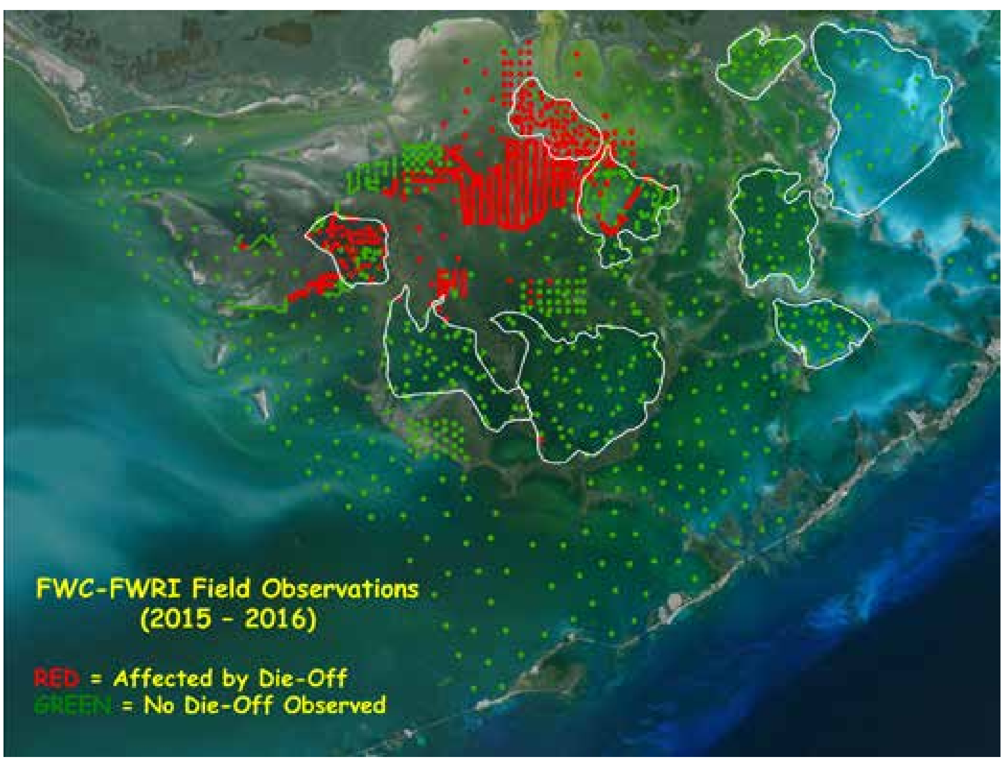


Figure 6.13. A visual survey was performed after the die-off to identify the region affected by the die-off including the area outside of the normal sampling basins (white outlines). The red dots represent locations where divers verified visibly impacted seagrass. Some areas were not accessible by boat due to extremely shallow water depths.

Across the 11 water years, baywide SAV index scores ranged from 51–70% and averaged 60% (Table 6.10). However, there was high variation among the five zones, with scores from 25% in the Southern region for most water years to 100% in the Northeast and Western zones in WY2014 and 2008, respectively. The Central and Southern zones consistently had the lowest scores ≤50%, while the Northeast and Transition zones maintained scores ≥60% (Table 6.10).

In WY2016, a seagrass die-off of *Thalassia testudinum* (turtle grass) in central Florida Bay was observed as a result of hot, dry, and salty conditions in the southern part of Everglades National Park (Hall et al. 2016; SFWMD 2017). The die-off was focused near the boundary between the Central and Western regions with one basin in either region showing impacts (Figure 6.13). Thus, the decrease in scores from WY2016 to WY2017 is muted. The Central and Western regions did experience a 34% and 33% decrease, respectively. The basin that was most impacted, Rankin Lake, decreased in spatial extent (percentage of sampling locations that had any seagrass) from 100% to 68% between WY2016 and WY2017 and the local abundance index (average density where seagrass is present on a scale of 0 to 1) decreased from 0.57 in WY2016 to 0.32 in WY2017 representing a 44% loss. Since the die-off primarily impacted the dominant species of seagrass in this area (*T. testudinum*), the presence of mixed seagrass species prevented complete denuding of the Bay bottom and allowed for faster recruitment afterwards. A mix of seagrass species in these areas is a restoration goal. SAV in the rest of the bay was maintained or increased during this period (Table 6.10).

The baywide SAV abundance measure for Florida Bay improved in WY2018 from 51% to 60%. This improvement is exemplified by a 0.5-fold increase at Rankin Lake, which coincided with the Central Bay score returning to the WY2016 level at 38% from 25%. The Western Bay score also returned to the WY2016 level in WY2018. Concurrent with these improvements in the Central and Western Bay was the expansion of the seagrass *Halodule wrightii* (shoal grass) colonizing bare sediment left by the death of *T. testudinum* indicating the beginning of successional recovery.

The increase in water column chlorophyll after Hurricane Irma in the summer of 2018 reduced available light to the seagrass community. Thus far, no further loss of seagrass has been observed, but the recovery may have been slowed since field impressions of recent conditions indicate that the extent and density of *H. wrightii* had stopped increasing.

Table 6.10. SAV abundance scores (0–100%) based on abundance for individual water years (WY) 2008–2017 across Florida Bay and within regional zones. SAV sampling occurs in 19 total basins within Florida Bay and can be separated into five zones. Each zone is composed of multiple basins (n). Scores are averages across the basins that comprise each zone.

Zone	n	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Baywide	19	70	60	64	61	57	60	60	60	56	51
Northeast	6	83	83	75	83	75	92	100	83	83	83
Transition	5	90	80	70	70	60	70	60	80	60	70
Central	4	50	38	50	50	50	38	38	38	38	25
Southern	2	25	25	50	25	25	25	25	25	25	25
Western	2	100	75	75	75	75	75	75	75	75	50

Zones: Northeast—Barnes Sound, Blackwater Sound, Duck Key Basin, Eagle Key Basin, Manatee Bay, Little Blackwater Sound
Transition—Alligator Bay, Davis Cove, Joe Bay, Little Madeira Bay, Long Sound
Central—Calusa Key Basin, Madeira Bay, Rankin Lake, Whipray Basin
Southern—Crane Key Basin, Twin Key Basin
Western—Johnson Key Basin, Rabbit Key Basin

Spotted Seatrout

Spotted seatrout is an important sportfish in Florida Bay. A Mann-Whitney U-test was used to determine significant differences in juvenile spotted seatrout densities between years within each sub-region. 2016 and 2017 were "high-population" years for juvenile spotted seatrout within most sub-regions of Florida Bay (Figure 6.14). It is important to note that these "high-population" years were not the result of improved water management in south Florida. Instead, both 2016 and 2017 had high rainfall and runoff to Florida Bay leading to better habitat quality for juvenile spotted seatrout in Florida Bay. It is also important to note that these two "high-population" years followed 8-years of "low-population" that led to decreased catch rates of adult spotted seatrout in some areas of Florida Bay.

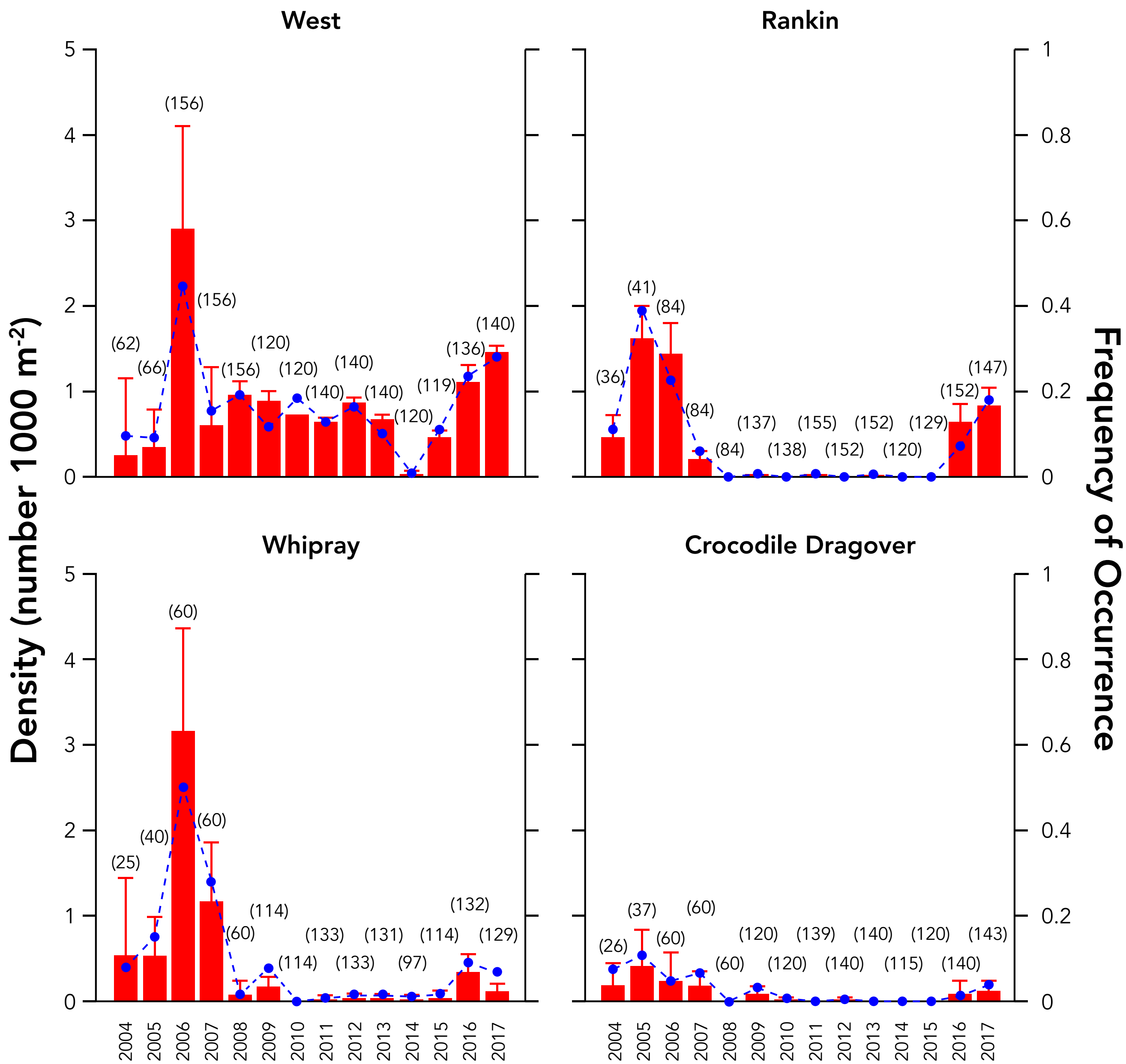


Figure 6.14. Density (number 1000 m^{-2} + standard error) as a bar chart with each error bar representing the standard error and frequency of occurrence as a scatter plot for juvenile spotted seatrout by area and year in Florida Bay. Values in parentheses indicate the number of stations sampled.

Roseate Spoonbills

Roseate spoonbills (*Platelea ajaja*) have been demonstrated to be an umbrella indicator species for Everglades restoration efforts that affect Florida Bay and metrics have been defined to assess the response of spoonbills to restoration efforts (Lorenz et al. 2009). The indicator metrics for spoonbills are total nest numbers for all Florida Bay and the numbers of nests for northeastern and northwestern areas, and estimated nest production and nesting success for the northeastern and northwestern nesting areas of Florida Bay, Figure 6.15.

Spoonbills were largely extirpated in Florida before 1900 due to excessive hunting for the millinery trade. In 1935, spoonbill nesting activity was found on Bottle Key in southern Florida Bay and intermittent estimates of total nest numbers have been collected since (Figure 6.16). Although spoonbills nest throughout Florida Bay (Figure 6.15), nesting became most concentrated in the northeastern region of the Bay beginning in about 1960 (Figure 6.16). Birds nesting in this region concentrate their foraging in the dwarf mangrove forests that line the mainland coast from Taylor River to Card Sound. Nest numbers began to decline following the completion of a set of canals and water control structures known as the South Dade Conveyance System (SDCS) in 1984. Spoonbills also began concentrating nesting in the northwestern region of Florida Bay (Figure 6.15) in the 1970's with a steady increase in numbers that coincided with the declining numbers in the northeastern region in the 1980's, however, numbers in the northwestern region also began to decline in the mid-2000's (Figure 6.16).

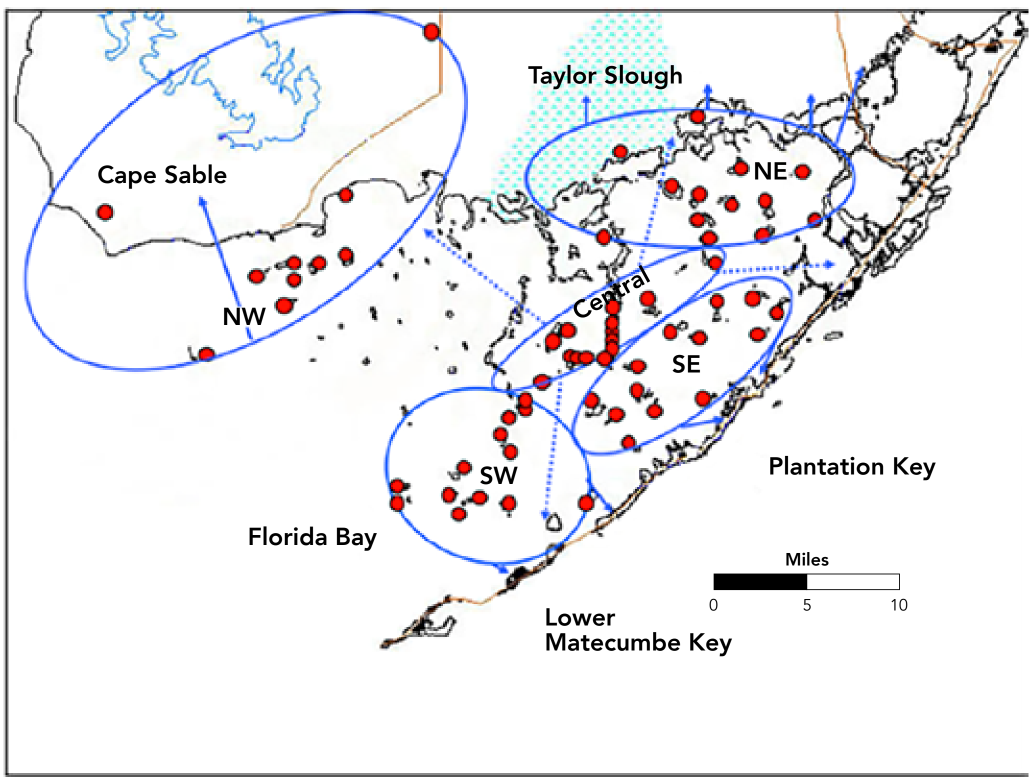


Figure 6.15. All known nesting locations (red circles) of roseate spoonbills in Florida Bay divided by regions (blue rings). Arrows indicate the primary foraging locations for each region.

Originally, the metrics for the northeastern and northwestern regions were aggregated together with the metric with the lowest estimate from either region being used to evaluate restoration efforts (Lorenz et al. 2009). The decision to aggregate the two regions was made before the now apparent decline in nest numbers in the northwest region. Given the rapid decline in nesting in the northwestern region, the regions should be evaluated separately because each region will be influenced by different components of restoration efforts. The northeastern region will be responding to restoration efforts that focus on Taylor Slough and the SDCS while the northwestern region will be more influenced by projects that restore Shark River Slough and Cape Sable.

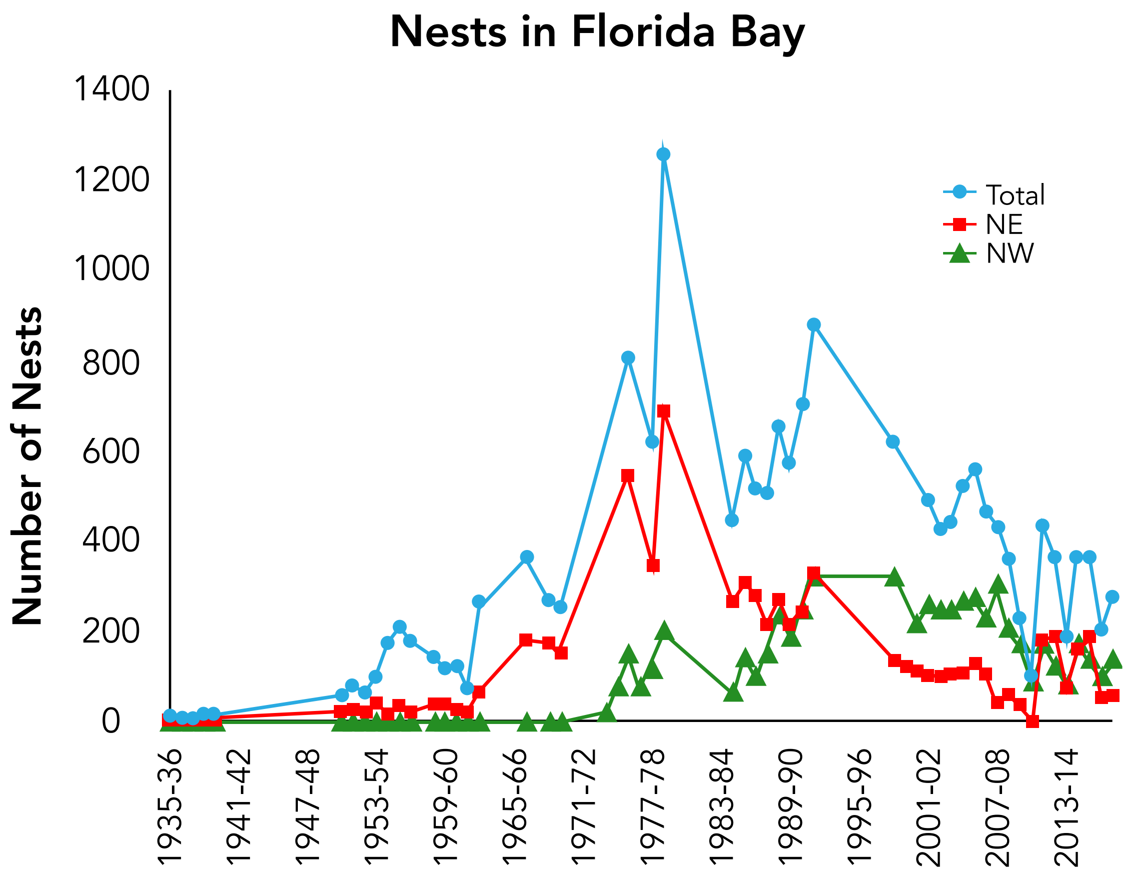


Figure 6.16. Number of roseate spoonbill nests in Northeastern, Northwestern, and overall Florida Bay.

The target for total spoonbill nests is 1258, the highest number of nests prior to completion of the SDCS. The scores are the average nests from the previous five years expressed as a percentage of 1258 (Table 6.11). All years from the 2012–13 nesting cycle through 2017–18 ranged from 21% to 27% and show no trend in response to ongoing restoration projects that affect Florida Bay.

The metric for the number of nests in northeastern Florida Bay is the five-year average expressed as a percentage of 688 nests (the maximum number of nests recorded prior to SDCS completion). This metric was even less encouraging than the total nests in Florida Bay ranging from between 14% to 23% and shows no change in trend in response to completion and operation of the C-111 Spreader Canal Western Project (C-111 SCWP) CERP project in 2012. The project was designed to increase flows through Taylor Slough but certain operations that were part of the design structure for the C-111 SCWP have not been implemented and the restoration benefits of the project have not been realized.

The metric for the number of nests in the northwest region is also expressed as a percentage, but is based on the minimum, maximum, and mean of the number of nests found in the northwest region at the time the metrics were established. Although better than either the total nests and northeastern region nests metrics, this metric indicates that the northwestern region is also declining. The metric ranged from 19% to 33% over the six-year period and followed a mostly declining trend. This region is dependent on projects that will restore flows to Shark River Slough and projects associated with Cape Sable which largely remain unimplemented.

Nest production is the average number of chicks produced per nest attempt (c/n) for a given year. The metric is the five year mean of these estimates and is expressed as a percentage of several thresholds (0–0.7 c/n is a declining population, 0.7 to 1.0 c/n is stable, >1.0 c/n is an increasing population, and 1.38 c/n was the average production prior to completion of SDCS). The nesting success metric is the percentage of years out of the past 10 that spoonbills nested successfully (i.e., produced 1.0 c/n or more on average).

For each region, the lowest of the two scores is the nest production and success metric. In the northeast, the nest production metric was high in 2012–13 (82% of target), but has steadily declined to 34% in 2017–18 (Table 6.12). In spite of this, spoonbills nesting in the northeastern bay have nested successfully in almost every year with 70% in 2012–13 and increasing to 80% from 2014–15 to 2017–18 (Table 6.12). The overall metric score for the northeast region is therefore the same as the nest production score except for 2012–13 when the nesting success metric (70%) was lower than the nesting production metric (82%; Table 6.12). In contrast to the northeastern region, spoonbill production in the northwestern region has greatly improved in recent years with a steady increase from 34% in 2013-14 to 88% in 2016–17 followed by a slight drop in 2017–18 to 79% (Table 6.12). The nesting success metric for the northwestern region was 60% for all years (Table 6.12). Therefore, the nest production and success metric for the northwest was the nest success metric for all years except for 2013–14 and 2014–15 when the nest production metric was lower than the success metric (Table 6.12).

The overall spoonbill metric is calculated as the average of the individual indicator metrics and can be thought of as the percentage of what the spoonbill population should look like if the bay were fully restored to pre-SDCS conditions. The overall spoonbill restoration metric ranged from 27% to 40% of restored for the period from 2012–13 to 2017–18 but appears to be approximately 30% in the more recent years with no indication that restoration efforts are improving the conditions needed for a fully restored indicator species.

Table 6.11. Individual annual scores for each metric and the overall spoonbill score as a percentage of a fully restored population.

Year	Total nests in Florida Bay score	Number of nests in NE Florida Bay score	Number of nests in NW Florida Bay score	NE production and success	NW production and success	Overall Spoonbill nesting score
2012-2013	24	14	33	70	60	40
2013-2014	21	14	21	45	34	27
2014-2015	23	18	20	53	46	32
2015-2016	27	23	25	37	60	34
2016-2017	24	19	19	39	60	32
2017-2018	22	16	20	34	60	30

Table 6.12. Scores of the nest production and nesting success metrics with the overall all combined metric for the two parameters.

Year	Nest production NE score	Nesting success NE score	NE production and success	Nest production NW score	Nesting success NW score	NW production and success
2012-2013	82	70	70	61	60	60
2013-2014	45	70	45	34	60	34
2014-2015	53	80	53	46	60	46
2015-2016	37	80	37	73	60	60
2016-2017	39	80	39	88	60	60
2017-2018	34	80	34	79	60	60

Prey Community

Fishes at six mangrove locations in the Taylor Slough and C-111 drainage basins north of Florida Bay have been sampled since 1990 (Figure 6.17). These areas were selected because they are primary foraging locations for wading birds nesting in Florida Bay. Since about 2000, sea level rise has been increasing water level at the historic foraging locations rendering them less suitable for wading birds foraging (roseate spoonbills in particular) prompting a reassessment of the published metrics (Lorenz et al. 2009). The prey fish indicator was originally a metric that was part of the Roseate Spoonbill Indicator but the spoonbill nesting parameters (nest numbers and nesting success) are strongly related to water depths at the foraging sites (Lorenz et al. 2009; Lorenz 2014) and therefore are directly affected by increasing sea levels. Given that spoonbill nesting metrics will be influenced by both restoration activities and continued sea level rise while the prey community structure will be more resistant to the effects of sea level rise, it was decided that the metric for prey community structure was a stand-alone indicator.

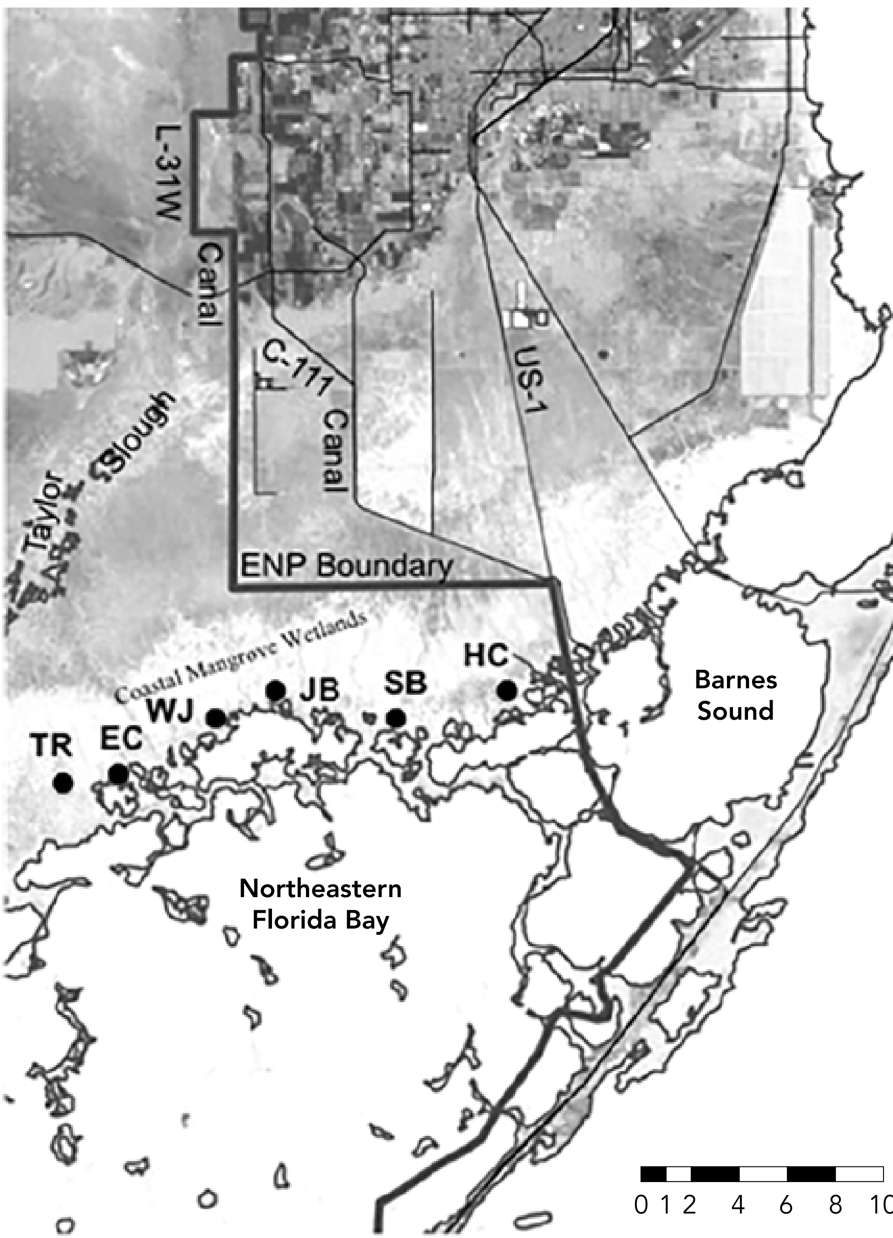


Figure 6.17. Location of six fish collection sites (black dots) in relation to the C-111 Canal.

Southern Coastal Systems

The prey community structure is the percentage of the fish prey base that are classified as freshwater species (Lorenz & Serafy 2006). This is based on the finding that prey are more abundant and have higher biomass when a significant component of all prey base fishes are freshwater species (Lorenz & Serafy 2006). Prey productivity is greater at lower salinity and the presence of freshwater species is representative of that increased production. The target is to have at least 40% of all prey fish be classified as freshwater with a percentage of higher than 5% indicating a positive response to restoration efforts.

Results cover the 5-year period from the 2012–13 water year to the 2016–17 water year (Table 6.13). The only year above the 5% threshold was 2013–14 although 2012-13 was nearing this threshold.

Table 6.13. Percentage of overall fish catch that were classified as freshwater species at the spoonbill foraging location presented in Figure 6.15.

Water year	Percent freshwater species of prey community
2012–2013	4.42
2013–2014	17.08
2014–2015	0.44
2015–2016	0.35
2016–2017	2.21

It was hoped that there would be a positive response seen in the prey community due to the completion and operation of the C-111 Spreader Canal Western Phase (C-111 SCWP). This project was completed in 2012, is located just upstream of the sampling sites and was designed to deliver more freshwater to the region. Unfortunately, the percentage of freshwater species was virtually non-existent for the two following years and still very low in 2016–17 indicating that the C-111 SCWP project may not be delivering the benefits that it was designed to have on Taylor Slough and Florida Bay, however, certain operations that were part of the design structure for the C-111 SCWP have not been implemented (i.e., raising the canal stages at the S-18C structure and minimizing flows to tide through the S-197 structure) and the restoration benefits may still be realized if these operations were implemented.

Crocodilians

At the end of WY17, current condition for the crocodile performance measure of growth in Florida Bay (from US-1 west to Cape Sable, including Buttonwood Canal and East Cape Canal) was 0.072 cm/day and below the restoration target of >0.15 cm/day. For the crocodile survival performance measure, current condition was 0.60 and well below restoration targets of >0.85 (Mazzotti et al. 2009; RECOVER 2015b).

The three-year trend in growth was stable. Data collected 1978–2015 in Everglades National Park (ENP), show a slower growth rate for crocodiles in NE Florida Bay compared with crocodiles from Flamingo/Cape Sable areas and West Lake area (Figure 6.18). High salinity conditions during the dry season strongly reduced growth rate (Briggs-Gonzalez et al. 2017a, c).

The five-year trend in mean monthly fall survival calculated using minimum known alive, is stable. Briggs-Gonzalez et al. (2017b) described calculating age-specific survival rates from capture-recapture of known-aged and marked individuals, rather than using the minimum known alive method. This new analysis is being incorporated to update crocodile survival targets. Using this new analysis with data from 1978–2015, crocodile hatchling survival was estimated to be 22% in south Florida (ENP and Biscayne Bay area, not including Turkey Point; Briggs-Gonzalez 2017c). One-year survival estimates varied between areas with low survival in NE Florida Bay (34%) relative to higher survival in Flamingo/Cape Sable area (53%) and Crocodile Lake National Wildlife Refuge (69%; Briggs-Gonzalez 2017c).

Targets for the crocodile performance measure of body condition are being developed (Fulton's K, calculated using snout-vent-length and mass). From captures made 1978–2015, average body condition was 2.17 and body condition was lowest for NE Florida Bay (Table 6.14), (Briggs-Gonzalez et al. 2017a, c). In the past

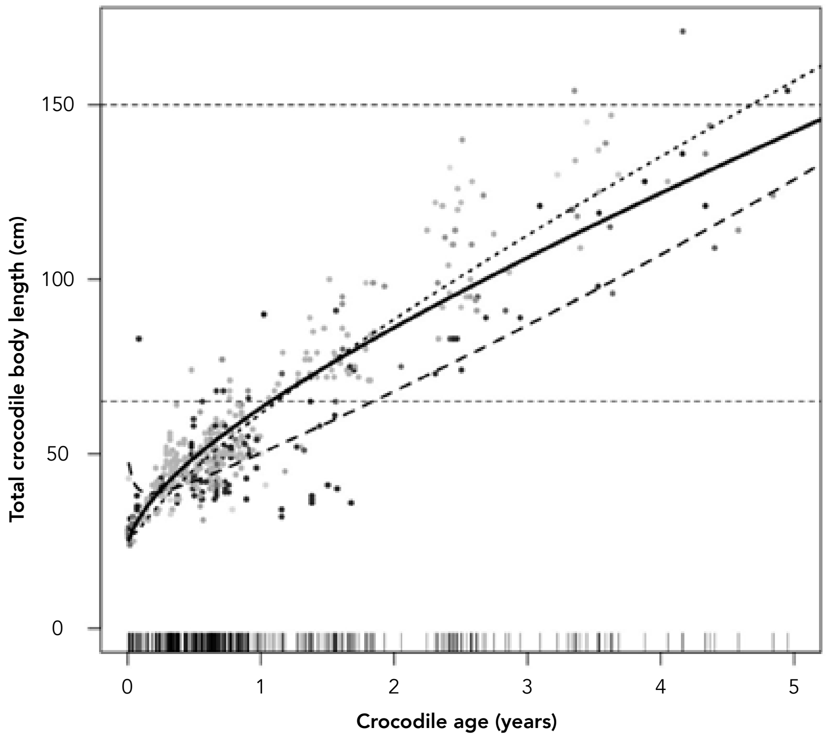


Figure 6.18. Growth from age 0 to 5 of American crocodiles (Crocodylus acutus) along a longitudinal gradient from captures 1978–2015. Tics represent frequency, dotted line represents 5% longitude (x = 493318, Flamingo and Cape Sable areas), bold line is average latitude (x = 523898, West Lake area) and dashed line is 95% longitude (x = 571612, NE Florida Bay). From Briggs-Gonzalez et al. 2017c.

ten years (2008–2017), crocodile body condition in NE Florida Bay has been increasing from an average of 1.82 to 2.07, but below average body condition in Flamingo and Cape Sable areas that are above 2.25 (Briggs-Gonzalez et al. 2018).

The crocodile performance measure of crocodile relative density or encounter rate targets are also being developed (number of crocodiles observed/km of shoreline surveyed). Nocturnal spotlight surveys were conducted from US-1 to Flamingo/Cape Sable from 2004–2015. Mean predicted value for crocodile relative density was 2.9 crocodiles/km and varied by location (Table 6.14). Estimates of crocodile relative density decreased with increases in salinity and showed a negative trend (Mazzotti et al. 2017).

There were 111 crocodile nests in Florida Bay in the WY17 nesting season. The majority of these (81) were in the Flamingo/Cape Sable area (Briggs-Gonzalez et al. 2018) compared with 30 in NE Florida Bay. From 2005–2016, 74% of crocodile nests were located in Flamingo/Cape Sable area (prior to 1995, historical nesting was in NE Florida Bay and accounted for 90% of crocodile nests (Briggs-Gonzalez et al. 2017a, b).

Table 6.14. Summary of relative density (#/km) and body condition (Fulton's K) of American crocodiles (Crocodylus acutus) in Everglades National Park and Biscayne Bay.

Location	Relative density (#/km)	Body condition (Fulton's K)
NE Florida Bay	0.92	2.03
West Lake Area	2.94	2.18
Flamingo/Cape Sable	11.65	2.26
Biscayne Bay	*not analyzed*	2.08

Diversion of freshwater flow from NE Florida Bay has been detrimental to crocodiles and is apparent in the performance measures with low crocodile growth and survival. With the completion of the C-111 Spreader Canal, freshwater flow and increased water delivery to Florida Bay will improve conditions and as more natural hydrologic patterns emerge, there should be an increase in growth and survival, increased relative density of crocodiles, and improved body condition. These projects, which are designed to increase freshwater flow into estuaries and lower salinities, will be beneficial to crocodiles over the next five years and increases in PMs and other metrics are expected, similar to what have been observed in Cape Sable area where restoration projects have improved conditions for crocodiles and other indicators (Brandt et al. 2014).

SOUTHWEST FLORIDA COAST

Flow

Lower Southwest Florida Coast hydrology

Restoration of the quantity, timing, and distribution of freshwater flow to the coast is critical to the health of the ecosystem within Everglades National Park (ENP). To evaluate restoration efforts, flows of several rivers and creeks within ENP were monitored from water years (WY) 1996 through 2017. Monitoring stations were instrumented in select rivers to represent flow from Shark River Slough and Lostmans Slough to the lower southwest coast (SWC) of ENP. During the monitoring period, three water operational periods were implemented: pre-Interim Operational Period (pre-IOP, WY1997–1999), Interim Operational Period (IOP, WY2000–2012), and the Everglades Restoration Transition Plan (ERTP, WY2013–2017). Annual flow volumes were compared during the three operational periods and also compared to the historical annual mean flow for the SWC of ENP and Florida Bay, respectively.

Flows to the Lower Southwest Coast of Everglades National Park

Five major river outlets (Lostmans River, Broad River, Harney River, Shark River, and North River) were monitored to represent the total flow to the SWC of ENP. The total annual flow volumes for the period of record (POR), WY2002–2017, are shown in Figure 6.19. The total annual flow volumes during the ERTP ranged from a minimum of 474,082 ac-ft in WY2015 to a maximum of 1,250,245 ac-ft in WY2014. During the ERTP, total annual flow was at or above the POR mean annual flow (1,110,297 ac-ft) in WY2013 and WY2014, but was below the POR mean in WY2015, WY2016, and WY2017. The lowest total annual flow to the SWC of ENP occurred in WY2015.

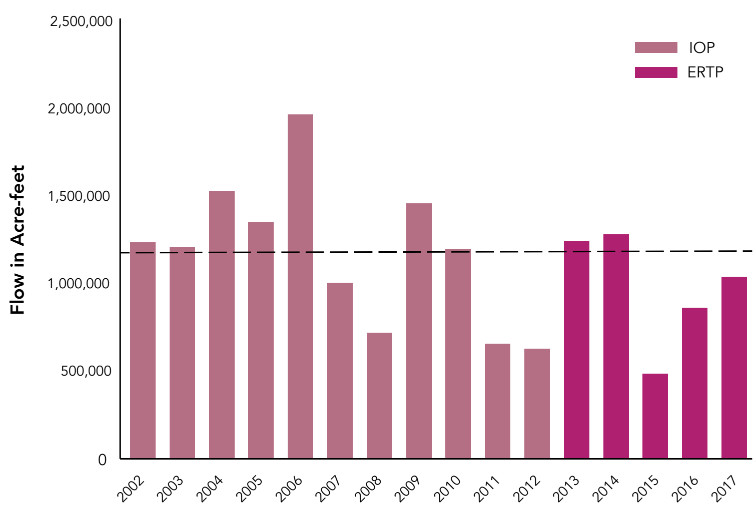


Figure 6.19. Total annual flows in acre-feet for the flow monitoring stations along the southwest coast of ENP. Dashed line is the mean annual flow (1,170,661 ac-ft) during IOP.

Total annual mean flows computed during the IOP and the ERTP were compared (Table 6.15). The total annual mean flow during the ERTP was about 190,000 ac-ft lower than the total annual mean flow during the IOP. The distribution of flow from Shark River Slough to the SWC of ENP during the IOP and the ERTP were also compared (Table 6.16). The results from Lostmans River were excluded from Table 6.16 because Lostmans River is located outside Shark River Slough. The percentage contribution of flows reported for Shark River and North River were higher during the ERTP than during the IOP. The results for the ERTP (Table 6.16) are likely lower for Harney River and higher for North River than actual flows due to large data gaps that occurred at Harney River in WY2015; nevertheless, the results indicate an eastward shift in the flow volume toward Shark River and North River when the WY2015 data are excluded.

Table 6.15. Summary statistics of rivers flowing to the SWC of ENP during the IOP and ERTP water operations.

Operational periods	Flow, in acre-feet				
	Minimum	Maximum	Mean	Median	Standard deviation
WY2002–2012 (IOP)	614,450	1,961,480	1,170,660	1,206,100	410,045
WY2013–2017 (ERTP)	474,082	1,250,245	977,496	1,019,649	314,407

Table 6.16. Percentage of flow along the southwest coast of ENP for the rivers draining Shark River Slough, WY2004–2017. Water years 2002-2003 were excluded due to incomplete years of flow data.

Basin	Flow, in percent of total flow	
	WY2004–2012 (IOP)	WY2013–2017 (ERTP)
Broad River	30	32
Harney River	37	9
Shark River	29	39
North River	4	21
Mean Flow	714,909	507,963

Upper Southwest Florida Coast

Freshwater flow to the TTI estuary has been altered by the construction of the Tamiami Trail and the Southern Golden Gate Estates (SGGE). The Picayune Strand Restoration Project (PSRP), which is associated with the CERP, has been implemented to improve freshwater delivery to the TTI estuary by removing hundreds of miles of roads, emplacing hundreds of canal plugs, removing exotic vegetation, and constructing three pump stations within the former SGGE development. Tributary flow during preliminary restoration for the Faka Union River (canal flow included), East River, and Pumpkin River during WYs 2008 and 2012, and 2014–2017 were analyzed to provide baseline data and preliminary analysis of changes due to restoration efforts.

Faka Union River was the main contributor of freshwater flow to the TTI estuary, and Pumpkin River provided minimal freshwater flow. The highest flows monitored at Pumpkin River (5,179 acre-feet) occurred in WY2014, corresponding with the highest rainfall (Figure 6.20). WY2014 is not available for East River. The highest flows monitored at Faka Union River (314,238 acre-feet) occurred in WY2017. The highest flows monitored at East River (43,461 acre-feet) occurred in WY2016, corresponding with the highest rainfall for the periods monitored. The rainfall data presented is from the SFWMD Dan House Prairie (DANHP) station, which is located near the Faka Union Canal weir at the Tamiami Trail. In WY2015 the percentage of monitored annual flow contributed by East River increased, and the percentage of flow contributed by Faka Union River decreased, compared to WY2008 and 2012. From WY2015 to 2017 the percentage of flow from East River as compared to Faka Union River remained between 12 and 24 percent. Pumpkin River accounts for 1% or less of the flow from the monitored tributaries and no changes in annual flow patterns have been observed at Pumpkin River.

During the study period, dry season streamflow (defined as November to April) at East River has generally increased compared to 2008 (Figure 6.25). While the 2017 dry season flows at East River were the lowest monitored since 2012, the overall dry season total flow value was positive, compared to 2008 which were negative. Higher dry season flows in East River may be in response to PSRP efforts. With PSRP, freshwater currently received by the Faka Union River and canal should be more evenly distributed spatially throughout the TTI region and increase freshwater flows at Pumpkin River.

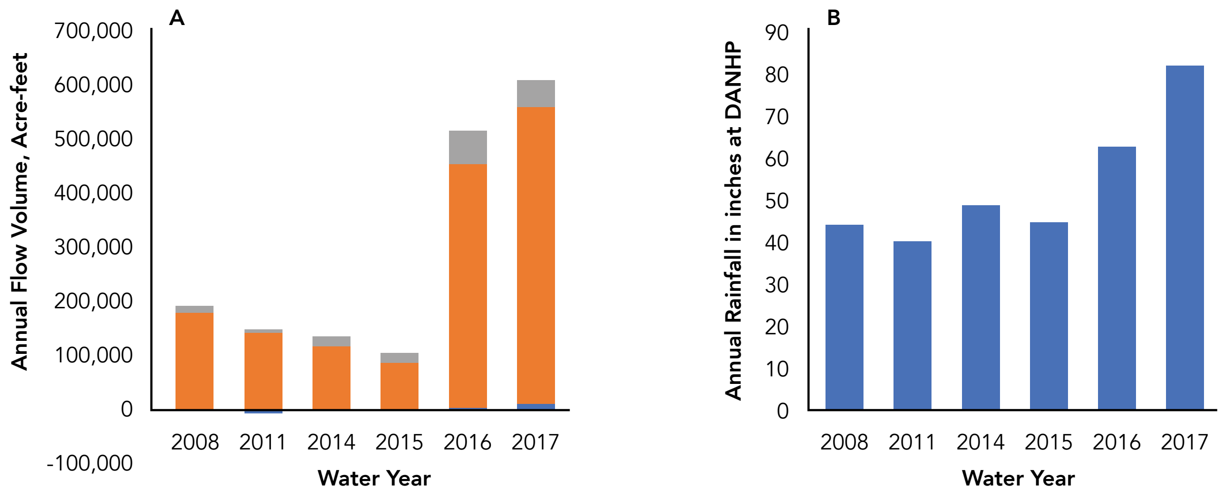


Figure 6.20. A. Annual flow volumes at Pumpkin River, Faka Union River and East River. Flows from Pumpkin River are minimal and cannot be seen on the graph for each year. B. Annual rainfall at SFWMD Dan House Prairie.

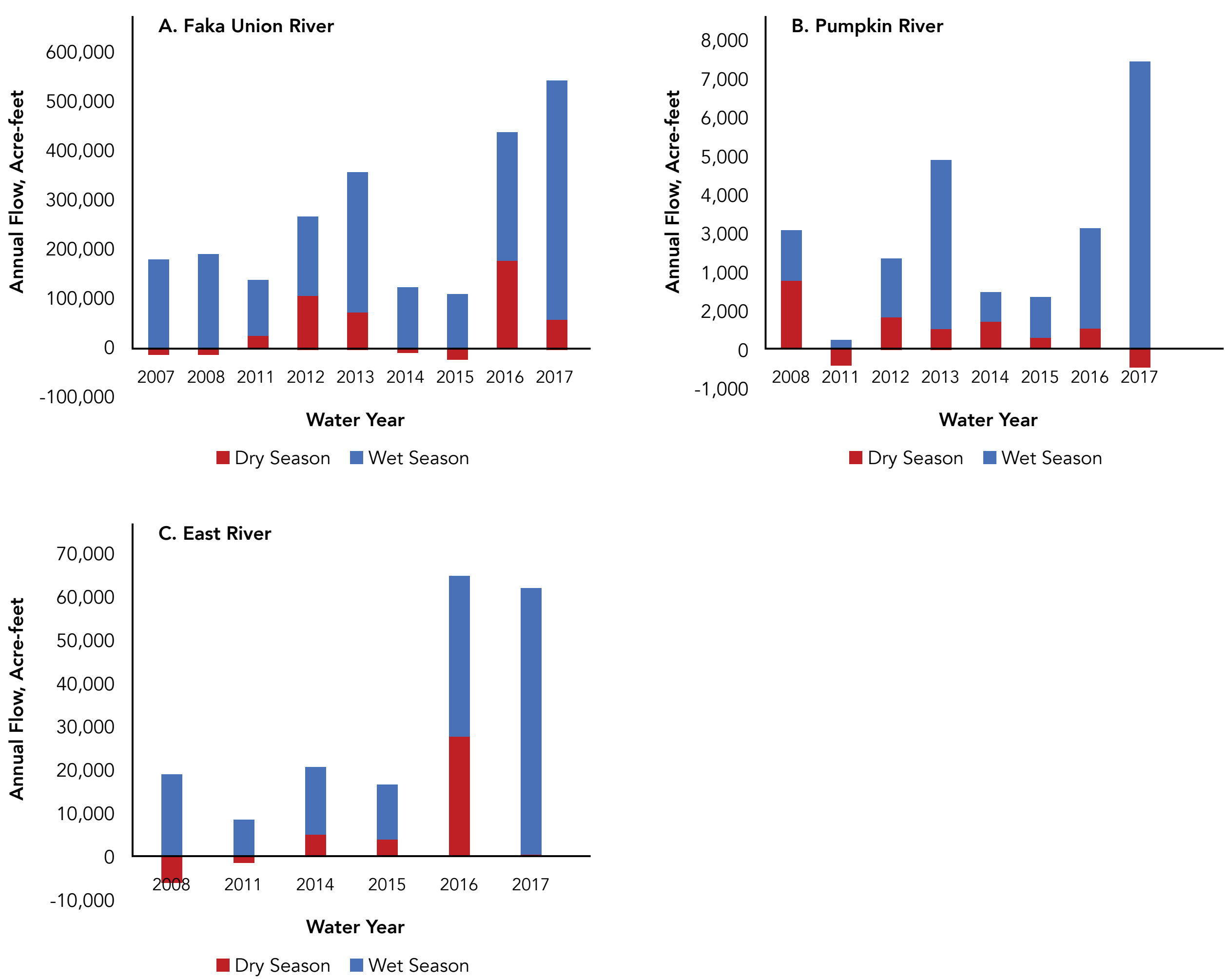


Figure 6.21. Annual flow at tidal tributaries, A, Faka Union River; B, Pumpkin River; C, East River.

Salinity

Lower Southwest Florida Coast

Salinity data collection for the Lower Southwest Florida Coast was discontinued in WY2014 at all USGS sites in the Shark River Slough.

Upper Southwest Florida Coast

Altered freshwater flows within the Ten Thousand Islands (TTI) region have caused large plumes of freshwater near the mouth of the Faka Union River, and elevated salinities in other tributaries, such as Pumpkin River. The Picayune Strand Restoration Project (PSRP) intends to redistribute the freshwater flow, creating more uniform salinity patterns within the Ten Thousand Islands Estuary. The United States Geological Survey (USGS) has monitored salinity at East River, Faka Union River, Pumpkin River, Blackwater River, and the Faka Union navigational channel boundary with the Gulf of Mexico (Faka Union Boundary) since 2007/2008. The sites to the west of Faka Union River had higher salinities, on average, than Faka Union River and East River (Figure 6.22). Faka Union River had the highest range in salinities, and Faka Union Boundary had the lowest range in salinities. Pumpkin River was the tributary with the lowest range in salinities. During water years 2011 to 2017 salinity was greater than 37 ppt, 9% of the time at East River, 8% of the time at Faka Union River, and 20% of the time at Pumpkin River. During the same timespan, salinities were less than 4 ppt 11% of the time at East River, 26% of the time at Faka Union River, and 0% of the time at Pumpkin River.

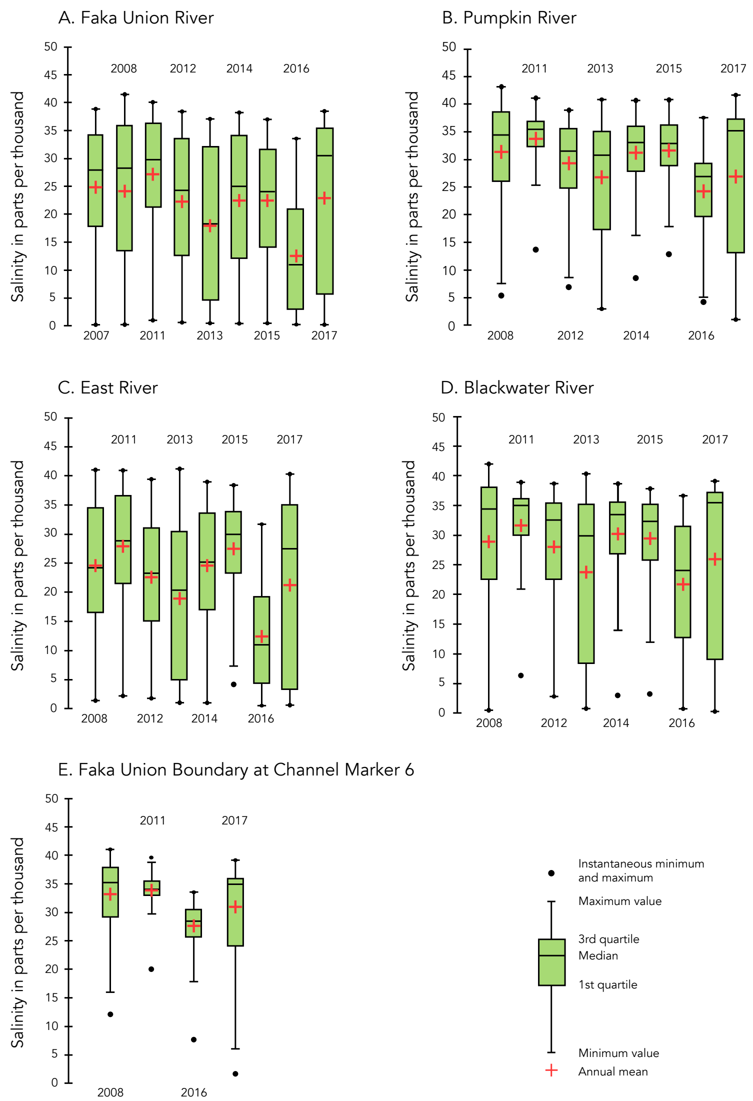


Figure 6.22. Boxplots showing salinity data by site and water year. A, Faka Union River; B, Pumpkin River; C, East River; D, Blackwater River; E, Faka Union Boundary at Channel Marker 6.

Water Year (WY) 2016 had the lowest annual median salinities recorded at all tributary stations. Faka Union River had the lowest instantaneous salinity measured during the study, 0.3 ppt in WY2016. The maximum salinity was 40.0 ppt in WY2012. The annual median salinity ranged from 14.1 ppt in WY2016 to 26.8 ppt in WY2017. The minimum salinity recorded at East River was 0.6 ppt in WY2017 and the maximum was 41.2 ppt in WY2014. The annual median ranged from 19.1 ppt in WY2016 to 27.9 ppt in WY2012. The minimum salinity recorded at Pumpkin River was 3.1 ppt during WY2013, and the maximum salinity recorded at Pumpkin River was 41.7 ppt in WY2017. Pumpkin River had the highest annual median salinity for the tributaries; values ranged from 28.4 ppt in WY2016 to 34.9 ppt in WY2011. The minimum salinity recorded at Blackwater River was 0.9 ppt in WY2017, and the maximum recorded was 40.4 ppt in WY2014.

The Faka Union Boundary station was located further from freshwater inputs than the other stations, and was expected to have more marine salinities, with less daily variation. WY 2017 is the only complete water year for the Faka Union Boundary station. In 2017 salinity ranged from 11.6 ppt to 38.7 ppt. The annual median was 32.9 ppt in WY2017.

Reductions in freshwater flow at the Faka Union canal should occur within the next five years as the PSRP progresses. Wet season salinities near the mouth of the Faka Union River should become less variable, and resemble more estuarine conditions. Freshwater that was once received by the Faka Union River and canal should be more evenly distributed spatially throughout the TTI region, decreasing salinities for western tributaries such as Pumpkin River.

Chlorophyll a

Water quality monitoring has been conducted by the SFWMD in inland and nearshore waters and by NOAA in more off-shore waters of the southwest Florida Shelf. In this report, the inland and nearshore sites at the Gulf of Mexico boundary (here called the Mangrove Transition Zone, MTZ) from Whitewater Bay to Cape Romano (including the Ten Thousand Islands, but excluding Rookery Bay) are included in a single region, as delineated in Boyer et al. (2009). The southwest Florida Shelf (SWFS) region parallels the MTZ region, but continues southward to the Florida Keys, west of Florida Bay.

The southwest coast's mangrove transition zone is a large area that includes strong inland-offshore and north-south gradients. With phosphorus supplied by the relatively P-rich Gulf of Mexico, and nitrogen supplied by the relatively nitrogen rich waters of the greater Everglades watershed, the area is highly productive, including the production of phytoplankton; the chla concentration thresholds between stoplights are higher here than in any other SCS sub-region (Table 6.17).

Over the past 13 years, there has been no clear pattern for the indicator in the MTZ, except the absence of annual medians above the 75th percentile of the pre-CERP reference period. Water quality conditions appear to have improved slightly since the reference period. In contrast, water quality conditions in the SWFS sub-region appear to have degraded since the reference period, with only one good year occurring in the past 14 years.

Table 6.17. Lower southwest coast algal bloom indicator stoplight scores, based on Boyer et al. 2009. Green results are considered good, yellow are fair, and red are very poor. Results are derived from chlorophyll a concentrations. Sub-regions shown are: Southwest Florida Shelf (SWFS); and southwestern mangrove transition zone (MTZ) from Whitewater Bay to Cape Romano. Years shown in black had insufficient data for reliable reporting.

Water year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
SWFS													
MTZ													

Conditions on SWFS reflect many large-scale functions along Florida's west coast, including nutrient output from multiple Florida watersheds, and the Mississippi River watershed. The extent to which Everglades restoration may influence these waters is uncertain, but likely to be relatively small at a large scale. Alternatively, the Florida Shelf boundary waters may have a strong effect on the southwest coast's mangrove transition zone, Florida Bay, and the Florida Keys. Phytoplankton blooms along the Everglades restoration boundary can impact CERP success.

Fish

Three key biotic indicators have been extracted for the Lower Southwest FL coast: common snook (*Centropomis undecimalis*), Florida largemouth bass (*Micropterus salmoides floridae*), and sunfishes (*genus Lepomis*). The first two are economically-valuable recreational fisheries in the Everglades, while the third constitutes an important prey source for them (Boucek & Rehage 2013). Monitoring efforts in the upper Shark River have been tracking the abundance of these three fish groups since 2004. This long-term dataset shows that the abundance of these species is highly seasonal, with a quadrupling of the snook and bass abundance between the wet and dry seasons, and a 12-fold increase in the abundance of sunfish prey in the dry season (Figure 6.23). These dry season increases in abundance are driven by 1) the displacement of marsh inhabitants into the estuary upon marsh drying (bass and sunfishes), and 2) the upstream movement of estuarine residents (snook). Snook move upstream to take advantage of this seasonal prey pulse that occurs most years (Boucek & Rehage 2013). The magnitude of this pulse is driven by hydrologic conditions (Boucek et al. 2016), and both snook and displaced marsh bass consume this pulse. Catches of all 3 groups in are negatively related to stage, such that more fish are caught at the lower stages of the dry season, showing this immigration and co-occurrence of predators and prey at the headwaters of the Shark River at the peak low flows of the dry season (Figure 6.24).

A desired condition was established for these coastal fishes by calculating a long-term average abundance over the 13 years of monitoring. The deviations from this long-term mean were evaluated across years for the 3 groups. Desired condition was focused in the dry season (shown as shaded horizontal lines in Figure 6.23), because these represent peak abundance in sampling, and thus cases where abundance was significantly lower than the long-term mean were examined. Notable deviations from the desired conditions occurred related to the 2010 extreme cold event, and the 2011 and 2015 droughts. For the 2010 cold event, there was significantly lower abundance of the tropical species snook between 2010–2012, with a recovery of high dry season snook numbers in 2013-4 (Stevens et al. 2016; Boucek et al. 2017). In contrast, the temperate taxa, bass and sunfishes, were unaffected by the cold event. For the two droughts, lower abundances were seen for all 3 groups in post drought years (2012 and 2015–2016, Boucek et al. 2016). Lower abundances post-drought may be the consequence of high mortality of the bass and sunfishes in the marshes, and to low movements of snook to the upstream reaches of the Shark River in response to low prey numbers.

For these three indicators, stressors driving deviation from the desired conditions relate to 1) extreme temperature events and 2) severe drying conditions. First, the 2010 cold event was the most severe cold event in the past 85 years (Boucek & Rehage 2014), and thus a climatic aberration that is largely unrelated to restoration actions (although responses to this climate event may interact with ecosystem state to drive effects). Severe drought conditions should be relieved by restoration actions. Increased freshwater inflows to Shark River Slough associated with CEPP and the construction of the second Tamiami Bridge should result in a lower frequency and severity of marsh drying that should lessen fish mortality and the lower fish abundances observed post-drought. Given the high 2016 flows and the extreme high flows resulting from Hurricane Irma, good conditions are expected for these indicators in the years to come.

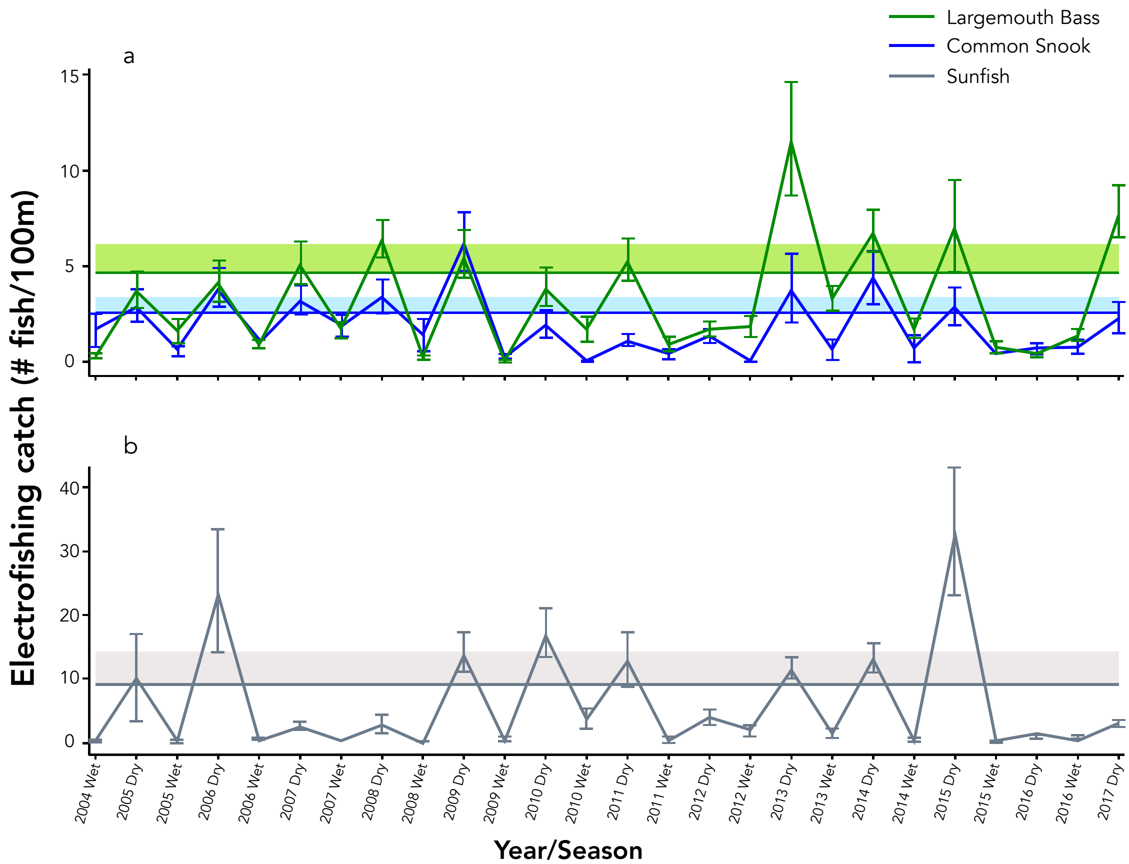


Figure 6.23. Time series of a) largemouth bass, common snook, and b) sunfish (prey) catch in the wet and dry seasons. Shaded area indicates +/- 1 SE (standard error) around the mean dry season catch (color-coded). Line at bottom of shading indicates the lower bound (-1 SE) used in assessment of deviations from a desired long-term average condition.

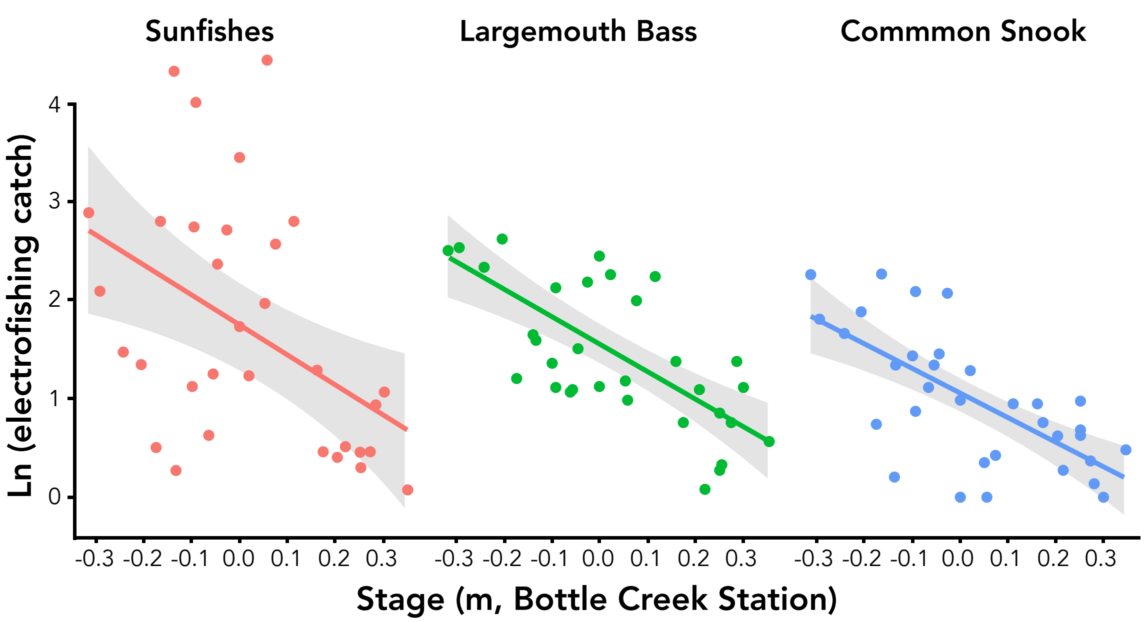


Figure 6.24. Relationships between electrofishing catch for the three key groups: sunfishes (prey), largemouth bass, and common snook, as a function of stage (Bottle Creek Station, headwaters of Shark River). Adjusted R squared values are 0.18 (sunfishes), 0.45 (bass), and 0.47 (snook).

Crocodilians

In WY17, the value for the current condition of the alligator performance measure relative abundance in Shark River Estuary (ENP-EST) was well below the target of >1.70 non-hatchling alligators/km (Hart et al. 2012; Figure 6.25). The current value of the body condition performance measure (Fulton's K, calculated using snout-vent length and mass) was below the restoration target of 2.27 (Figure 6.26).

The trend in relative abundance over the past 5 years was stable. The trend in body condition over the past 3 years was negative. Trends are a part of the performance measure and the target is to have a stable (if abundance exceeds 1.70 alligators/km or body condition exceeds 2.27 Fulton's K) or increasing trend (Mazzotti et al. 2009; RECOVER 2014b).

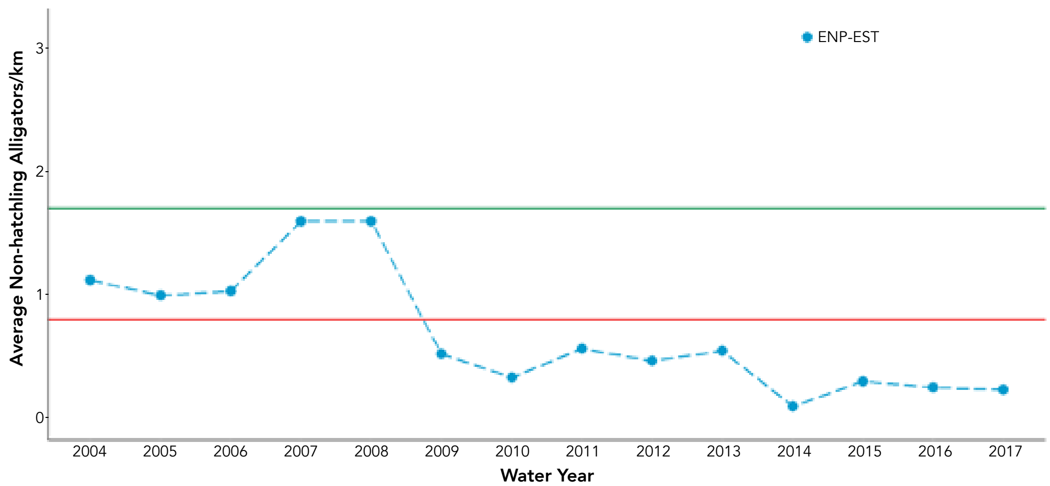


Figure 6.25. Average non-hatchling alligators/km of two spring surveys by water year in Shark River (ENP–EST). Top green line indicates restoration target. Bottom red line indicates conditions well below the restoration target. Red indicates substantial deviations from restoration targets creating severe negative condition that merits action. Green indicates the situation is within the range expected for a healthy ecosystem within the natural variability of rainfall.

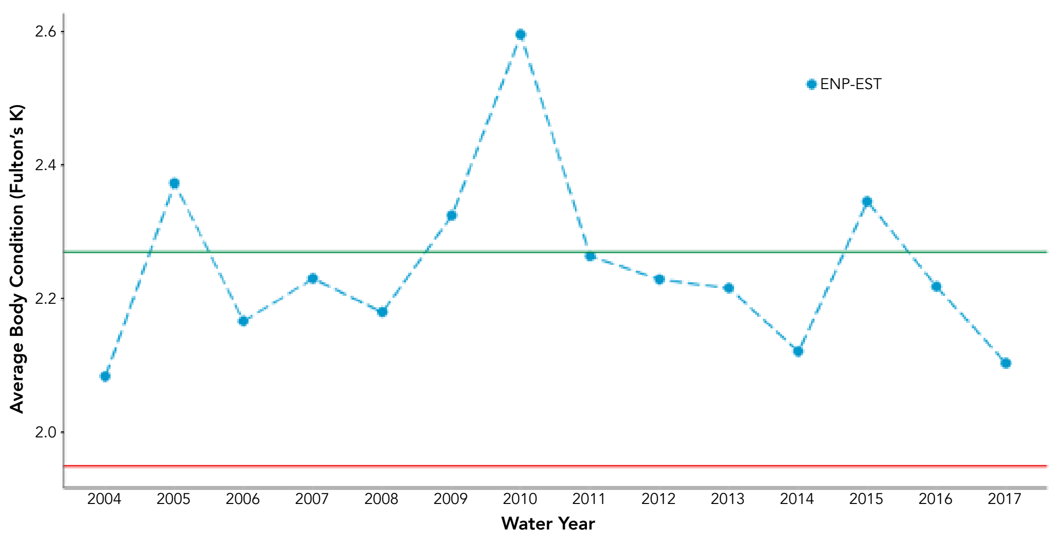


Figure 6.26. Average alligator body condition (Fulton's K) Shark River (ENP-EST). Sampling occurs in Spring and Fall. Top green line indicates restoration target. Bottom red line indicates conditions well below the restoration target. Red indicates substantial deviations from restoration targets creating severe negative condition that merits action. Green indicates the situation is within the range expected for a healthy ecosystem within the natural variability of rainfall.

Using data from 1998-2013, Fujisaki et al. 2016 documented higher abundance in Shark River in the wet season when salinity is generally lower compared to in the dry season when salinity is higher. In addition, there was a negative trend over time in number of alligators in the dry season and an overall negative effect of salinity on relative abundance. It's hypothesized that fluctuations in alligator body condition in Shark River are due to both fluctuations in salinity and fluctuations in food resources that may be fluctuating with changing salinity.

Encounters with American crocodiles on surveys and capture events in Shark River has begun. The expectation is that as the crocodile population increases and ecosystem restoration continues that more animals will be observed in rivers, ponds, and shorelines along the Southwest Florida Coast and more nests will occur on beaches exposed to the Gulf of Mexico.

Projects that increase freshwater flows to the southwest coast will have a positive impact on both alligators and crocodiles. Both will benefit from more natural salinity patterns that promote production of fish and other prey resulting in better body condition. In addition, as freshwater flows lower salinity, there will be more alligators and more alligator nesting adjacent to freshwater mangrove areas where they nested historically.

6.4 DISCUSSION

Drought conditions

Low rainfall conditions combined with high water temperatures plagued the Florida Bay Watershed throughout water years 2015–2016 (May 1, 2014 through April 30, 2016). This combination of environmental influences resulted in conditions for Florida Bay which violated the Florida Bay Minimum Flows and Levels (MFL). MFL criteria are thresholds beyond which significant ecological harm is expected to occur. This drought was documented in the 2017 South Florida Environmental Report (Figure 6.27).

Overall, the rainfall was so low that it fell below the 10th percentile by June 2015. This led to a lack of water flow (77,644 ac-ft) which contributed to high water temperatures, elevated beyond the 75th percentile from June to December 2015. Due to the drought, salinities in Florida Bay were elevated to as high as 70 ppt in central and western Florida Bay. All of these factors combined to cause violations of two of the MFL criteria (Figure 6.28), which means that significant ecological harm can occur, and was subsequently seen in the late summer of 2015 with a large-scale seagrass die-off (McDonald 2017).

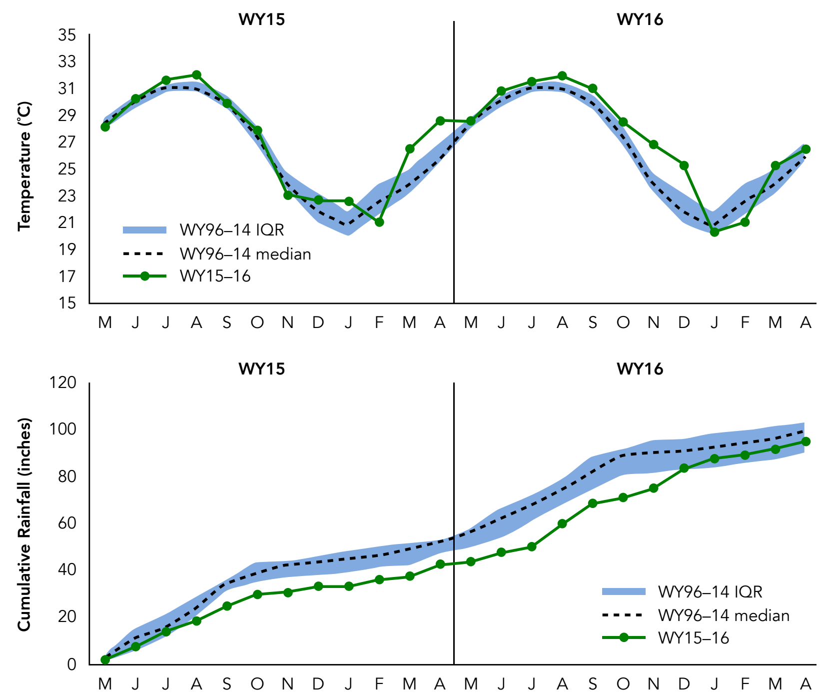


Figure 6.27. Temperature and cumulative rainfall for WY2015 and WY2016 as compared to the 25th, 50th, and 75th percentiles for the time period of WY1996–WY2014. The blue area represents the range between the 25th and 75th percentiles or the interquartile range (IQR). Temperature and rainfall data from 8 and 14, respectively, ENP platforms were averaged to produce a spatial composite for the southern ENP and northern Florida Bay area (McDonald 2017).

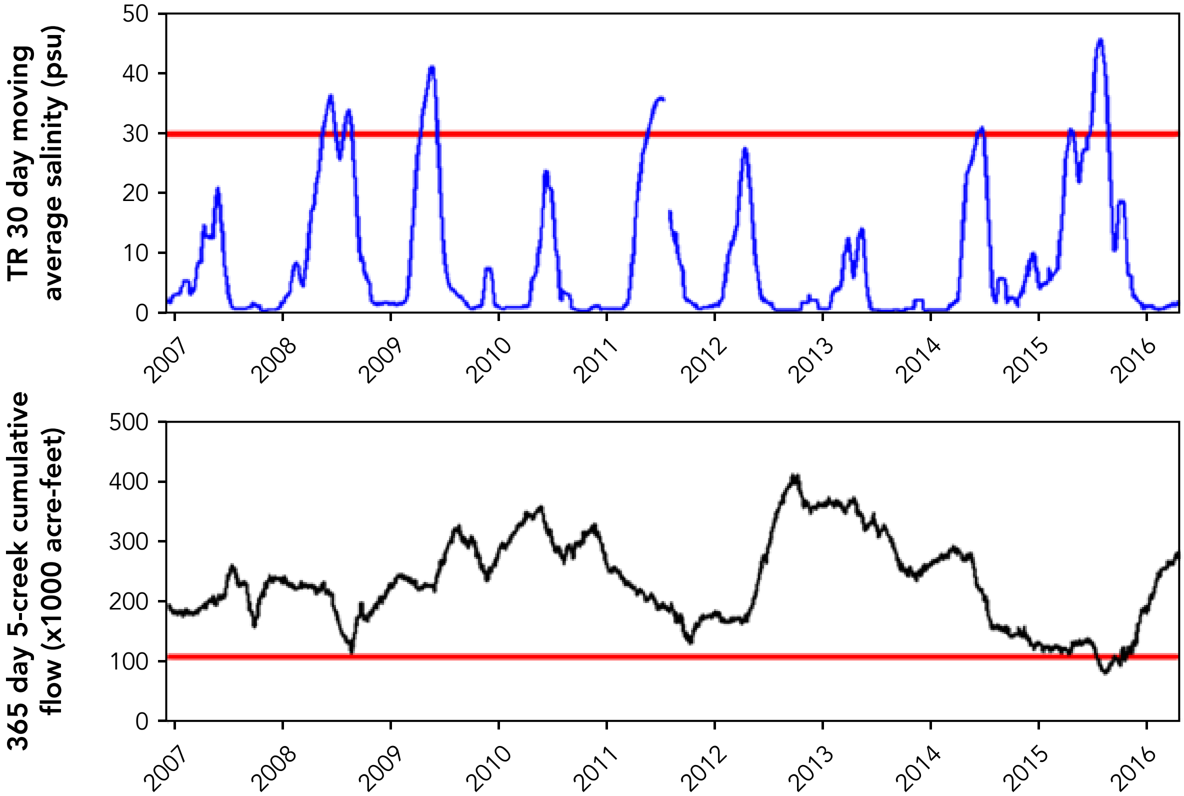


Figure 6.28. The two criteria tracked for the Florida Bay MFL Rule: (1) the 30-day moving average salinity at the ENP-Taylor River platform (top) and (2) the 365-day moving sum for flow from the five creeks (bottom). The 105,000 ac-ft flow threshold and 30 salinity threshold for the MFL criteria are denoted by red lines on the graphs. Flows below the red line and salinities above the red line constitute exceedances of the MFL. Flow data are provisional for October 2015 forward and supplied courtesy of USGS (McDonald 2017).

Chlorophyll a, algal blooms, and seagrass die-off

Water quality monitoring and assessment in the SCS provides information on the status and trends of nutrient concentrations, phytoplankton blooms, and light conditions. The phytoplankton bloom indicator is based on the concentration of chlorophyll *a* (chla) concentrations in the water column. These concentrations are a proxy of phytoplankton biomass and an indicator of overall water quality conditions, as phytoplankton biomass typically corresponds with the availability of nutrients and light in a given water body. This bloom indicator is relevant to the overall ecological health of the coastal system, as phytoplankton blooms can decrease light penetration through the water and impact the productivity and viability of SCS seagrass habitat (Rudnick et al. 2005; Kelble et al. 2005).

The indicator, from Boyer et al. (2009), is in the form of a "stoplight", and has been used in the South Florida Ecosystem Restoration Task Force report on System-Wide Ecological Indicators for Everglades Restoration. The goal is to sustain SCS spatial zone-specific long-term chla concentrations at or below the median concentration of SCS waters during a pre-CERP reference period (early-mid 1990s to 2004). In essence, the target is for CERP to "do no harm" to SCS water quality. Green, yellow, and red categories of the indicator correspond to observed annual median chla being below the reference median, between the reference median and 75th percentile, or above the reference 75th percentile.

Annual phytoplankton bloom stoplight indicator scores results from water-years (WY) 2017 and 2018 for all 10 sub-regions of the SCS, are shown in Figure 6.29. Scores are also presented for these sub-regions from WY2005 through 2018 in Table 6.18.

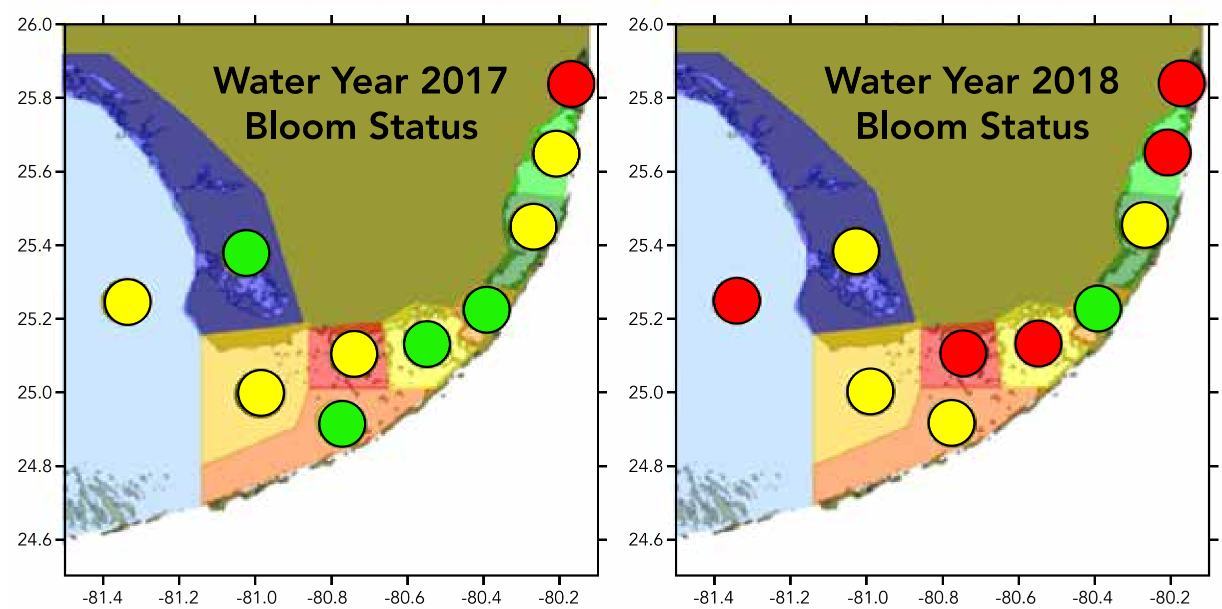


Figure 6.29. Southern Coastal Systems phytoplankton bloom stoplight indicator results for WYs 2017 and 2018. Hurricane Irma appears to have strongly impacted the indicator scores (bloom status) in WY2018.

Table 6.18. Florida Bay and lower southwest coast algal bloom indicator stop-light scores, based on Boyer et al. 2009. Green results are good, yellow are fair, and red are poor. Results are derived from chlorophyll a concentrations measured by SFWMD, Miami-Dade DERM, and NOAA monitoring programs. Sub-regions shown are: Southwest Florida Shelf (SWFS); southwestern mangrove transition zone (MTZ); western Florida Bay (WFB); southern Florida Bay (SFB), north-central Florida Bay (NCFB); northeastern Florida Bay (NEFB); Barnes Sound, Manatee Bay and Blackwater Sound (BMB); southern Biscayne Bay (SBB); central Biscayne Bay (CBB); and northern Biscayne Bay (NBB). The System-Wide score represents the median condition of the set of sub-regions, without spatial weighting. Years shown in black (B) had insufficient data for reliable reporting.

Water year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
System-wide	Green	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red
SWFS	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Red	Red	Gray	Gray	Green	Yellow	Yellow	Red
MTZ	Green	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Yellow
WFB	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow
SFB	Green	Yellow	Yellow	Red	Green	Yellow	Green	Green	Green	Green	Yellow	Yellow	Green	Yellow
NCFB	Green	Yellow	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Red
NEFB	Green	Red	Yellow	Yellow	Green	Green	Yellow	Yellow	Red	Yellow	Green	Green	Green	Red
BMB	Green	Red	Red	Red	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green
SBB	Yellow	Red	Red	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow
CBB	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Yellow	Red
NBB	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Red	Red

The primary findings from these results are: 1) that northern and central Biscayne Bay had poor indicator scores over the past five years; 2) most of the SCS had poor scores in WY2018, likely as a result of Hurricane Irma's impact; 3) after at least 8 consecutive years of good chla indicator scores in north-central and western Florida Bay, scores became cautionary (yellow) or poor in WY2016 or 2017, likely from nutrient release with seagrass die-off in summer and fall of WY2016, combined with Hurricane Irma impacts in WY2018; and 4) Hurricane Irma appears to stimulate phytoplankton blooms through most of the SCS.

Within the past decade, Biscayne Bay has been plagued with algal blooms and a seagrass die-off (Section 2.5). Since 2008 a bloom of green macroalgae (*Anadyomene* spp.) has persisted in the northwestern bay and once covered an area of approximately 60 km^2. The bloom has displaced once healthy seagrass beds, but it appears to be shrinking in spatial extent. The bloom is in an area of high levels of dissolved nutrients, as well as presence of sucralose which is an indicator of human waste water. Recently, an incipient bloom of green macroalgae (*Ulva ohnoi*; an introduced species) was detected in the Deering Estate area along the western shore of central Biscayne Bay.

In extreme northern Biscayne Bay in the Julia Tuttle Causeway Basin, a once large bed of high biomass/high density manatee grass (*Syringodium filiforme*) began dying off and by 2016 it was estimated that 45% of the bed had been lost. As the seagrass has died off in the basin, turbidity and sediment resuspension has increased which exacerbates the problem.

Exotic species

Invasion of exotic flora and fauna is an ever more prevalent concern in south Florida ecosystems. These species are able to occupy or take over niche space where no natural enemies occur. A number of these species outcompete native flora and fauna for resources, specifically food, water, and shelter. The knowledge level regarding specific impacts and the cumulative effects on the south Florida ecosystem is limited. It is uncertain what the presence of specific exotic species indicates about the state and overall health of the communities where they are found. Thus, exotic species are not included as an ecological indicator in this chapter. However, the significance of their presence and impact is an important issue in the SCS Region.

Florida has more nonnative reptiles and amphibians than anywhere else in the world, with 180 introduced species and more than 60 that are established (breeding) (Krysko et al. 2016). South Florida is particularly susceptible to nonnative wildlife invasions as a result of its subtropical climate, island-like geography, major ports of entry for animals into the United States, thriving trade in exotic pets, and occasional destructive hurricanes which increase risks of escapes and spread. Invasive aquatic species have already been recognized as a potential barrier to successful ecological restoration of greater Everglades ecosystems (National Research Council 2005; South Florida Ecosystem Restoration Task Force 2015).

Restoration of natural systems in south Florida is under increasing threat of invasion by nonnative reptiles, including Burmese pythons (*Python bivittatus*), northern African pythons (*Python sebae*), Nile monitors (*Varanus niloticus*), tegu lizards (*Salvator* & *Tupinambis* spp.), and spectacled caiman (*Caiman crocodilus*) (South Florida Ecosystem Restoration Task Force 2015). Multiple state and federal agencies along with universities and non-governmental organizations have joined together to manage this invasion and minimize impacts on ecosystem restoration (South Florida Ecosystem Restoration Task Force 2015). Information on the impacts of management activities of these nonnative reptiles is variable and informal.

Exotic species currently monitored in the SCS are: Burmese python, Argentine black and white tegu, and spectacled caiman. The pattern of invasion of the Burmese python throughout the SCS is: 1) their abundance is increasing; 2) their population distribution is expanding; and 3) they have an established impact. The pattern of invasion of the Argentine black and white tegu is: 1) their abundance is increasing; 2) their population distribution is expanding; and 3) they have an established impact. Lastly, the pattern of invasion of the spectacled caiman is: 1) there is no change in their abundance; 2) their population distribution is expanding; and 3) their impact has not been established but there is potential for impact on native species and communities.

6.5 RESTORATION

The Southern Coastal Systems Region relies on freshwater entering the Greater Everglades' southern estuaries in order to maintain ideal conditions for SAV and associated estuarine species. Large volumes of freshwater historically flowed south through the Everglades and were distributed via Shark River Slough, Taylor Slough, and historic rivers and creeks. However, reduced and channelized flows since the 1940's have significantly increased salinity, thereby degrading habitat and reducing fish and other fauna. Data provided in this chapter show the continued degradation of the SCS due to the lack of freshwater flow to and within the region. Restoration projects implemented through CERP will reestablish the freshwater flow in order to restore estuarine ecology in the southern Everglades (SCS Region). Current projects including BBCW and PSRP, will be nearing construction completion within the next 5 years (dependent on funding) which will provide a positive step forward in restoring freshwater flows along both the east and west coastal areas of the SCS Region. The C-111 projects and CEPP will provide freshwater to Taylor Slough and Shark River Slough, in turn providing freshwater to the centrally located areas of the SCS Region. These CERP projects will provide the proper balance of freshwater and saltwater, less turbidity, and a healthier and more robust habitat for recreational opportunities, such as improved fishing and wildlife observation for residents and visitors.

The status and anticipated activities of restoration projects affecting the SCS over the next 5 years are described below. Completion of these projects should move the restoration needle significantly closer to the desired conditions for the SCS.

Picayune Strand Restoration Project

The Picayune Strand Restoration Project (PSRP) encompasses an area of sensitive environmental land (most of Picayune Strand State Forest) located in southwestern Collier County between the Florida Panther National Wildlife Refuge to the north, Fakahatchee Strand State Park to the east, and Collier-Seminole State Park and Ten Thousand Islands National Wildlife Refuge to the south. Its purpose is "to restore and enhance the wetlands in Golden Gate Estates (previous name for PSRP) and in adjacent public lands by reducing over-drainage. Implementation of the restoration project plan would also improve the water quality of coastal estuaries by moderating the large salinity fluctuations caused by freshwater point discharge of the Faka Union Canal. The plan would also aid in protecting the City of Naples' eastern Golden Gate well field by improving groundwater recharge."

The selected plan from the 2004 Project Implementation Report/Environmental Impact Statement was Alternative 3D which divided the Picayune Strand Restoration Project in to a number of components. In 2016, a Limited Re-evaluation Report identified design refinements necessary to the Picayune Strand Project in order to better achieve goals, while reducing potential harmful impacts to the Florida manatee, and to provide better flood risk management. As of April 2018, three pump stations (Merritt, Faka Union, and Miller) have been constructed, Prairie Canal and Merritt Canal have been plugged, and most roads east of Miller Canal have been cleared to natural grade, and the tieback levee and manatee mitigation feature have been constructed. In FY18-19, the Eastern Stair-steps will be plugged and eastern 1 mile of 118th Ave SE and 134th Ave SE will be cleared to natural grade. The Southwest Protection Feature is currently in the planning and design phase and is not anticipated to be constructed until FY21/22. The remaining project components will not be completed until the Southwest Protection Feature is implemented. More detailed information regarding the Picayune Strand Restoration Project can be found at: http://www.saj.usace.army.mil/Missions/Environmental/Ecosystem-Restoration/Picayune-Strand-Restoration-Project/.

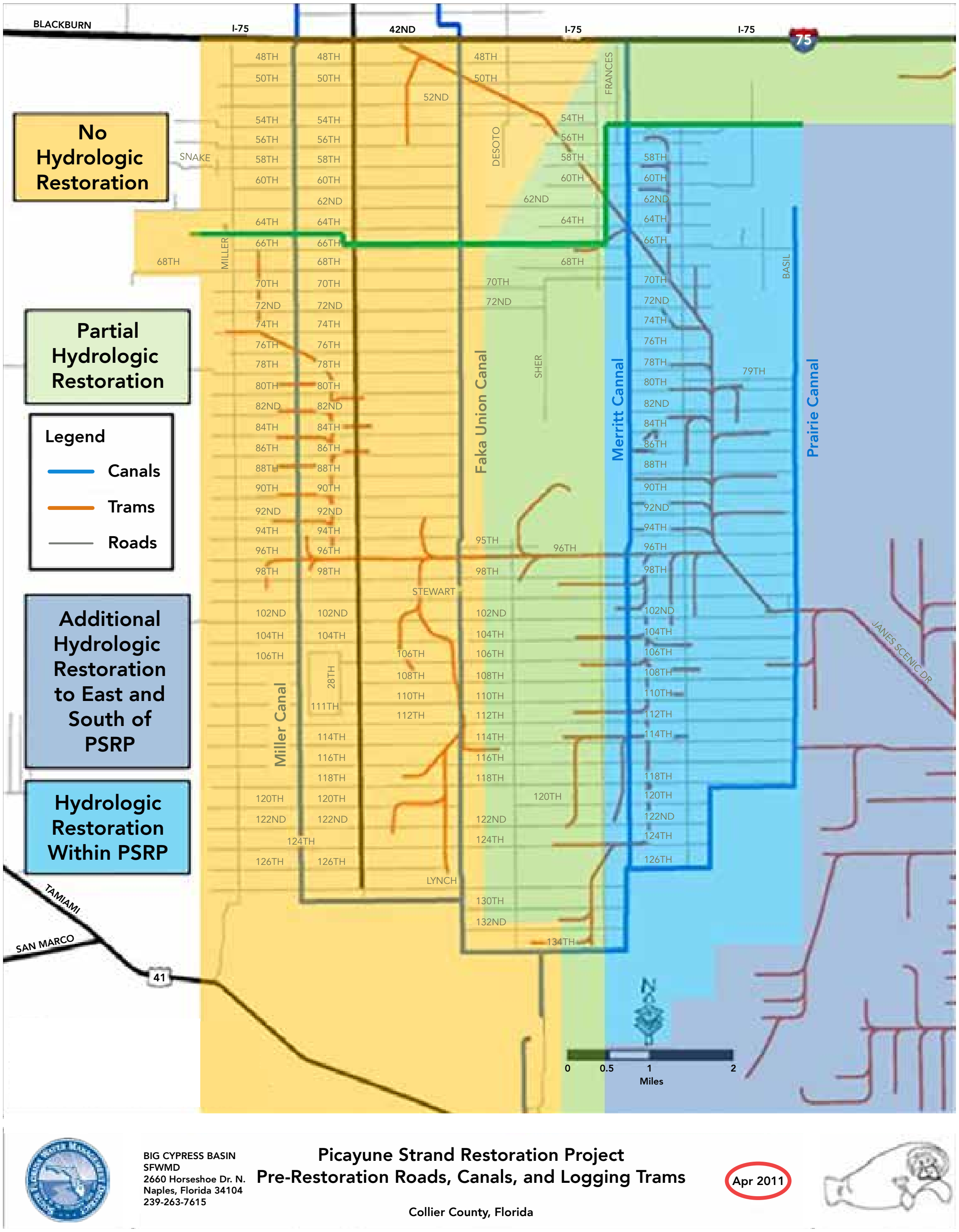


Figure 6.30. Hydrological restoration status of the Picayune Strand Restoration Project following the restoration of the Eastern Stair Steps (southeast location) Phase in FY19/20.

C-111 Projects

The C-111 Spreader Canal Phase I (Western) has been in operation since summer 2012 either in the testing phase or full implementation of the new structures, S-199 and S-200. S-18C headwater stage has not been incrementally increased as originally proposed due to flooding concerns in the South-Dade agricultural area. In 2015, SFWMD began the South Dade Study (https://www.sfwmd.gov/our-work/south-dade-study) which included modeling to examine methods of reducing flood risk to the urban and agricultural areas to the east while increasing water flow to the natural areas in the west. Study results created the Florida Bay Initiative (https://www.sfwmd.gov/our-work/florida-bay) which included a new structure and altered operations of existing structures to increase water movement westward in the L-31 West Canal (Figure 6.31).

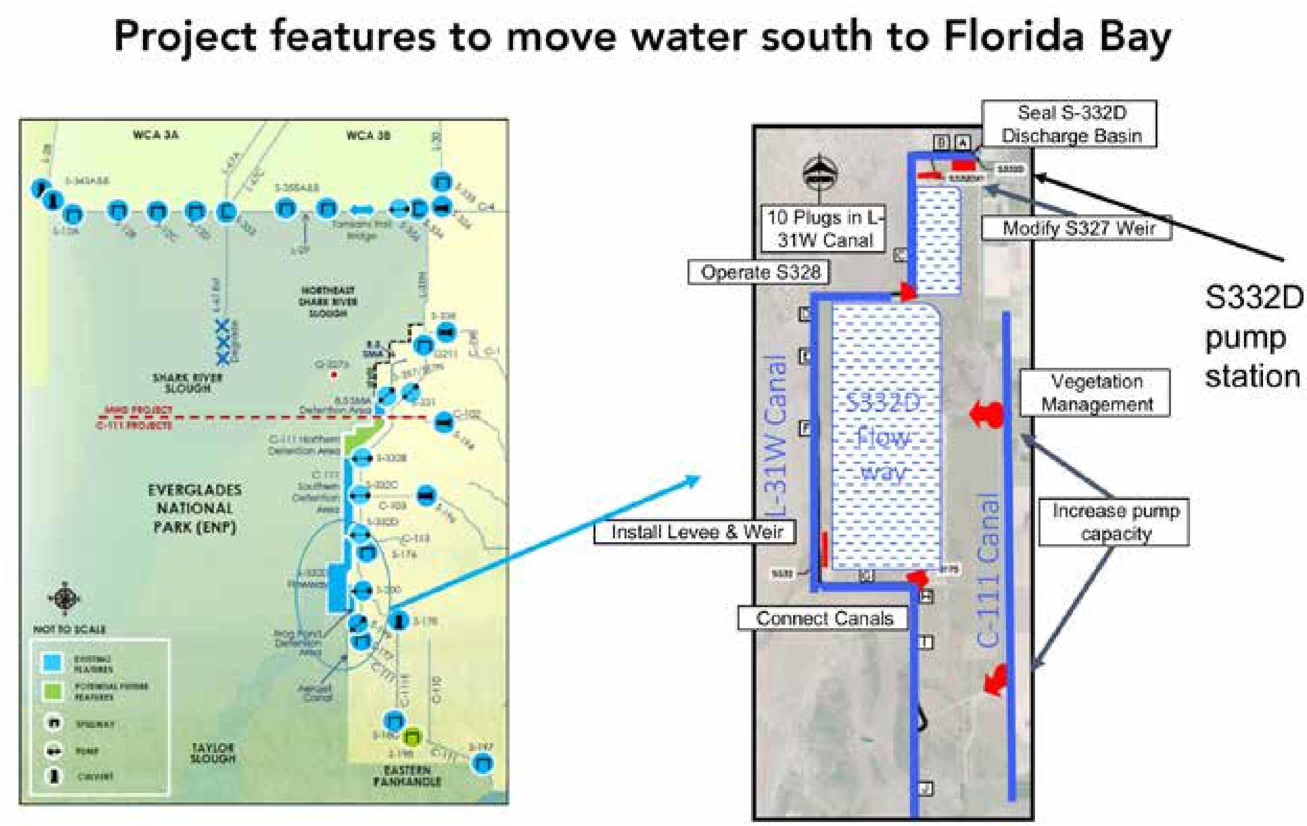


Figure 6.31. The Florida Bay Initiative to move more water to Florida Bay included adding plugs to the L-31 West Canal, a new G-737 structure, degrading an existing weir, increasing pump capacity at S-199 and S-200 pump stations, and operating the existing S-328 structure. Most components are complete and operating with the exception of the increased pump capacity which is in progress.

Concerns about potential water quality impacts to Everglades National Park (ENP) led the SFWMD and ENP to devise an adaptive management plan for the Upper Taylor Slough area (UTS) (Figure 6.32). This joint effort collects data on marsh water quality, periphyton composition, and fish assemblages at 12 locations to the west of the L-31 West Canal in the northern most reaches of Taylor Slough. Sampling began in July of 2017 for periphyton and November 2017 for fish after some initial contracting delays. Additionally, soil, periphyton, and fish data from the Florida Coastal Everglades Long Term Ecological Research Site (http://fcelter.fiu.edu) will be leveraged. Annual interagency and interinstitution adaptive management meetings are planned in the early summer. The first adaptive management meeting was held on June 20, 2018 where initial preliminary data were presented as a baseline for ongoing efforts.

Biscayne Bay Coastal Wetlands

Deering Estate component completed in March 2012. Since December 2012, over 82,159 ac-ft of available water has been diverted from the C-100 canal via the Deering Estate component. During WY2018, S-700 diverted approximately 17,103 ac-ft of fresh water from the C-100 canal to the historic remnant wetlands near Cutler Creek east of Old Cutler Road in the form of sheet flow.

Vegetation within the vicinity of the Deering Estate component is responding to improved hydrology demonstrated by die-off of upland vegetation, emergence of wetland species and expansion of sawgrass. Surface water salinity decreased to <1 ppt in response to the pumping of fresh water from the Deering Estate component pump station into the historic remnant wetlands near Cutler Creek. Groundwater salinity near the Deering Estate also responded to the input of fresh water from S-700 into the historic remnant wetlands, salinity decreased to less than 10 ppt. Sawgrass coverages increased more than 9 acres in east of L-31E levee since 2013. The District recently recommended changes in operation of Deering Estate pump station S-700

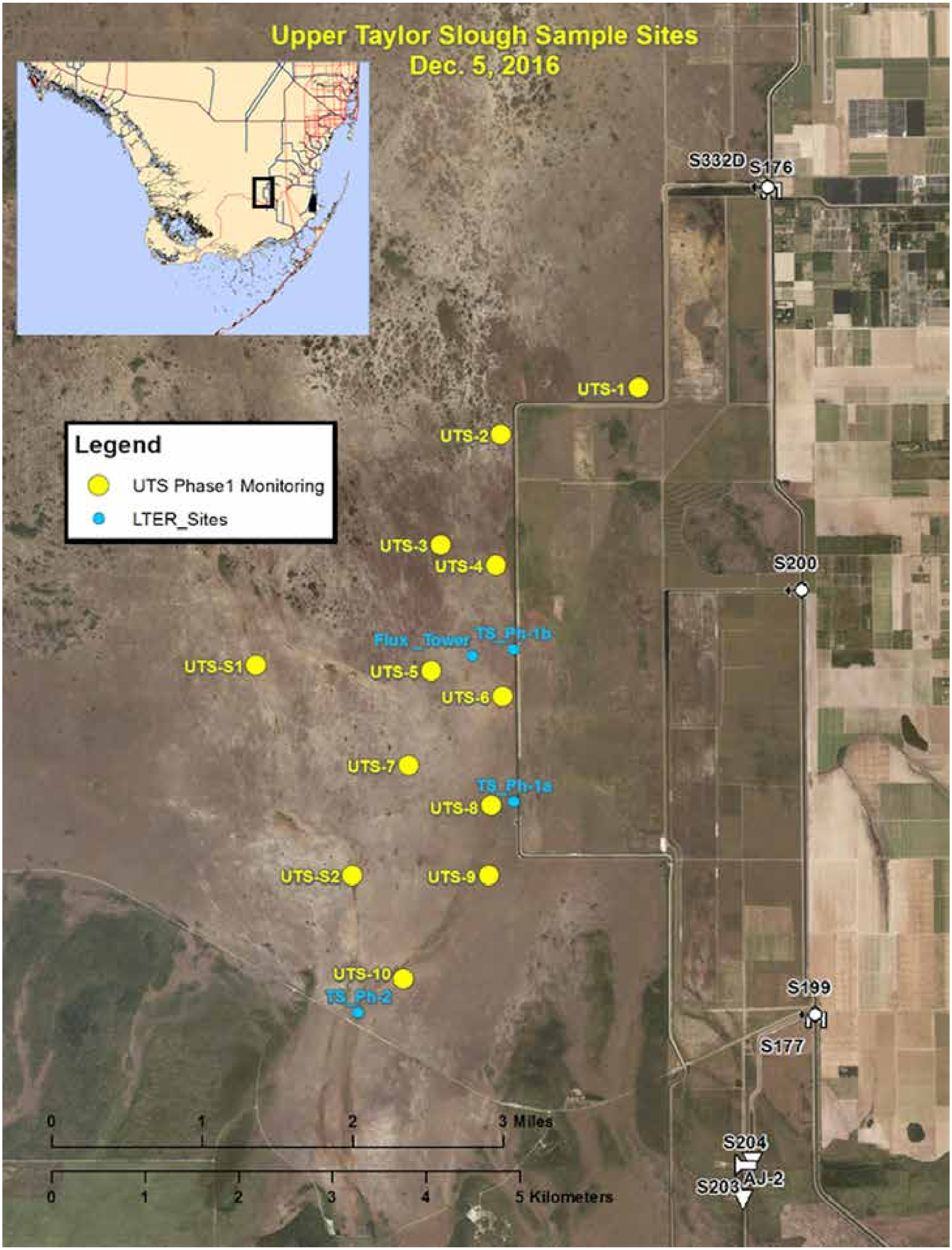


Figure 6.32. Locations of water quality, periphyton, and fish monitoring to assess impacts of increasing water movement toward the Taylor Slough headwaters. The monitoring is a joint effort funded through ENP and SFWMD with experts from Florida International University.

using a 25-cubic feet per second (cfs) pumping and regime that will improve the condition for developing natural wetland hydroperiods. Other recommendations were made that would ensure desired sheet flow across wetlands by introducing water in optimal locations. L-31E Interim electric pump was installed in March 2016 and became in operation in August 2017 and approximately 22,000 ac-ft freshwater diverted through pump to L-31E tidal wetlands and Biscayne Bay.

The most immediate need for this project is to complete Phase 1 of the Environmentally Preferred Plan (EPP), also known as Alternative O. Primary missing components of Phase 1 are the Cutler Wetlands Flow-way, C-102 and C-103 pump stations for the L-31E Flow-way component, and the 400-acre freshwater wetland component located between the C-103 and North Canals. The Cutler Wetlands Flow-way is perhaps the most important Phase 1 component as it has the potential to restore and conserve as large an extent of coastal wetlands as the Deering Estate and L-31E Flow-ways combined. The SFWMD submitted a funding request from the State of Florida in FY2018 to update the design of the Cutler Flow-way component. Also, planning for Phase 2 of the BBCW Project should begin as soon. Phase 1 alone restores only 44% of coastal wetlands anticipated to be restored by the EPP. Please refer to the Biscayne Bay Coastal Wetlands annual report for additional information: http://apps.sfwmd.gov/sfwmd/SFER/2018_sfer_final/v3/appendices/v3_app2-3.pdf.

Central Everglades Planning Project (CEPP)

One of the primary goals of Central Everglades Planning Project (CEPP) is to improve the quantity, quality, timing and distribution of water to Florida Bay. The RECOVER evaluation of CEPP documented significantly increased freshwater flow to Florida Bay through major sloughs for the CEPP Tentatively Selected Plan (TSP; Alt4R2) compared to the future without project condition. Of particular note were the predicted substantial flow increases through Shark River Slough by the TSP, which would benefit the Lower Southwest Coast and Florida Bay. The TSP shows an ecologically beneficial decrease in salinity compared to the existing condition and future without project condition. Ecological indicators used in the evaluation indicate significant improvements in SAV, juvenile spotted seatrout, and American crocodiles with the TSP.

CEPP is still in the planning phase. Due to its size and complexity, project implementation will be phased and involve the integration of multi-year construction through individual Project Partnership Agreements (PPAs) between the USACE and the SFWMD. The USACE is beginning preparation of a National Environmental Policy Act (NEPA) assessment for the development of a Validation Study for the CEPP South component. The specific benefits to SCS in CEPP South include conveyance features that deliver and re-distribute existing water from WCA-3A to WCA-3B, ENP and Florida Bay. Construction of CEPP South features will also prepare the system for the additional inflows from Lake Okeechobee by providing the necessary additional outlet capacity from WCA-3A. The Validation Study will confirm project components, construction sequencing, and project dependencies identified in the 2014 CEPP Final Project Implementation Report and Environmental Impact Statement (2014 CEPP PIR/EIS) and Chief's Report. The integrated NEPA document will be completed in FY 2019, after which, contracts related to the individual features identified in CEPP South PPA would be awarded for construction. The 2014 CEPP Final PIR/EIS is available at: http://141.232.10.32/pm/projects/proj_51_cepp.aspx.

Sunset at Nine Mile Pond. Photo credit: Lyanna L.

LOOKING AHEAD

7.1 RECOVER IS WORKING TO RESTORE THE EVERGLADES

The Restoration Coordination and Verification (RECOVER) program is a multi-agency team of scientists, modelers, planners and resource specialists who organize and apply scientific and technical information in ways that are most effective in supporting the objectives of the Comprehensive Everglades Restoration Plan (CERP). Over the past five years (2012–2017), RECOVER has made progress in accomplishing its goals. RECOVER supported CERP projects, through evaluation of alternative plans, adaptive management plans, and performance measures. RECOVER published the 2014 System Status Report; developed a technical report on climate change impacts; and participated in the development of a progress report to the United States Congress. Additionally, RECOVER developed and updated CERP guidance memoranda, conceptual ecological models, system-wide performance measures, and developed a program-level adaptive management plan.

7.2 PROJECT PLANNING AND IMPLEMENTATION

Goals and actions

Establishing a process for incorporating new science and information into the design and operations of CERP projects is vital for Everglades restoration because new science and monitoring data is continuously evolving, and there are often substantial time gaps from when the projects were in the planning phase to when design begins. A process is needed where RECOVER can interact with project teams and provide new science and systemwide monitoring data to the teams as they move forward with design and construction.

RECOVER will review and provide input to project-level monitoring plans, AM plans, and operation plans; obtain project-level data to include in the RECOVER SSRs; and help the project teams update and identify AM opportunities in the design and operation of their project.

Guidance for RECOVER and CERP projects

RECOVER recently established a formal process for incorporating new science and information into the design, construction, and operation of CERP projects (CERP Guidance Memorandum 66). All ongoing CERP projects now have a RECOVER Point of Contact to serve as the liaison to implement this new process, and it is anticipated that these project-level/RECOVER interactions will identify and implement adaptive management (AM) measures that can improve hydrological and ecological performance of CERP projects. In 2017, under this new role, RECOVER provided AM recommendations to BBCW Project Managers that should improve project performance, improve efficiencies, and increase benefits for that project.

Projects in the planning phase

Relevant to Everglades restoration, there were three active CERP projects and one non-CERP project in the planning phase during the past five years. The project delivery teams and RECOVER have worked together to develop the science needed to support the development, evaluation and selection of the best alternatives to meet the project's goals and objectives. RECOVER and project specific performance measures were used and RECOVER evaluation of the performance of the selected plan was used in the development of the project implementation reports (PIR).

Loxahatchee River Watershed Restoration Project (LRWRP):
The purpose of the LRWRP is to restore and sustain the overall quantity, quality, timing, and distribution of fresh water to the federally designated "National Wild and Scenic" Northwest Fork of the Loxahatchee River for current and future generations. This project also seeks to restore, sustain, and reconnect the area's wetlands and watersheds that form the historic headwaters for the river. Implementation of the project will provide multiple benefits:

- Help restore more natural water deliveries to the river and estuary.
- Promote improved health, connectivity and functionality of the wetland and upland watershed.
- Increase the quantity and quality of habitat available for native wildlife and vegetation.

The project area includes approximately 753 square miles located in central and northern Palm Beach County and southern Martin County. Within that area are Jonathan Dickinson State Park, Pal Mar East/Cypress Creek, Dupuis Wildlife and Environmental Management Areas, J.W. Corbett Wildlife Management Area, Grassy Waters Preserve, Loxahatchee Slough, the last remaining riverine cypress stands in Southeast Florida in the Nationally designated Wild and Scenic Northwest Fork Loxahatchee River, and the Loxahatchee River Estuary.

Lake Okeechobee Watershed Restoration Project (LOWRP):
LOWRP is an Everglades restoration planning effort that will improve water levels in Lake Okeechobee, improve the quantity and timing of releases to the St. Lucie and Caloosahatchee estuaries, restore degraded habitat for fish and wildlife in the study area, and increase the spatial extent and functionality of wetlands.

After being put on hold in 2006, planning efforts restarted in 2016. The project was re-scoped under USACE's new planning paradigm and a new array of alternatives was analyzed. A Tentatively Selected Plan (TSP) was chosen and documented in an integrated Project Implementation Report and Environmental Impact Statement (PIR-EIS).

The LOWRP TSP will capture, store, and redistribute water entering the northern part of Lake Okeechobee to:

- Improve lake stage levels.
- Improve releases to the Caloosahatchee and St. Lucie estuaries.
- Restore/create wetland habitats.
- Reestablish connections among natural areas that are spatially and/or hydrologically fragmented.

Western Everglades Restoration Project (WERP):
Planning efforts started in August 2016 for WERP. The project aims to improve the quality, quantity, timing and distribution of water needed to restore and reconnect the western Everglades ecosystem.

WERP, also known as the Big Cypress/L-28 Interceptor Modification CERP Project, identified the need to restore and reconnect the western Everglades ecosystem. The purpose of this project, as defined within the CERP, is to re-establish sheetflow from the West Feeder Canal across the Big Cypress Seminole Indian Reservation and into Big Cypress National Preserve, maintain flood protection on Seminole Tribal lands and ensure that inflows to the North and West Feeder Canals meet applicable water quality standards.

SB10 Everglade Agricultural Area Project:
Although this project is not officially a CERP project and was completed by the state under the USACE section 203 program, it is very important to the continued progress of everglades restoration. In May 2017, Florida Governor Rick Scott signed legislation that provided over $1 billion to increase water storage south of Lake Okeechobee as an effort to reduce harmful lake releases to the Caloosahatchee and St. Lucie estuaries.

The Water Resources Law of 2017 (Laws of Florida, Chapter 2017-10, Senate Bill 10) directs the expedited design and construction of a water storage reservoir in the Everglades Agricultural Area (EAA) to provide for a significant increase in southern storage to reduce high-volume releases from Lake Okeechobee. The reservoir will be designed to hold at least 240,000 acre-feet of water and include water quality features necessary to meet state and federal water quality standards. The law requires the South Florida Water Management District (SFWMD) to meet certain timelines for implementing the project.

Projects being implemented

There are a number of projects currently being implemented, which include both CERP and non-CERP "foundations projects". A foundation project is one that is not officially part of the CERP program but is complimentary to and a necessary component in order to meet the overall restoration goals.

North of Lake Okeechobee, the final contract needed to complete the Kissimmee River Restoration project was awarded. Work continues on the rehabilitation of the Herbert Hoover Dike.

East of the lake, construction of the C-44 Reservoir and Stormwater Treatment Area component of the Indian River Lagoon-South project, continues. The reservoir will store up to 15 feet of water on 3,400 acres while the stormwater treatment area will help clean water as it finds its way back into the St. Lucie Canal (C-44).

West of the lake, the water management district is working on the C-43 West Basin Storage Reservoir project. This 10,500 acre reservoir will capture and store water from the Caloosahatchee River (C-43) during the wet season so it can be released when needed during the dry season to supplement low flows in the Caloosahatchee Estuary near Fort Myers.

South of Lake Okeechobee, plans are being refined for the first constructible elements of CEPP that Congress authorized in 2016. CEPP's focus is construction of features that improve conveyance of water into the Southern Everglades. Features include degrading levees in Water Conservation Area 3 and increasing capacity of water control structures that will improve flow toward Everglades National Park.

In the southern Everglades, construction continues on features associated with the Modified Water Deliveries to Everglades National Park (Mod Waters), Tamiami Trail Bridge and C-111 South Dade projects. These features will allow water managers to send more flow into Northeast Shark River Slough while providing flood mitigation for property owners in the area.

In the southwest part of the system for the Picayune Strand Restoration Project, three pump stations are complete and are designed to direct water to wetlands to help restore habitat in the Picayune Strand State Forest. Road removal and grading restoration phase north of the Tieback levee has started and will be complete before the end of 2018. The Eastern Stair Steps clearing and plugging restoration phase started and will be completed during this upcoming dry season.

The Biscayne Bay Coastal Wetlands project aims to provide more natural delivery of fresh water over a broad area is expected to provide more stable salinity conditions and reestablish appropriate estuarine salinities for fish and shellfish nursery habitat in tidal wetlands and the nearshore bay. Monitoring of initial operations and adaptive management features are showing positive results to nearshore Biscayne Bay.

7.3 ADVANCING EVERGLADES SCIENCE FOR ADAPTIVE MANAGEMENT

A RECOVER five-year planning effort was completed in 2017 and is being used to strategically guide RECOVER's science program which will be updated every two to three years as progress is made and to best align RECOVER with the shifting needs of the CERP. The RECOVER Five Year Plan provides a forward-looking vision to guide goals and priorities of RECOVER. A few key efforts are listed below.

It is important to point out that CERP and RECOVER leverage a great amount of science in the restoration community besides what RECOVER finances directly. This includes: hydrology, water quality monitoring and research, peat collapse studies, plant, soil, water, bird and mammal monitoring under the Long Term Ecological Research program, as well as studies funded by Department of the Interior and SFWMD.

Updates to Conceptual Ecological Models (CEMs)

As part of the RECOVER Five Year Plan, the CEMs for each region and the total system CEM are being updated based on new science and what was learned over the past 15 years. The associated hypothesis clusters that frame the Monitoring and Assessment Plan (MAP) are also being reviewed and updated.

CEMs as used in CERP, are non-quantitative planning tools used to identify major ecological and anthropogenic drivers and stressors on natural systems, the ecological effects of these stressors, and biological attributes or indicators of these ecological responses (Ogden et al. 2005). A set of CEMs has been developed for south Florida restoration to support integration of science and policy, and they are key components of the AM program developed for CERP. These CEMs are being used as planning tools to guide and focus scientific support for south Florida restoration initiatives, and to build understanding and consensus among scientists and managers regarding the set of working hypotheses that explain the sources and effects of major anthropogenic changes in the natural system.

CEMs have become an essential part of south Florida's restoration planning process because both scientists and managers depend on the models to help build scientific consensus regarding ecosystem linkages and responses, to identify performance measures used both to plan the design of the restoration programs and assess responses of the natural systems during implementation of each program, and to determine research needs. Managers appreciate these models because of their role in organizing effective application of science in support of decision making for restoration. Scientists value the intellectual and integrative processes of developing working hypotheses and laying out linkages in CEMs as a basis for identifying gaps in knowledge and setting research priorities.

Updating Interim Goals and Interim Targets

The path toward restoring the Everglades is marked out by Interim Goals and Interim Targets (IG&IT). Interim Goals are distinct from Interim Targets. Interim Goals are expressed as either predictions of ecosystem response to CERP implementation, or as desired levels of performance and reflect incremental accomplishments toward achieving CERP goals. Interim Targets are defined as anticipated incremental improvements in water supply (agriculture, municipal/industry) and other socio-economic indicators over the course of CERP implementation. Each require separate agreements among the agencies cooperating in the effort to restore the Everglades. However, consistency and compatibility between the Interim Goals and the Interim Targets is maintained with the intention that progress on the CERP will provide benefits for both ecological and other water resource-related needs.

Interim Goals

As defined in §385.3 of the Programmatic Regulations (DOD 2003), Interim Goals are used for two major purposes in CERP. First, used in CERP planning as a guide for project design, as a criterion for development of CERP project scheduling, and to assist in comprehensive plan updates and modification using adaptive management. Second, used as benchmarks for the comparison with field information during the implementation and operation of CERP projects, in order to assess whether ecosystem performance is moving toward CERP restoration goals (Table 7.1). If CERP projects are not moving toward Interim Goals, then an adaptive management strategy should be undertaken. Interim Goals play a significant role in informing the adaptive management program for CERP.

RECOVER provided its Technical Report (RECOVER 2005) to the Departments of the Army and Interior and the State of Florida (through the SFWMD) to be used as a reference in the development of the Intergovernmental Interim Restoration Goals Agreement. The above signatories to the Agreement (http://141.232.10.32/pm/recover/igit_subteam.aspx) supported the continued development and refinement of the recommended indicators and Interim Goals contained within the RECOVER Report. As a part of its 5-Year Work Plan (2016), RECOVER launched a major initiative to update and revise its original 2005 technical report. As hydrologic and ecological modeling is accomplished winter 2018 and into early 2019, RECOVER will compile a new technical report with recommendations for a revised list of Interim Goal indicators and predicted system response to the restoration program in the years ~2026 and ~2036.

In a long-term restoration program such as CERP, it is important that goals are set with a means of tracking them over time, as restoration projects are implemented. RECOVER issued its technical report in 2005 to facilitate creating the Intergovernmental Interim Goals agreement (2007) and also developed and began implementation of the MAP to track restoration progress. Through its 5-Year Work Plan, a new project has begun to revise the 2005 Technical Report. As such, it is anticipated that a new set of Interim Goal indicators will be recommended to amend the 2007 Intergovernmental Agreement.

Interim Targets

Interim Targets will not be directly assessed as part of this review. Many state and regional water supply statutes, rules, and policies have changed since 2000 when CERP was first authorized. An effort to understand what potential impact these changes may have on modeled performance should be undertaken. Examples of these changes include the Lower East Coast Regional Water Availability Rule, the Lake Okeechobee System Operations Manual 2008 (LOSOM08) and the Lake Okeechobee Service Area Water Availability Rule. Also, many of the planning assumptions from the Integrated Delivery Schedule have evolved. As a result, the development of a strategy will be required to explore how future incremental predictions may correspond to future planning efforts for IG&ITs. Aspects of the Interim Targets can be addressed in the development of updated performance measures and assessment methods.

Today's population of nearly eight million people is four times the number of people that the existing water management system was designed to serve. Drought-induced water supply shortages and storm-induced flooding combined with the significant population growth increased demand on the water management system. The CERP will help meet these demands primarily by increasing storage capacity in the system, enabling water managers to make this water available to urban and agricultural users as well as the natural system, and, in some cases, to hold this water to reduce flooding impacts. The Interim Targets predict a reduced frequency of water shortages, increased protection of the Biscayne aquifer against saltwater intrusion, and maintained flood protection capacity.

CERP is intended to help the State of Florida meet existing and future municipal, industrial, and agricultural water supply requirements in the region during a 1-in-10 year drought event. CERP projects will capture water discharged to tide by storing it in reservoirs and underground wells. More water storage capacity will provide water managers with more flexibility in how water can be moved through the Central and Southern Florida Project. Ultimately, this will increase the amount of fresh water available for all water users, including people and the environment. By increasing the storage capacity through the CERP, there will be fewer water restrictions for the people of south Florida and less competition for water between people and the natural system. Not only will water supplies be enhanced, but flood protection will be maintained, and in some situations, improved.

The tools employed in predicting progress toward meeting Interim Targets are numerical or computational models, which allow forecasting how the water supply and flood protection indicators will respond to changes brought about by the CERP. To generate the data necessary to predict the Interim Targets in 2005, the South Florida Water Management Model simulated conditions for the south Florida ecosystem for 1995, 2010, 2015, and 2050 with all CERP projects built. Currently, evaluation and assessment methods are under development with more recent hydrological models and additional years of data. Table 7.2 contains the current targets and evaluation performance measures.

Table 7.1. The Interim Goals by region.

Geographic Region	Ecological Interim Goals
Northern Estuaries	American Oysters
	Submerged Aquatic Vegetation
Lake Okeechobee	Algal Blooms
	Aquatic Vegetation
Greater Everglades	Periphyton Mat
	Ridge and Slough Pattern
	Tree Islands
	Aquatic Fauna
	American Alligator
	Wading Bird Nesting
	Snail Kite
	Marl Prairie Landscape
Southern Coastal Systems	Submerged Aquatic Vegetation
	Juvenile Shrimp densities
	American Crocodile
	Algal Blooms

7.4 PROJECTS (2020–2025)

All CERP projects in the planning phase over the past five years, discussed above, are anticipating completion of their PIR's and authorization in the Water Resources Development Act 2020. The only planning activity that is anticipated during this five-year span of time is Aquifer Storage and Recovery/DECOMP phase 2 and C-111 spreader canal west. Other non-CERP projects that are also critical to the restoration process will be nearing critical milestones during this five-year period. These include Modified Waters Deliveries to ENP, Combined Operational Plan completion 2020; Herbert Hoover Dike construction complete 2022; Tamiami Trail Phase 2 construction completion 2021; Kissimmee River Restoration construction completion 2020; and Lake Okeechobee Regulation Schedule beginning in 2019.

Planning and implementation

Most CERP projects have been through the planning phase, but a few efforts remain such as ASR/DECOMP phase 2, C-111 Eastern Spreader canal, and BBCW phase 2. A study will be underway to revise the Lake Okeechobee Regulation schedule.

It is expected that during the next five years the CEPP will be doing detailed designed and implementing several components including water storage, water treatment and conveyance canals. The Caloosahatchee River (C-43) West Basin Storage will continue with construction and will enter its operational testing period. The BBCW L-31 East Flow-way will be completed and the Cutler Wetlands will be constructed, The C-111 Spreader Canal Western Project will also be under construction. In the PSRP, the road removal will be completed, and the flood protection features will be constructed. In IRL-S the C-23/C-24 North reservoir will be in the construction phase, by the end of this period work should also begin on the STA's and the C-25 Reservoir. The C-44 Reservoir and STA should be completed and begin its operational testing period. Construction on the Herbert Hoover dike will continue and the final construction contract for the completion of the Kissimmee River restoration will be completed. Tamiami Trail next steps phase two should also be completed. RECOVER will have a major role in the adaptive management of these projects.

7.5 SCIENCE (2020–2025)

The Vulnerability Analysis

The purpose of the vulnerability analysis is to develop and establish an ecological network model to evaluate ecosystem vulnerability and provide decision support for Everglades Restoration management actions within CERP. The development and application of an ecosystem vulnerability model was called for in RECOVER's Five-Year Plan (RECOVER 2016). The vulnerability analysis will identify areas, ecological components, and processes that are most vulnerable to stressors of various types and the expected ability of current or future restoration actions to mitigate or minimize this vulnerability. It will also identify information needs and recommend programmatic modifications and specific adaptations to mitigate or minimize vulnerability.

Interim Goals and Targets (IG&IT)

As described above, the IG&IT's need to be confirmed and indicators revised as needed. This task will incorporate feedback from the Science Review and Integration task to update conceptual ecological models (CEMs) and hypotheses clusters and the task to review performance measures. RECOVER will coordinate the list of indicator revisions with the South Florida Ecosystem Restoration Task Force ecological indicators report, with emphasis on the 2018 report. After that the team will recommend revisions to the MAP as needed to

Table 7.2. Interim Targets and evaluation performance measures.

Interim Targets	Evaulation PMs
Water Volume	Amount of water captured by the CERP, where it comes from, and where it goes
Water Supply for Lower East Coast	Frequency of Water Restrictions for the Lower East Coast Service Area (WS-2)
Water Supply for Lake Okeechobee	Lake Okeechobee Stage (LO-1, LO-2, LO-3), Frequency of Water Restrictions for the Lake Okeechobee Service Area (WS-1)
Protect Biscayne Bay from Saltwater Intrusion	Prevent Saltwater Intrusion of the Biscayne Aquifer–Meet MFL Criteria for Biscayne Aquifer (WS-4), Prevent Saltwater Intrusion of the Biscayne Aquifer in South Miami-Dade County (WS-5), Southern Coastal Systems Salinity (under revision)
Flood Control: Root Zone Groundwater Levels in the South Miami-Dade Agricultural Area East of L-31N	Potential for High Water Levels in South Miami-Dade Agricultural Area (WS-3)
Flood Control: Groundwater Stages for Miami-Dade, Broward, and Palm Beach Counties and Seminole Tribe Surface Water Management Basins	Comparison of Stage Differences of Water Levels in South Miami-Dade Agricultural Area (WS-6)
Flood Control: Flood Water Removal Rate for the Everglades Agriculture Area (EAA)	Potential for High Water Levels in South Miami-Dade Agricultural Area (WS-3)
Surface Water Storage Capacity	Appendix to Band 1

bring the Interim Goal target metrics in line with MAP monitoring. Hydrologic modeling from the Interagency Modeling Center to support this effort will continue. New predictions will be made and reported on in the next Report to Congress. Finally, a revision of The RECOVER Team's Recommendations for Interim Goals and Interim Targets for the Comprehensive Everglades Restoration Plan report (RECOVER 2005) will be made.

Coordination with the Integrated Modeling Center (IMC)

The IMC is a joint modeling center developed to provide modeling expertise to the CERP program. The center is made up of modelers from both the USACE's and the SFWMD. Over the years they have continually updated their tools and provided support to all CERP planning and evaluation needs. Over the next five years they will be concentrating on several new tasks and upgrades to continue to advance the level of accuracy and adapt to changes in south Florida currently and into the future, the main focus of these efforts is in the following areas:

- Modeling data extension for regional planning tools for 1965–2016 period of simulation (currently 1965–2005);
- Improved integration of regional planning tools to cover the entire south Florida domain;
- Anticipated recalibration of the Regional Simulation Model Glades Lower East Coast Service Area (RSMGL) which covers the Everglades and the populated areas of the Lower East Coast;
- Expanded modeling tool set to complement and enhance regional modeling application including expanded use of optimization tools (including iModel), innovative approaches to evaluate project resilience across a broad range of hydrologic conditions; and
- Application of improved methodologies to estimate the spatial effects of sea level rise conditions on model tidal boundaries.

MAP refinement

The purposes of the CERP Monitoring and Assessment Plan (MAP) is 1) to provide a framework that supports measurement of systemwide responses to determine how well CERP is achieving its goals and objectives; and 2) support and enable AM for guiding management operations (particularly water management operations) and updating and improving the Plan when needed.

The 2004 MAP was revised in 2009 and included the linkages of monitoring with AM, Interim Goals, project-level assessments, and MAP sustainability (RECOVER 2009). The monitoring components under the Adaptive Assessment and Monitoring Program have been modified over time since the 2009 MAP (RECOVER 2009) to allow for new knowledge gained and increasing or decreasing amounts of information about an indicator. The actual monitoring work from the MAP 2009 was impacted by budget availability and shifting priorities. There is potential to conduct a more comprehensive MAP update that will consider factors such as the latest developments in the CEMs and hypothesis clusters, the ecological vulnerability analysis, and evaluation of the performance measures. This update will incorporate new science knowledge gained since the last MAP update from the SSRs, principal investigators, annual reports, and new pertinent research, with the most recent recommendations from the National Research Council and latest Integrated Delivery Schedule in mind. Planned construction activities as well as climate change and sea level rise will be factored into this update as well.

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Everglades landscape at Royal Palms visitor center. Photo credit: Emily Nastase.