Comprehensive Everglades Restoration Plan

2012 System Status Report Interim Update

December 2012

Restoration Coordination and Verification

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ACRONYMS AND UNITS OF MEASUREMENT

2005B3	Future Without CERP (planning scenerio for Florida Bay salinity performance measure)
2008LORS	2008 Lake Okeechobee Regulation Schedule
90%CL	90 percent confidence limit
ºC	degrees Celsius
µg/L	microgram per liter
μm^3/mL	cubic micrometer per milliliter
AdH Model	Adaptive Hydraulics Model
ArcGIS	a system for designing and managing geographic information produced by ESRI
ArcGIS10	a version of ArcGIS
ArcSDE	ArcGIS Spatial Database Engine
AZTI	AZTI-Tecnalia, a nonprofit, private foundation
BBCW	Biscayne Bay Coastal Wetlands
BBSM	Biscayne Bay Simulation Model
BISECT	Biscayne Southern Everglades Coastal Transport Model
C&SF Project	Central and Southern Everglades Project
C-111SC Project	C-111 Spreader Canal Project
CEPP	Central Everglades Planning Project
CERP	Comprehensive Everglades Restoration Plan
CERP0	Future With CERP planning scenario (planning scenerio for Florida Bay salinity performance measure)
CERP2000	CERP Existing Condition Baseline (planning scenario for Biscayne Bay salinity performance measure)
cfs	cubic feet per second
cfs/dy	cubic feet per second per day
CID	CERP Integrated Database
CL	confidence limit
DBHYDRO	SFWMD’s hydrometerologic, water quality and hydrogeologic data retrieval system
DECOMP	Water Conservation Area 3 Decompartmentalization and Sheet Flow Enchancement Project
DIN	dissolved inorganic nitrogen

DIP	dissolved inorganic phosphorus
DOM	dissolved organic matter
ECO-PCX	National Ecosystme Planning Center of Expertise
EDEN	Everglades Depth Estimation Network
EFDC	Environmental Fluid Dynamic Code
ENFA	ecological niche factor analysis
ERDP	Everglades Research Database Production
FATHOM Florida Bay	a dynamic spatially-explicit mass balance model
FHAP-SF	South Florida Fisheries Habitat Assessment Program
FIAN	Fish and Invertebrate Assessment Network
FIU	Florida International University
ft msl	feet mean sea level
FTLOADDS	Flow and Transport in a Linear Overland-Aquifer Density Dependent System
FY	Fiscal Year
g dw/m^2	grams dry weight per square meter
GIS	geographic information system
GPS	global positioning system
HSI	habitat suitability index
LTER	Long-Term Ecological Research
m	meter
M-AMBI	AZTI's Marine Biotic Index
MAP	Monitoring and Assessment Plan
MECB	Modified Existing Condition Baseline (planning scenario for Southern Biscayne Bay salinity performance measure)
mg/L	milligram per liter
MLR	multiple linear regression
ModWaters	Modified Water Deliveries – Everglades National Park & Tamiami Trail
MSX	multinucleate sphere X
N	nitrogen
NE	northeastern
NGVD	National Geodetic Vertical Datum

NH_4	ammonium
NMDS	nonmetric multi-dimensional scaling
NO_x	nitrate + nitrite
NOAA	National Oceanic and Atmospheric Agency
NSM	Natural Systems Model (also a planning scenario for salinity in southern Biscayne Bay)
NSM-ALT	Alternative NSM (planning scenerio for salinity in southern Biscayne Bay)
NSRSM	Natural System Regional Simulation Model (also a planning scenario for salinity in southern Biscayne Bay)
NSRSM-ALT	Alternative NSRSM (planning scenerio for salinity in southern Biscayne Bay)
NW	northwestern
P	phosphorus
PHAST	model that simulates multi-componenet reactive solute trasport in three-dimensional saturated groundwater flow systems
ppb	parts per billion
ppt	parts per thousand
psu	practical salinity unit
QA/QC	quality assurance/quality control
QAOT	Quality Assurance Oversight Team
QAR	Quality Assessment Report
RECOVER	Restoration Coordination and Verification (Team or Program)
RMA10	a multi-dimensional hydrodynamic numerical model (now callded TABS-MDS)
RMSE	root mean square error
RSM	Regional Simulation Model
SAV	submerged aquatic vegetation
SD	standard deviation
SEACOM	Florida Bay Seagrass Community Model
SFER	South Florida Environmental Report
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
SOP	suggested operating procedure

SRP	soluable reactive phosphorus
SSR	System Status Report
SWIFT2D	Surface-Water Integrated Flow and Transport in Two Dimensions model
TABS-MDS	a multi-dimensional hydrodynamic numerical model (formerly RMA10)
TIME	Tides and Inflows in the Mangroves of the Everglades Model
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
TTI	Ten Thousand Islands
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WCA	Water Conservation Area
WSE	Water Supply and Environmental (Lake Okeechobee regulation schedule)
WV2	World View 2
WY	Water Year (May 1–April 30)

CHAPTER 1

INTRODUCTION

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CHAPTER 1 INTRODUCTION

The 2012 System Status Report (SSR) Interim Update is the fourth in a series of systemwide reports that aim to provide an accounting of the Comprehensive Everglades Restoration Plan (CERP) Monitoring and Assessment Plan (MAP) program. The goal of the MAP is to document status and trends of the defining attributes and key indicator species of the South Florida ecosystem, as well as address key questions (uncertainties) about achieving ecosystem restoration goals. A comprehensive understanding of the system enables the successful use of adaptive management principles to track and guide restoration activities to ultimately achieve restoration success.

This interim update does not provide a full assessment of the system monitored under the MAP program as the 2009 SSR did (see http://www.evergladesplan.org/pm/ssr_2009/ssr_main.aspx . A full assessment will again be provided in the 2014 SSR that is currently being developed. For 2012, progress within the MAP program is reported along with some ecological indicator status updates that revealed new information on restoration status or important technical tool developments.

As with previous SSRs, the updates are provided on a regional level. The four regions are Lake Okeechobee, Northern Estuaries, Greater Everglades, and Southern Coastal Systems (***Figure 1-1***). In addition, program-level updates are also provided.

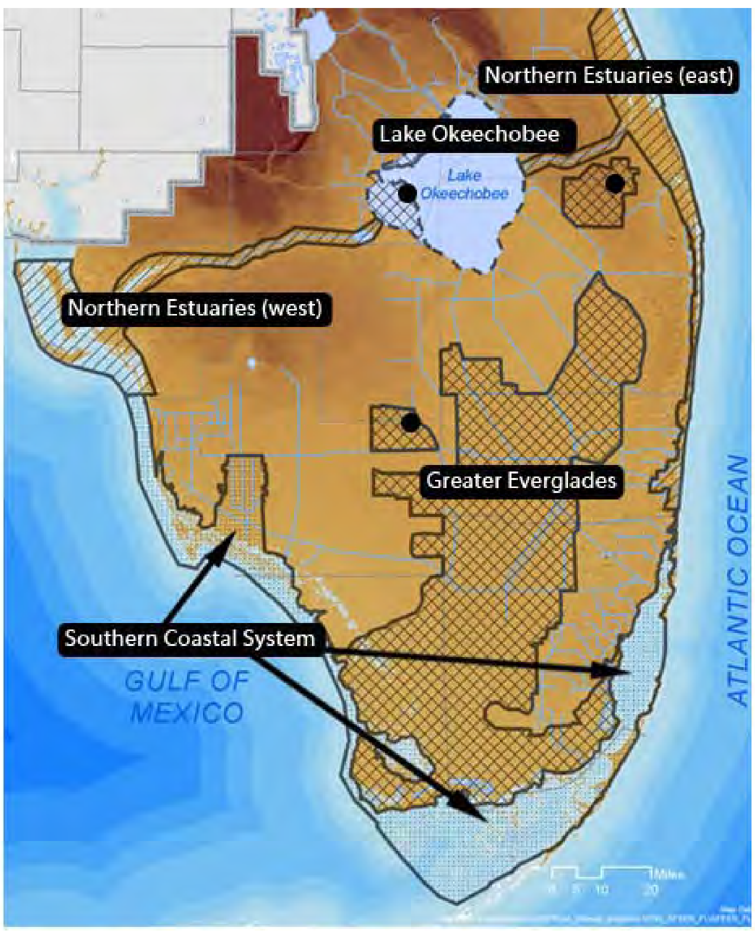

FIGURE 1-1. MAP REGIONS.

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CHAPTER 2

PROGRAM-LEVEL UPDATES

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CHAPTER 2 PROGRAM-LEVEL UPDATES

INTRODUCTION

Since the *2009 System Status Report* (SSR) (RECOVER, 2010; http://www.evergladesplan.org/pm/ssr_2009/ssr_main.aspx) was developed, the Restoration Coordination and Verification (RECOVER) Team has made progress on several program-level efforts. These include (1) optimization, prioritization and streamlining of the Comprehensive Everglades Restoration Plan (CERP) Monitoring and Assessment Plan (MAP), (2) assistance to CERP projects and the Central Everglades Planning Project (CEPP); (3) Quality Assurance Oversight Team (QAOT) contributions to RECOVER, and (4) development of a game plan for the production of the 2014 SSR.

FY 2012 MAP Monitoring Optimization and Prioritization

RECOVER was tasked by the Design Coordination Team in November 2010 to optimize CERP-wide monitoring and prioritize the MAP monitoring components due to a reduction in funds available in Fiscal Year (FY) 2012 for MAP monitoring. This effort built upon previous efforts to coordinate, optimize, and streamline monitoring.

MAP regional coordinators facilitated the first part of the optimization process for each of the four MAP regions (Greater Everglades, Southern Coastal Systems, Northern Estuaries, and Lake Okeechobee). In these workshops, the scientific experts who designed MAP monitoring based on conceptual modeling, performance metrics, and/or restoration targets, discussed changes to sampling stations, methods and/or parameters in detail after first reviewing the scientific and data objectives, and relationship to restoration for each monitoring component. Once workshop participants—principal investigators contracted by RECOVER, scientists and science managers from agencies, and appropriate project delivery team members—optimized the monitoring, they conducted scenario analyses using hypothetical budget reduction levels. Participants were asked how they would implement each monitoring component given a specific reduction in budget (e.g., 25, 50, and 60 percent budget reductions). Results of the process (including discussion) and scenario analyses were documented for use during the prioritization process.

In late-August 2011, the monitoring was evaluated for priority by MAP region and then systemwide. For the prioritizations, the RECOVER regional coordinators and prioritization team members met with regional teams (composed of principal investigators and other subject matter experts) and the Regional Prioritization Team (composed of RECOVER members, agency staff, and project delivery team members) to prioritize monitoring in each region. The MAP Systemwide Prioritization Team then prioritized across regions all MAP monitoring components.

Due to budget reductions, the MAP monitoring components were either reduced or not funded for FY 2012 and 2013. ***Table 2-1*** documents changes in monitoring and the ability of the FY 2012–2013 MAP in assessing the objectives of projects and the performance of CERP.

An effort is underway to review the FY 2011 MAP prioritization process, documented in the RECOVER Monitoring and Assessment Plan (MAP) Regional and System-wide Prioritization Process dated August 2011, to determine if potential improvements exist that will aid in prioritizing MAP monitoring components in future years.

TABLE 2-1. DETAILED MAP FY 2012 PRIORITIZATON RESULTS WITH 59 PERCENT REDUCTION.

Shaded cells indicate the monitoring was not funded in FY 2012.

Contract Name	Description of Monitoring	Priority	MAP Region	Proposed Percent Reduction	What Is Lost – Impact of Reduced Funding on Monitoring	Value/Use of Remaining Monitoring Data
West Coast Oyster Monitoring (Caloosahatchee Estuary)	Oysters serve as an excellent indicator species because salinity conditions suitable for oysters produce optimal conditions for a suite of other desirable estuarine organisms. Also, given their sedentary nature, it is easy to determine cause-and-effect relationships between water quality and health of these organisms. Five aspects of oyster ecology are being monitored in the Caloosahatchee River Estuary: (1) density of adult oysters, (2) reproduction and recruitment, (3) juvenile oyster growth and survival, (4) physiological condition as measured by condition index, and (5) distribution and frequency of the oyster disease dermo (*Perkinsus marinus*)	1	Northern Estuaries	25.8%	• Reduction in the number of sampling stations (reduce from five to three per month with three repetitions) will decrease statistical ability to detect change as CERP projects are implemented. • Reduction in the number of parameters, including elimination of condition index, monitored per station may decrease the ability to understand changes in oyster reefs over time and link these changes to implementation of CERP projects. Doing a detailed analysis of the exiting 10-year data set will allow us to make reductions to the program that will minimize detrimental effects.	• The remaining data will be critical for use in evaluation of restoration success, discerning project effects, operating the Central and Southern Florida Project (C&SF Project), and adaptive management. Data will also help with stoplight indicator development.
East Coast Oyster Monitoring (St. Lucie Estuary, Loxahatchee River Estuary and Lake Worth Lagoon)	Oysters serve as an excellent indicator species because salinity conditions suitable for oysters produce optimal conditions for a suite of other desirable estuarine organisms. Also, given their sedentary nature, it is easy to determine cause-and-effect relationships between water quality and health of these organisms. Five aspects of oyster ecology are being monitored in the St. Lucie Estuary, Loxahatchee River Estuary, and Lake Worth Lagoon: (1) density of adult oysters, (2) reproduction and recruitment, (3) juvenile oyster growth and survival, (4) physiological condition as measured by condition index, and (5) distribution and frequency of the oyster diseases dermo (*Perkinsus marinus*) and multinucleate sphere x (MSX) (*Haplosporidium nelsoni*)	1	Northern Estuaries	20.0%	• Reduction in the number of sampling stations (reduce stations from six to three per month with three repetitions in the St. Lucie Estuary only) will decrease statistical ability to detect change as CERP projects are implemented. Stations in the Loxahatchee River Estuary and Lake Worth Lagoon were dropped. Limited sampling will be done by the Loxahatchee River District in the Loxahatchee River Estuary. • Reduction in the number of parameters (eliminate monitoring for condition index, MSX, dissolved oxygen, and pH) monitored per station may decrease the ability to understand changes in oyster reefs over time and link these changes to implementation of CERP projects. Doing a detailed analysis of the existing 10-year data set will allow us to make reductions to the program that will minimize detrimental effects.	• The remaining data will be critical for use in evaluation of restoration success, discerning project effects, operating the C&SF Project, and adaptive management. Data will also help with stoplight indicator development.
Wading Birds & Aquatic Fauna Monitoring (includes Biscayne Bay)	Assessing the demersal prey base fish community in reference to salinity and water levels allows for the inference of the relative value of the wetlands to higher trophic levels (e.g., wading birds). This project studies aquatic fauna in the mangrove zone of Florida and Biscayne bays, as well as wading bird colony location, size and timing in Florida Bay and roseate spoonbill nesting success in Florida Bay.	1	Southern Coastal Systems	36.0%	• Loss of 60 percent of prey fish monitoring sites, including all control sites in Cape Sable, significantly reduces the ability to detect cause-and-effect changes in the roseate spoonbill (*Platalea ajaja*) population resulting from the C-111 Spreader Canal (C-111SC) Project, Water Conservation Area 3 Decompartmentalization and Sheet Flow Enhancement Project (DECOMP), non-CERP projects such as Tamiami Trail Bridge Project and Modified Water Deliveries (ModWaters), and changes to operations (Combined Operations Plan). Spatial coverage is severely reduced. Control site, Shark River Slough sampling, hydrologic sampling, and target site are lost. • Loss of the ability to make upstream to downstream comparisons in the area most likely to be affected by the C-111SC Project. • Loss of the ability to tie hydrology to prey fish distribution and abundance in response to implementation of CERP projects (e.g., C-111SC Project).	• Spoonbill nest surveys and focal colony success (how many chicks actually fledge) will continue to be monitored. Six hydrology and prey fish stations with be retained, along with several long term stations (data has been collected 1990). The focus will be on the C-111SC and ModWaters areas of influence.
Coastal Gradients – Monitoring of Flow, Salinity, and Nutrients in the Greater Everglades and Southern Coastal Systems	RECOVER MAP funds 10 monitoring stations that, together with the existing coastal monitoring network, create a network of 40 sites that can be analyzed for coastal gradients of flow, salinity, and nutrients. The purpose of this network is to collect real-time data in the coastal zone of Everglades National Park and report on the interactions between the Everglades mangrove transition zone and freshwater wetlands. This network supplies critical hydrologic information where none previously existed and establishes a baseline data set of hydrologic conditions prior to any CERP watershed modification.	1	Southern Coastal Systems	56.9%	• Significantly reduced ability to detect salinity, flow, water level, and nutrient changes from the C-111SC Project, CERP/non-CERP projects that affect lower Shark River Slough (e.g., Tamiami Trail Bridge), and the effects of operations to Everglades National Park. • Loss of 40 percent of hydrologic stations in Florida Bay and the southwest Florida coast (18 total stations) significantly impairs regional hydrology assessment, including detection of saltwater intrusion. • Loss of hydrologic data that is critical for existing hydrologic, water quality, and ecological model development.	• Monitoring stations (stage, flow, and salinity) focused on the C-111SC Project and ModWaters areas of influence along the coastal mangrove fringe in Florida Bay and the southwest Florida coast will be retained. We will be able to detect changes in stage and flow and subsequently salinity resulting from C-111SC Project and ModWaters with less certainty.
Florida Bay Juvenile Sportfish Monitoring	The spotted seatrout (*Cynoscion nebulosus*) spends its entire life history within Florida Bay, and distributions vary in response to salinity. Thus data collected on their population dynamics will help to delineate changes due to water management versus natural variability. Relationships to salinity can be used in the evaluation process to predict the impact of a CERP project(s) on sportfish populations in Florida Bay.	1	Southern Coastal Systems	0.0%	• Shift of monitoring to eastern Florida Bay to capture change from implementation of the C-111SC Project may eliminate sampling in western Florida Bay, which is the most productive basin for juvenile sportfish • Inability to estimate the regional effects of CERP/non-CERP projects and operations to economic benefits for the region.	• Ability to detect change to sportfish populations in central and eastern Florida Bay resulting from C-111SC Project and ModWaters effects on the estuaries.
South Florida Fish Habitat Assessment Program (FHAP-SF)	FHAP-SF provides data on submerged aquatic vegetation (SAV) in Florida Bay and Lostman's River to southern Biscayne Bay. This program documents the status and trends of seagrass distribution, abundance, and reproduction, and epiphyte loads. It also provides process-oriented data such as photosynthetic efficiency. Resource managers can use these data to address ecosystem response issues on a near real-time basis and to weigh alternative restoration options.	1	Southern Coastal Systems	35.8%	• Loss of an early indicator of water quality changes and nutrient availability. Without these indicators, we may not be able to detect impending algal blooms, which results in a decline in seagrass health. • Early indicators of water quality and nutrients availability being lost are (1) pulse-amplitude modulated fluorescence, which is an early indicator of changes in water quality, and (2) epiphyte abundance, which is an early indicator of water column nutrient increase.	• Ability to detect change to SAV communities in central and eastern Florida Bay resulting from C-111SC Project and ModWaters effects on the estuaries.

TABLE 2-1. CONTINUED.

Shaded cells indicate the monitoring was not funded in FY 2012.

Contract Name	Description of Monitoring	Priority	MAP Region	Proposed Percent Reduction	What Is Lost – Impact of Reduced Funding on Monitoring	Value/Use of Remaining Monitoring Data
Biscayne Bay Salinity Monitoring	The Biscayne Bay Salinity Monitoring Network's primary purpose is to provide the quality and quantity of data sufficient for determining the effects of CERP implementation on salinity regimes in Biscayne Bay and for other investigators to use in their analysis of effects on organisms. This project provides descriptive, spatial, and temporal analysis of salinity patterns in Biscayne Bay, and data from this project has been used to develop freshwater inflow needs for Biscayne National Park.	1	Southern Coastal Systems	42.6%	• Loss of 21 salinity monitoring sites (two-thirds of the sites) throughout Biscayne Bay, Card Sound, and Manatee Bay resulting in less certainty in determining salinity (distribution and patterns) both in the immediate vicinity of the Biscayne Bay Coastal Wetlands (BBCW) Project and at the larger, regional scale. • Loss of sites impairs ability to assess RECOVER's Biscayne Bay salinity performance measure. • Loss of salinity monitoring in central and northern Biscayne Bay inhibits the ability to detect regional changes. • Biscayne Bay monitoring has been combined to increase sampling efficiency. Principal investigators provided a combined scope for Biscayne Bay salinity, epifauna, SAV, and mangrove fish monitoring that decreases costs 44.5 percent by sharing field technicians.	• Monitoring stations (hi-resolution salinity) focused on the BBCW and C-111SC project areas of influence will be retained. We will be able to detect changes in salinity resulting from the C-111SC Project and BBCW projects.
Hydrology & Salinity Monitoring in Ten Thousand Islands	There is little information regarding the present day quantity, timing, and quality of freshwater flow to the Ten Thousand Islands (TTI) estuaries. This study complements an ongoing United States Geological Survey (USGS) effort designed to measure the discharge and salinity of rivers flowing from Tamiami Trail towards the TTI in order to help with identifying desirable surface water flow rates and assessing restoration success. Specifically, this project operates and maintains four flow monitoring stations and one boundary conditions monitoring station in the TTI and describes the hydrodynamic characteristics and the temporal and spatial salinity variability of creeks and estuaries within the TTI area in relation to prominent physical boundaries, which are generally composed of mud flats, ridges, and oyster beds.	1	Southern Coastal Systems	18.4%	• Loss of flow data at the East River control site. Stage and flow are not closely correlated here. We cannot secondarily calculate flow and will not be able to compare flow from remaining sites against a control. • No flow at a newly established station in Palm River; this station captures additional flows to the western estuaries from the Picayune Strand Restoration project are, which were not originally anticipated.	• Five monitoring stations to include the three basins referenced in the *Picayune Strand Restoration Final Integrated Project Implementation Report and Environmental Impact Statement* (USACE and SFWMD, 2004)— Pumpkin, Faka Union, and Fakahatchee bays. Three of the five stations in the area anticipated to reflect the greatest changes in flow from the project will retain flow, stage, and salinity measurements. One new station in Palm River will reestablish a station where USGS collected eight months (October 2003–April 2004) of stage and salinity measurements.
Everglades Depth Estimation Network (EDEN)	EDEN is an integrated network of roughly 260 gauging stations (25 of which are maintained by RECOVER) that assist with real-time water level monitoring, ground elevation modeling, and water surface modeling that provides scientists and managers with current (1999–present), online water depth information for the Greater Everglades. This enables the assessment of biotic responses to hydrologic change.	1	Greater Everglades	30.0%	• About 12 to 15 of the RECOVER MAP funded water-level gages (RECOVER has funded 25 gages which are about 10 percent of the network) were discontinued in March 2012. • A less dense network of gages will result in a corresponding loss of accuracy in the daily water level surfaces for the Everglades. • Because gages are used to estimate missing data at nearby gages, a less dense network reduces the ability to fill data gaps, which are common in remote locations like the Everglades, and produce consistent model results.	• The EDEN daily water level surfaces and other EDEN hydrologic data sets for the Everglades will continue to be produced on a real-time basis for EDEN users and available on a publically accessible website. • Users include scientists, water management operators, and water resource managers who use the EDEN data for correlation of biological and ecological data with hydrology, development of performance measures, decisions for water management operations, and input as hydrology for biological and ecological models.
Wet Season Trophic Sampling	An overarching hypothesis for Everglades restoration is that hydrology controls the production and concentration of aquatic prey organisms, which in turn determine the magnitude and success of wading bird nesting during any given year. A set of hypothesized mechanistic relationships between hydrology, productivity of the prey base, and the behavioral patterns of several representative wading bird species are being tested in order to determine how large populations of wading birds that were one of the defining characteristics of the predrainage Everglades ecosystem can most effectively be restored. The wet season is the period of production of aquatic prey populations, which is directly related to hydroperiod.	1	Greater Everglades	43.0%	• Reduced ability to use prey fishes to make systemwide inferences resulting from implementation of CERP projects and C&SF Project operational changes, such as the those resulting from the Lake Okeechobee Regulation Schedule Study (USACE, 1999) due to loss of dry season sampling. • Complete loss of periphyton and fish sampling information for Lake Okeechobee, Pal Mar (part of the Hungryland Wildlife and Environmental Area), and J.W. Corbett Wildlife Management Area that describes the water quality and prey-based fishes affected by Lake Okeechobee operations and within the Indian River Lagoon watershed. • No species identification of periphyton (an indicator of water quality and depth), which provides a linkage between hydrologic and water quality impacts of operations on wading bird production in the Everglades. Periphyton is both a food source and habitat for wading bird prey (e.g., fish). • Loss of information that contributes to interim goals reporting, stoplight reports, and five-year reports to Congress.	• In order to nest successfully, wading birds rely on having enough prey (high densities) and thus we need to know the status and the trends of prey fish densities. • This project will continue to deliver population data on key aquatic fauna and periphyton as an index of patterns of production in time and space. The goal is to help understand this information with respect to ecosystem restoration.

TABLE 2-1. CONTINUED.

Shaded cells indicate the monitoring was not funded in FY 2012.

Contract Name	Description of Monitoring	Priority	MAP Region	Proposed Percent Reduction	What Is Lost – Impact of Reduced Funding on Monitoring	Value/Use of Remaining Monitoring Data
Dry Season Aquatic Fauna Sampling	An overarching hypothesis for Everglades restoration is that hydrology controls the production and concentration of aquatic prey organisms, which in turn determine the magnitude and success of wading bird nesting during any given year. A set of hypothesized mechanistic relationships between hydrology, productivity of the prey base, and the behavioral patterns of several representative wading bird species are being tested in order to determine how large populations of wading birds that were one of the defining characteristics of the predrainage Everglades ecosystem can most effectively be restored. The dry season is a period of concentration of aquatic prey populations, which is controlled by rates of water level recession.	1	Greater Everglades	40.0%	• Loss of information as to how operations and climatic variation affect wading bird prey and wading bird nesting success due to loss of wet season sampling. • Loss of a field technician, which results in loss of vegetation transect monitoring. • No MAP contribution to the annual South Florida Wading Bird Report • Loss of information that contributes to interim goals reporting, stoplight reports, and five-year reports to Congress.	• Ability to analyze dry season wading bird prey density and nesting success.
Wading Birds Monitoring	This project continues to build on an existing database of wading bird reproductive success and productivity information extending back to the 1960s for wood storks (*Mycteria americana*) and to the 1930s for roseate spoonbills. The area of study covers Water Conservation Areas (WCAs) 1, 2, and 3, Everglades National Park, and Big Cypress National Preserve. This data set has already served as an early warning of the collapse of ecosystem function, the widespread contamination of the wetland biota with mercury, and the critical functions provided by droughts.	1	Greater Everglades	10.0%	• Loss of information as to how operations and climatic variation affect wading birds. The situation is exacerbated by potential loss of ModWaters funding for wading bird monitoring (i.e., there would no longer be a systemwide wading bird survey). • Loss of vegetation transects. • Loss of information that contributes to interim goals reporting, stoplight reports, and five-year reports to Congress. • Loss of permit-required mercury monitoring by the South Florida Water Management District (SFWMD) (MAP pays for transportation). If it is necessary to continue mercury monitoring, the SFWMD would need to pick up transportation costs.	• Wading birds are key species in determining the health of the Everglades as a whole. Provided ModWaters funding is continued, this study helps to retain systemwide information on the distribution and nesting success of wading birds.
Monitoring Tree Island Condition in Southern Everglades	Tree islands are important centers of biodiversity embedded within the marsh mosaic. Changes in water management associated with hydrologic restoration will result in changes in the internal water economy of tree islands, as well as in the risk of fire, which in turn will lead to changes in plant function and species composition. Data collected by this project will enable the linkage of marsh hydrology predicted by models or attained in the real world with ecological responses of tree islands to determine the success of restoration activities. The areas of focus are Everglades National Park and Shark River Slough	1	Greater Everglades	40.0%	• Loss of ability to assess tree island productivity (tree island canopy structure), which is an indication of Everglades "health" due to loss of litter dynamic sampling and water level sampling. • Loss of one field technician. • Loss of information that contributes to interim goals reporting.	• Ability to assess water stress on the species composition of tree islands and contribute information to real-time operations.
Landscape Pattern – Ridge, Slough, and Tree Island Monitoring	This project focuses on three components: (1) mapping vegetation features from aerial photographs, (2) aerial surveys for classification of tree island type, and (3) ground surveys of water depth and plant community structure. Data on these components will be used to quantify aspects of the hydrologic regime, determine relationships between vegetation and water depth, quantify the distribution and spatial structure of peat elevations, and ground-truth broader-scale maps based on remote sensing and aerial surveys. This will maximize the likelihood of change detection during CERP implementation.	1	Greater Everglades	56.0%	• Complete loss of sampling in the Arthur R. Marshall Loxahatchee National Wildlife Refuge and the marl prairies within Everglades National Park, which supports the understanding of ModWaters and C-111SC Project restoration performance. Ridges and sloughs will only be sampled in WCA 2, WCA 3, and Everglades National Park. • Loss of ground sampling at three tree island in Shark River Slough. • Loss of mapping the “health” of ridge and slough patterning (one of the defining characteristics of the Everglades). • Loss of information that contributes to interim goals reporting.	• Continued ability to characterize ridge and slough landscape, including elevation and vegetation patterns, albeit within a reduced spatial extent.
Tree Island Monitoring	This project expands upon an existing network of monitoring wells. New wells have been installed on tree islands in order to quantify groundwater discharge and tree island-marsh hydrologic connectivity across a disturbance gradient. The areas of focus are WCA 3A and WCA 3B. Monitoring well, isotopic, and transpiration data can then be used as a diagnostic tool to assess tree island functioning and health to inform CERP implementation.	1	Greater Everglades	10.0%	• Loss of information used to better develop tree island performance measures and hydrologic connectivity between tree islands and the marsh. This information is used for system operations due to decreased sampling frequency. • Loss of information that contributes to interim goals reporting.	• Only work being performed on tree islands that compares belowground processes (productivity) on islands that range from “pristine” to almost wholly degraded. This information will allow us to understand why some of the tree islands are dying.
Monitoring of Marl Prairie Slough Gradients	In the southern Everglades, marl prairie habitats are present on either side of Shark River Slough. Vegetation structure and composition gradually change along an elevation and depth gradient, thus transects have been established to monitor changes in vegetation along that gradient. Changes in vegetation can then be related to changes in hydrology resulting from restoration activities.	1	Greater Everglades	20.0%	• Loss of plant community monitoring in western marl prairies (at a 5-meter fine scale), which provides information about systemwide hydrology and is an indicator of hydrologic change and restoration effects. • Loss of understanding about gradients from marl prairie to slough that cause changes in vegetation in response to changes in hydrology. • Loss of information that contributes to interim goals reporting.	• Can inform system operations for timing and distribution of water releases to Northeast Shark River Slough in support of ridge and slough habitat.
Lake Okeechobee Wading Bird Monitoring	This study focuses on populations of white wading birds in Lake Okeechobee, and collaborates with other studies in Florida Bay, the Everglades, and the Big Cypress region. It builds on an existing database of nesting effort, reproductive success, and productivity information extending back to the 1960's, or further in case of the Wood Stork. This data is critical in that it addresses the hypothesis that restored hydrology will generate more dense populations of fish and macroinvertebrates, enhance foraging opportunities for wading birds, and increase breeding and nesting in the coastal areas.	1	Lake Okeechobe e	14.0%	• Loss of the ability to correctly identify the start, peak, and/or end of wading bird nesting season due to reduced sampling from six to four months. • Reduced sampling may lead to underestimates of nest failure rates (i.e., if they initiated and then failed between sampling visits). • Next year's data may not be directly comparable to previous years if our sample times and/or size has changed.	• Retains some ability to assess nesting success of wading birds in Lake Okeechobee.

TABLE 2-1. CONTINUED.

Shaded cells indicate the monitoring was not funded in FY 2012.

Contract Name	Description of Monitoring	Priority	MAP Region	Proposed Percent Reduction	What Is Lost – Impact of Reduced Funding on Monitoring	Value/Use of Remaining Monitoring Data
Monitoring of Oysters in the Ten Thousand Islands	Freshwater diversion from natural flowways in the TTI by basin development and road construction has adversely impacted downstream estuaries by changing their salinity regimes and water quality. The Picayune Strand Restoration Project, located in southwestern Florida, will alter the existing salinity regime; however, the timing and quality of freshwater flow to the TTI and its effects on the nearshore benthic community is not yet well defined. This project will provide a comprehensive baseline of oyster population and health in the estuaries downstream of the Picayune Strand Restoration Project.	1	Southern Coastal Systems	Not Applicable	• This oyster monitoring was added to fill a gap in monitoring for the Picayune Strand Restoration Project on the downstream estuaries of the TTI. No consistent and continuous ecological monitoring under the MAP exists to detect the effects of hydrologic changes to the TTI estuaries.	• Addition of only ecological parameter being monitored by the CERP to measure the effects of the Picayune Strand Restoration Project on the downstream estuarine health.
Submerged Aquatic Vegetation (Indian River Lagoon, St. Lucie Estuary, Lake Worth Lagoon, and Caloosahatchee River Estuary)	Historically, natural freshwater discharges facilitated the presence of healthy floral and faunal communities, including SAV. As development increased, however, management practices resulted in coastal areas with frequent high and low salinity extremes and degraded ecology. This monitoring aims to collect baseline data, quantify relationships between freshwater discharges and subsequent salinity and water quality patterns, and quantify how salinity and water quality patterns in turn impact SAV distribution, community structure, and variability. SAV is a key indicator of restoration success.	2	Northern Estuaries	83.0%	• A reduction in monitoring (loss of 15 stations) will focus only on specific areas of the estuary (upstream in the Caloosahatchee River Estuary and closest to the St. Lucie Estuary in the Indian River Lagoon) and therefore will not provide the larger picture of other non-CERP induced changes.	• By using in-house SFWMD resources, a program, although limited in scope, will be kept in place in key areas of the Northern Estuaries (St Lucie and Caloosahatchee River estuaries) where we would expect to see the first effects of CERP implementation. These would include the C-44 and C-43 canals and any changes to Lake Okeechobee operations.
Monitoring of Ridge and Slough Maintenance and Degradation	The core mechanism for the maintenance of the ridge and slough landscape is peat accretion. High production in ridges creates a stable vegetative configuration at higher soil elevations. Low production in sloughs creates another at lower soil elevations. Loss of the patterning would be catastrophic. This project aims to better understand how the ridge and slough landscape is maintained and identify the critical thresholds above and/or below which those mechanisms are altered and landscape change ensues. The area of focus is the hydrologic gradient between northern WCA 3A north through the best conserved areas of southern WCA 3A, the stabilized areas of WCA 3B, and the impounded areas at the southern end of WCA 3A.	3	Greater Everglades	61.4%	• Partial loss of the ability to detect elevation and nutrient/phosphorus changes in ridges and sloughs. Diminishes the ability to detect phosphorus patterns in soils (e.g., ridges generally have higher soil phosphorus concentrations than sloughs) due to loss of ground sampling at three tree islands in southern Shark River Slough. • Partial loss of understanding of mechanism necessary to restore ridge and slough patterns. • Loss of analytic modeling and expertise in chemical analysis. • Loss of information supporting interim goals reporting.	• Maintain reduced ability to detect change in ridge and slough pattern. The ridge and slough pattern is a defining characteristic of the Everglades.
Biscayne Bay Mangrove Fish Monitoring	It is hypothesized that within mainland mangrove habitats, CERP-related impacts will likely be the strongest and most easily discerned from other effects. This study is the longest running fish monitoring study ever conducted in Biscayne Bay and adjacent waters. Data is collected on seasonal and spatial variation in fish composition and diversity, as well as frequency of occurrence, density, and size structure. Emphasis is placed on evaluating relationships between the shoreline fish community and variation in salinity/freshwater flow to evaluate restoration success.	4	Southern Coastal Systems	24.1%	• Loss of sampling sites in northern Biscayne Bay (specifically loss of dry season sampling). Also loss of the only long-term fish monitoring conducted in northern Biscayne Bay and Card Sound. This decreases the ability to detect operational changes on the central and northern portions of Biscayne Bay. • Inability to assess seasonal variability of fish abundance and distribution and compromises performance measure development (specifically, use of goldspotted killifish [*Floridichthys carpio*] as a performance measure). • Discontinues laboratory-based habitat suitability index (HSI) validation so the ecological tool will not be available for use for evaluations and assessments for CERP projects. • Limited ability to document changes to nearshore SAV habitat and associated fauna. • Biscayne Bay monitoring has been combined to increase sampling efficiency. Principal investigators provided a combined scope Biscayne Bay salinity, epifauna, SAV, and mangrove fish monitoring that decreases costs by 44.5 percent by sharing field technicians.	• Ability to detect change to mangrove fish populations in Manatee Bay, Card Sound, and Biscayne Bay resulting from implementation of the C-111SC and BBCW projects. This project comprises the only remaining ecological indicator for Biscayne Bay.
Benthic Infaunal Monitoring in the St. Lucie Estuary and Indian River Lagoon	Benthic infaunal communities (worms and mollusks that live in the soft sediment on the estuary bottom) are primarily stationary, and are therefore continuously exposed to changes in the environment. This is one of the main reasons why benthic infaunal monitoring is commonly regarded as one of the best tools for evaluating the health and long-term changes within the marine environment. The main objectives of this project are to evaluate the present health status of the St. Lucie Estuary and Indian River Lagoon, determine the cause of long-term changes, pinpoint and evaluate anthropogenic disturbances, and calculate a health index for each monitored site in order to monitor change over time.	5	Northern Estuaries	41.3%	• Reduction in the number of stations monitored from 15 to 9 will decrease our ability to detect changes as CERP projects are implemented and will give us a less complete coverage of all of the areas of the estuary that may be impacted. • The reduction will decrease our ability to distinguish between natural changes and those brought about by the CERP implementation.	• Stations in key areas will allow us to continue on a limited basis to assess the current and future health of the benthic community in the St. Lucie Estuary.
Monitoring of Marsh Mangrove Fishes	This project was developed to improve understanding of the role of the marsh-mangrove ecotone in the southern Everglades as habitat for freshwater fishes. Historically, nesting (and likely foraging) by wading birds occurred in the highest numbers in this area, yet very little is known about what drives prey abundance, distribution, and concentration in this part of the ecosystem. The goal is to understand how the fish community will respond to restoration conditions, which are expected to increase the pooling of fresh water at the ecotone, resulting in a wider and seasonally-extended oligohaline zone.	6	Greater Everglades	43.1%	• Loss of the ability to detect change between saltwater (estuarine) and freshwater (marsh) habitat for fishes with loss in sampling (loss of drop net, North River site, and minnow traps). Changes at this interface are an early indicator of CERP effects as projects are constructed. • Loss of information that contributes to interim goals reporting and stoplight reports.	• Compares seasonal marine fish population in creeks and their diet, testing the hypothesis that larger marine predators are eating bird food fish due to the lack of freshwater discharge. • Only testing done at the saltwater-freshwater interface ecotone biota.

TABLE 2-1. CONTINUED.

Shaded cells indicate the monitoring was not funded in FY 2012.

Contract Name	Description of Monitoring	Priority	MAP Region	Proposed Percent Reduction	What Is Lost – Impact of Reduced Funding on Monitoring	Value/Use of Remaining Monitoring Data
Vegetation Mapping in Everglades National Park	In order to assess restoration of the Everglades and document changes in species composition and distribution, production of a spatially and thematically accurate vegetation map for Everglades National Park and the Big Cypress National Preserve is necessary. This mapping project involves field collection, remote sensing procedures, and vegetation map interpretation.	7	Greater Everglades	2.4%	• Delay of photo interpretation of aerial imagery flown in 2009 (delay = undesirable lapse in time between aerial imagery and interpretation).	• Pre-CERP baseline mapping for Everglades National Park is needed in order to discern change from ModWaters and C-111SC Project implementation. • Provides an entire photo-interpreted pre-CERP baseline map in Everglades National Park and will be finished in four years, using six-year old photos.
Biscayne Bay Nearshore Submerged Aquatic Vegetation Monitoring	This study focuses on nearshore benthic habitats (greater than 500 meters from the shore) of southern Biscayne Bay to evaluate spatial patterns of abundance of SAV in relationship to (1) distance to shore and (2) water management canals that discharge fresh water from upland sources. The initial findings of this effort have already indicated distinct seasonal and species-specific patterns of abundance and spatial distribution of seagrasses and macroalgae that are directly influenced by the inflow of fresh water into nearshore Biscayne Bay. These areas are critical nursery habitats for pink shrimp (*Farfantepenaeus duorarum*) and economically-valuable fishes such as gray snapper (*Lutjanus griseus*), hogfish (*Lachnolaimus maximus*), spotted seatrout, and pinfish (*Lagodon rhomboides*).	8	Southern Coastal Systems	52.1%	• Loss of dry season sampling and loss of the seasonal variability component. • Loss of spatial coverage, including control areas and only area of overlap with the other regional SAV project (Manatee Bay) • Sampling only between Matheson Hammock and north of Barnes Sound. • Complete loss of macroalgae monitoring and loss of the ability to develop macroalgal indicators. • SAV performance measure for Biscayne Bay, Card Sound, and Barnes Sound cannot be developed. Performance measures are a primary tool that RECOVER uses to assess CERP effects and evaluate CERP alternatives. • Biscayne Bay monitoring has been combined to increase sampling efficiency. Principal investigators provided a combined scope for Biscayne Bay salinity, epifauna, SAV, and mangrove fish that decreases costs 44.5 percent by sharing field technicians.	• Habitat information connects the changes in hydrology via the BBCW Project to fauna. • Several of these habitat and faunal indicators have the ability to provide economic valuation to restoration benefits. • Ability to directly link SAV to water quality.
Monitoring of Biscayne Bay Epifaunal Communities	The epifaunal community is the principal source of prey for recreationally and commercially important fish that inhabit the SCS during all or a part of their lifetime. This project emphasizes community-based performance, directly addressing the restoration objective of reestablishing an estuarine fish and invertebrate community in nearshore South Biscayne Bay. It is a critical element in an integrated sampling regime that is examining the ecology of the seagrass systems and mangrove systems in relation to each other and spatial and temporal salinity patterns.	9	Southern Coastal Systems	55.6%	• Lose dry season sampling (lose seasonal variability). • Up to 50% reduction in sampling (results in loss of statistical power). • Lose caridean shrimp ID and abundance studies. • Limited development of predictive models and habitat suitability indices to be used in performance measures. Performance measures are a primary tool that the RECOVER program uses to assess CERP effects and evaluate CERP alternatives.• Biscayne Bay monitoring has been combined to increase sampling efficiency. PIs provided a combined scope Biscayne Bay salinity, epifauna, SAV, and mangrove fish monitoring that decreases costs 44.5% by sharing field techs.	• Estimate of effects of the BBCW Project and regional operations on epifaunal communities (pink shrimp and other invertebrates) and their ties to economic benefits for Biscayne Bay, Card Sound, and Barnes Sound.
Alligator and Crocodile Monitoring	Responses of crocodilians are directly related to the suitability of environmental conditions, including hydropattern. CERP hypotheses related to alligators and crocodiles state that restoration success or failure can be evaluated by comparing recent and future trends and status of crocodilian populations with historical population data and model predictions. Importantly, these data can be used in an analysis designed to distinguish between the effects of CERP and those of non-CERP events such as hurricanes or droughts.	10	Greater Everglades	100.0%	• Loss of information for keystone (alligator) and endangered species (crocodile). • Loss of crocodile information in support of the C-111SC and BBCW Projects. • Loss of information that contributes to interim goals reporting and the stoplight report.	• No monitoring remains.
Monitoring Aquatic Fauna in Big Cypress	Previous quantitative data on aquatic fauna communities is nearly nonexistent for the Big Cypress National Preserve; however, these forested wetlands formerly functioned as critical feeding and nesting sites for wading birds. This project collects quantitative baseline data on the constituent aquatic communities and their ecology in order to detect changes in natural and artificial habitats resulting from restoration activities.	11	Greater Everglades	100.0%	• Loss of fish and invertebrate information in eastern Big Cypress. This was the only monitoring ongoing in the Big Cypress National Preserve.	• No monitoring remains.
Sediment Elevation Tables	In 1998, the USGS began establishing surface elevation tables at the hydrology stations on Lostman's and Shark Rivers. Monitoring is focused on examining impacts of altered freshwater inflow regimes on coastal wetland hydrology and salinity regimes, effects on primary productivity, and on the dynamics of sediment elevation.	12	Greater Everglades	100.0%	• Loss of the measurement of sediment accumulation in the mangrove zone. • Loss of a long-term study to measure sea level rise.	• No monitoring remains.
Fish and Invertebrate Network (FIAN) - USGS Component	Studies quantifying seagrass-associated fish and invertebrate community composition and abundance using the one-square meter throw trap have been ongoing in South Florida since 1983. FIAN aims to quantify seagrass-associated fish and invertebrate (i.e., shrimp and crabs) populations and communities and their associations with prevailing environmental conditions (e.g., salinity and temperature) and seagrass/algae habitat (SAV). FIAN samples pink shrimp and concurrent habitat and environmental conditions in all three major southern coastal ecosystems–Florida Bay, Biscayne Bay, and the southwestern coast mangrove systems, including Whitewater Bay.	13	Southern Coastal Systems	100.0%	• Loss of the ability to estimate effects of the CERP (C-111SC and BBCW projects), non-CERP (ModWaters), and regional operations on pink shrimp populations and invertebrates, the connectivity between changes in hydrology to associated estuarine habitat and sportfish, and the tie to economic benefits. • Loss of pink shrimp monitoring, which is an indicator species and used as a stoplight indicator and an interim goal. • Loss of the development of predictive models and habitat suitability indices for potential indicator species, which could be used in performance measures. Performance measures are a primary tool RECOVER uses to assess CERP effects and evaluate CERP alternatives.	• No monitoring remains.

TABLE 2-1. CONTINUED.

Shaded cells indicate the monitoring was not funded in FY 2012.

Contract Name	Description of Monitoring	Priority	MAP Region	Proposed Percent Reduction	What Is Lost – Impact of Reduced Funding on Monitoring	Value/Use of Remaining Monitoring Data
Fish and Invertebrate Network (FIAN) - National Oceanic and Atmospheric Administration (NOAA) Component	Studies quantifying seagrass-associated fish and invertebrate community composition and abundance using the one-square meter throw-trap have been ongoing in South Florida since 1983. FIAN aims to quantify seagrass-associated fish and invertebrate (i.e., shrimp and crabs) populations and communities and their associations with prevailing environmental conditions (e.g., salinity and temperature) and seagrass/algae habitat (SAV). FIAN samples pink shrimp and concurrent habitat and environmental conditions in all three major southern coastal ecosystems–Florida Bay, Biscayne Bay, and the southwestern coast mangrove systems including Whitewater Bay.	14	Southern Coastal Systems	100.0%	• Loss of the ability to estimate effects of CERP (C-111SC and BBCW projects), non-CERP (ModWaters), and regional operations on pink shrimp and invertebrates the connectivity between changes in hydrology to associated estuarine habitat and sportfish, and the tie to economic benefits (pink shrimp). • Loss of pink shrimp, which is an indicator species and used as a stoplight indicator and an interim goal. • Predictive models and HSIs will not be developed for potential indicator species, which could be used in performance measures. Performance measures are a primary tool RECOVER uses to assess CERP effects and evaluate CERP alternatives.	• No monitoring remains.
Water Quality, Salinity & Circulation Monitoring	The goals of this project are to monitor and understand water quality variability and circulation and transport variability in the South Florida coastal region surrounding and including Florida Bay and the Florida Keys National Marine Sanctuary on tidal to interannual time scales; to monitor and understand the role of the Loop Current and Florida Current in influencing water quality along the southwestern Florida shelf and the Florida Keys including the Dry Tortugas; and to monitor and understand the advection and dispersion of nutrient loads discharging on the southwestern Florida shelf and directly into Florida Bay.	15	Southern Coastal Systems	100.0%	• This project was not funded in FY 2011 nor FY 2012. • Loss of the ability to see salinity and other water quality conditions across the entire estuary (Florida Bay) over time. • Loss of supplemental data to augment the continuous salinity monitoring information generated by the National Park Service and SFWMD.	• No monitoring remains.

SUPPORT TO PROJECTS

RECOVER science, monitoring, and research under the CERP MAP supports project planning and implementation in the following ways: (1) research to support model and performance measure development to evaluate project benefits and systemwide performance; (2) science and monitoring components to decrease scientific uncertainty and support the development of project monitoring and adaptive management plans; and (3) report restoration project success and new information to adjust project implementation and improve restoration performance. These are discussed in more detail in the following subsections.

Modeling and Performance Measures

Performance measures are planning tools, which often include ecological models used to help design the restoration program as part of the CERP planning process, to predict restoration response and to assess the response of the natural system during and after project implementation. Quantitative performance measures help project planners determine the degree that proposed alternative plans are likely to meet restoration objectives, and compare projected benefits among alternative plans. Performance measures and their targets are additionally used to help define the content of monitoring plans designed to assess project or program performance or to indicate the need for adjustments to improve success. MAP monitoring reported under the SSR has been used to improve RECOVER systemwide and regional performance measures that have been used by the following projects to determine benefits: Biscayne Bay Coastal Wetlands, Broward County Water Preserve Area, C-111 Spreader Canal, C-43 Reservoir Storage, Indian River Lagoon South, Site 1 Water Impoundment, and the CEPP. The CEPP Pilot Project is exclusively using RECOVER performance measures in their evaluations of project performance and development of habitat unit calculations because they have been vetted through the RECOVER review process and do not require additional model review by the United States Army Corps of Engineers (USACE) other than approval by the National Ecosystem Planning Center of Expertise (ECO-PCX). The RECOVER performance measures being used by the CEPP to develop habitat units are listed in ***Table 2-2***. MAP monitoring components that supported development of ecological planning tools used in the CEPP are listed in ***Table 2-3***. RECOVER performance measures can be found online at http://www.evergladesplan.org/pm/recover/eval_team_perf_measures.aspx.

TABLE 2-2. RECOVER PERFORMANCE MEASURES USED BY THE CEPP FOR EVALUATION OF PROJECT BENEFITS.

Performance Measure Title	Location on the Web
Lake Okeechobee Performance Measure – Lake Stage	http://www.evergladesplan.org/pm/recover/recover_docs/et/lo_pm_stage_081409.pdf
Northern Estuaries Performance Measure – Salinity Envelopes	http://www.evergladesplan.org/pm/recover/recover_docs/et/ne_pm_salinityenvelopes.pdf
Greater Everglades Performance Measure – Inundation Pattern in Greater Everglades Wetlands	http://www.evergladesplan.org/pm/recover/recover_docs/et/061807_prev_ge-2.pdf
Greater Everglades Performance Measure – Sheet Flow in the Everglades Ridge and Slough Landscape	http://www.evergladesplan.org/pm/recover/recover_docs/et/ge_sheetflow_01.pdf
Greater Everglades Performance Measure – Dry Events in Shark River Slough	http://www.evergladesplan.org/pm/recover/recover_docs/et/061807_prev_ge-1.pdf
Greater Everglades Performance Measure – Slough Vegetation	http://www.evergladesplan.org/pm/recover/recover_docs/perf_measures/ge_slough_veg_pm_final_092611.pdf
Greater Everglades Performance Measure – Extreme High and Low Water Levels in Greater Everglades Wetlands (hydrologic surrogate for soil oxidation)	http://www.evergladesplan.org/pm/recover/recover_docs/perf_measures/ge-03_090408.pdf
Southern Coastal Systems Performance Measure – Salinity in Florida Bay	http://www.evergladesplan.org/pm/recover/recover_docs/perf_measures/062812_rec_pm_scs_salinity_flbay.pdf

TABLE 2-3. CEPP ECOLOGICAL MODELS AND PLANNING TOOLS SUPPORTED BY RECOVER MONITORING.

Model or Tool	Description and Location on Web
Everglades Landscape Vegetation Succession Model (ELvES)	Landscape patterns – freshwater estuarine vegetation, ridge and slough, tidal creek, marl prairie
American Alligator Habitat Suitability Index (HSI)	Wetland trophic – American alligator http://www.evergladesplan.org/pm/recover/recover_docs/ret/pm_ge_alligator.pdf
Wood Stork Foraging Probability Model/Water Depth Assessment Tool (WDAT)	Wading bird foraging and nesting patterns
Small-Sized Freshwater Fish Density	Wetland trophic relationships for fish
Oyster HSI	Northern Estuaries oysters habitat http://www.evergladesplan.org/pm/recover/recover_docs/et/ne_pm_oysterhabitat.pdf

Monitoring and Adaptive Management Plan Development

The MAP provides a framework to monitor and measure systemwide responses to multiple CERP projects and operations being implemented in order to determine how well CERP is achieving its goals and objectives. In addition, the MAP monitoring data that is reported in the SSR is intended to support and enable adaptive management for updating and improving CERP project design, construction, and operations as needed. Projects are required to first consider using MAP monitoring to support project monitoring for restoration success needs. Because the monitoring designs are at a systemwide scale (detecting change over a larger area and longer period of time from multiple project effects), the monitoring may not always be designed to detect smaller-scale project improvements. However, there are a number of cases where specific MAP monitoring components are being used for project monitoring or as a supplement to project specific monitoring and adaptive management plans: Biscayne Bay Coastal Wetlands, Broward County Water Preserve Area, C-111 Spreader Canal, C-43 Reservoir Storage, Indian River Lagoon South, Site 1 Water Impoundment, and the CEPP. This coordination between RECOVER and projects ensures monitoring and reporting efforts are not redundant and makes the best use of agency resources to monitoring restoration success. ***Table 2-4*** presents an example of the C-111 Spreader Canal and RECOVER monitoring coordination.

Reporting Restoration Success

The 2014 SSR will report on projects that have been constructed—C-111 Spreader Canal, Biscayne Bay Coastal Wetlands, and Picayune Strand Restoration—to document restoration success. The SSR is one vehicle for projects to report progress towards restoration over longer time periods. Projects will use the South Florida Environmental Report for annual restoration success reporting, as well as specific project-level assessment reports when necessary.

TABLE 2-4. C-111 SPREADER CANAL MONITORING FULLY OR PARTIALLY FUNDED BY THE RECOVER MAP.

Parameter	Purpose	Methodology	Funding	Target
Wetland Surface Water Flow		Coastal Gradients	South Florida Water Management District (SFWMD), Everglades National Park, USGS, and RECOVER MAP (Coastal Gradients).	Maintain hydroperiods in Everglades National Park marsh.
Salinity	Spatial mapping of wetland salinities are proposed to document shifts in salinity zones near the coast.	Measure nearshore salinity at two sites in Florida Bay. Project funded salinity includes spot salinity monitoring at 15 transects in creeks. USGS Coastal Gradients monitoring. 22 sites from Everglades National Park. Biscayne salinity monitoring at three sites. Coastal Everglades Florida International University (FIU) Long-term Ecological Research (LTER)/National Science Foundation 26 stations.	RECOVER Coastal Gradients project (USGS) and FIU LTER, Everglades National Park, SFWMD, Biscayne Bay National Park, project funds.	Salinity is a primary RECOVER performance measure for restoration in this region and the project is expected to produce more natural salinity patterns in the coastal wetlands, Florida Bay, Manatee Bay, and Barnes Sound.
Water Quality	Assessment of project effects on freshwater input/output and nutrient export from western Taylor Slough lakes.	Nutrient status at sites downstream of freshwater inflow to the wetlands (from canals or detention areas) and along select sites of the coastal gradients transects, including nutrient concentrations in a subset of creeks with USGS flow monitoring to estimate nutrient loading.	RECOVER Coastal Gradients project (USGS) and FIU (LTER), Everglades National Park, SFWMD, Biscayne Bay National Park, project funds	No increase.
Vegetation	Wetland vegetation productivity will be measured to assess the effects of changing water distribution across the project area.	Vegetation sampling will be conducted along transects in the eastern portion of the project domain, including both saline coastal marshes and freshwater marshes. For each site, plant community composition, biomass, and productivity will be measured annually in at least nine plots. In addition, vegetation aerial mapping to occur in Everglades National Park, model lands, southern glades.	Vegetation transect monitoring is partly funded by the MAP. Remote sensing and photogrammatric are partially funded by the MAP.	The project's modification of hydropattern and salinity are expected to lead to ecological change toward RECOVER restoration goals and this change will largely occur via changes in plant community structure and cover, which are primary RECOVER performance measures.
SAV	Changes in SAV (along with hydrology and salinity) are needed to understand causes of prey base change.	SAV monitoring estimates benthic macrophyte cover. Coring estimates seagrass shoot densities and biomass.	Extensive SAV monitoring is conducted by the FHAP-FS, which is supported by RECOVER, project funds, and the Miami-Dade Department of Environmental Resource Management.	The project's modification of hydropattern and salinity are expected to lead to ecological change toward RECOVER restoration goals and this change will largely occur via changes in plant community structure and cover, which are primary RECOVER performance measures.
Freshwater Wetland Prey Base	Restoring natural hydroperiods in the southern Everglades wetlands should increase the number of high quality foraging areas for wading bird populations when they nest in the dry season.	Fish samples are taken in both coastal creek and wetland flat habitats using 9 one-square meter drop traps.	Funded by the MAP. SAV communities have also been surveyed by the Florida Audubon Society across these areas, along upstream-downstream transects to encompass salinity gradients (Joel Trexler, FIU).	Restoring natural hydroperiods in the southern Everglades wetlands should increase the number of high quality foraging areas for wading bird populations when they nest in the dry season.
Saltwater Wetland Prey Base	Prey base sampling provides an estimate of the net production of marsh fishes and other fauna at the end of the wet season.	Throw trap samples are collected from randomly selected sites within areas of sparse emergent macrophytes that are delineated for each cell. Parameters measured from throw trap samples include the density, species composition, and size class distribution of fishes and associated fauna.	RECOVER MAP funds monitoring of the regional population densities and distributions of marsh fishes and associated aquatic invertebrates (Jerry Lorenz, Florida Audubon Society).	Redistribution of freshwater inflow from the project is expected to reestablish a positive salinity gradient along a greater portion of the shoreline and to reestablish estuarine conditions in northeastern Florida Bay. These hydrologic changes are expected to increase the diversity, abundance, and biomass of fish in the ponds, creeks and flats of the salinity transition zone. Such a response is described in biological performance measures currently defined for the CERP by RECOVER.
Spotted Seatrout	Data collected is summarized and analyzed to (1) quantify the status of year 1 juvenile seatrout densities and the annual trend; and (2) determine spatial distributions in relation to environmental variables, especially salinity.	Trawl sampling.	MAP and NOAA funded.	Increase spotted seatrout juvenile densities directly downstream of Taylor Slough.

TABLE 2-4. CONTINUED.

Parameter	Purpose	Methodology	Funding	Target
Estuarine Fish and Invertebrates	An increase in the diversity and abundance of the estuarine component of this assemblage (i.e., the euryhaline fauna) and a decrease in abundance of the purely marine forms would indicate progress toward the desired estuarine conditions in nearshore Florida Bay.	This monitoring quantifies fish species abundance and community composition along with measures of SAV abundance and composition. Data collected are summarized and analyzed to (1) quantify the composition of the faunal assemblages present; (2) determine spatial distributions in relation to environmental variables, especially salinity; and (3) track change over time in distributions, abundance, and species assemblages.	FIAN funded by the MAP, USGS, and NOAA. Fisheries independent monitoring by Everglades National Park and the Florida Fish and Wildlife Conservation Commission	This monitoring addresses the CERP premise that changes in salinity lead to increases in shoal grass (*Halodule wrightii*) enhancing productivity resulting in increases in the relative and absolute abundance of estuarine fish and invertebrates.
Spoonbill Nesting Success	Recreating historic distribution of flows (temporally and spatially) through the C-111 basin coastal wetlands should improve the reliability of food supplies, and result in an escalation of spoonbill nesting effort and success in the northeastern colonies.	The Florida Audubon Society surveys roseate spoonbill nests on 34 Florida Bay keys that were historically used as nesting colonies. These colonies are divided into five distinct nesting subregions based on each colony's primary foraging location. Nests are counted by entering an active colony and thoroughly searching for nests on foot. Nesting success is also estimated for the four active subregions through mark and revisit surveys of the most active colony within the subregion. These surveys entail marking between 15 and 50 nests shortly after full clutches had been laid and revisiting the nests on an approximate two-week cycle to monitor chick development. In order to build relationships between hydrologic conditions, prey availability, and spoonbill nest productivity. In addition, roseate spoonbills and their nests are counted during aerial reconnaissance flight surveys conducted by Everglades National Park staff in areas of the southern Everglades C-111SC Project footprint.	Florida Audubon, Everglades National Park, MAP, and project funded.	Restoring more natural hydrologic patterns, including a natural recession of water levels in the dry season and reduction in water management-induced reversals, should allow for improved foraging conditions for spoonbills and an increase in nest productivity, goals explicitly described in the RECOVER Greater Everglades module performance measure for roseate spoonbills.
Wading Birds	Redistribution of freshwater inflow from the C-111SC Project is expected to reestablish a more natural hydropattern in southern Everglades marshes. These hydrologic changes are anticipated to increase the diversity and abundance of wetland prey base fish and invertebrates.	Aerial surveys by fixed-wing aircraft are conducted by Everglades National Park staff in the dry season. These flights are made on a monthly basis between December and May across large areas of Everglades National Park to count numbers of wading birds, and between February and July at specific colonies to count numbers of wading bird nests. Of interest for the C-111SC Project are basins identified as Lone Pine Key/South Taylor Slough Mangrove and Eastern Panhandle Mangrove Estuary and the nesting colonies identified as Lower Taylor Slough, Cuthbert Lake, and Paurotis Pond. Transects are flown in an east-west direction, at a separation distance of approximately 2 kilometers and an altitude of approximately 60 meters above ground surface. All wading birds and their nests are counted, identified, and located by global positioning satellite (GPS) during the flights. The amount of surface water available for foraging is also described as part of these surveys.	Everglades National Park, MAP, and project funded.	Restoring more natural hydrologic patterns, including a natural recession of water levels in the dry season and reduction in water management-induced reversals, should allow for improved foraging conditions for wading birds and an increase in nest productivity, goals explicitly described in the RECOVER Greater Everglades module performance measures.
Juvenile Crocodiles	Monitoring crocodiles addresses the project objective of reducing hypersaline conditions in the estuaries by evaluating the extent to which suitable nursery habitat for hatchling and juvenile crocodiles is restored in the nearshore waters and mangrove wetlands of the project area. Suitable nursery habitat includes maintaining salinity regimes conducive to the growth and survival of these life stages.	Diurnal and nocturnal surveys for crocodiles and nests will be conducted annually. All mangrove shorelines, creeks and canals will be surveyed by spotlight during nocturnal hours. Spotlight surveys of the shoreline will be conducted from a skiff using a 200,000-candlepower blue spotlight. For canals and shallow creeks, less powerful 50,000-candlepower head lamps will be used. Surveys will be started after sundown each sampling night. Locations and times of sightings of crocodile activity will be recorded along with a description of the habitat and physical parameters. Crocodiles will be captured, measured, and marked whenever possible. Capture will be either by hand, with tongs, or with a self-locking wire noose. Size estimates will be made for animals that cannot be caught. The following information will be recorded: previous tail marking, total length, snout vent length, weight, and sex. Suitable nesting habitat will be searched on foot during daylight hours during the period of nest preparation (spring). Areas where signs of nests were reported, including a mound, eggshells, or digging activity, will also be investigated. Confirmed nest sites will be visited from July 15 until hatching. Hatchlings will be located at night by flashlight or during the day by searching the immediate vicinity of the nest. Hatchlings will be captured by hand or with tongs, and the same data will be recorded as for other captures described above.	MAP funded.	Restoration of oligohaline and mesohaline conditions along the mangrove shoreline of Florida Bay should provide better quality hatchling and juvenile crocodile habitat. The target is to meet all of the life stage requirements to support the continued recovery of this endangered species.

QAOT CONTRIBUTIONS TO RECOVER

The QAOT was established by CERP Guidance Memorandum 041 to provide guidance on monitoring procedures, quality assurance/quality control (QA/QC) and data validation for CERP projects, and to be the forum to develop consistency among the various entities involved with environmental monitoring, data quality and QA/QC processes. See http://www.cerpzone.org/documents/cgm/CGM_041.01_QAOT_20100721_Final_Signed.pdf for more information.

During Water Years 2011–2012 (May 1, 2010–April 30, 2012), the QAOT has implemented activities to address recommendations made in the *2009–2010 Quality Assessment Report for Water Years May 1, 2008–April 30, 2010*, which is available online at http://www.evergladesplan.org/pm/pm_docs/qaot/051911_qaot_qar.pdf, and a number of recommendations for improvement were identified. The QAOT employed a variety of methods to evaluate QA/QC procedures implemented for the CERP that could impact data quality. These methods included a review of QA/QC processes, evaluation of field monitoring activities, and assessment of laboratory performance. A detailed summary of the QAOT activities highlighted in the following paragraphs is also provided in the *2011–2012 CERP Quality Assessment Report* (QAR).

Several QAOT/CERP documents were updated as part of the QA/QC review process. The *Quality Assurance System Requirements Manual* was updated (see http://www.evergladesplan.org/pm/program_docs/qasr.aspx), three CERP guidance memorandas were revised (see http://www.evergladesplan.org/pm/program_docs/cerp-guidance-memo.aspx), one QAOT standard operating procedure (SOP) was updated, one QAOT SOP was created (see http://www.evergladesplan.org/pm/qaot.aspx#sop), and the *QAOT Project Management Plan* was revised and approved. Three monitoring plans for CERP projects were reviewed. Project-level assessments, which included project monitoring plans, project-specific field audits, and reviews of CERP data quality, were conducted for 10 CERP projects. The QAOT also conducted five program-level activities: (1) a comparison study of chlorophyll-*a* sampling and analysis procedures, (2) a review of 14 water quality reports and documents for the inclusion of quality system elements, (3) a review of the organization and format of 33 Decompartmentalization Physical Model SOPs, (4) development of eight biological/ecological SOPs, and (5) coordination and presentation of the Fourth Quality Assurance Workshop on September 14–15, 2011 (see http://www.evergladesplan.org/pm/qaot.aspx#workshops). See Chapters 4 and 10 of the 2011-2012 QAR for additional information.

On-site field audits and/or observations were conducted to assess field monitoring activities. Field audits for six CERP water quality projects were conducted. Field techniques were determined appropriate for the required data collection except for one significant finding related to equipment calibration. Hydrologic, meteorologic, and hydraulic data acquisition field audits included visits to 18 United States Geological Survey (USGS) stations. The results from the audits indicated that, in general, equipment was properly maintained and operated at each station. Recommendations included improving calibration documentation. One on-site biological/ ecological monitoring field visit was conducted. All field biological/ecological sampling was conducted in accordance with the monitoring plan. See Chapter 5 of the 2011-2012 QAR for additional information.

The QAOT completed on-site quality assessments of seven organics and seven inorganics laboratories that may generate data for the CERP under existing statement of works or contracts with the South Florida Water Management District (SFWMD) or the USACE. Findings in the organics laboratories included method deviations related to method detection limits, analytical procedures, and data traceability. Findings in the inorganic laboratory audit reports included deviations from method analytical procedures, treatment and acceptance criteria for quality control samples, and lack of adequate detail in SOPs. In most cases, corrective actions were undertaken by the laboratories to mitigate the findings. Performance evaluation samples were provided to two of the seven organics laboratories. All reported results fell within the control limits. Two inorganic water performance evaluation samples were provided to laboratories that are analyzing or could potentially analyze chemistry samples for the CERP. In 2010, 53 percent of the results were scored as either very good/satisfactory or good. In 2011, 62 percent of the results fell within these two categories. See Chapter 6 of the 2011-2012 QAR for additional information.

An assessment of CERP data quality represented by a snapshot of analytical data in the SFWMD's hydrometeorologic, water quality, and hydrogeologic data retrieval system, DBHYDRO, and Everglades Research Database Production (ERDP) databases and analytical data from one aquifer storage and recovery project was conducted during the reporting period. Analysis of analytical chemical and standard water quality data indicated that approximately 2 percent of Water Years 2011–2012 data snapshot had qualifiers indicating that data quality could be compromised. Water quality collected for the Kissimmee Aquifer Storage and Recovery project during three testing cycles indicated that 3.0 to 3.9 percent of the samples had quality-related data qualifiers. A data qualifier is a code or flag that is added to data to serve as an indication of the quality of data (see Table 7-2 of QAR for list of data qualifiers). For 13 hydrologic data types in DBHYDRO, 2 percent of the data were missing, 9 percent were estimated, and less than or equal to 1 percent were not processed during the reporting period. The implementation of quality system elements for CERP Phase I and Phase II environmental assessment projects was assessed by reviewing 14 project documents. Based on the document review, most of the important quality system elements were addressed.

The QAOT continued communication and outreach efforts and collaboration with other CERP entities. Eight initiatives identified in previous QARs were completed during Water Years 2011–2012.

Quality assurance is a continuous process improvement cycle of "plan, do, check, and act". Additional recommendations that will be assessed in the future include working with the Design Coordination Team and project delivery teams to locate and centralize CERP data; working with the land acquisition team to ensure that CERP-related data are being maintained in CERP data repositories and that statements of work and monitoring plans are provided to the QAOT for review; conducting biological/ecological assessments based on current SOPs; establishing processes to review, tag, and investigate hydrologic and hydraulic data issues; and develop a process to ensure that data qualifiers are added to compromised data identified during laboratory and field audits. For additional information on the QAOT, see http://www.evergladesplan.org/pm/qaot.aspx.

2014 SYSTEM STATUS REPORT GAME PLAN

RECOVER has begun planning and initial preparation work for the 2014 SSR. Building off the impressive 2009 SSR, the 2014 SSR will focus heavily on using the webument (web-based document) to convey new information on ecosystem status to technical staff, project delivery teams, and higher-level science coordination teams (i.e., RECOVER Leadership Group and Science Coordination Group). Responding to lessons learned from managers, peer reviews, and the SSR technical team that participated in the 2009 SSR effort, the 2014 SSR will develop storylines to better link science to management decisions (project plans, designs, operations, and implementation) and provide the significance and context of the findings. The following is a short hypothetical example storyline from the Northern Estuaries:

> The past several years (2010–2012) were drier than average and freshwater discharges to the Northern Estuaries were reduced compared to the long-term average. This resulted in a reduced number of high flows going to the estuaries and increased frequency of Lake Okeechobee stages meeting optimal ranges. However, low flow events were similar or slightly worse compared to the long-term average. The high salinity, marine portions of these systems responded differently than the low salinity, fresher portions to drier climatic conditions. The observed ecological responses in the more marine regions of the estuary provide a glimpse of the responses expected when implementation of CERP projects (i.e., C-43 Reservoir, Indian River Lagoon – South, Lake Okeechobee Watershed, CEPP, and additional CERP storage, treatment, and conveyance south to the Greater Everglades) reduces high freshwater discharges to these systems. By contrast, responses in the oligohaline regions provide examples of dry season effects that other CERP projects (i.e., C-43 Reservoir and C-43 Aquifer Storage and Recovery) will ameliorate.

The Northern Estuaries SSR results will be reported in a way that connects the results to this storyline, helping RECOVER principle investigators analyze and report their data, and regional teams integrate multiple restoration indicator results into one overall story.

Not all indicators will be part of each regional and systemwide storyline but the storyline should reflect the general status of the system in the context of why restoration is important and inform managers of success or unexpected changes. For all other indicators, each region will report on the status and trends (the “what happened”) data sets analyzed in the 2009 SSR, if new data is available. Emphasis will be on trends and significance of current status (past four years) compared to the previous data set. When possible, to better detect change from projects and operations versus climate variability, principle investigators will extend the data sets both with new information or historical non-MAP funded monitoring for the same indicators, if methods and sampling design are comparable.

Keeping with the original intent of the MAP in supporting CERP’s program-level adaptive management program, regional teams will report, where possible, why the observed conditions (status and trends) occurred (the “why it happened”) by asking the following questions:

- Do results confirm the systemwide hypotheses stated in the MAP and RECOVER conceptual ecological models about why the trends are occurring?
- How do the status and trends compare to expected CERP restoration targets as stated by RECOVER performance measures, and restoration status given projects, operations, or climatic events that have occurred?

- Were the past three to four years better, worse, or no change from the longer-term trend, and how do ecological responses relate to physical parameter responses (e.g., hydrology, water quality, and food availability)?

Where applicable, regional teams will report how new information from monitoring has been used to update understanding (address key uncertainties) of hydrological-ecological relationships related to achieving restoration success, to inform regional operations, and support project planning via performance measures, modeling tools, systemwide regional evaluations, and monitoring and adaptive management plans.

Finally, RECOVER recognizes the need to explain technical results in more common terms using similar frameworks and language so that more general audiences can better understand and then support the value of the monitoring efforts. To support writing the SSR executive summary and key findings for managers, agency decision-makers, United States Congress, nonagency stakeholders, and the general public, the general framework provided in ***Figure 2-1*** will be used for organizing and reporting information about each indicator and how they are related.

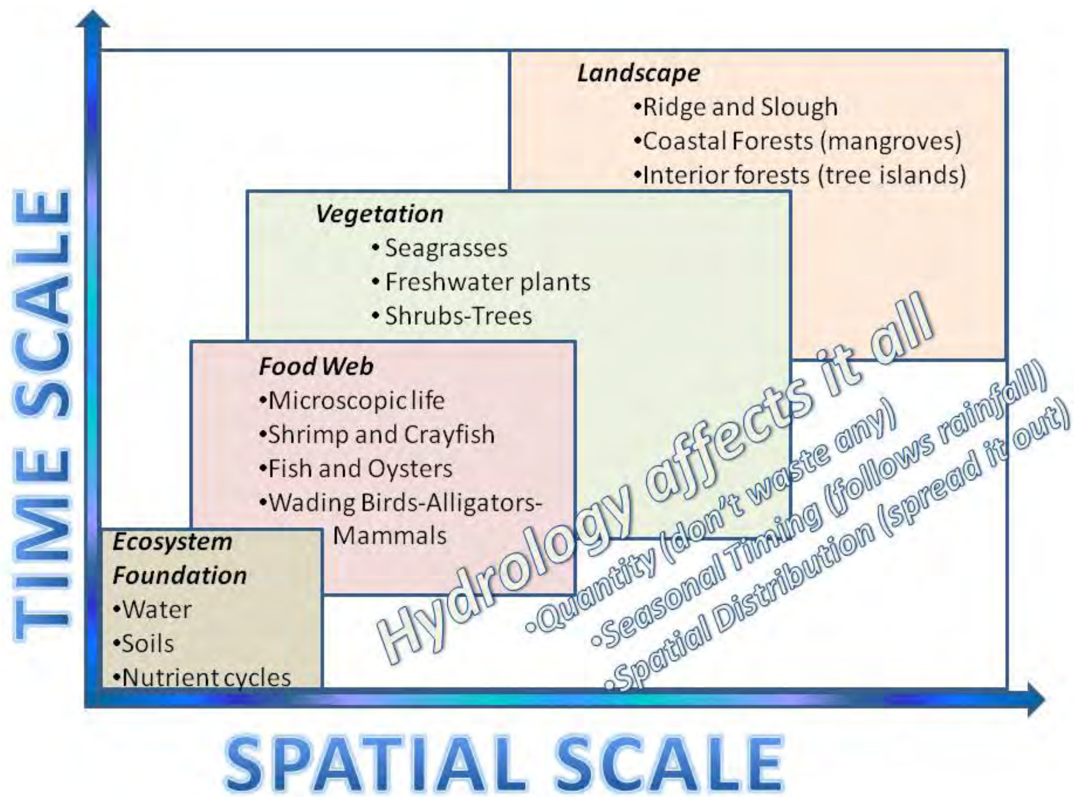

FIGURE 2-1. GENERAL FRAMEWORK FOR ORGANIZING AND REPORTING INFORMATION FOR EACH INDICATOR WITHIN THE SSR EXECUTIVE SUMMARY AND KEY FINDINGS.

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CHAPTER 3

LAKE OKEECHOBEE MODULE

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CHAPTER 3 LAKE OKEECHOBEE MODULE

INTRODUCTION

Lake Okeechobee is a shallow, eutrophic lake located in central South Florida. Historical and background information, including its importance to the south Florida ecosystem and the impacts development has had on the lake can be found in the *2007 System Status Report* (SSR) (RECOVER 2007), which is available on line at the following link: http://www.evergladesplan.org/pm/recover/recover_docs/at_ssr_2007/2007_ssr_final_sect_4_lake_okeechobee.pdf. Additional information was provided in the 2009 SSR. The Lake Okeechobee Module of the 2009 SSR is available online from http://www.evergladesplan.org/pm/ssr_2009/mod_lo.aspx. A map of Lake Okeechobee is provided in ***Figure 3-1***.

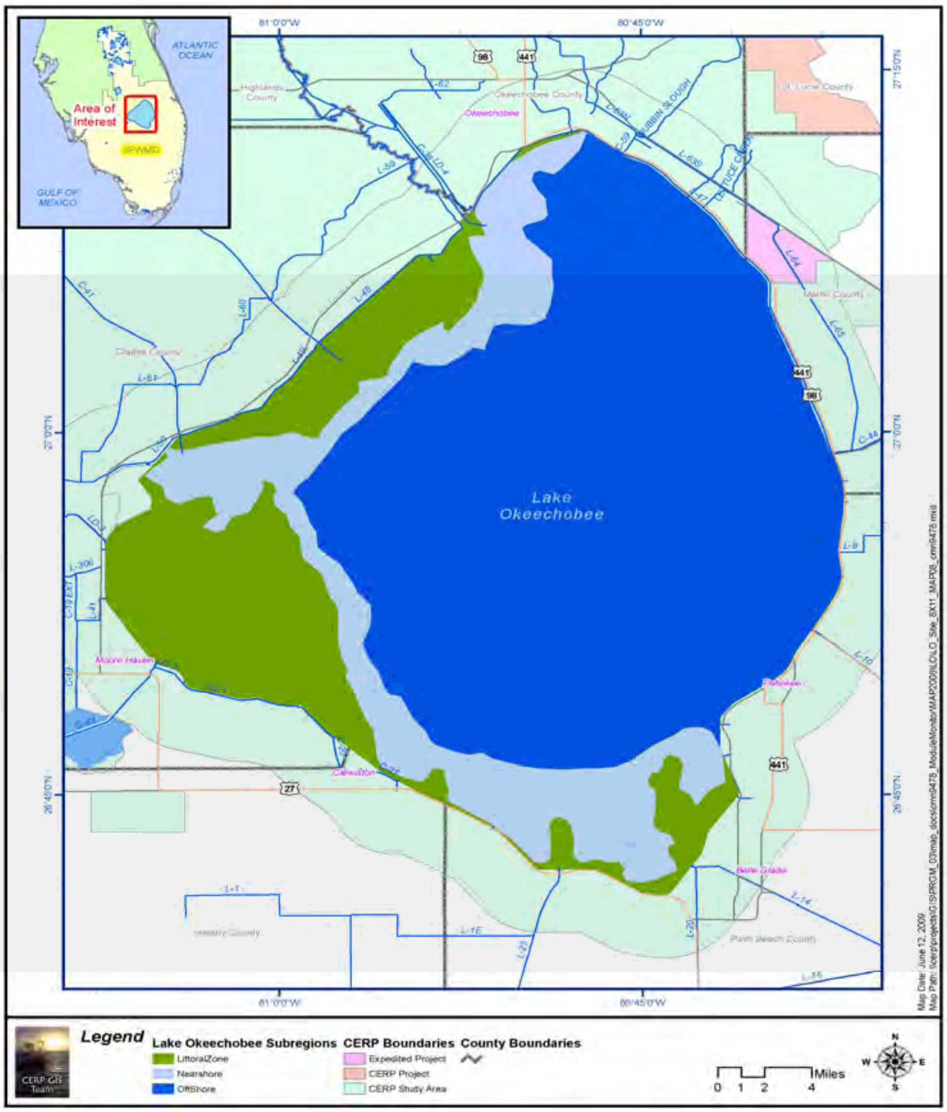

FIGURE 3-1. MAP OF LAKE OKEECHOBEE

Assessments for Lake Okeechobee are based on interrelationships that exist between water level and nutrient condition, and those key flora and fauna communities that respond to or are affected by them. Lake Okeechobee has three subregions: littoral marsh, nearshore region and open water. These subregions are functionally dissimilar and may respond to changes in water level and water quality quite differently.

In 2012, Lake Okeechobee assessments were produced for the some of the stressors and attributes previously reported on in the 2009 SSR (RECOVER, 2010) *http://www.evergladesplan.org/pm/ssr_2009/mod_lo.aspx*: lake stage, water quality, phytoplankton and submerged aquatic vegetation (SAV). More detailed assessments on thise components as well as assessments for the remaining three attributes—periphyton, native fish and macroinvertebrates—will be included in the full 2014 SSR.

WATER QUALITY AND STAGE

Introduction

Lake Okeechobee water quality data from both the pelagic (open water) and nearshore water quality monitoring stations were evaluated over the past three water years: Water Year 2010 (WY2010)–WY2012 (May 1, 2009–April 30, 2012). These annual water quality values and five-year rolling averages (2008–2012) were compared to those previously reported in the *2005 South Florida Environmental Report* (SFER) (Havens et al., 2005) and the 2009 SSR (RECOVER, 2010). These water quality average values also were compared against quantitative performance measure restoration goals. None of the performance measure restoration goals were achieved when compared to the WY2010–WY2012 or the five-year rolling average values. See the Lake Okeechobee Water Quality Results of the 2009 SSR at http://www.evergladesplan.org/pm/ssr_2009/hc_lake_o_wq_results.aspx and Chapter 8 of the 2013 SFER at http://my.sfwmd.gov/sfer (Zhang and Sharfstein, 2013).

While implementation of restoration projects within the lake and watershed is expected to improve water quality attributes through reduced water column nitrogen, phosphorus, total suspended solids and chlorophyll *a* concentrations, the detection of these improvements may take several decades after restoration activities are completed to occur because of the lake's large internal nutrient pool. A reduction in nutrients in Lake Okeechobee and its watershed will significantly enhance the restoration success of the Everglades and the coastal estuaries in terms of improved water quantity, quality and timing of water leaving the lake.

Methods and Analysis

Long-term monitoring efforts continue at both pelagic and nearshore stations (***Figure 3-2***) to examine physical, chemical and ecological trends and patterns in Lake Okeechobee and its watershed. The most recent update of the Lake Okeechobee monitoring regime is reported in the 2013 SFER (Zhang and Sharfstein, 2013).

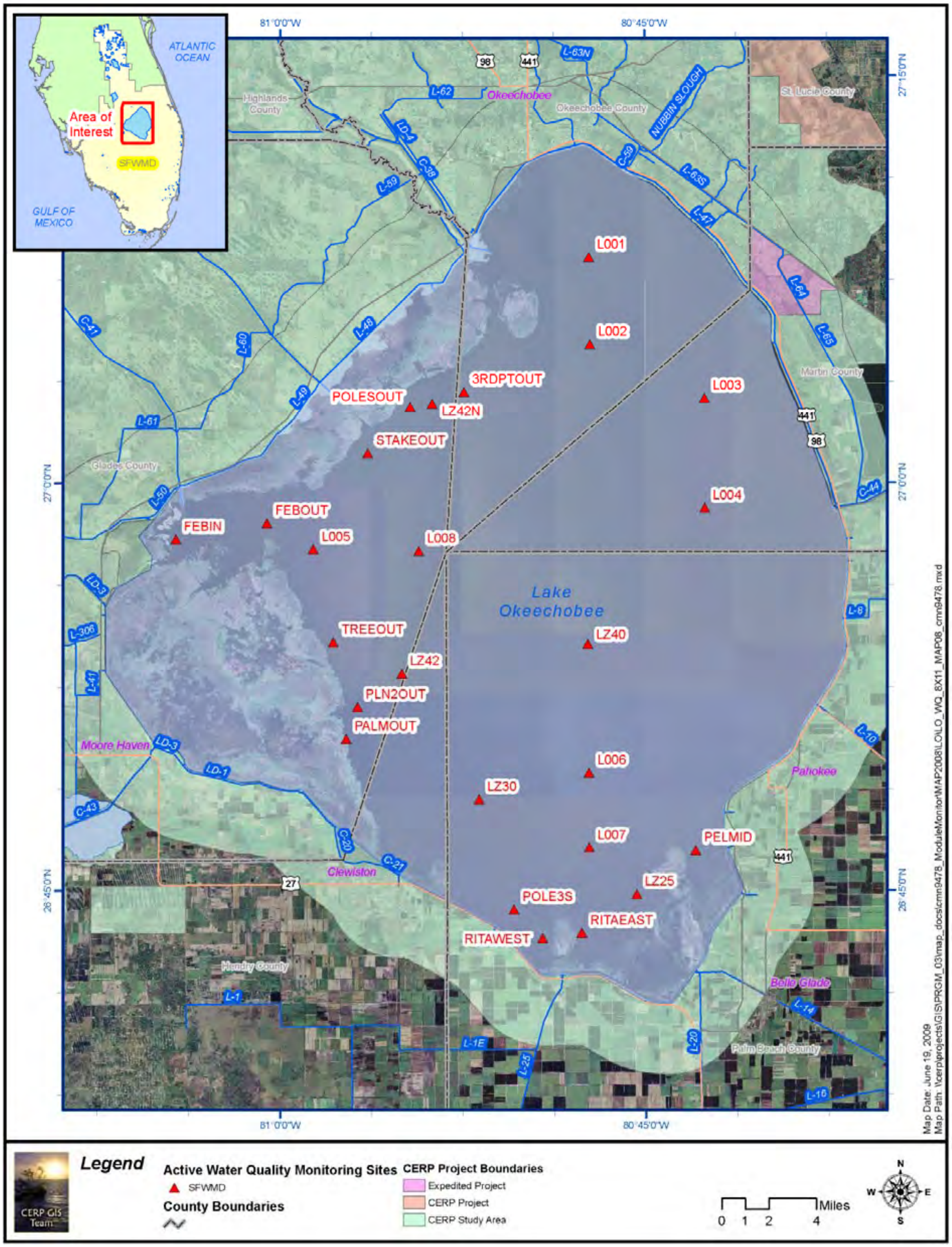

FIGURE 3-2. WATER QUALITY SAMPLING STATIONS IN LAKE OKEECHOBEE.

Data from both pelagic and nearshore stations over the last three water years (WY2010–WY2012) and five-year (2008–2012) rolling averages also were compared to both the two previous five-year water year means and to performance measures developed specifically for the lake. The pelagic performance measures include water column total phosphorus (TP) concentration, total nitrogen (TN):TP ratio, soluable reactive phosphorus (SRP):dissolved inorganic nitrogen (DIN) ratio, percent algal blooms, and TP loads to the lake. Additional water quality data from the nearshore stations were averaged for the same water year period and compared to nearshore goals. These data included nearshore TP and the percent of time where Secchi disk transparency was equal to the water column depth at the nearshore submerged aquatic vegetation (SAV) sites during May to September.

Results

Stage

Lake Okeechobee has multiple uses, which have previously been described in Havens et al. (1996) and the 2009 SSR (RECOVER, 2010). Despite the imbalance between Lake Okeechobee inflows and outflows—a function of the large watershed drained by the lake and the flow limitations of its discharge structures—which can result in rapid increases in lake stage, the current stage regulation schedule (2008 LORS) is designed to maintain the lake approximately one and a half feet lower than the previous schedule (Water Supply and Environmental [WSE]). The schedule was revised primarily as a result of concerns over the safety and integrity of the Herbert Hoover Dike. The schedule has been in place for the past three water years (May 1, 2009–April 30, 2012). Lake stage since WY2010 has exceeded 15 feet mean sea level (ft msl), near the top of the ecologically beneficial stage envelope, only once, during May 2010 (***Figures 3-3*** through ***3-5***). Otherwise, the lake has stayed between the total maximum daily load (TMDL) elevation of 11 feet National Geodetic Vertical Datum (ft NGVD) and 15 ft NGVD except for two periods. During the first, a brief period in May 2009, the lake fell to 10.5 ft NGVD. The second was a six-month period from May through October 2011 when the lake remained below 11 ft NGVD, reaching a minimum elevation of 9.6 ft NGVD.

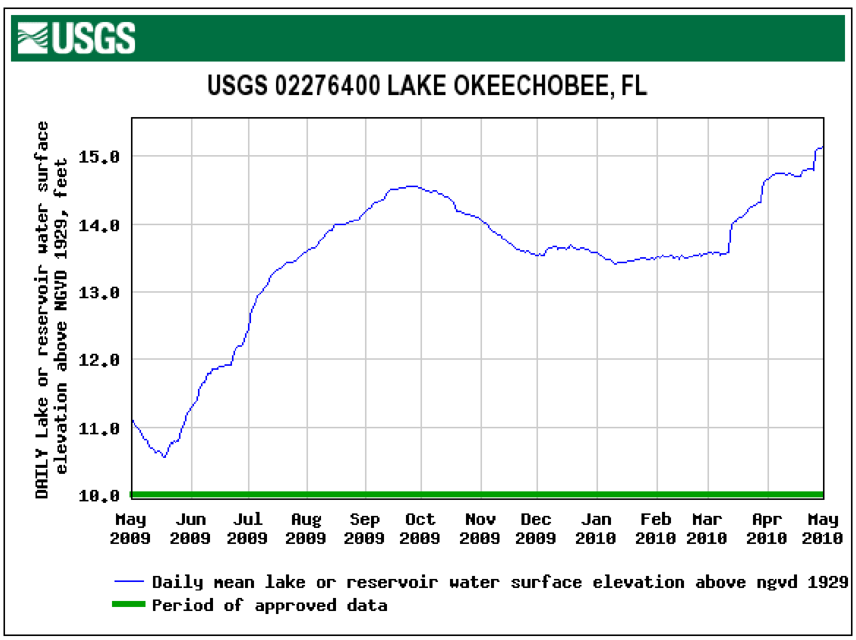

FIGURE 3-3. LAKE OKEECHOBEE STAGE HYDROGRAPH FOR WY2010.
(Note: USGS – United States Geological Survey.)

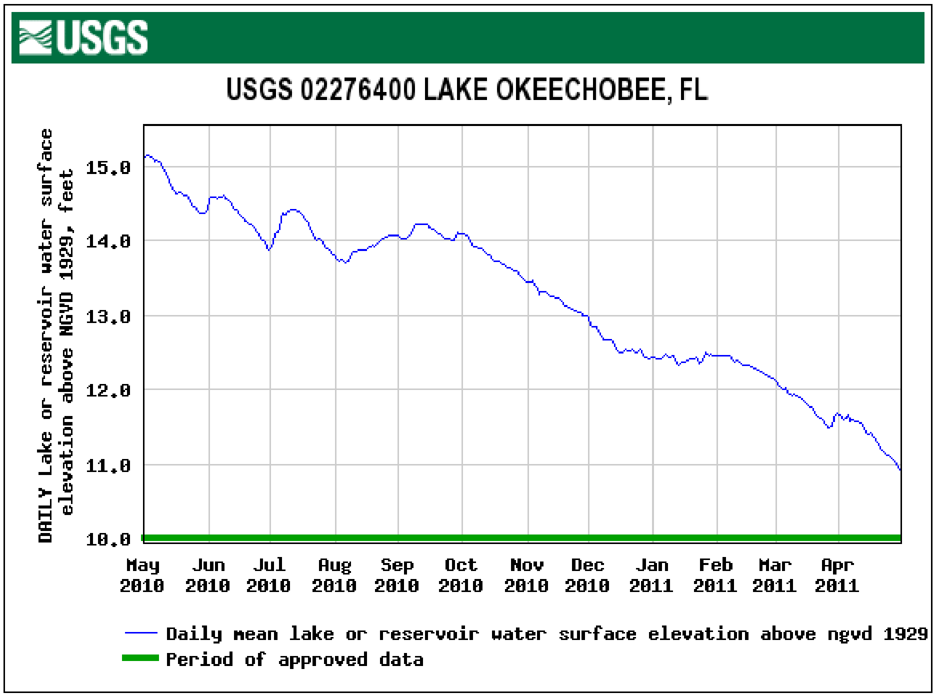

FIGURE 3-4. LAKE OKEECHOBEE STAGE HYDROGRAPH FOR WY2011.

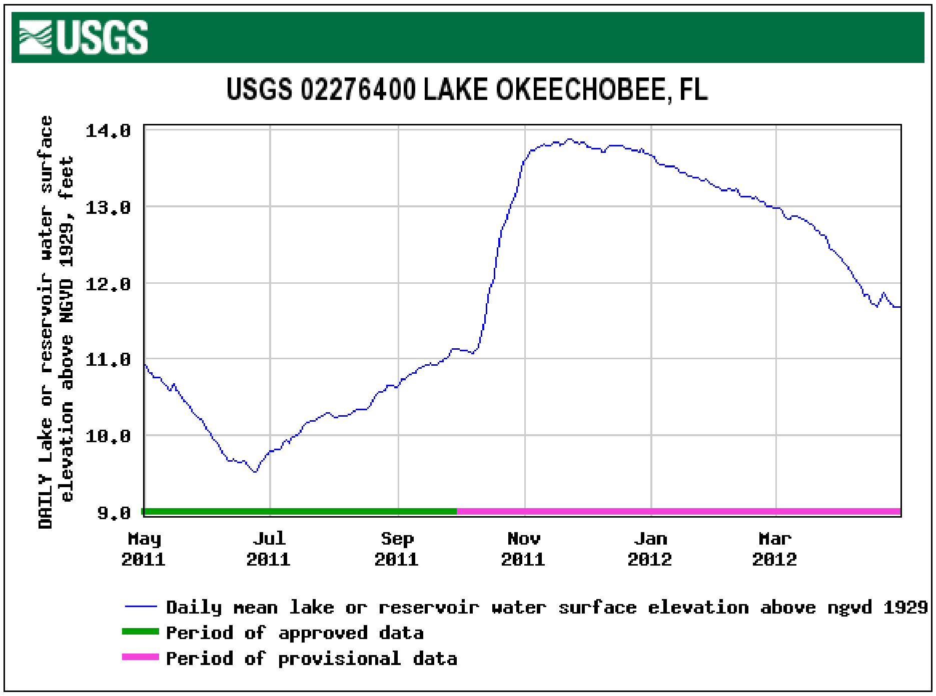

FIGURE 3-5. LAKE OKEECHOBEE STAGE HYDROGRAPH WY2012.

Inflows

When comparing the total water inflows to Lake Okeechobee since WY1989 (***Figure 3-6***), the three periods of extended drought (1989–1991, 2000–2001 and 2007–2008) are readily apparent in that they had the lowest water year total inflows (less than 700,000 cubic feet per second per day [cfs/dy]). Interestingly since WY1989, there have been five water years in which total inflows were less than 500,000 cfs/dy, with the lowest two water year total inflows occurring during two of the three prolonged drought periods previously mentioned (2001 and 2007). The two more recent drought periods also appear to have had the lowest total inflows over the 23-year period of record.

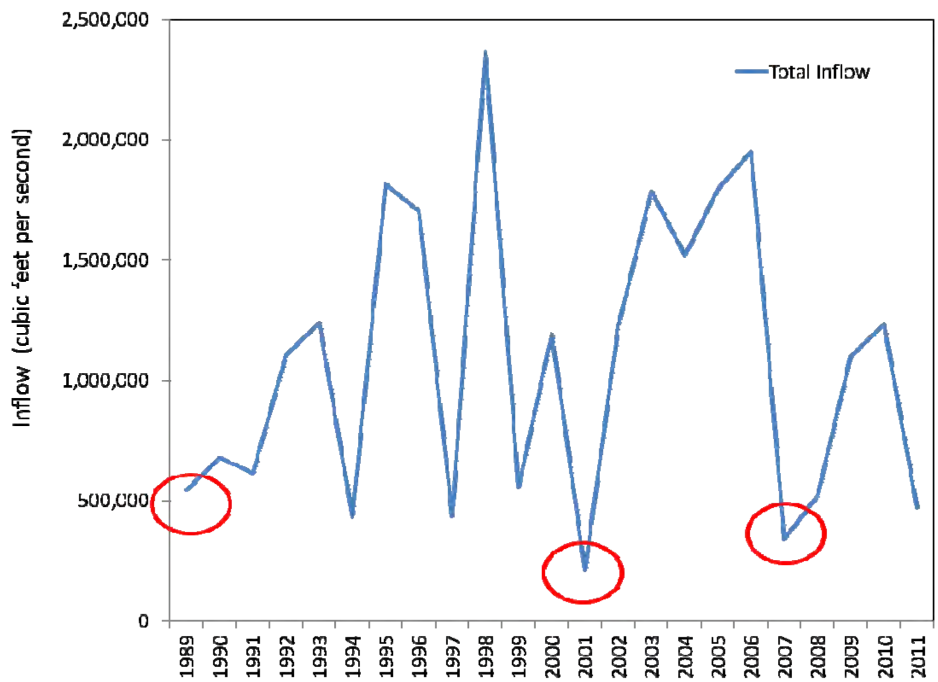

FIGURE 3-6. TOTAL WATER INFLOWS INTO LAKE OKEECHOBEE WY2010-2012.

Red circles illustrate prolonged drought periods.

Nutrient Loading

Excessive phosphorus loads to Lake Okeechobee originate from agricultural and other anthropomorphic activities in the watershed. During the past three years, TP loads in metric tons per year (mt/yr) were lowest in WY2011 reflecting severely reduced inflow to the lake as the result of an ongoing drought (***Figure 3-7***), which is also reflected in the WY2008–WY2012 five-year average (***Figure 3-8***). Since 1999, the five-year average loads have been lowest during the WY2008–WY2012 period. Nevertheless, the most recent five-year average annual TP load (396 mt/yr), was still nearly three times higher than the TMDL of 140 mt/yr considered necessary to achieve the target in-lake TP goal of 40 parts per billion (ppb) (FDEP, 2001; Havens and Walker, 2002). While there is no performance measure for nitrogen loading to Lake Okeechobee, the average loads for WY 2009–WY2012 (***Figure 3-9***) show the same pattern as that for TP loading.

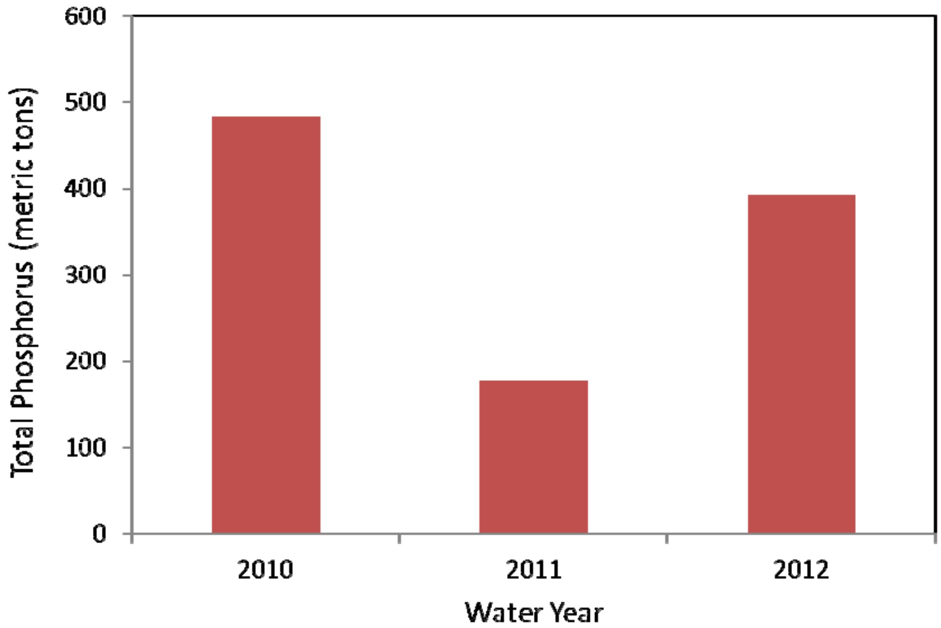

FIGURE 3-7. TP LOAD TO LAKE OKEECHOBEE WY2010–WY2012.

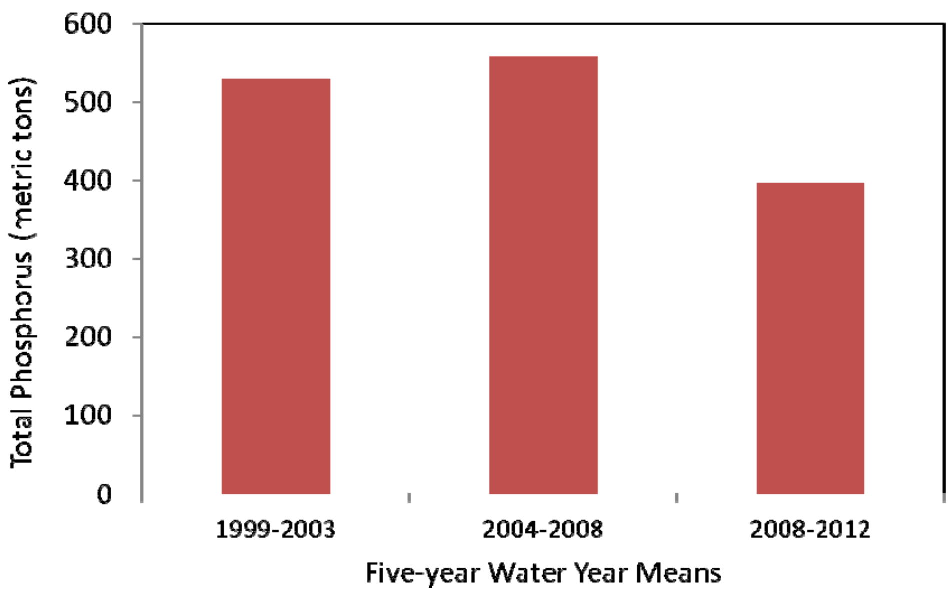

FIGURE 3-8. COMPARISON OF PREVIOUS AND CURRENT FIVE-YEAR MEANS OF TP LOAD TO LAKE OKEECHOBEE.

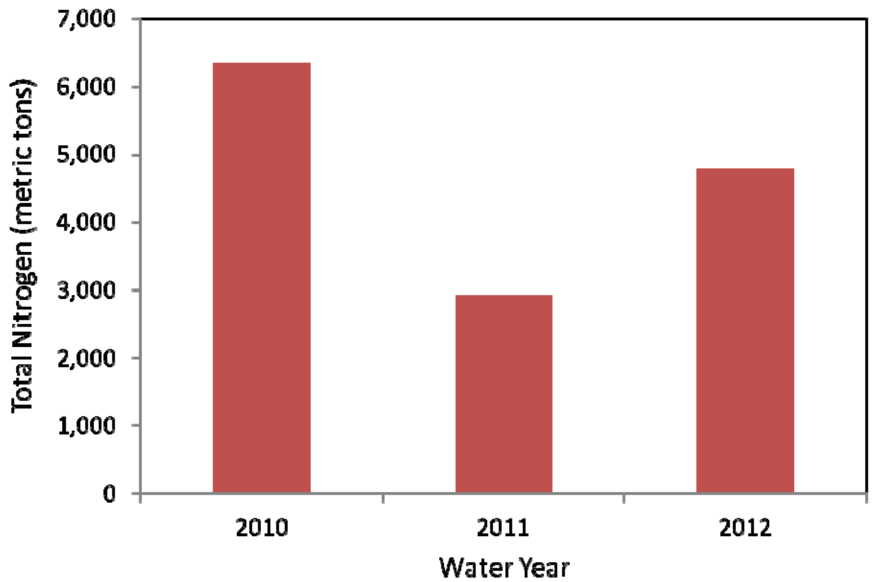

FIGURE 3-9. TN LOAD TO LAKE OKEECHOBEE FOR WY2010–WY2012.

Total Phosphorus Concentrations

Pelagic water column TP concentrations displayed a declining trend during the past three water years; receding from 118 to 92 ppb (***Figure 3-10***). Nearshore water column TP concentrations did not display the same trend however, remaining at approximately 60 ppb during all three water years.

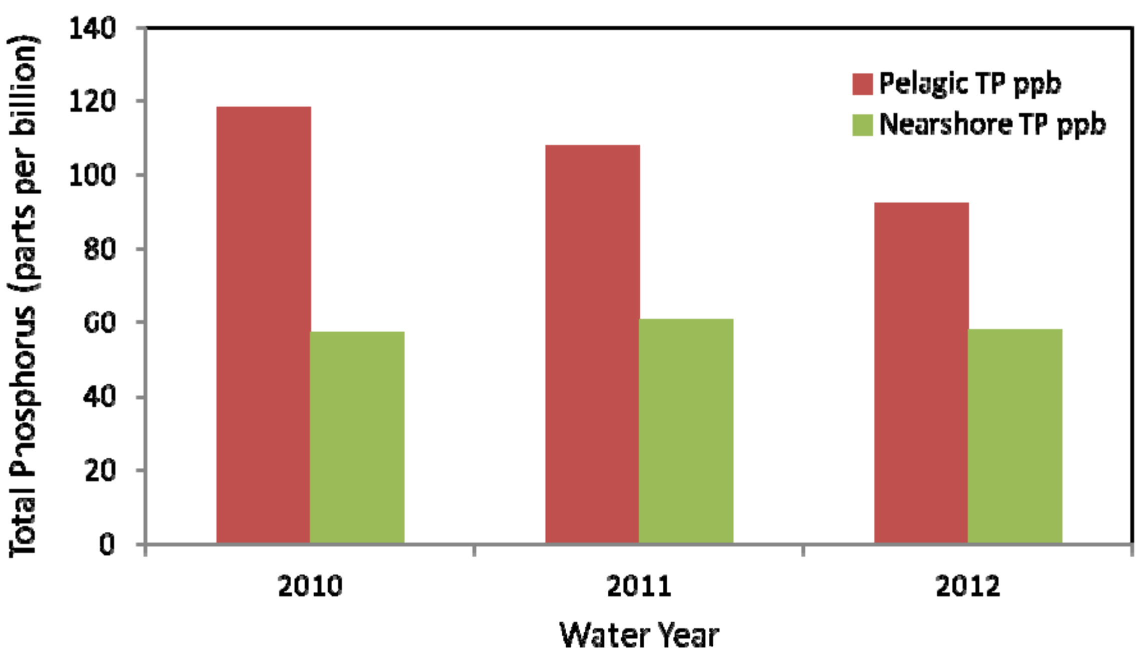

FIGURE 3-10. PELAGIC (OPEN WATER) AND NEARSHORE TP CONCENTRATIONS WY2010–W2012.

The patterns for the five-year average pelagic and nearshore water column TP concentrations were similar (***Figure 3-11***). They were highest in both regions of the lake during the WY2004–WY2008 period. There was a difference among the two regions in the lowest water column TP concentrations. The pelagic region average TP concentration was lowest during the WY1999–WY2003 period, while in the nearshore region, the TP concentration average was lowest during the WY2008–WY2012 period.

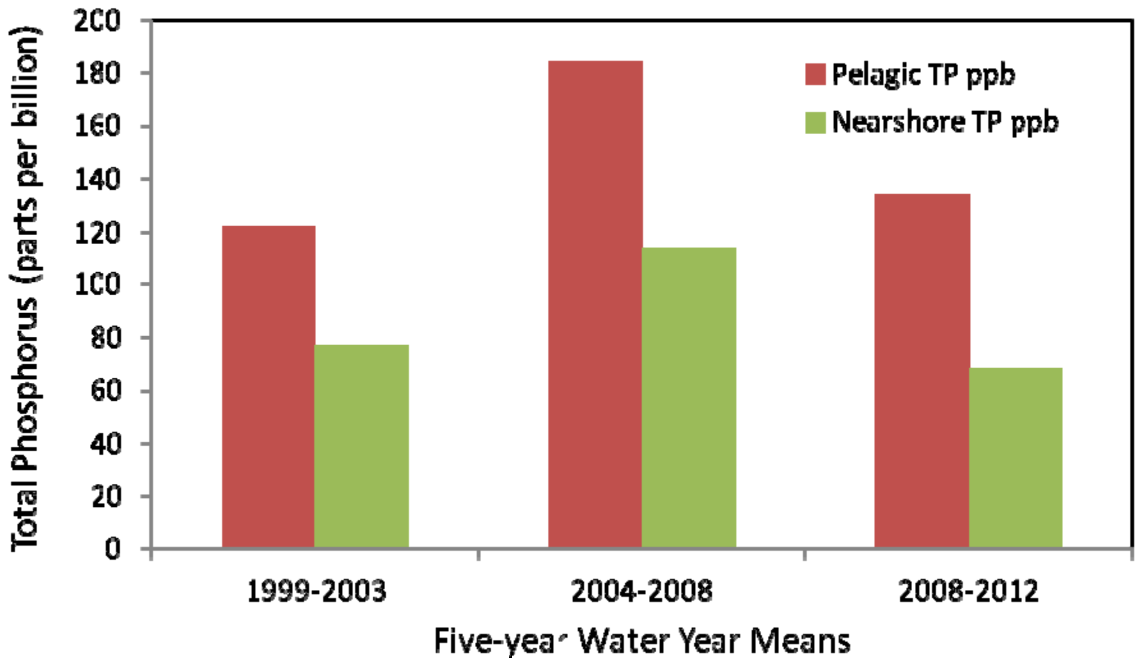

FIGURE 3-11. COMPARISON OF PELAGIC (OPEN WATER) AND NEARSHORE TP CONCENTRATIONS FOR PREVIOUS AND CURRENT FIVE-WATER YEAR MEAN VALUES.

Performance Measures

Comparing the most recent five-year averages to the performance measure's currently being used to assess the environmental status of Lake Okeechobee indicates that none of the performance measures's are being met (see the SFER 2013; Zhang and Sharfstein, 2013). TP loading and water column TP concentrations continue to exceed the performance measure goals, while the pelagic TP:TN and DIN:SRP ratios continue a longstanding trend of being lower than the performance measure goals, suggesting that nitrogen rather than phosphorus continues to be the limiting nutrient. Algal bloom frequencies (as chlorophyll *a* concentrations) continue to exceed the performance measure goal, while the nearshore water column clarity goal (as Secchi disk visibility) likewise continues to not occur at all SAV monitoring sites during the May–September period. It should be noted that performance measure goals are occasionally met (e.g., algal bloom frequency during WY2012) or almost achieved due to variability among water years.

Discussion

While Lake Okeechobee generally has been at lower lake stages and has experienced reduced nutrient runoff during the past three water years, the water quality data suggest that these two factors alone are not sufficient to allow the lake to meet the ecological restoration performance measure goals for significantly reduced water column nutrients, phosphorous rather than nitrogen-limitation of nuisance algal blooms, and greatly increased nearshore water column transparency. Therefore, while the lake has generally been in the ecologically desirable stage envelope since 2007, improving water quality attributes in both the pelagic and nearshore regions appear to be predicated on additional nutrient control measures in both the lake and surrounding watershed.

Lower lake stages and reduced nutrient runoff over the past five water years has coincided with ecological improvements in portions of the food web, such as fish community population growth, increased nearshore SAV and emergent plant coverage, and increased associated periphyton (by biovolume). Coincident with these positive ecological trends has been a lack of widespread nuisance algal blooms since 2005. Therefore, while the water quality data suggest that lower lake stages and reduced nutrient inputs have not resulted in a significant decrease in eutrophication of Lake Okeechobee, several of the lake’s nearshore biotic components suggest that the lower lake stages and reduced nutrient inputs have coincided with the reestablishment of the SAV, emergent plant and fish communities.

Conclusions

Lake stage and water inflow during WY2010–WY2012 may have provided a look at potential future post-Comprehensive Everglades Restoration Plan (CERP) hydrologic conditions, reflecting water storage projects projected to be constructed primarily north of Lake Okeechobee. While these hydrologic conditions had primarily positive impacts on key biotic components of the lake ecosystem, even with reduced nutrient inputs as a result of the reduced inflows, recent water quality data suggests that there is a need for additional nutrient reduction projects, both within and outside of the lake, and there will be a significant delay in the reduction of eutrophic conditions in the lake due to the existing large internal phosphorus load.

Additional details relating to Lake Okeechobee water quality issues can be found in Chapter 10 of the the 2007, 2008, 2009, 2010 and 2011 SFERs and in Chapter 8 of the 2012 and 2013 SFERs. These are all available online at http://my.sfwmd.gov/sfer.

PHYTOPLANKTON

Introduction and Background

Phytoplankton monitoring has been an important component of Lake Okeechobee research since the late 1980s (Phlips et al., 1997). Phytoplankton monitoring has been conducted on a monthly to quarterly basis since 1994 and has been important because algal blooms (defined as chlorophyll *a* concentrations greater than or equal to 40 ppb) have periodically been documented. These algal blooms can negatively affect drinking water quality for municipalities around the lake although this is less of a concern since only the City of Okeechobee still uses the lake for a portion of their drinking water. Microcystin, a cyanotoxin, which can cause health problems in humans, pets and livestock, also has been monitored since 2004. More background information and data analyses for phytoplankton data collected prior to 2009 can be found in the 2009 SSR (RECOVER, 2010) available online at www.evergladesplan.org/pm/ssr_2009/ssr_main.aspx.

Since the onset of a long-term drought in 2007, conditions considered to be generally favorable for widespread and frequent cyanobacteria-dominated blooms have persisted in the nearshore region of Lake Okeechobee. Generally low (e.g., less than 13 feet mean sea level [ft msl]) lake stages have allowed light to penetrate to the bottom of the water column and while the prolonged drought has resulted in reduced annual nutrient loading to the lake, water column nutrient concentrations nevertheless remain in the eutrophic category. For example, nearshore mean annual water column total phosphorus has been roughly 60 micrograms per liter (µg/L) between 2009 and 2011. Yet, no blooms of any significance have been observed since August 2005, two months prior to the passage of Hurricane Wilma over the lake.

Two performance measures have been developed through the Restoration Verification and Coordination Program (RECOVER) to assess the state of phytoplankton in Lake Okeechobee (see documentation at www.evergladesplan.org/pm/recover/recover_docs/et/lo_pm_cyano-diatom.pdf). The phytoplankton community is considered to reflect less nutrient enrichment when the diatom to cyanobacteria biovolume ratio exceeds 1.5:1. Similarly, an interim goal of less than 5 percent of pelagic chlorophyll *a* concentrations exceeding 40 milligrams per liter (mg/L) has been defined as the desired level of phytoplankton bloom frequency (http://www.evergladesplan.org/pm/recover/recover_docs/et/lo_pm_waterquality.pdf)

The restoration goals for Lake Okeechobee with regard to phytoplankton are as follows:

- Alter bloom composition with cyanobacteria comprising less than 50 percent.
- Decrease cyanobacterial bloom frequency.
- Reduce cyanobacteria dominance and increase diatoms such that the diatom to cyanobacteria ratio becomes greater than 1.5:1.

Monitoring and Recent Results

The current phytoplankton monitoring project was initiated in 1994 and is currently conducted on a quarterly basis at the sites previously described in the 2009 SSR. Phytoplankton biomass as chlorophyll *a*, community composition and biovolumes are determined. Diatom to cyanobacteria ratios are calculated from the percent total biovolumes. Cyanotoxin concentrations were determined on a monthly basis at six sentinal sites around the lake. However, in 2011, these sites were modified to correspond to sites that are routinely sampled on a monthly basis for standard water quality parameters. The monitoring and analysis is discussed in more detail in the 2007 SSR (RECOVER, 2007) (www.evergladesplan.org/pm/recover/assess_team_ssr_2007.aspx).

Results

Community Composition

As was noted previously in the SSR 2009, nonmetric multi-dimensional scaling (NMDS) ordination analysis suggests that year and season continue to be the two most influential factors in the phytoplankton community structure. The biggest differences in the phytoplankton community structure occurred among years (R=0.82, p=0.001) and then among seasons (***Figure 3-12***). The differences in the phytoplankton communities became more pronounced as the interval between years increased. Some of the most significant (R>0.9, p=0.001) among-years differences in phytoplankton biovolumes and taxonomic composition occurred between 1994, 1995, 2000, 2001 and each of the subsequent years although it should be noted that during 1994 and 1995, comparable samples were not collected for all four quarters and no comparable biovolume data exist for 1996–1999. Large fluctuations in lake stage occurred between 2000 and 2005, followed by multiple years of generally low lake stages between 2007 and 2011. While there were a few adjacent years where the phytoplankton communities were not substantially different either in taxonomic composition or community abundances (as biovolumes), the smallest differences were between 2009 and 2011 and these differences were much smaller than among other adjacent years. The largest difference among 2009, 2010 and 2011 was marginal (R<0.24, p=0.002) between 2009 and 2011 (***Figure 3-12***). With the exception of the winter-spring seasons, where the communities were marginally different (R=0.23, p=0.001), there were moderate differences in the communities among the other seasons (R-values 0.42 to 0.58) (***Figure 3-12***). The phytoplankton communities were most different between fall-spring and fall-winter whereas the communities were least different among the winter-spring seasons (R=0.25, p=0.001).

The within-year phytoplankton communities were the most similar (53 percent mean similarity value) in 1994 while being the most variable (31 percent mean similarity value) in 2005. The phytoplankton communities tended to be more similar throughout the year prior to 2002 and generally fluctuated between 35 and 45 percent for the remaining years. From 1994 through 2003, a mixture of cyanobacteria, cryptophytes and diatoms were most often found in the samples while diatom taxa were most often found in samples between 2004 and 2011.

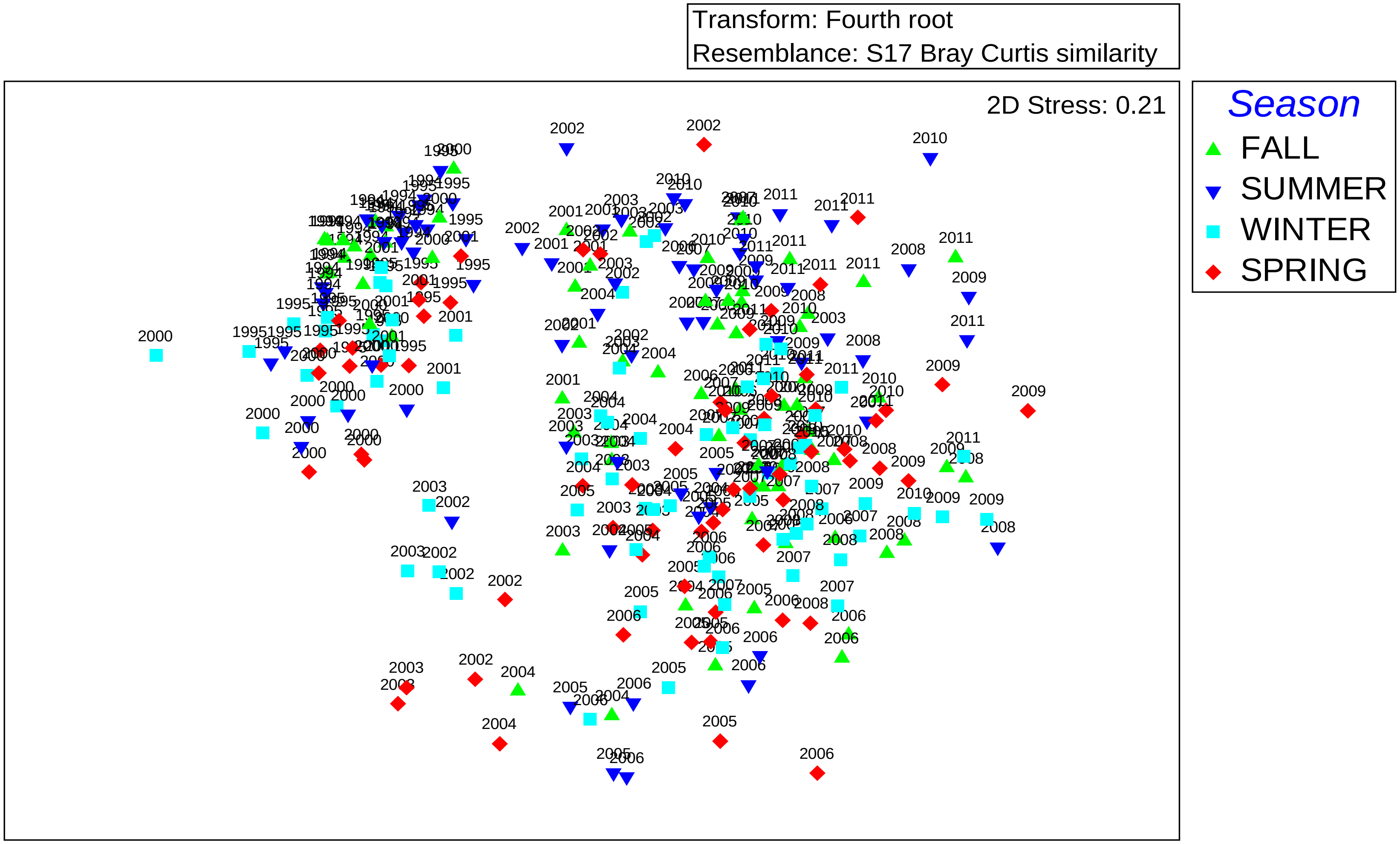

FIGURE 3-12. PHYTOPLANKTON COMMUNITY ORDINATION PLOT BY YEAR AND SEASON.

Among the years, when the communities were the most dissimilar (greater than 90 percent mean dissimilarity values), the general pattern was differences between cyanobacteria abundances during the earlier years (1994–2003) and diatoms more recently (2004–2011). When comparing the earlier years to more recent years, it was generally differences in the presence or abundance of cyanobacteria taxa contrasted with diatom taxa presence or abundances that comprised the majority of the largest differences in the phytoplankton communities. These results suggest that the phytoplankton assemblage experienced an increase in diatom importance and variability, especially from 2004 through 2011, while cyanobacteria became less important. Diatoms also were the dominant algal division from 2004 through 2011, while most of the cyanobacteria taxa contributed to a very small proportion of the community similarity and among-communities dissimilarity values. Since 2009, two cyanobacterial taxa (*Cylindrospermopsis*, *Planktolyngbia*) and *Cryptomonas* sp. have become more abundant and may be signaling a shift back to less diatom dominance.

Differences in phytoplankton communities on a seasonal basis were less compared to differences in the phytoplankton communities among years but among the seasons, moderate differences were observed ($R<0.44$, $p=0.001$, ***Figure 3-12***). The biggest difference among phytoplankton communities on a seasonal basis was between spring and fall ($R=0.58$, $p=0.001$). The most similar communities ($R=0.23$, $p=0.001$) were observed between winter and spring. Diatom taxa contributed most to the similarities between the winter and spring phytoplankton communities, while cyanobacteria and a mix of cryptophytes and several diatom taxa contributed most to the similarites between the summer and fall communities, respectively. Between seasons, the highest phytoplankton community dissimilarities were contributed by differences in primarily diatom taxa abundances. The stress value associated with the two-dimensional among-years and seasons plot was sufficiently high to caution their use for anything beyond examination of general trends, or may simply reflect the large data set (Clarke and Warwick, 2001).

Very little difference was observed in the phytoplankton communities among differing lake stages, when classifying them as "high" (greater than 15.5 ft msl), "medium" (12.5 to 15.5 ft msl) or "low" (less than 12.5 ft msl) ($R=0.06$), although marginal differences were observed ($R=0.25$, $p=0.001$) among these stage classifications when examined within each year. The greatest difference among the phytoplankton communities was observed between high and medium lake stages ($R=0.27$, $p=0.001$), suggesting that larger changes in the phytoplankton community occurred as the lake varied between high and medium stages, relative to community changes between other stage comparisons. Similarly, very little difference was observed in the phytoplankton communities among sites ($R=0.12$, $p=0.001$), whether examined on an among-years or an among-seasons basis. The largest difference was between the phytoplankton communities at 3POLE (near the northwestern tip of Ritta Island in the southern nearshore region), FEB (near the mouth of Fisheating Bay) and LZ40 (in the center of the lake), but the largest difference ($R=0.37$, $p=0.001$) among these site comparisons suggests that the communities were not substantially different. These comparisons suggest that temporal factors were more important in influencing the phytoplankton community structure relative to variability in either lake stage or geographic location. Since photosynthetic behavior was shown to be homogenous among sites during higher lake stages and heterogeneous under lower lake stages (Maki et al., 2004), it is perhaps surprising that larger differences in the phytoplankton communities were not observed under different lake stages. The marginal differences in the phytoplankton community under varying lake stages may reflect the decreased representation of the two nearshore sites during periods of very low lake stage as sampling was not conducted because these sites were inaccessible.

Stepwise addition of water quality variables suggested a positive but weak relationship (Spearman ρ=0.21, P=0.01) between a combination of 16 transformed water quality variables (depth, Secchi:total depth ratio, water column temperature, pH, specific conductance, chlorophyll *a*, ammonium (NH_4), nitrate+nitrite (NOx), TP, SRP, the ratios of TP to TN and DIN to SRP, and mean daily lake stage and wind speed) and the phytoplankton community composition. Similarly weak positive correlations between combinations of subsets of these variables also were observed. Surprisingly, no autocorrelation was found among the measured water quality variables.

Biomass Determination

Annual total biovolumes were variable at both the nearshore and pelagic sites, and were similar among both regions for most years (***Figure 3-13***). The highest total biovolumes for both regions occurred in 1994 and the lowest were recorded in 2005 and 2006 (nearshore) and 2005 and 2008 (pelagic). The low annual biovolumes during 2005 and 2006 may have been related to extremely low light levels in the water column after the passage of the hurricanes in 2004 and 2005. It is unclear as to what may have been related to the low pelagic total biovolumes in 2008. Mean annual biovolumes varied between 2,440,152 cubic micrometers per milliliter (μm^3/mL) in 1994 and 198,711 μm^3/mL in 2005 at the pelagic sites. At the nearshore sites, the maximum annual biovolume was very similar to that at the pelagic sites during 1994, while the minimum was 426,625 μm^3/mL in 2006. The mean annual total 2009–2011 biovolume in both regions was roughly 60 percent of the mean 1994–2006 abundances.

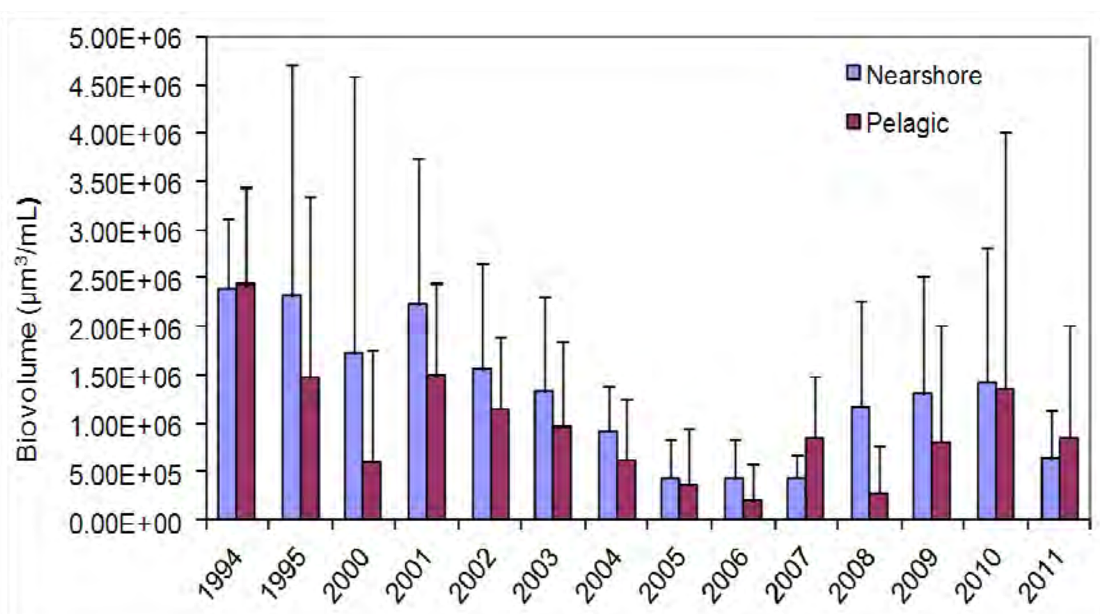

FIGURE 3-13. ANNUAL MEAN PHYTOPLANKTON BIOMASS IN TOTAL BIOVOLUMES ± 1 STANDARD DEVIATION (SD) AT BOTH NEARSHORE AND PELAGIC SITES.

Biomass as mean annual chlorophyll *a* concentration has been less variable relative to biovolumes and very similar among the regions for all years (***Figure 3-14***). Mean 2009–2011 annual chlorophyll *a* concentrations were between 14 and 28 µg/L and 13 and 21 µg/L in the nearshore and pelagic regions, respectively. The annual mean chlorophyll *a* concentrations for the 1994–2006, 2007–2011 and 2009–2011 periods have been approximately 20 µg/L and 17 µg/L in the nearshore and pelagic regions, respectively. Algal bloom frequency, as previously defined (Havens et al., 1995) continued to be very infrequent during this period. Early stages of algal blooms (e.g., small green flecks in the water column) were observed on average once a year (from quarterly samples) at either one of the nearshore or pelagic sites, but a large-scale surficial bloom has not been observed since August 2005.

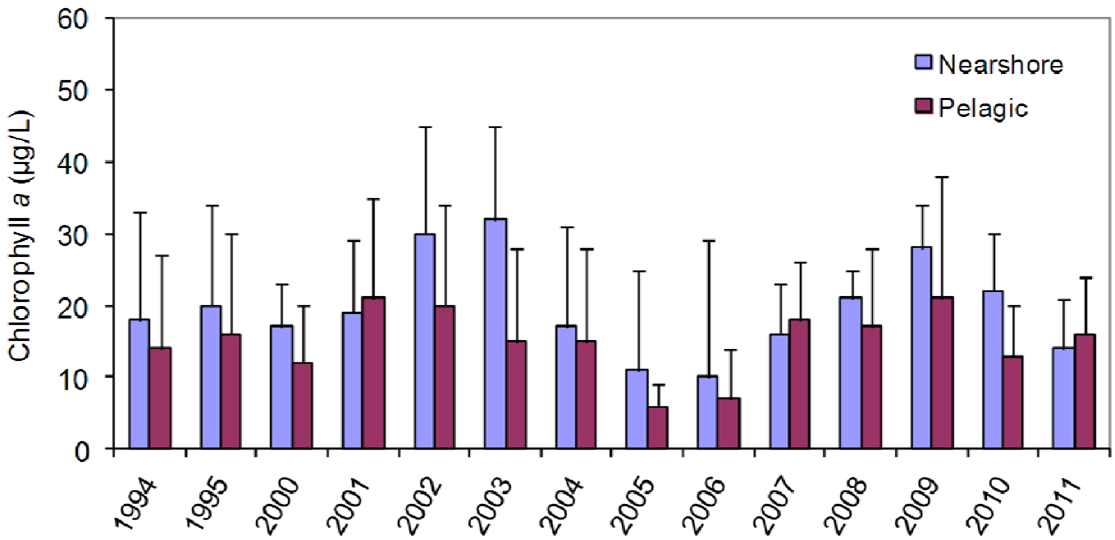

FIGURE 3-14. ANNUAL MEAN PHYTOPLANKTON BIOMASS AS CHLOROPHYLL *A* ± SD AT BOTH NEARSHORE AND PELAGIC SITES.

Diatom to Cyanobacteria Ratio

Diatom to cyanobacteria ratios were less than 1:1 between 1994 and 2002. Since 2004, the ratios have exceeded 1.5:1 in both the nearhsore and pelagic regions every year except for 2010, when the nearshore ratio declined to 1.3:1 (***Figure 3-15***). Since 2004, the diatom genera *Fragilaria*, *Aulacoseria*, *Cyclotella* and *Stephanodiscus* have become increasingly important in both biovolumes and frequency of detection. With relatively low lake stages, light penetration of the sediments in the nearshore region, an excess of nutrients and a lack of large-scale disturbances since 2008, it is somewhat surprising that cyanobacteria have not regained their dominance in the nearshore phytoplankton community during the 2009–2011 monitoring period. Perhaps prolonged nitrogen limitation, increased grazing by fish and macroinvertebrates, or some other unmeasured factor may be responsible for both lack of recovery of phytoplankton abundance and cyanobacteria dominance that was characteristic of Lake Okeechobee prior to the hurricanes. Alternatively, meroplankton, often comprised of pelagic diatom taxa (Phlips et al., 1997), has been found in the water column during low lake levels and this easily resuspended component of the nearshore phytoplankton community may be the dominant component during periods of lower lake stages. Overall, meeting or exceeding the restoration target prior to a period of time when water quality has not met restoration targets (e.g., 40 µg/L for pelagic TP concentrations) in Lake Okeechobee, suggests that the current performance measure may not be representative of a meaningful restoration goal for the lake and should be modified.

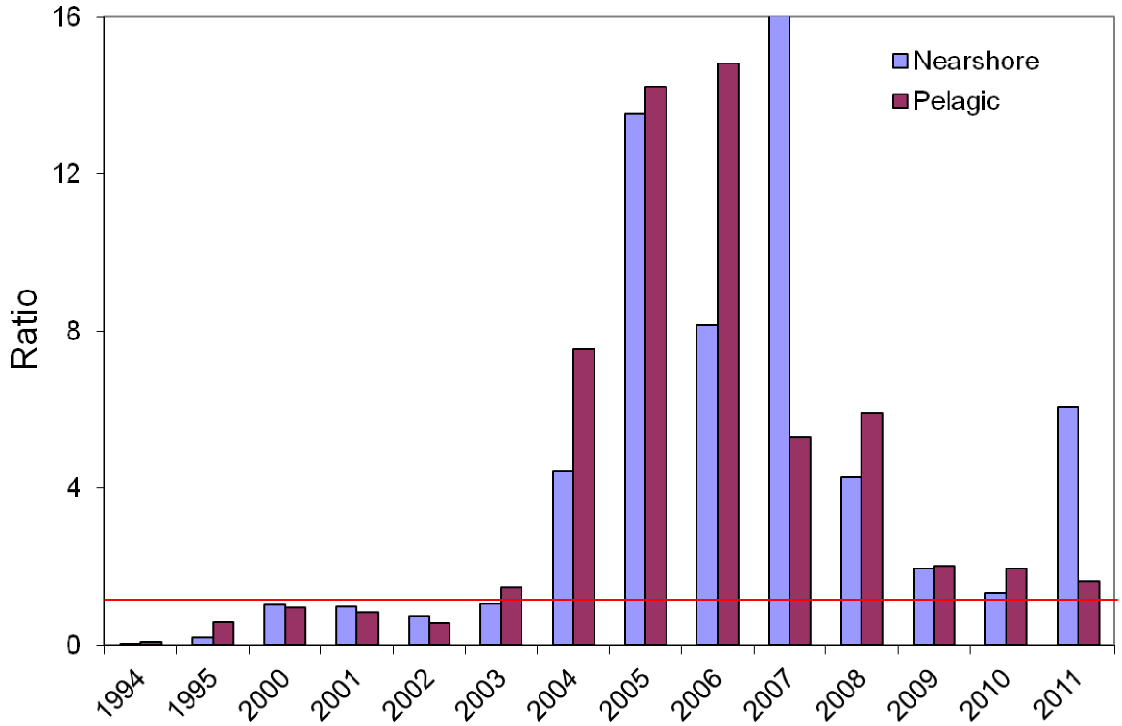

FIGURE 3-15. ANNUAL MEAN DIATOM TO CYANOBACTERIA RATIO AT BOTH NEARSHORE AND PELAGIC SITES.

Cyanotoxins

Monthly microcystin concentrations were measured at nine sites located in the northern, western and southeastern areas of the nearshore region of Lake Okeechobee between May 2004 and April 2011. In an attempt to reduce monitoring costs, six of these sites were moved to nearby long-term monthly water quality sites in May 2011 and the remaining sites are no longer being sampled. With the exception of the months between Hurricanes Frances and Wilma, when microcystin concentrations were between 15 and roughly 25 µg/L, microcystin concentrations have almost always been below the World Health Organization drinking water standard of 1 µg/L (***Figure 3-16***). Regression analysis has suggested that microcystin and the previous month's chlorophyll *a* concentration have the best relationship. The dashed vertical line in the graph indicates when the number of monitoring sites was reduced.

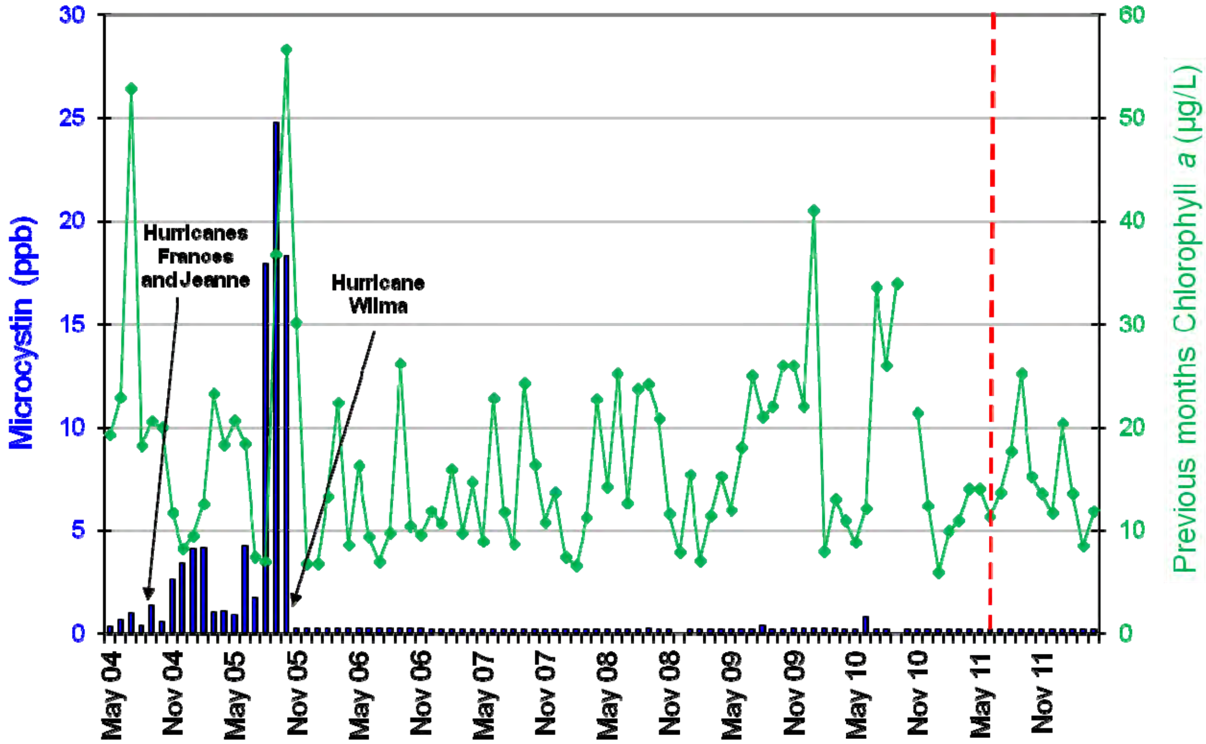

FIGURE 3-16. MEAN MICROCYSTIN AND PREVIOUS MONTH MEAN CHLOROPHYLL *A* CONCENTRATIONS.

Summary

The variability in the 1994–1995 and 2000–2011 community composition data suggest that these changes may be a reflection of the large-scale disturbance events that the lake has experienced. First, several years of very high lake stages occurred between 1995 and 2000, followed by a lake drawdown and prolonged drought in 2001. Large lake stage fluctuations then occurred between 2001 and 2004, followed by extremely high (greater than 100 mg/L) turbidity, which followed the passage of three hurricanes in 2004 and 2005 and remained high into 2006. From 2007 through 2011, lake stages were generally below or in the ecologically beneficial stage envelope (12.5–15.5 ft msl). During 1994 and 1995, taxa that most often were found in the samples during any one year were predominantly the cyanobacteria genera *Lyngbya*, *Anabaena*, and *Oscillatoria* along with the diatom *Melosira* and the cryptomonad genera *Cryptomonas* and *Rodomonas*. After 2002, these groups were increasingly composed of diatom genera such as *Fragilaria*, *Aulacoseria* and *Cyclotella*. Since 2004, at least four of the top five most commonly found taxa have been diatoms. The only exception was 2009, where diatoms comprised only three of the top five most commonly found taxa. Several of these taxa, such as *Thalassiosira proschkinae*, and species of the genera *Aulacoseria*, *Cyclotella* and *Stephanodiscus* are nutrient tolerant and indicative of eutrophic or hyper eutrophic conditions (Yang et al., 2008).

Since little spatial difference has been observed in the phytoplankton community among the quarterly monitoring sites since 1994, phytoplankton appears to be most strongly influenced by temporal and seasonal factors. This contrasts with previous spatially heterogeneous ecological characterizations of the lake (Phlips et al., 1993), including phytoplankton (Aldridge et al., 1995; Cichra et al., 1995).

Correlations between water quality variables and community composition were weak when examined with data collected from the 1994–1995 and 2000–2011. This continues to suggest that relationships between the phytoplankton community structure and physical and chemical variables may vary spatially and temporally. Alternatively, unmeasured variables may be more influential in the phytoplankton community structure than those that were measured.

It is anticipated that restoration of Lake Okeechobee water quality might result in reduced nearshore and pelagic zone nutrient concentrations, which in turn would result in less frequent algal blooms. However, the lack of frequent phytoplankton blooms since 2005, without the lake attaining either the target total maximum daily load (TMDL) or water column nutrient concentrations in any year, suggests that the relationship between nutrients and phytoplankton blooms may not be as strong as originally perceived. It appears that generally lower lake stages and a lack of large-scale disturbance events may be equally as, or more important than, achieving water column nutrient reductions, when evaluating the ecological health of Lake Okeechobee in terms of the phytoplankton community.

SUBMERGED AQUATIC VEGETATION

Introduction and Background

SAV is one of the most important biotic components in Lake Okeechobee, since it provides habitat for fish, wading birds, macroinvertebrates and other links in the aquatic food web and it directly affects water quality attributes. Lake levels, periodic wind-driven water column turbidity, and major disturbance events such as hurricanes can have strong negative impacts on nearshore SAV. The areal coverage and abundance of SAV is highly variable on an annual basis. More information about the pre-2009 data can be found in the 2009 SSR (RECOVER, 2010) available online at http://www.evergladesplan.org/pm/ssr_2009/hc_lake_o_sav_results.aspx

The RECOVER SAV performance measure and interim goal consist of two targets: (1) annual summer areal coverage of at least 40,000 acres of total SAV and (2) at least 50 percent of the SAV being comprised of vascular species. The performance measure and interm goal can be found at www.evergladesplan.org/pm/recover/recover_docs/et/lo_pm_vegetationmosaic.pdf and www.evergladesplan.org/pm/recover/recover_docs/igit/igit_mar_2005_report/ig_2-4_lakeoaquaticveg.pdf, respectively.

Monitoring

SAV in the nearshore region of Lake Okeechobee has been monitored since 1999 at two scales. Plant biomass and species composition is monitored along fixed transects on a quarterly basis while whole lake species-level annual summer grid-cell mapping to estimate areal coverage is conducted each August. This past year, the quarterly transect monitoring was changed to a grid-based approach to allow direct comparisons to be made between annual and quarterly data. Both monitoring programs are conducted using a boat-based sampling methodology. Remote sensing as a mapping technique has not been attempted due to frequently poor water column transparency prior to 2007 and, more recently, due to budgetary constraints.

Transect Monitoring

SAV transect monitoring prior to spring 2011 was conducted at sites located along 16 fixed transects oriented in a inshore to offshore direction in the nearshore region of the Lake (***Figure 3-17***). These sites represented a subset of sites that were sampled in the Lake Okeechobee Ecosystem Study (Zimba et al., 1995) in the late 1980s and early 1990s and covered the region where SAV beds historically occurred. This allowed for comparisons to be made with the historical data. However, since these transect sites were not located at any of the annual mapping grid-cell centroid sampling locations, no direct comparisons could be made with the annual mapping data collected over the past 11 years. To make the transect data comparable to the annual mapping data, SAV transect sampling was modified to be conducted along transects created using a subset of 54 grid cells from the annual grid map. Since the transect and annual mapping sites are now identical, results from past annual mappings can be plotted and compared with the results from the new quarterly transect mapping. More details on transect monitoring can be found in the 2009 SSR.

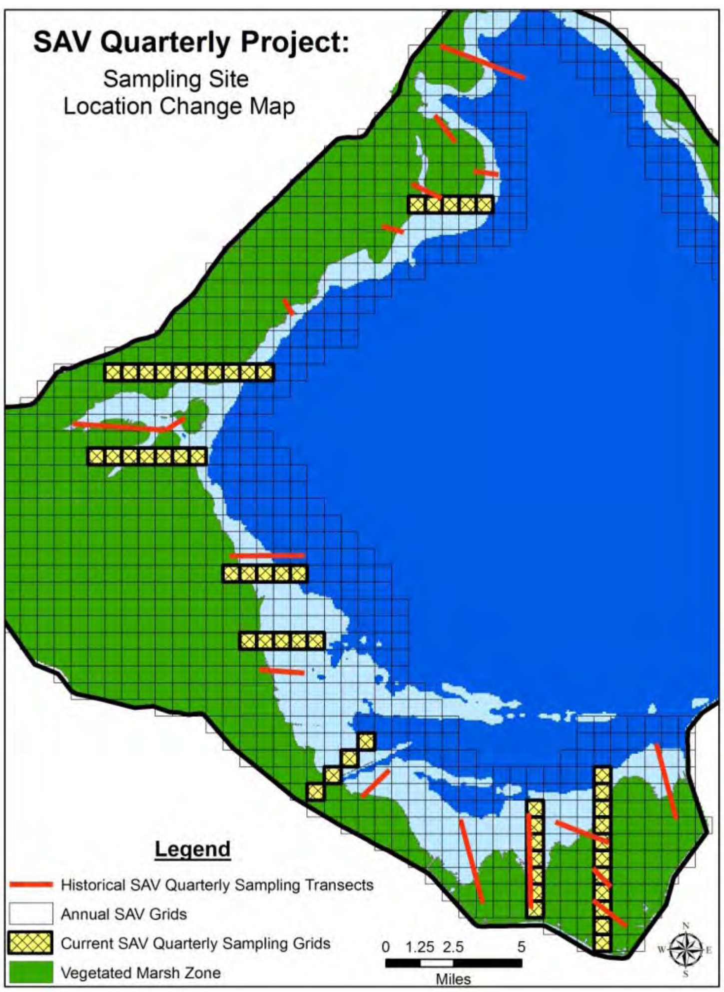

FIGURE 3-17. CURRENT AND PREVIOUS SAV TRANSECT LOCATIONS IN LAKE OKEECHOBEE

Annual Mapping

The total spatial extent, species distribution and acreage of SAV is determined for the entire nearshore area at a spatial scale sufficient to detect significant changes The annual mapping grid is shown in ***Figure 3-18***. More details on annual mapping can be found in the 2009 SSR.

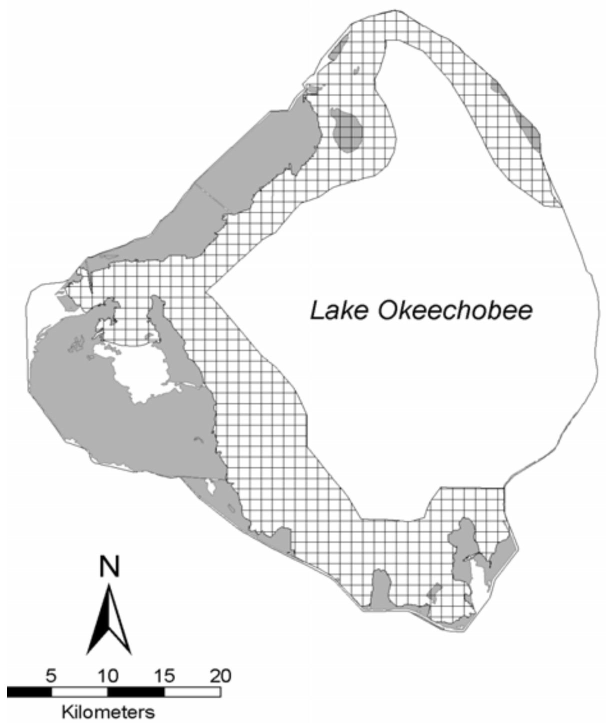

FIGURE 3-18. ANNUAL SAV MAPPING SAMPLING GRID FOR LAKE OKEECHOBEE

Results

Transect Monitoring

The trend in visually estimated SAV densities based on the quarterly monitoring grid cell subset suggests that SAV in Lake Okeechobee has been slowly recovering from Hurricanes Frances, Jeanne and Wilma, which impacted the lake in 2004–2005 (***Figure 3-19***), and resulted in extremely high water column turbidity and lake stages that persisted into spring 2006. While SAV densities have not recovered to pre-hurricane (August 2004) levels, there has been a gradual overall increase in both the number of sites with plants and in the number of sites with moderate (5 to 50 grams dry weight per square meter [g dw/m^2]) to dense (> 50 g dw/m^2) biomass, especially since the prolonged drought of 2007–2008.

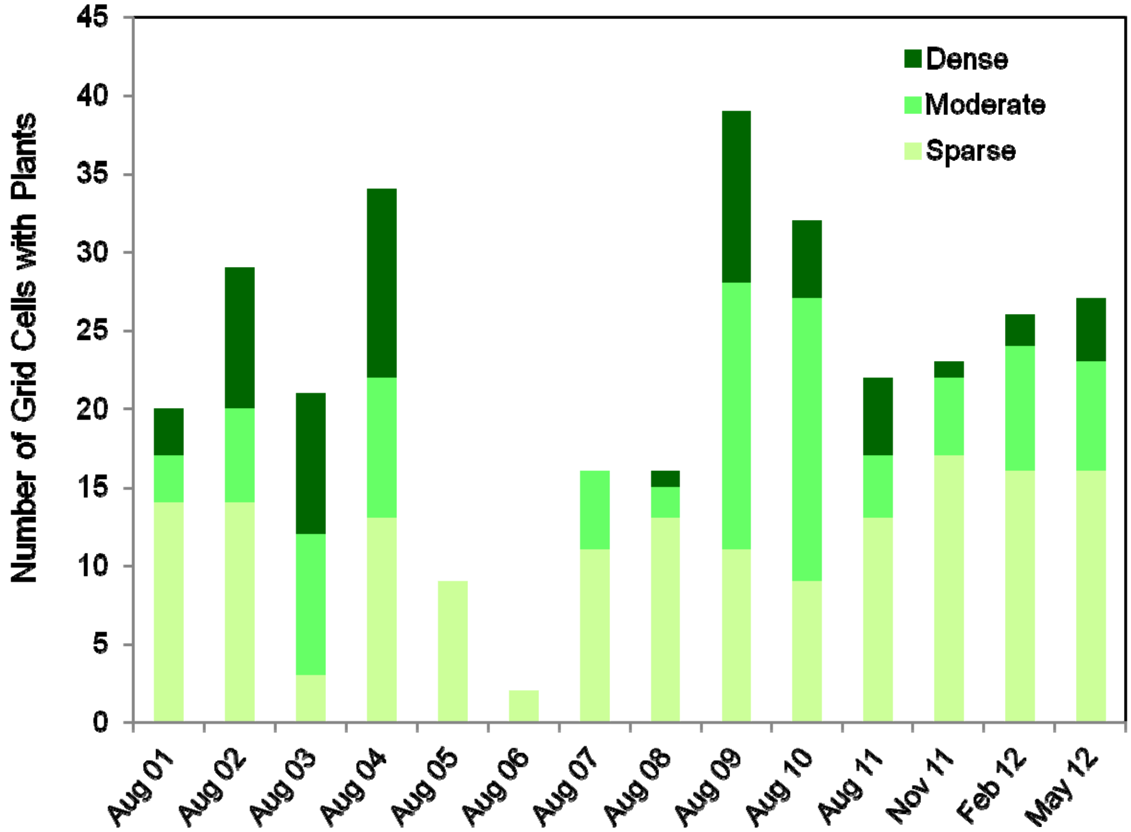

FIGURE 3-19. ESTIMATED GRID CELL TRANSECT SAV VISUAL DENSITIES IN LAKE OKEECHOBEE.

Annual Mapping

Summer SAV coverage in Lake Okeechobee during the 2009–2012 period has been less variable relative to earlier years; varying between approximately 36,000 and 47,500 acres (***Table 3-1*** and ***Figures 3-20*** through ***3-23***). The lake achieved its performance measure targets of 40,000 acres of overall SAV with 50 percent or more consisting of vascular species during 2010 and 2012. During 2011, neither of the two performance targets were met, while in 2009, the total acres target was met but the vascular species target was not met.

TABLE 3-1. ACREAGE OF DOMINANT PLANTS IN LAKE OKEECHOBEE 2009–2012.

Plant Type (Genus)	Common Name	Areal Coverage (acres)			
		August 2009	August 2010	August 2011	August 2012
Ceratophyllum	hornwort	12,489	9,695	2,718	6,178
Chara	chara	25,278	7,792	27,429	23,475
Hydrilla	hydrilla	15,816	12,327	6,178	14,579
Potamogeton	pondweed	1,380	2,667	494	3,459
Vallisneria	eelgrass	6,497	4,004	6,919	11,120

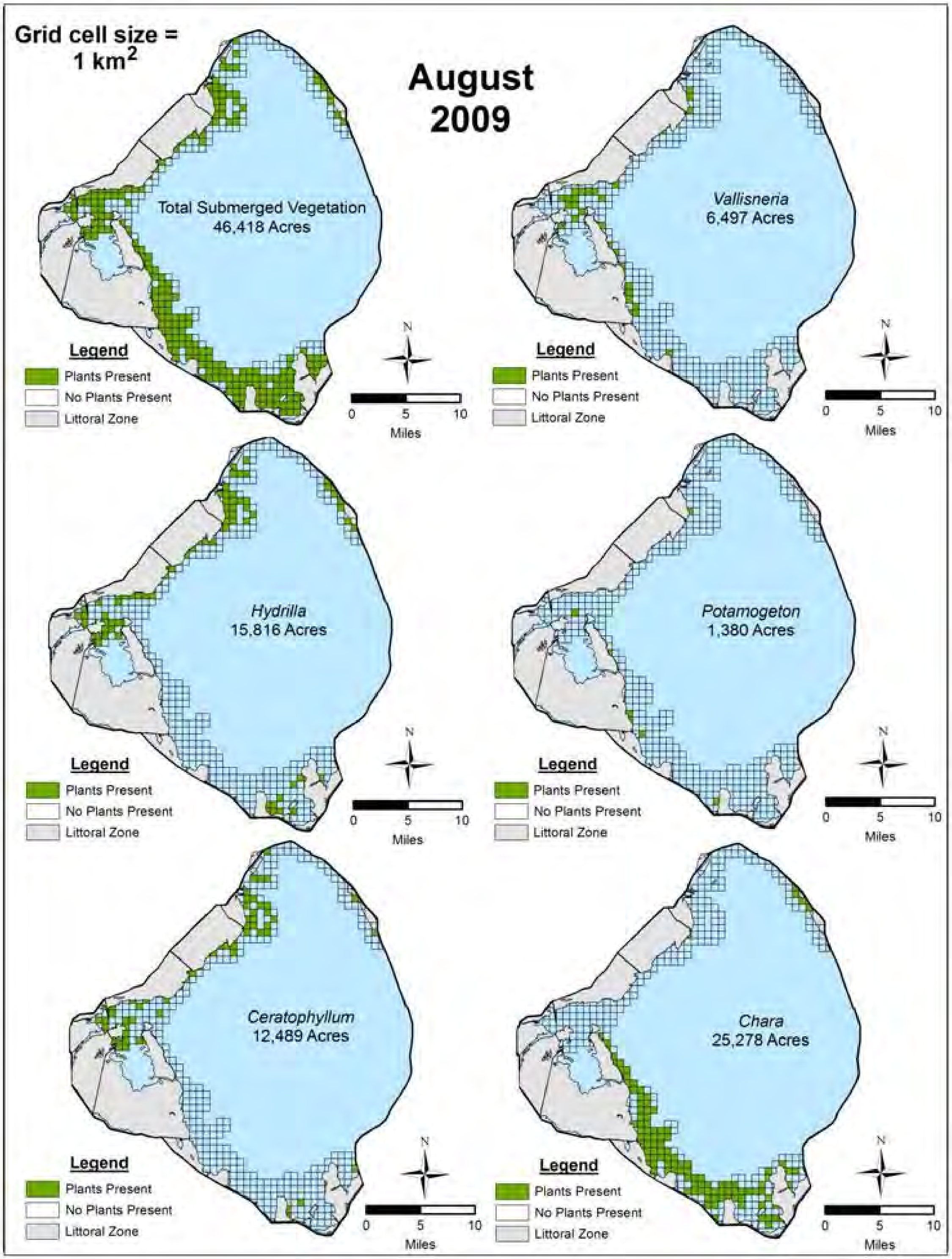

FIGURE 3-20. ANNUAL SAV MAPPING RESULTS 2009.

(Note: km^2 – square kilometer)

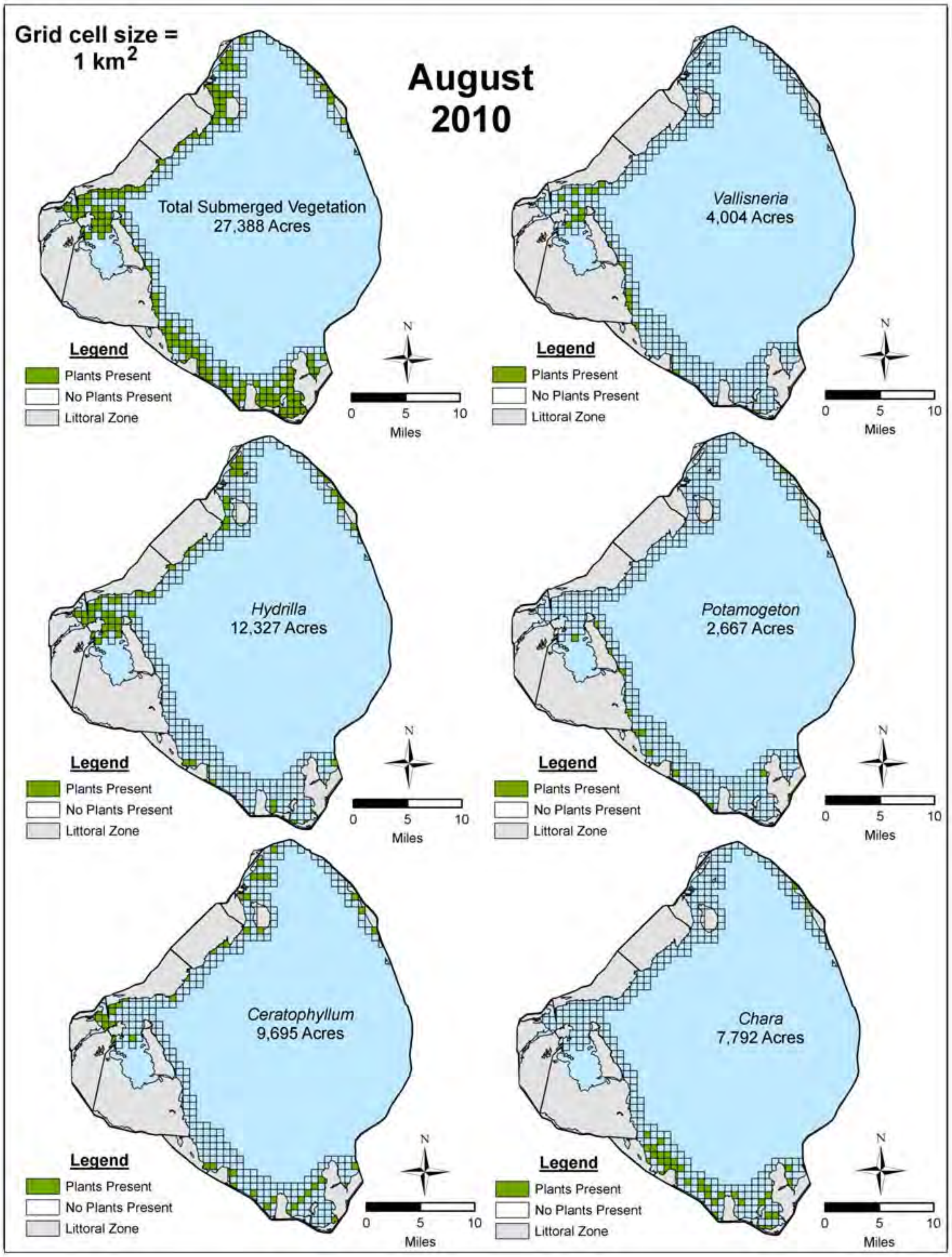

FIGURE 3-21. ANNUAL SAV MAPPING RESULTS 2010.

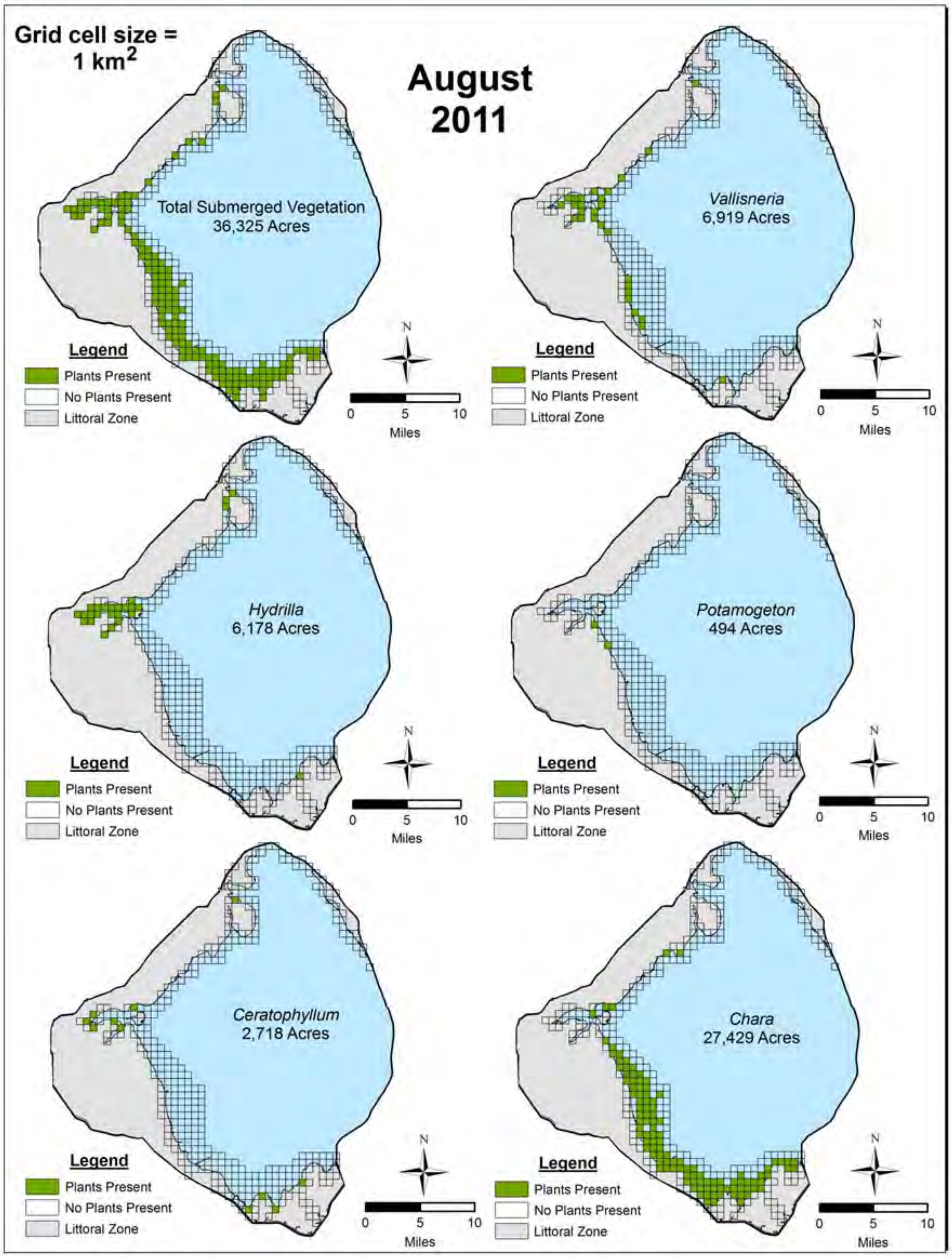

FIGURE 3-22. ANNUAL SAV MAPPING RESULTS 2011.

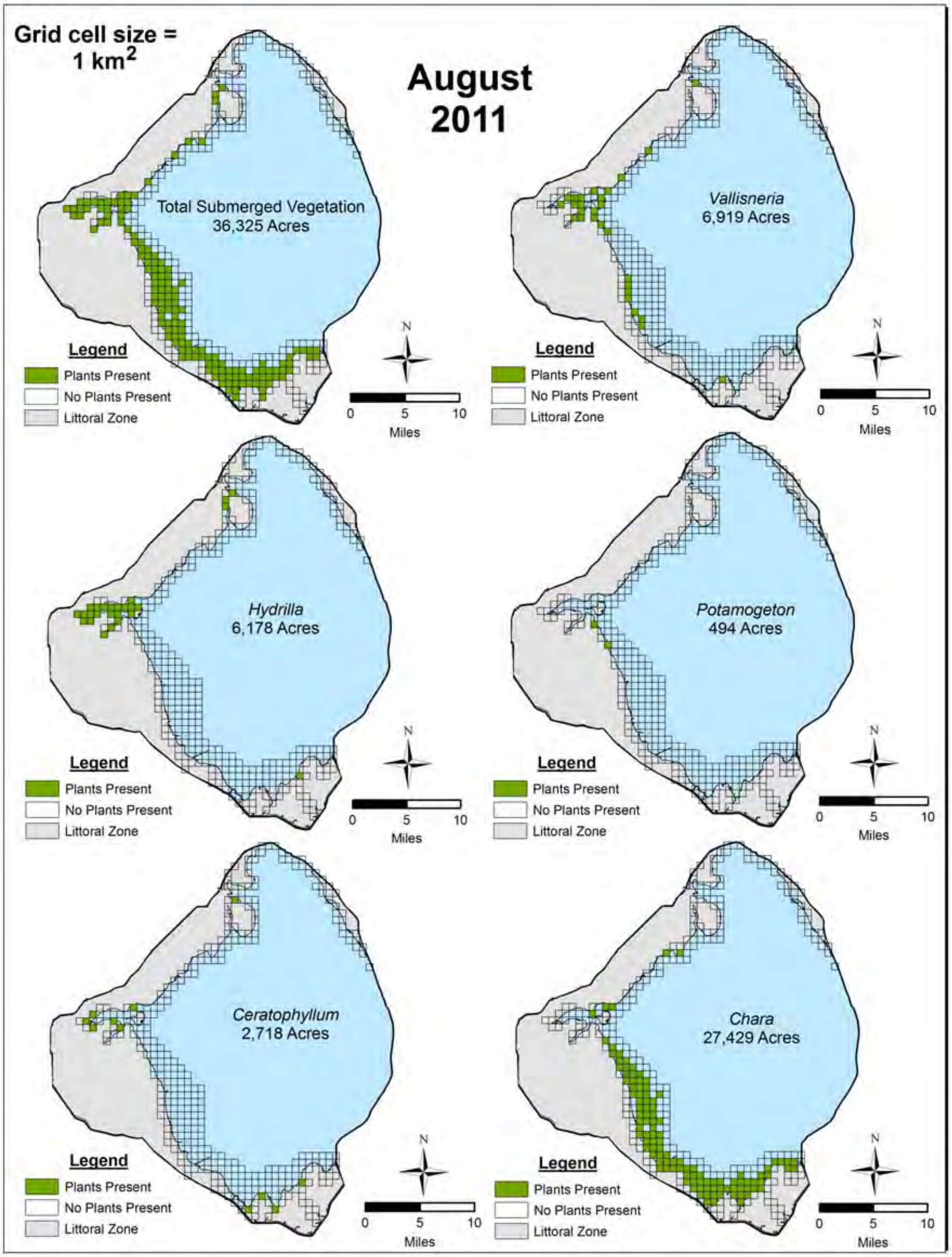

FIGURE 3-23. ANNUAL SAV MAPPING RESULTS 2012.

The influence of lake stage, species succession, and community recovery lag times are evident when examining the past several years of SAV biomass and areal coverage. After the prolonged drought during 2007–2008, SAV recovery proceeded with areal coverage expanding until it exceeded the 40,000-acre target in 2009. However, the predominant SAV species during this period was the macroalga chara (*Chara* spp.), a typical pioneering species. Colonization by vascular SAV species lagged behind *Chara*, so that both the areal coverage and percent vascular targets were not achieved until 2010. In 2011, another drought reduced lake stages, drying out habitat that had previously been colonized by vascular SAV, but at the same time allowing a lakeward expansion of SAV consisting primarily of *Chara*. Consequently, the lake again missed both its areal coverage and percent vascular targets. However, in 2012, with the lake at a somewhat higher elevation, the SAV community shifted shoreward again (***Figure 3-24***) with newly colonized sites along the lakeward edge being lost and replaced by renewed colonization of more typical inshore habitat.

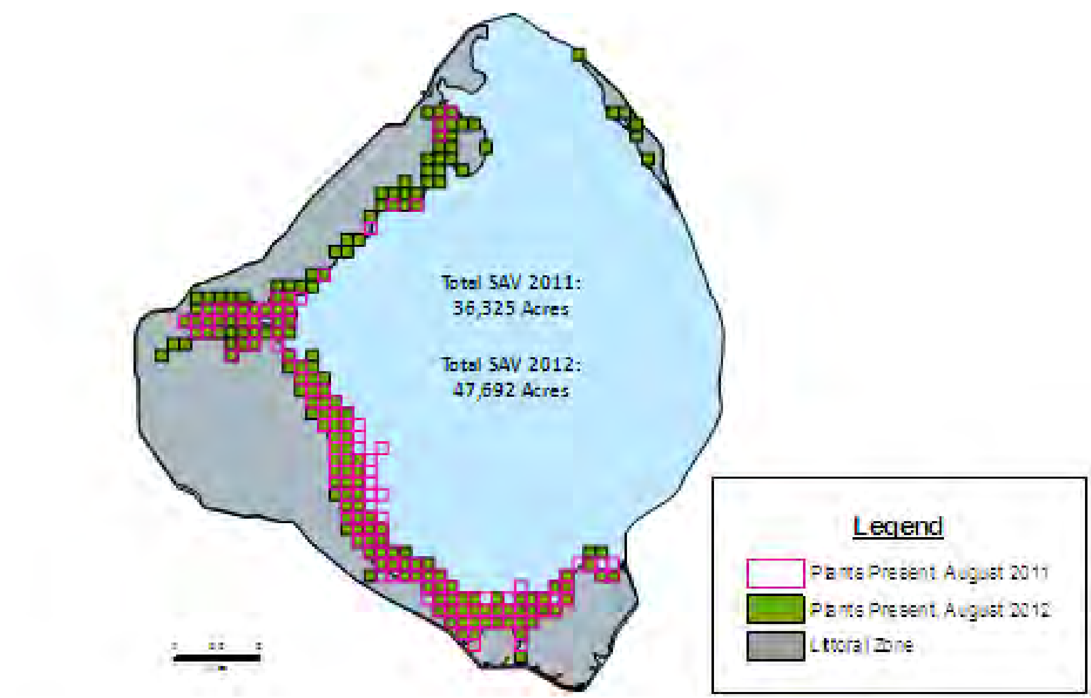

FIGURE 3-24. COMPARISON OF SAV DISTRIBUTION IN 2011 AND 2012.

Overall, lake stage generally continues to be somewhat lower than the long-term mean stage over the past several decades, and previously SAV-dominated areas inshore have become emergent marsh habitat, dominated by both emergent and terrestrial plants. For example, approximately 4,700 acres that was open water SAV habitat in South Bay prior to 2007 is currently emergent marsh habitat. If the lake continues to remain near the lower end of the desired stage envelope or lower, the enlarged marsh habitat likely will continue to occupy formerly open water SAV habitat while SAV colonizes areas offshore that were previously too deep and light limited to support substantial underwater plant growth. However, South Florida's variable climate and frequent hurricanes, coupled with the disproportion between the lake's potential tributary inflows and outflows can result in rapid reversals, as was observed after the recent passage of Tropical Storm Isaac, which increased lake stage by almost one meter over a three-week period.

Recent (2009–2012) vascular SAV taxa areal coverage, with the exception of eelgrass (*Vallisneria* spp.) during 2012, continues to be lower than during the peak in summer 2004. This appears to be primarily due to less nearshore colonizable area associated with lower lake stages and lakeward expansion of emergent marsh habitat. With low to very low lake stages for most of the current reporting period, hornwort (*Ceratophyllum* spp.), hydrilla (*Hydrilla* spp.) and pondweed (*Potamogeton* spp.) areal coverage during 2012 was less than 60 percent of their respective areal coverages during 2004. Conversely, *Vallisneria* areal coverage during 2012 exceeded its 2004 coverage by roughly 27 percent while *Chara* during 2012 covered roughly 85 percent of area it covered in 2004. In the case of *Ceratophyllum*, *Hydrilla* and *Potamogeton*, it appears that these species are not colonizing further offshore at a rate proportional to their loss from nearshore open water habitat. Conversely, *Chara* and *Vallisneria* have colonized an area further offshore that is comparable in size to the nearshore habitat they formerly occupied, which has recently converted to emergent marsh.

Having the lake within the recommended stage envelope as often as possible, which the current lake operating schedule (2008 LORS) should assist in doing, barring frequent hurricane or drought events, is important for the continued reestablishment and maintenance of the vascular SAV community. Maintaining this range of lake stages also will enable the reestablishment of emergent vegetation in areas of the short hydroperiod marsh that have become dominated by terrestrial vegetation, and allow SAV to recolonize areas that have become emergent marsh (although offshore beds of SAV may be lost due to increasing depth resulting in light limitation). Current risks are (1) continued low lake stages might result in an extended recovery period once lake levels return to more normal ranges and (2) a very rapid rise in lake stage as occurred as a result of the hurricanes in 2004 and 2005 and appears to be occurring again as a result of the record rains produced by Tropical Storm Isaac would nearly completely eliminate the existing submerged and emergent vegetation communities and require a multi-year recovery period before conditions could stabilize.

The 2000 to 2012 annual distribution and spatial coverage maps for the major SAV taxa reflect the dynamic nature of SAV distribution and spatial coverage in Lake Okeechobee. If restoration projects such as adding substantial water storage north of the lake enable better control of lake stages, the SAV community might be expected to respond with reduced interannual variability, relatively high areal coverage and overall increased biomass. A positive shift in the vascular to non-vascular ratio also might be anticipated.

Except perhaps for the impacts of major physical disturbance events such as hurricanes and droughts, the probability for successful utilization of this assessment tool is high. However, since past performance has demonstrated that Lake Okeechobee can periodically attain this performance measure prior to the implementation of any substantial restoration activities, a metric for interannual stability in SAV community structure probably needs to be added.

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CHAPTER 4

NORTHERN ESTUARIES MODULE

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CHAPTER 4 NORTHERN ESTUARIES MODULE

The Northern Estuaries Module contains estuaries on both Florida coasts with the Caloosahatchee River Estuary, San Carlos Bay and Estero Bay on the west coast and the St. Lucie Estuary, Southern Indian River Lagoon, Loxahatchee River Estuary and Lake Worth Lagoon on the east coast (***Figure 4-1***). Detailed descriptions of these individual water bodies can be found in the *2006 System Status Report* (SSR) (RECOVER 2007) available online at http://www.evergladesplan.org/pm/recover/assess_team_ssr_2006.aspx. Additional information can be found in the 2009 SSR (RECOVER 2010) available online at http://www.evergladesplan.org/pm/ssr_2009/mod_ne.aspx.

For this 2012 update, updates on assessment efforts in the Northern Estuaries are provided for oysters and benthic macroinvertebrates. In addition, a benthic mapping effort has been undertaken in the Northern Estuaries since the 2009 SSR was published. The results of this effort are also provided in this update. A full assessment of the Northern Estuaries will be provided in the 2014 SSR.

OYSTERS

Introduction

This section provides updates on progress made towards improving the assessment methods for oysters as well as a summary from the stoplight indicator report on the status of eastern oysters (*Crassostrea virginica*) within the Northern Estuaries. These efforts include (1) an update of the Caloosahatchee River Estuary Oyster Habitat Suitability Index (HSI) model, (2) statistical analysis to test relationships between salinity fluctuations and oyster metrics using ten years of water quality and oyster data from the Caloosahatchee River Estuary, and (3) mesocosm studies to determine oyster early life stage salinity tolerance.

Additional informaton on oysters in the Northern Estuaries can be found in the 2009 SSR. See http://www.evergladesplan.org/pm/ssr_2009/hc_ne_oyster_results.aspx.

Habitat Suitability Index

An HSI is a scoring model used to evaluate water management operations on plant and animal habitats. The Oyster HSI for the Caloosahatchee Estuary analyzes the responses of both the larval and adult stage oysters and "scores" the performance of a particular run relative to their baseline conditions. The HSI scores are then averaged to produce a yearly HSI for oysters. The model scores from zero to one, with zero meaning undesirable impacts and one meaning more desirable impacts.

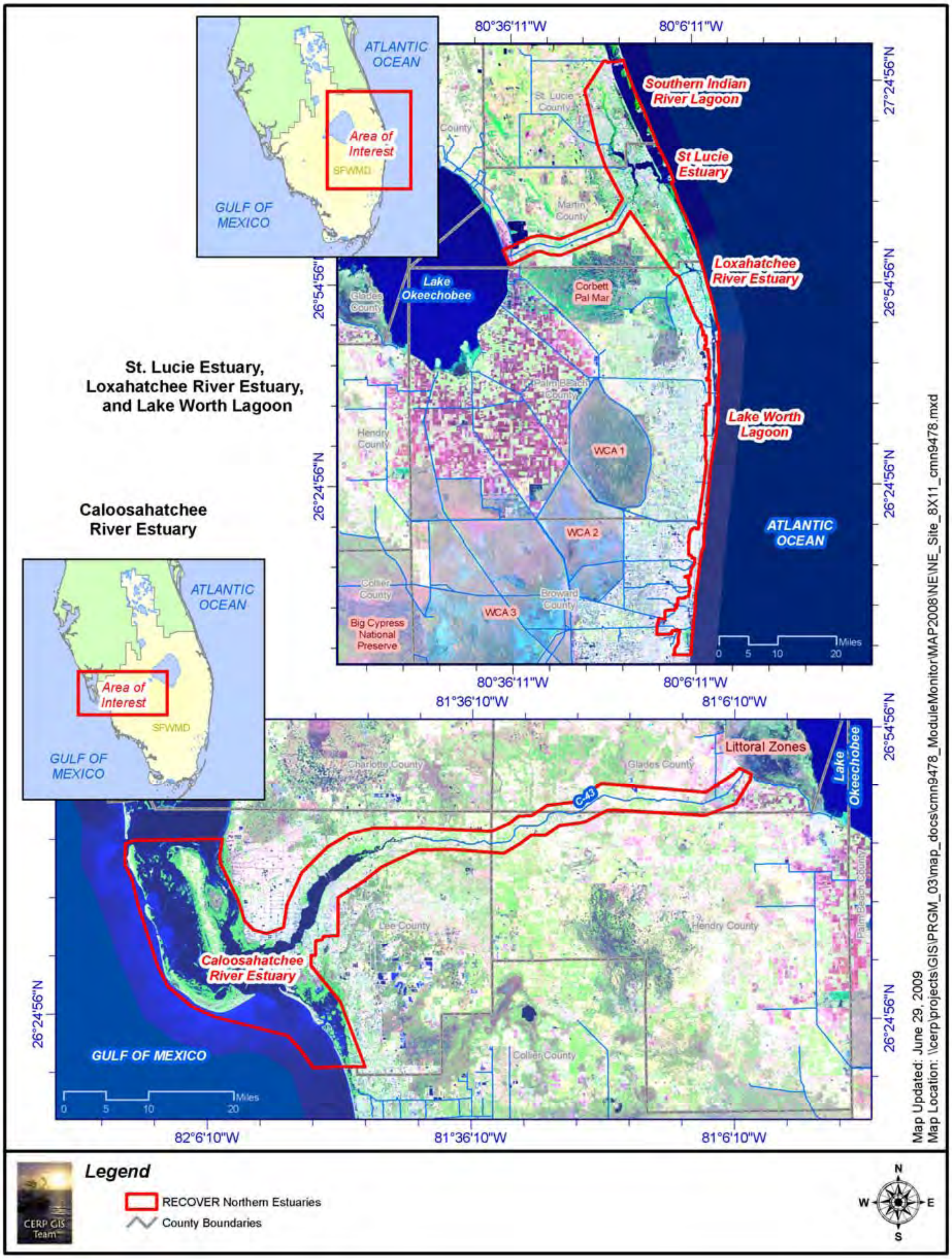


FIGURE 4-1. MAP OF THE NORTHERN ESTUARIES.

The Oyster HSI model for the Caloosahatchee River Estuary, which was developed in 2007 (Barnes et al., 2007), has been updated and integrated with ArcGIS10. This integration moved the HSI into a true geographical information system (GIS) environment that allows centralized storage within ArcSDE (Spatial Database Engine), which is a server-software subsystem that aims to enable the usage of relational database management systems for spatial data. The spatial data may then be used as part of a geodatabase. This integration provides the capability of running scenarios by altering flows and salinity. Potentially, additional parameters and/or species can be added (***Figure 4-2***).

ArcGIS10 also provides the opportunity to create web-enabled applications and to access existing web services. ArcGIS10 also provides the ability to communicate with other database systems such as the Comprehensive Everglades Restoration Plan (CERP) Integrated Database (CID), the Data Catalog, and any other accessible database management system.

The upgraded Oyster HSI can utilize specific data gathered at collection stations in the estuary. The data being used in the Oyster HSI is salinity, flow and water temperature. This data is loaded into a centralized database and processed to create HSI values of the oyster species per week (***Figure 4-3***). The tool then allows the user to view the HSI values of the oyster species over time. This provides the user with the ability to manipulate data for planning purposes.

Several modifications were made to optimize the model output as well as the user interface. For example, HSIs were originally calculated once every month and averaged for the year. While the mean salinity for the month may seem optimal, large freshwater discharges or runoff from the watershed could occur during this timeframe that are extremely detrimental to oysters but masked due to averaging. Therefore, the revised model utilizes salinity values averaged over a one-week period to capture episodic events and oyster HSIs are calculated weekly (***Figure 4-4***) and then averaged for the year.

Recent experiments examining salinity tolerances of oyster gametes, embryos and larvae under controlled laboratory conditions allow us to further optimize the stressor-response curves used in predicting oyster habitat suitability indices. Recent experiments suggest that while gametes and embryos are less tolerant of salinities below 15 parts per thousand (ppt) and oyster larvae are less tolerant of salinities below 10 ppt, early spat (less than 3 to 4 millimeters in length) appear to be tolerant of salinities above 10 ppt for up to two to three weeks. These responses are being used to optimize the oyster HSI and to field validate the model output.

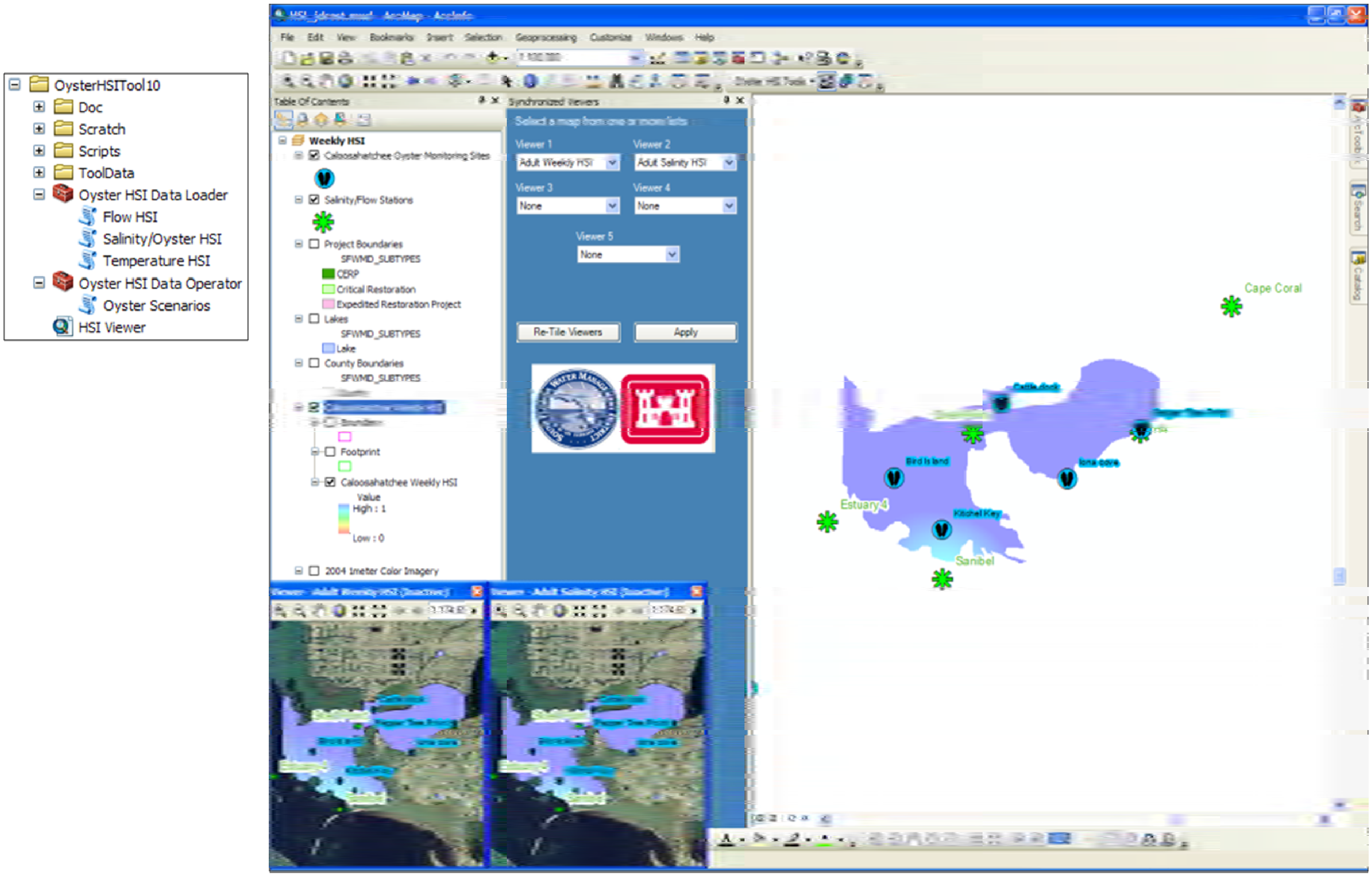


FIGURE 4-2. ARCGIS10 DATA INPUT SCREEN AND OUTPUT VIEW.

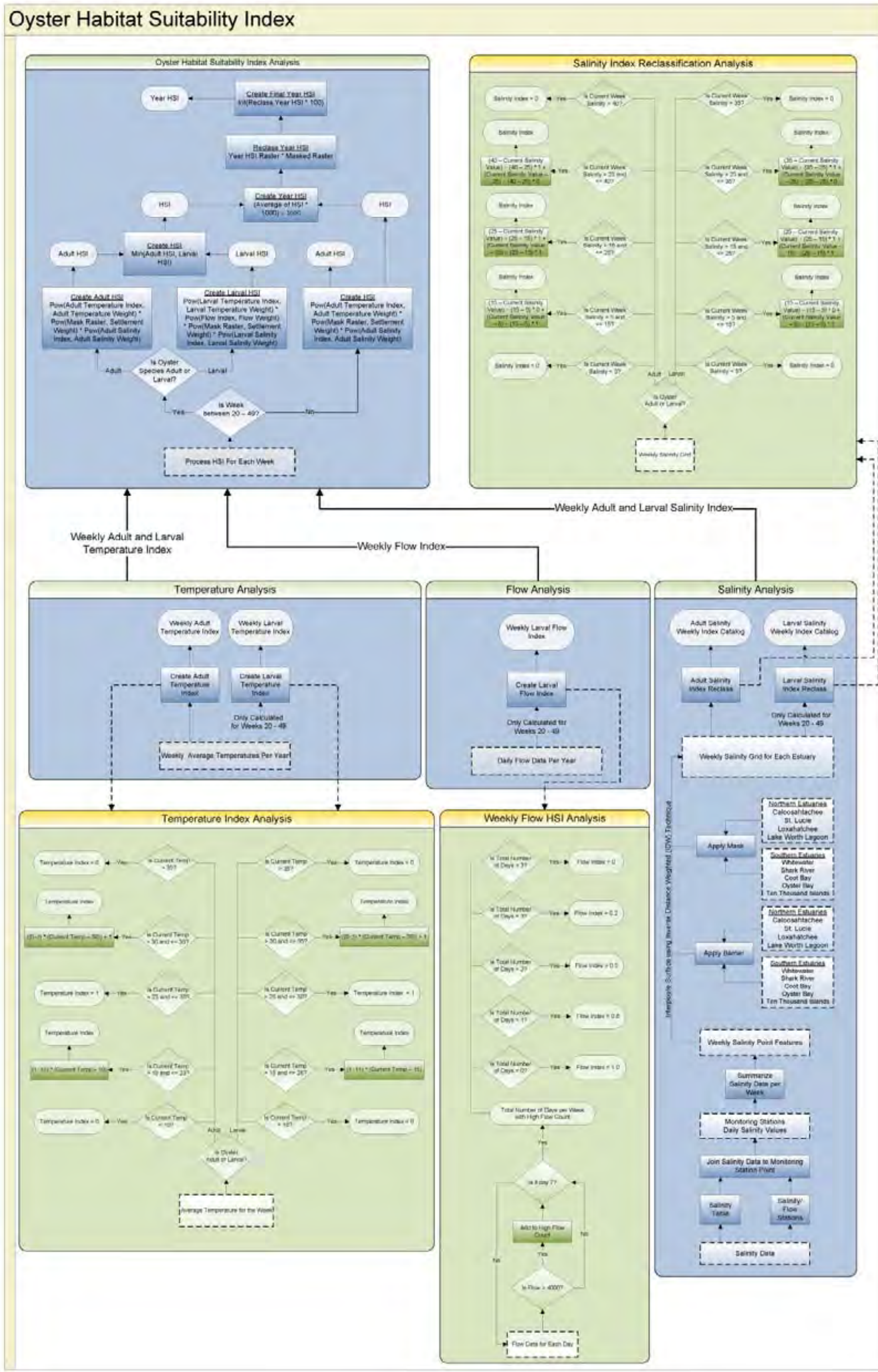


FIGURE 4-3. OYSTER PARAMETERS THAT ARE USED TO CALCULATE WEEKLY HSI VALUES.

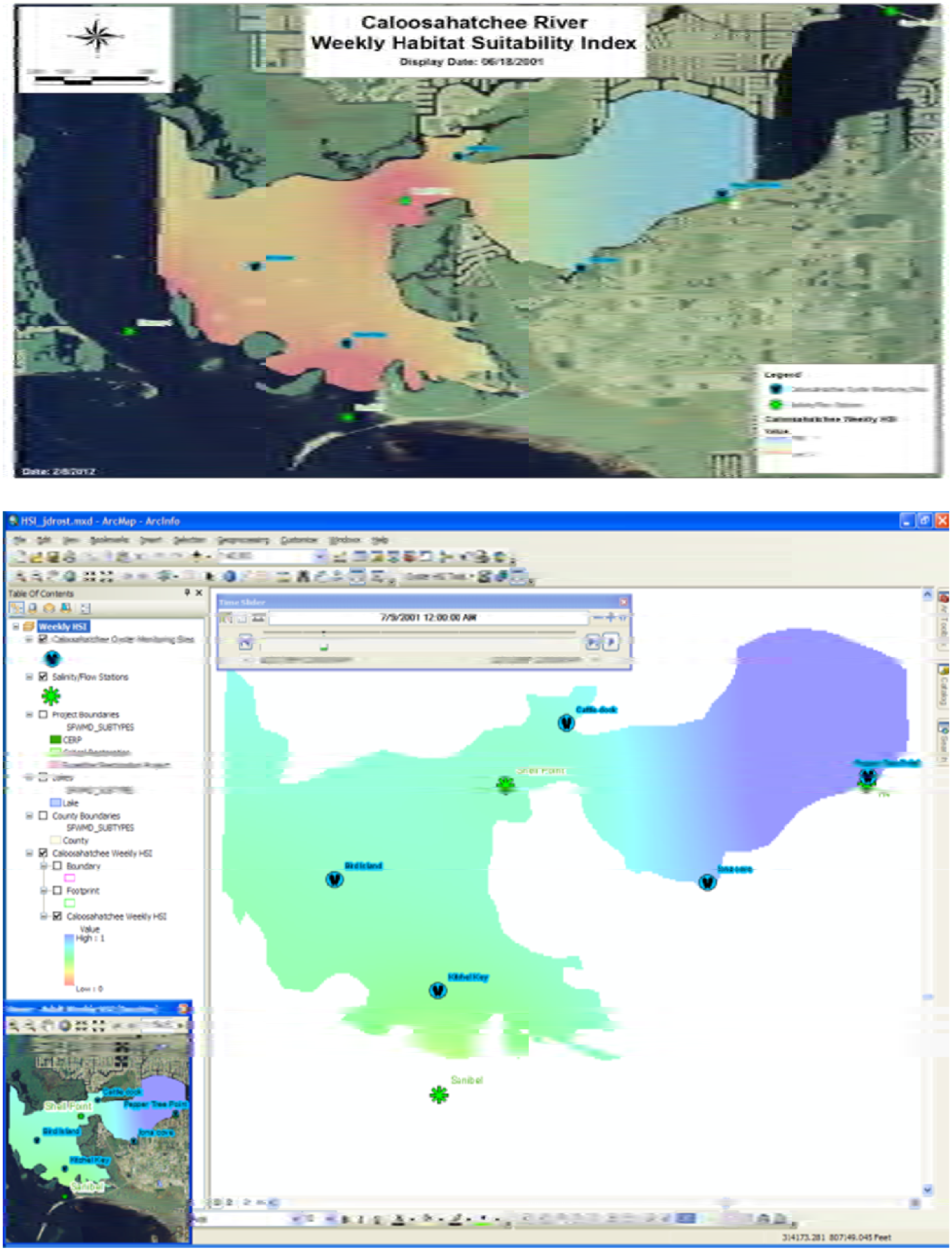


FIGURE 4-4. OYSTER HSI OUTPUT OF WEEKLY VALUES.

Analysis of Oyster Metrics in the Caloosahatchee Estuary

Study Objectives

The *CERP Monitoring and Assessment Plan* (RECOVER, 2009) lists a key uncertainty associated with the eastern oyster as "... the sampling design may need to be adjusted to better capture the spatial variation of responses. Seasonal trends may need to be examined before any adjustments are made." The objectives of this project were to conduct statistical analyses and evaluate a ten-year study (2000–2010) with regard to achieving the objectives below. This information will ultimately assist with CERP project design and development of operational manuals for adaptive management for use by the South Florida Water Management District and United States Army Corps of Engineers to minimize impacts on estuarine and coastal habitats.

Specifically, this project did the following:

- Conducted statistical analyses testing for the dependence of variation in oyster condition index, disease prevalence and intensity, spat settlement, growth and other oyster-related measurements (***Table 4-1***) on variation in freshwater inflow at the S-79 structure and salinity in the downstream Caloosahatchee River Estuary (***Figure 4-5***).

- Evaluated the monitoring program with respect to (1) the number and location of stations required to assess the response of oyster population abundance and spatial distribution to anticipated changes in freshwater inflow/salinity, and (2) ability of the current oyster response variables to reflect changes in freshwater inflow/salinity.

TABLE 4-1. A LIST OF VARIABLES DIVIDED INTO PHYSICAL AND BIOLOGICAL OYSTER METRICS.

Variable	Definition	Minimum	Median	Maximum
Physical Variables				
Flow	Freshwater inflow at S-79 (in cubic feet per second [cfs]) (sample size 122)	0.00	803.68	11,592.00
Salinity	Salinity (in ppt)	0.00	26.68	42.69
Temperature	Temperature (in degrees Celsius)	13.34	26.21	32.66
Tidal	Tidal flow (in cfs) (sample size 122)	57.95	222.91	3842.20
Rain	Rain at S-79 (in inches) (sample size 122)	0.00	0.10	0.62
Biological Variables				
Gonad index (mgonind)	Gonad variable that measures the reproductive stage of the oyster; mean of replicate observations; high is good	0.80	1.70	4.90
Spat_per_shell	Number of spat per oyster shell after one month deployment; high is good	0.00	1.01	141.50
Pmscore	*Perkinsus marinus* infection score; low is good	0.00	1.00	3.87
Condition index	Ratio of dry weight oyster shell to meat; high is good	0.34	2.24	5.58

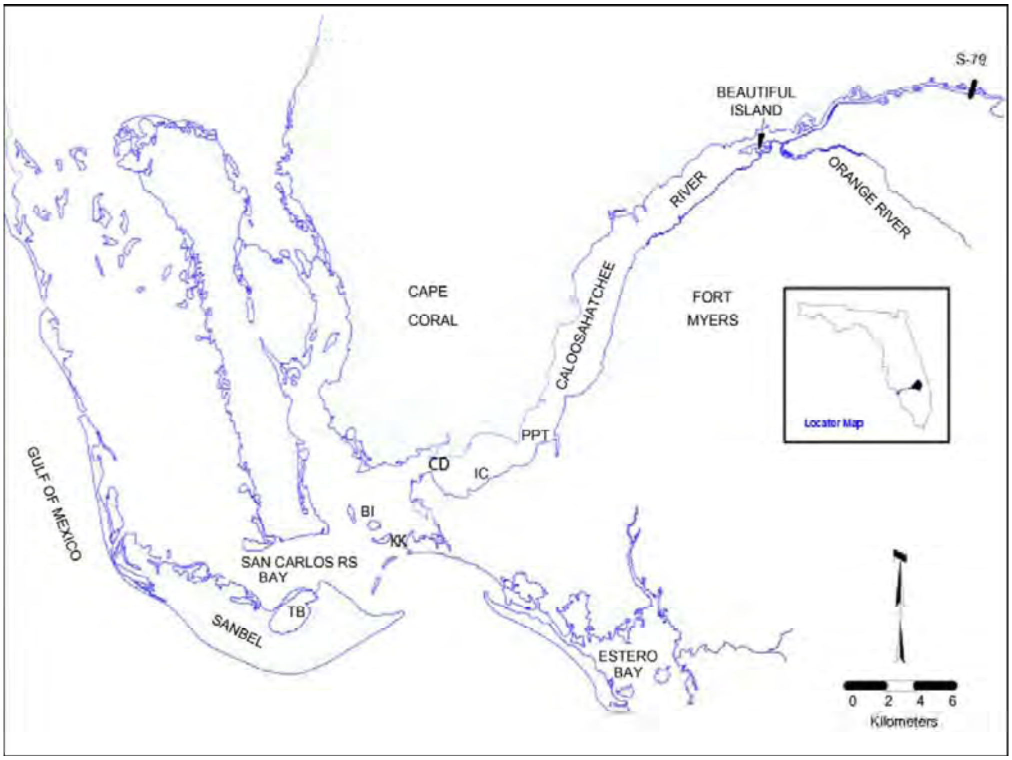


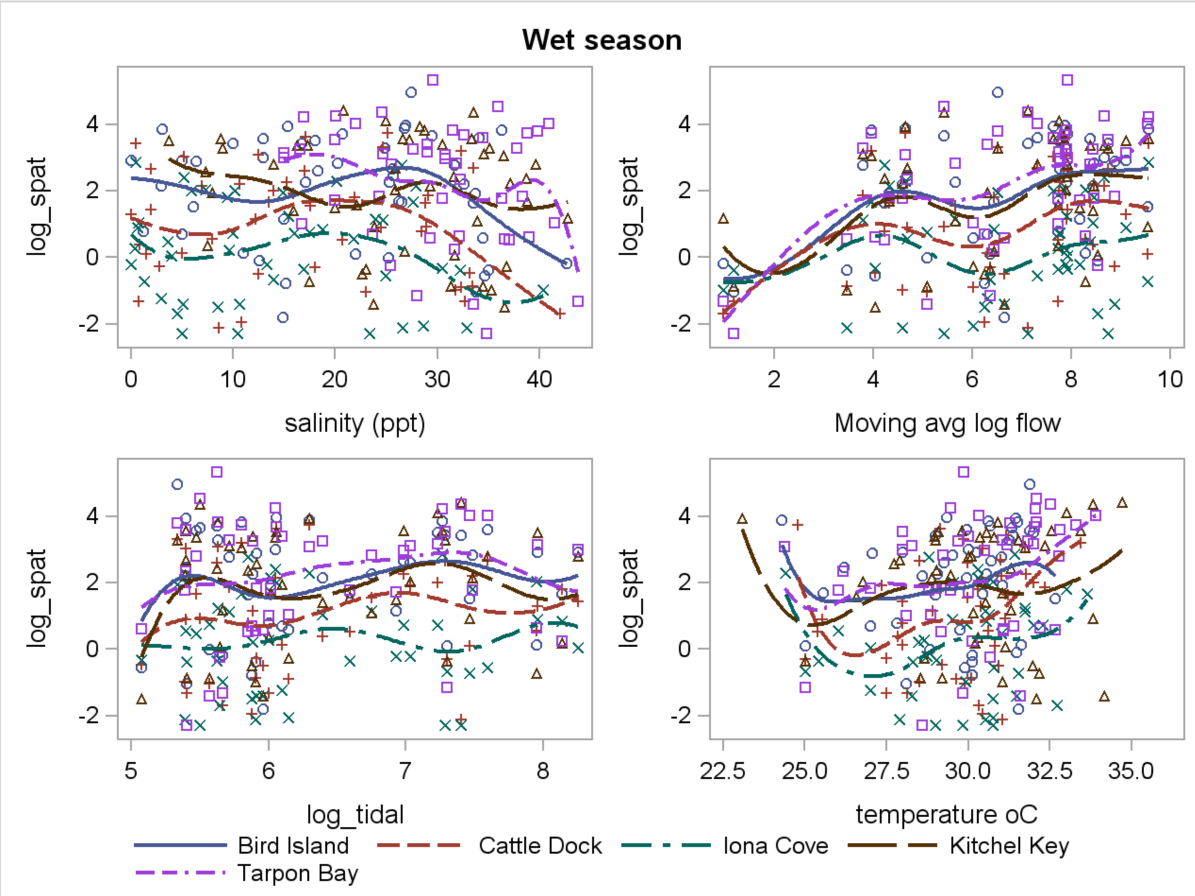
FIGURE 4-5. OYSTER SAMPLING LOCATIONS WITHIN THE CALOOSAHATCHEE RIVER ESTUARY.

Key Findings

Due to Fiscal Year 12 Restoration Coordination and Verification program (RECOVER) monitoring budget reductions, funding for oyster monitoring in the Caloosahatchee River Estuary was reduced and the project scope was revised. Outcome from data mining the first ten years of oyster monitoring was used along with best professional judgment to modify the sampling and analysis approach to best achieve project objectives. It was determined that Tarpon Bay, one of the current sampling stations, would be eliminated since data from it and the closest station (Kitchel Key) were providing similar results. In addition, given the location of Tarpon Bay inside a bay with a narrow opening and its own freshwater source, it may not reflect a distance-gradient from the S-79 structure in the Caloosahatchee River Estuary. Monitoring oyster condition index was also eliminated since the trend established in the first ten years was adequate to meet the programs objectives. In order to further reduce costs, continuous water quality monitoring was eliminated and the principal investigator is required to perform monthly monitoring of temperature, salinity and dissolved oxygen during each oyster sample collection.

The analysis suggests that the stations near S-79 tend to be more controlled by flow from the S-79 structure. Other factors such as watershed runoff from the tidal basin and tidal influence tend to be important at sites farther from the structure. To develop better models for salinity, it is necessary to measure those variables influencing these downstream stations, which are up to 28 miles (45 kilometers) downstream from the S-79 structure.

Although there is a moderate predictive relationship for two oyster indices—spat per shell (***Figure 4-6***) and gonadal index—and water temperature, salinity and flow, additional sampling could improve the model. Strengthening the connection between flow and station measurements could enhance analysis. Flow at the S-79 structure is measured at an almost instantaneous timescale while salinity and oyster data are collected at a monthly time interval.



Key: avg – average; log_spat – log of spat per shell; log_tidal – log of tidal flow; °C – degrees Celsius; ppt –parts per thousand.

FIGURE 4-6. PLOTS FOR THE LOG OF SPAT PER SHELL FOR THE WET SEASON.

Log_tidal is log of tidal flow.

Analyses using observational data can be augmented with data from controlled mesocosm experiments. In a controlled experiment, a factor, such as salinity, can be varied while holding other factors fixed. This will lead to stronger cause-and-effect relationships and better estimates of optimal conditions. This will also help with variable selection in the models and lead to improved management decisions.

Laboratory experiments are specifically recommended to identify the shape of the exposure-response curve describing the effect of salinity on reproduction and development of early life stages of oysters. Estimates of optimal values as well as the equivalent of LD_{50} and EC_{50} values would be useful as well. Another recommended experiment is a study of the effect of acute and gradual salinity changes on larval survival. Laboratory or mesocosm studies could be designed to determine optimal values of flow and salinity, controlling for other factors. These studies would be useful for corroboration of the results of the field observations and lead to stronger causal models.

Early Life Stage Salinity Tolerance

During the statistical analysis to test relationships between salinity fluctuations and various oyster metrics discussed above, it became clear that the effects of salinity on the survival and growth of oysters' early life stages (***Figure 4-7***) were insufficiently monitored or understood. A main recommendation of this analysis was to augment the observational data collected in the Caloosahatchee River Estuary with controlled mesocosm experiments to identify the shape of the exposure-response curve describing the effect of salinity on oyster reproduction. A mesocosm is an experimental tool that enables one to study a small part of the natural environment under controlled conditions.

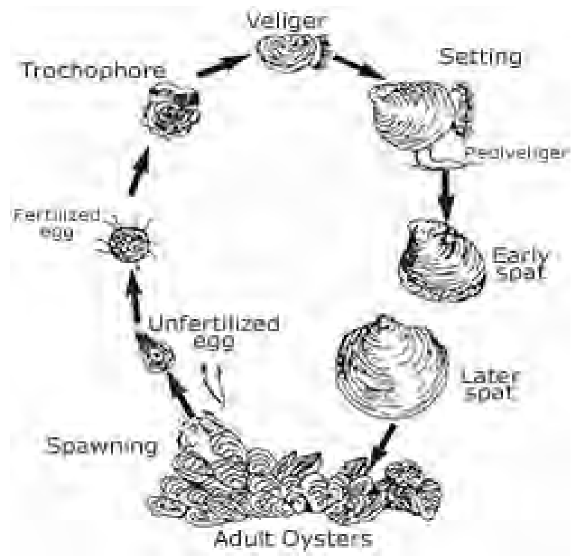


FIGURE 4-7. OYSTER LIFE CYCLE.
(Berrigan et al., 1991)

The majority of freshwater inflows from the watershed and regulatory releases from Lake Okeechobee occur during the wet season (summer months) when oysters are reproductively active. How the magnitude and duration of salinity changes impact early life stages will be determined during April 2012–September 2016 using mesocosms. The results of this work will provide a link between observational field studies and controlled laboratory experiments. During this study, various life stages of oysters (i.e., gametes, embryos, larvae and early spat) will be exposed to acute and gradual salinity changes. Results of these experiments will enable us to better predict ecological responses of oysters in local estuaries. This information can also be used to augment decision making as well as assist in determining the frequency and duration of freshwater releases into Southwest Florida estuaries (flow targets).

The first study will focus on the effect of acute changes in salinity on early life stages of oysters in the Caloosahatchee River Estuary. Subsequent studies will focus on the effect of acute changes on adult oysters as well as the effect of gradual salinity changes on early life stages.

Salinity has significant influence not only on the growth, survival and reproduction of adult oysters, but also on early life stages (Shumway, 1996; Volety et al., 2009). Previously published works on salinity effects were conducted in diverse geographic locations in the United States (Shumway, 1996). Although oysters and their responses adapt to local conditions, most of the work to date has focused on adult oysters at only a few salinity regimes (Volety et al., 2003). In Southwest Florida, oyster spawning occurs annually between April/May–October/November and is dependent primarily on temperature and rainfall. Salinity varies dramatically during these periods and can range from 0 ppt to 42 ppt, depending on the amount of rainfall/freshwater inflow and geographic location within the estuary. The hypothesized susceptibility of oyster life stages is as follows: early life stages > juveniles > young oysters > adults.

Salinity Treatments

Salinities at upstream to midstream locations in the Caloosahatchee River Estuary during spring season (March–May) range between 20 and 28 ppt. For this reason, 25 ppt will be treated as a control. Gametes, embryos, larvae and early spat will be maintained at 25 ppt and subjected to acute salinity change. Salinity treatments will include: 0–5, 10, 15 and 20 ppt to simulate various freshwater inflow regimes, and 30, 35 and 40 ppt to simulate little or no freshwater releases (drought conditions). There will be a minimum of 3–5 replicate tanks for each treatment, with each replicate using at least 2,000–4,000 embryos/larvae or 50 early spat, enabling a good statistical comparison. Experimental duration will be for up to four weeks for each experiment (***Table 4-2***).

TABLE 4-2. LIFE STAGES OF OYSTERS AND END POINTS TO BE MEASURED UPON ACUTE SALINITY CHANGE.

Life Stage	Duration of Life Stage	Duration of Exposure	Metrics Measured
Gametes		4 days	Fertilization success Embryonic development Develomental abnormality Percent survival
Embryos	6–12 hours	7 days	Embryonic development Develomental abnormality Percent survival Growth
Veliger / Pediveliger	1–21 days	2–4 weeks	Larval development Develomental abnormality Percent survival Growth
Early Spat	1–3 months	2 weeks–1 month	Survival Growth

Data Analysis and Water Management

This study will examine the effects of freshwater (salinity) on various early life stages of oysters. Results can be used to better inform resource managers regarding regulation of freshwater inflows into the estuaries to maintain and facilitate oyster larval recruitment and continued development of oyster reefs. For example, early life stages of oysters may tolerate salinities of less than 5 ppt for one week, but not two weeks. Flows into the estuary can be adjusted to meet the salinity target and limit the releases to one week or less. Once salinity and flow limits are established for various oyster life stages, then protocol may be developed to guide water management based on time of year, life cycle stage and meteorological conditions.

Excerpt from 2012 Systemwide Ecological Indicators

Summary Findings

The status of the eastern oyster is characterized by a stoplight indicator. The eastern oyster status continues to not meet restoration targets due to too much fresh water in the summer and too little fresh water in the winter. Current conditions in the Northern Estuaries (Caloosahatchee River Estuary, St. Lucie Estuary, Lake Worth Lagoon and Loxahatchee River Estuary) show that restoration actions are still merited and the status of oysters is expected to improve when hydrologic conditions are restored to more natural patterns.

Key Findings

- Too much fresh water inflows into the Northern Estuaries during the summer months and too little fresh water inflows during the winter months, disrupting natural patterns and estuarine conditions. The oysters in these estuaries are still being impacted by this unnatural water delivery pattern. Too much fresh water impacts reproduction, larval recruitment, survival and growth. Too little fresh water impacts the survival of oysters due to higher predation and disease prevalence and intensity of dermo caused by *Perkinsus marinus*.

- Overall status of oysters in all of the Northern Estuaries is below restoration targets and requires action in order to meet restoration goals.

- Oyster responses and populations in the Northern Estuaries are below targets and may be in danger of declines under current salinity levels. Growth rates and recovery rates for abundances suggest that oyster index scores could be expected to increase given proper hydrologic conditions through restoration.

- Restoration of natural patterns (reduced freshwater flows in the summer and increased freshwater flows in the winter) along with substrate enhancement (addition of cultch) is essential to improving performance of oysters in the estuaries.

- Continued monitoring of oysters in the Northern Estuaries will provide an indication of ecological responses to ecosystem restoration and will enable us to distinguish between responses to restoration and natural variation.

BENTHIC MACROINVERTEBRATES

Benthic macroinfauna, invertebrate worms, clams and other organisms living in bottom sediments have historically been monitored to assess condition of the environment. Species composition and abundance information is typically summarized in an index whose value measures environmental condition. Infauna have been sampled in the St. Lucie Estuary and the adjacent Southern Indian River Lagoon since 2005.

In order to account for differences between salinity regimes and the varying levels of diversity and richness within each salinity regime, AZTI's Marine Biotic Index (M-AMBI) is used in conjunction with these values to create an ecological quality score, or M-AMBI score. In this way, the level of diversity and abundance of invertebrate taxa, as well as the proportion of disturbance sensitive taxa, can be determined. Sites are placed on a status gradient: high, good, moderate, poor and bad with reference conditions used as the high boundary.

Average M-AMBI values for 2009–2011 indicate that most of the sites within the St. Lucie Estuary (sites M1, M2, M4, M5, M6, M14 and M15; ***Figure 4-8***) exhibit good ecological status. Site M3 is the only estuary site that shows moderate ecological status. All of the sites in the Southern Indian River Lagoon (M7, M8, M9, M10, M11, M12 and M13) exhibit good ecological status. Several of the Southern Indian River Lagoon sites—M9, M10, M12 and M13—show M-AMBI scores that are approaching the high category. Sites within the St. Lucie Estuary are exposed to a higher degree of nutrient runoff and abrupt salinity changes, which could contribute to their slightly lower scores than sites in the lagoon. Further analysis is needed to determine the reason site M3 is still showing moderate status.

Examining yearly averages of M-AMBI values over time for each site from 2005 through 2011 allows for a better understanding of trends at each site (***Figures 4-9*** through ***4-15***). Several of the St. Lucie Estuary sites—M1, M2, M4, M5, M6 and M15—have shown a general positive trend over the past six years. Sites M1, M4 and M5 have shown the greatest improvement, going from poor to good status. Site M3 is the only estuary site that seems to have deteriorated, fluctuating from moderate to good during 2005–2010, and then making a sudden drop in 2011 to poor. More research is required to identify possible causes of this sudden change. All of the Southern Indian River Lagoon sites have either shown a small but steady improvement, or remained consistent over the past six years. Site M9 has made the most significant improvement within the Southern Indian River Lagoon with high ecological status in 2011.

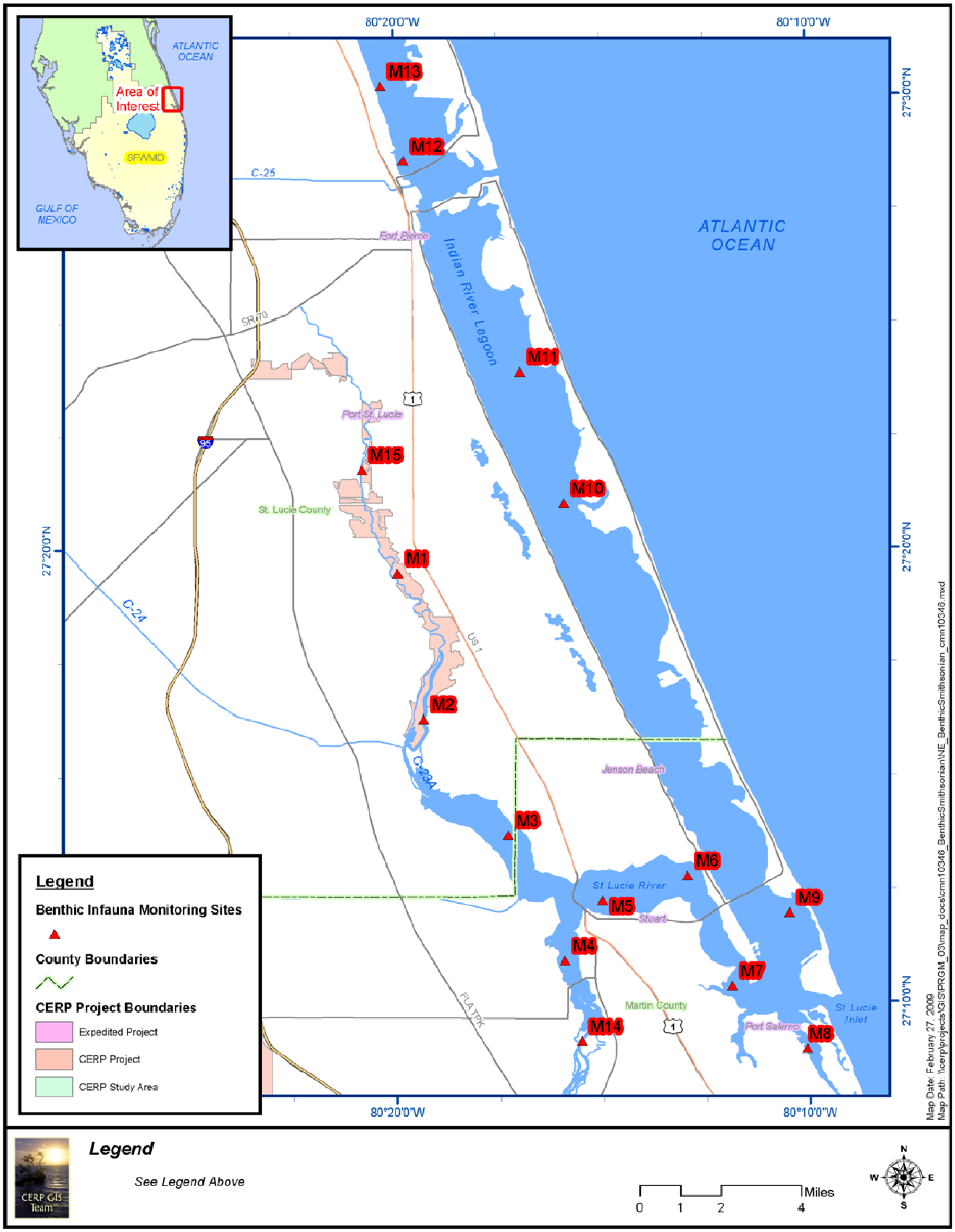


FIGURE 4-8. BENTHIC MACROINVERTEBRATE SAMPLING SITES IN THE ST. LUCIE ESTUARY AND SOUTHERN INDIAN RIVER LAGOON.

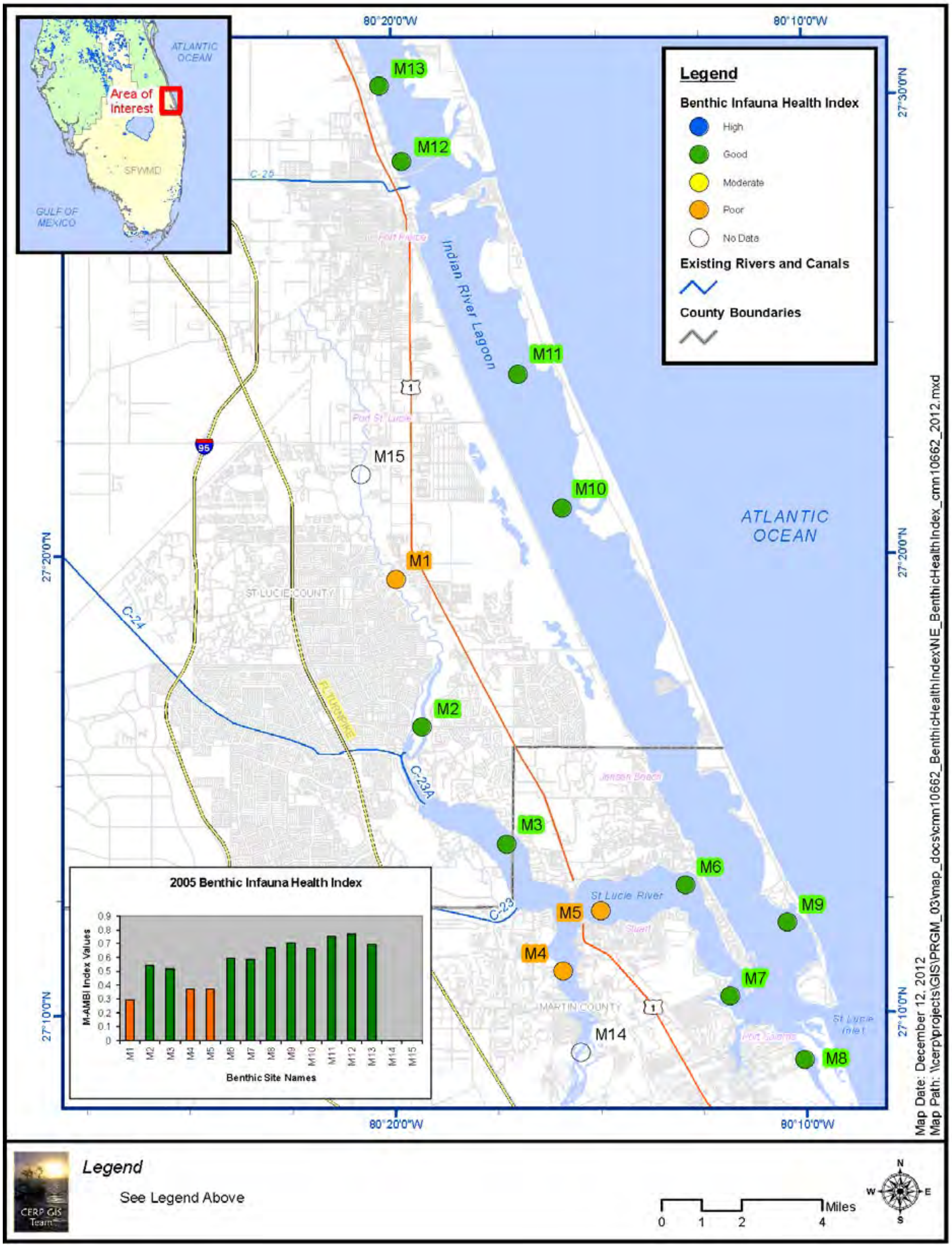


FIGURE 4-9. BENTHIC MACROINVERTEBRATE HEALTH INDEX FOR 2005.

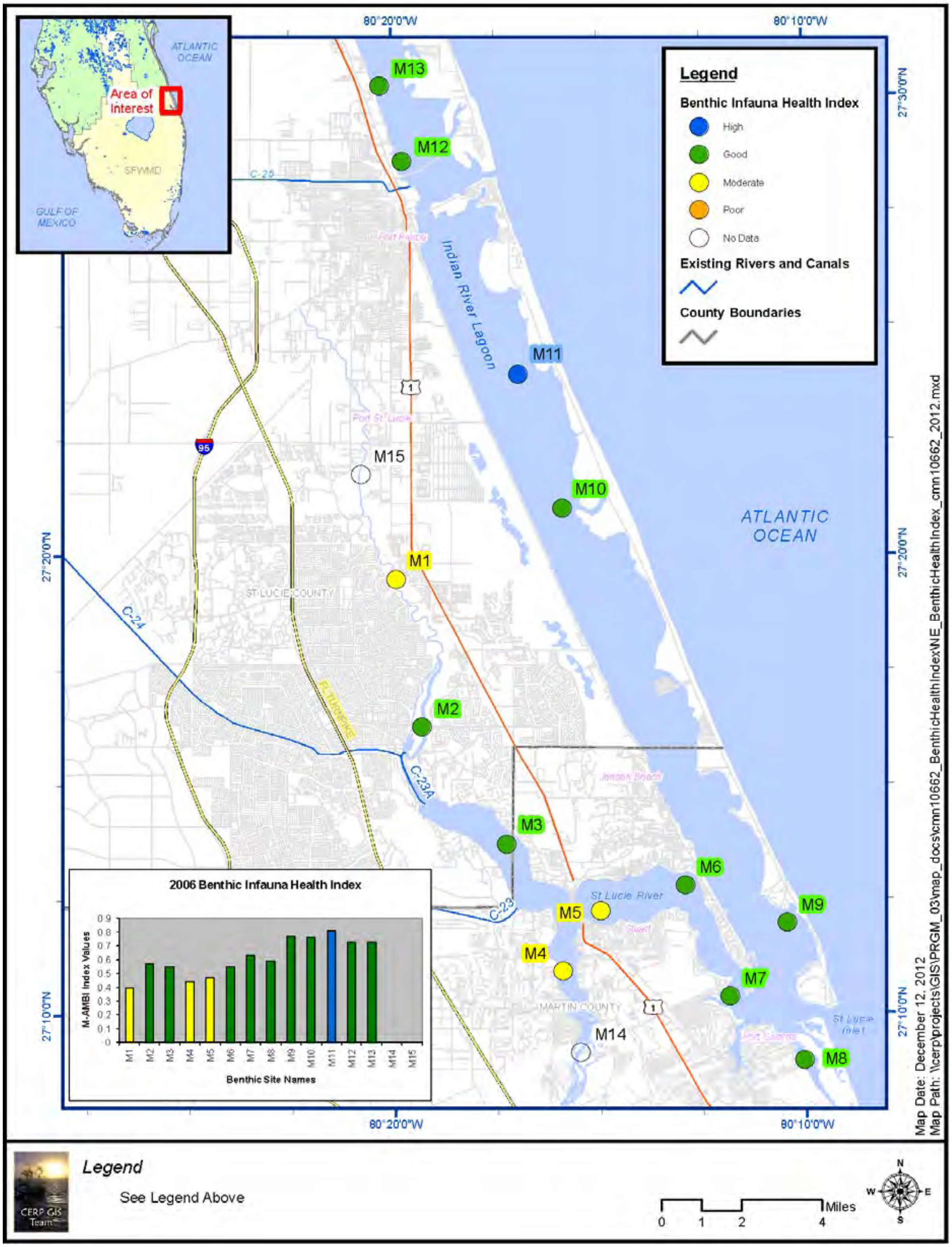


FIGURE 4-10. BENTHIC MACROINVERTEBRATE HEALTH INDEX FOR 2006.

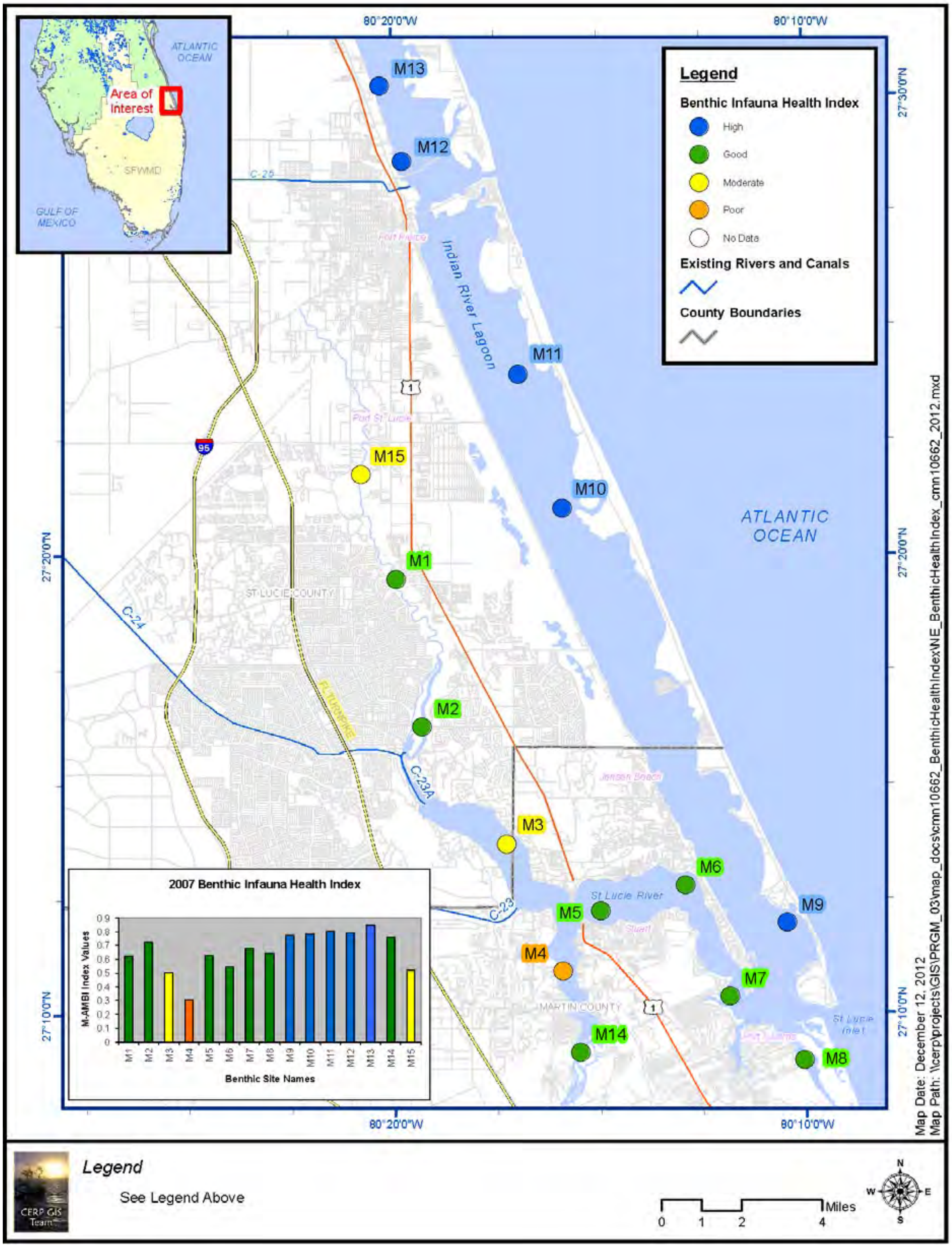


FIGURE 4-11. BENTHIC MACROINVERTEBRATE HEALTH INDEX FOR 2007.

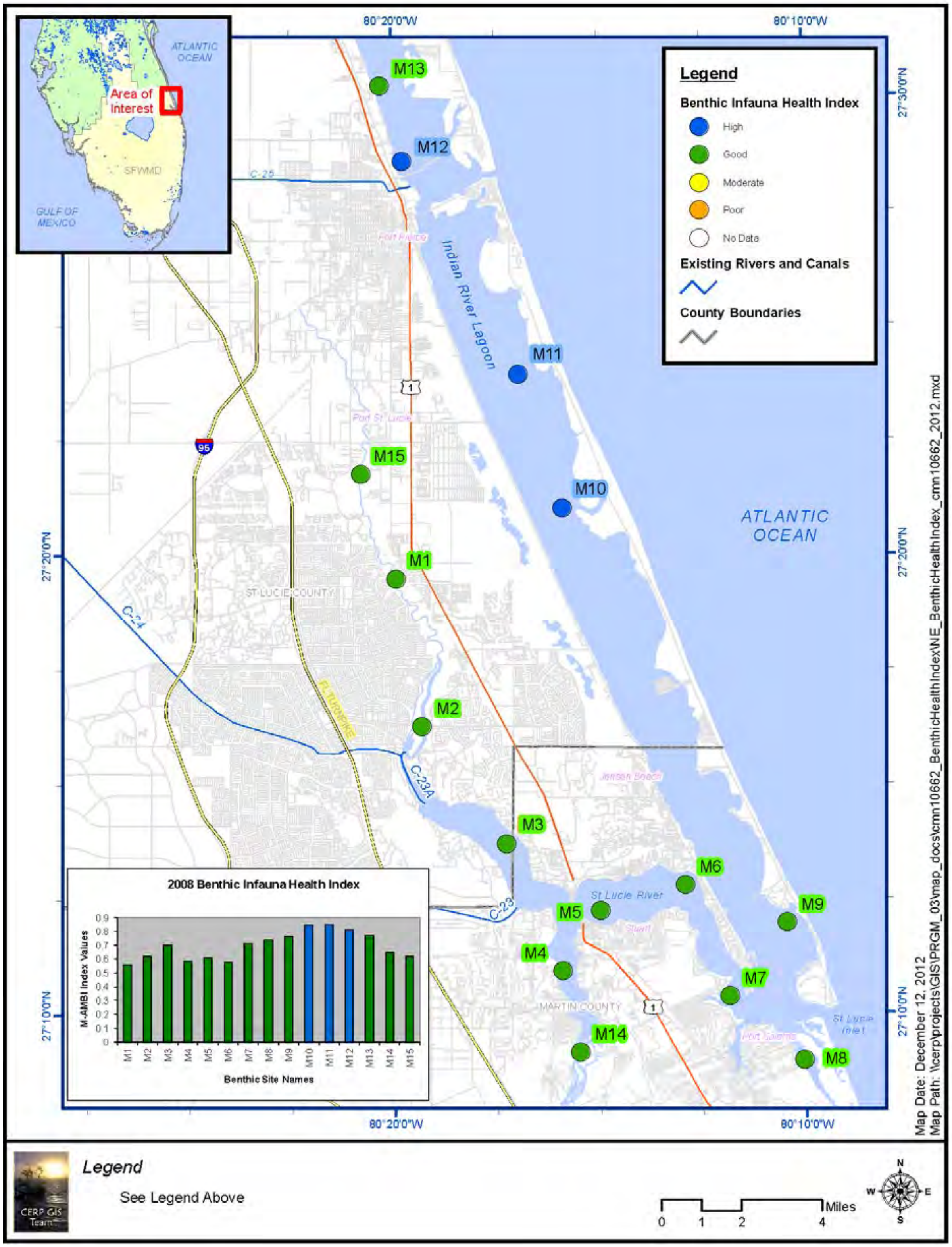


FIGURE 4-12. BENTHIC MACROINVERTEBRATE HEALTH INDEX FOR 2008.

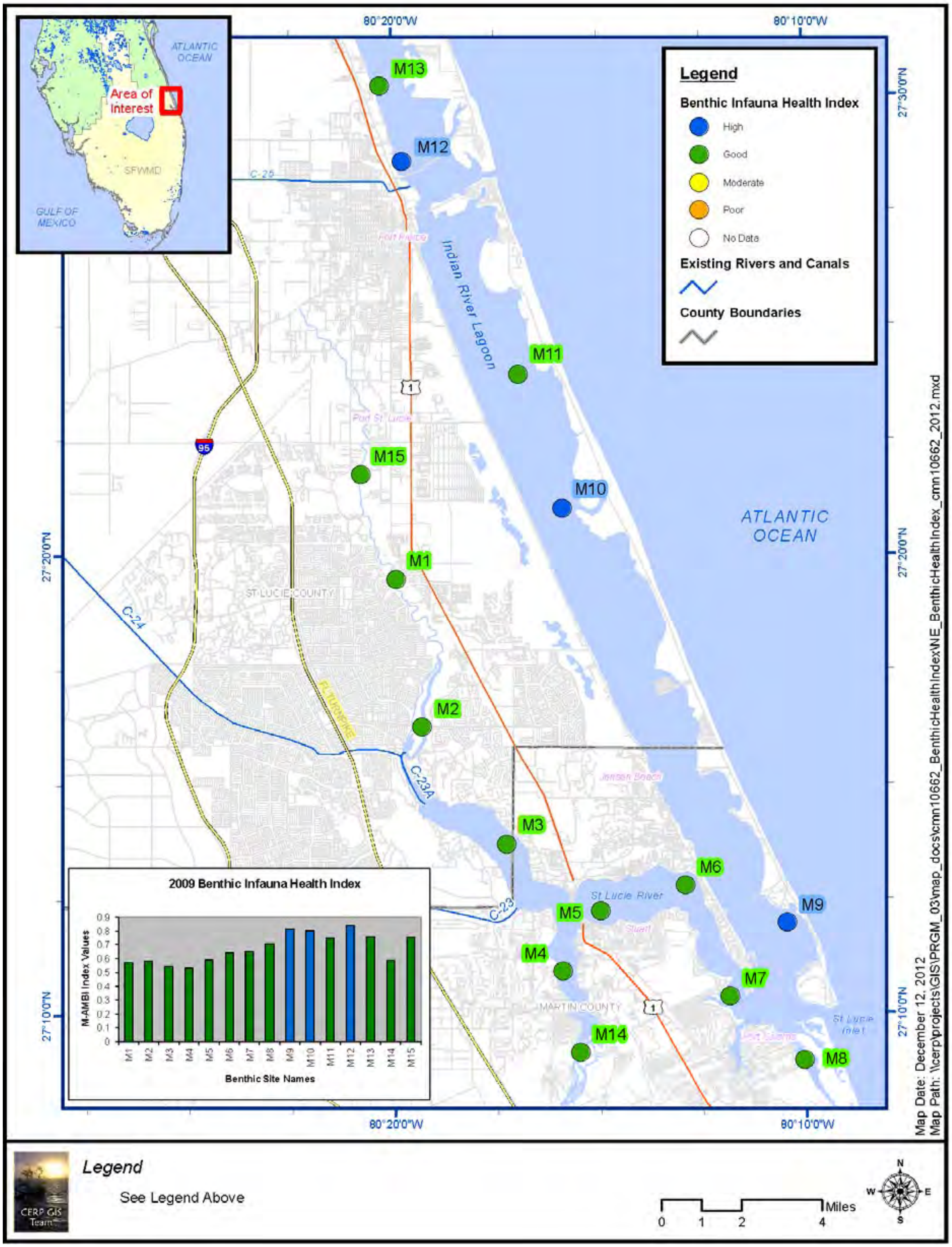


FIGURE 4-13. BENTHIC MACROINVERTEBRATE HEALTH INDEX FOR 2009.

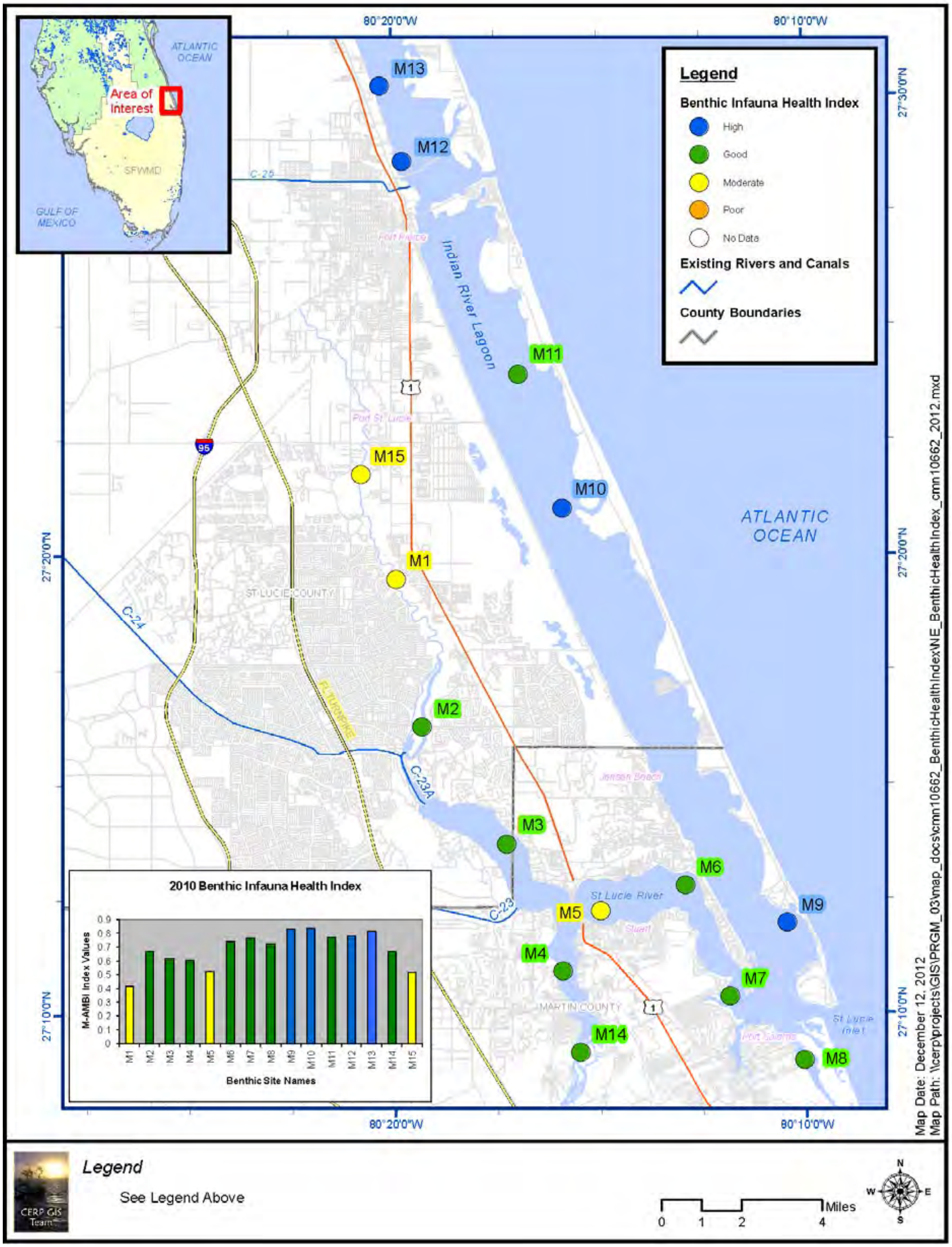


FIGURE 4-14. BENTHIC MACROINVERTEBRATE HEALTH INDEX FOR 2010.

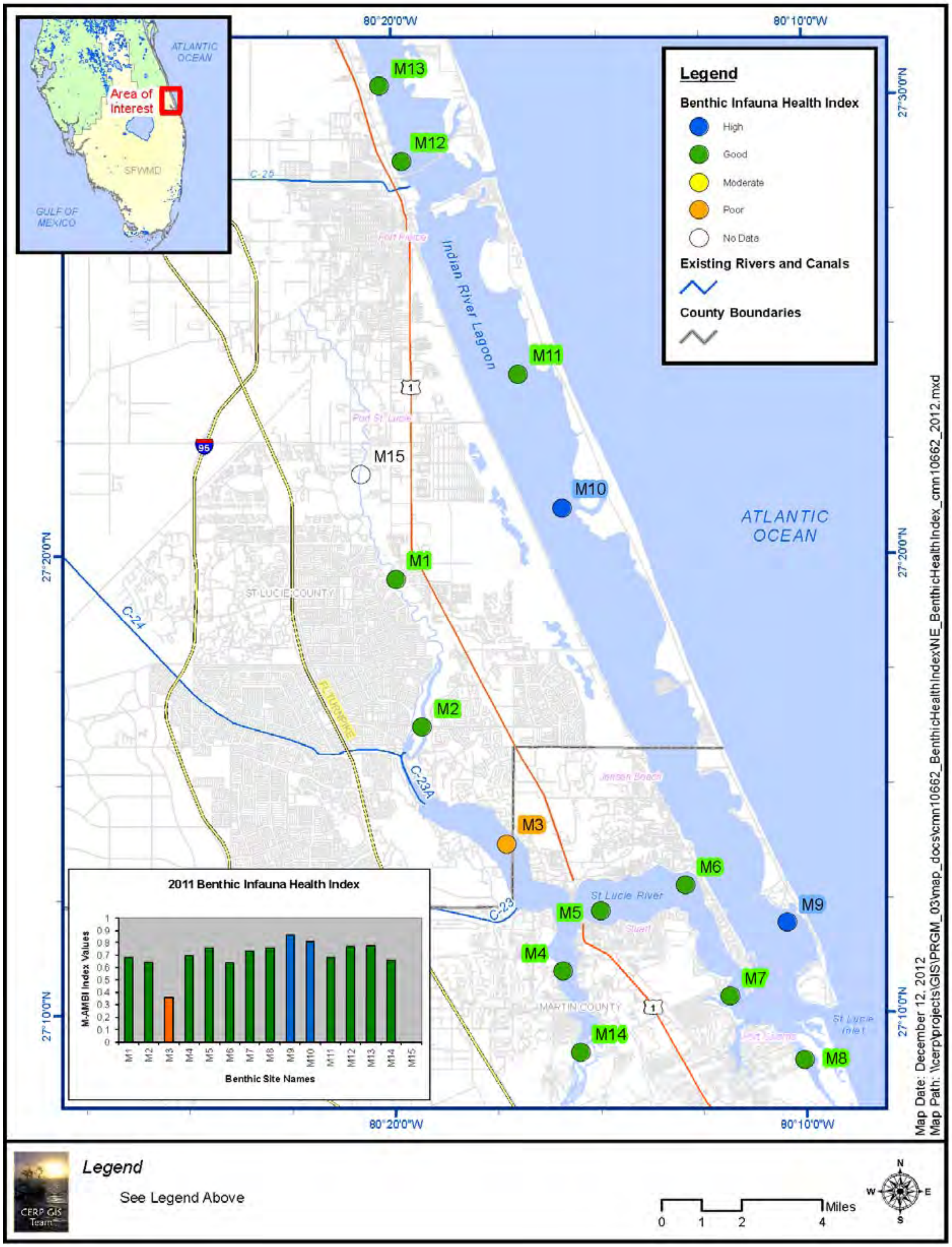


FIGURE 4-15. BENTHIC MACROINVERTEBRATE HEALTH INDEX FOR 2011.

BENTHIC MAPPING

Introduction

Between 2010 and 2011, Dial Cordy and Associates, Inc. mapped the Caloosahatchee River Estuary, St. Lucie Estuary, Loxahatchee River Estuary and Lake Worth Lagoon for bottom type (i.e., shell, silt, mud and muck) and location of oyster beds and submerged aquatic vegetation (SAV). In addition, densities of live oysters, as well as presence/absence of oyster reefs and SAV beds, were examined in these estuaries at select locations.

While limited monitoring of oyster reef and SAV health has occurred since the late 1990s, this mapping effort focused on using a common sampling protocol in all four estuaries to map the estimates of oyster and SAV extent and distribution/coverage, and complete a comprehensive map of substrate bottom type and morphology. Mapping of the benthic habitats and bottom types in the subject estuaries is essential since the spatial location and extent, as well as health, of oyster reefs, SAV, and bottom types influence the natural expansion of oyster reefs and SAV and success of restoration activities. This additional mapping is critical to understand where increases in oyster and SAV spatial coverage could occur in response to CERP projects and operations that improve quantity, quality, timing and distribution of basin and Lake Okeechobee flows to the estuaries.

Methods

The benthic sampling effort used a four prong approach: (1) calibration of the side-scan sonar and Quester Tangent Sideview Classification software in known oyster reef areas with varying substrate types, (2) remote sensing survey of all four estuaries, (3) field intensive groundtruthing of data to classify benthic habitat types, and (4) extensive mapping and quantitative assessment of live and dead reefs and oyster shell lengths of live oyster reefs. Maps of benthic substrate and oyster reef were developed as a base map for future reporting comparisons.

Results

St. Lucie Estuary

Eight substrate classification types, totaling over 4,400 acres, exist within the survey boundaries of the St. Lucie Estuary (***Figures 4-16*** and ***4-17***). These substrate classes range from thick muck (greater than 1.0 foot) to sand, of which thick muck is approximately 53 percent of the total substrate within the survey area.

Over 350 acres of the 4,343-acre survey area were identified as containing either oysters in varying physical morphology (clump or reef) or SAV from surveys conducted in May 2010 (***Figures 4-18*** and ***4-19***). Oyster reefs were the primary habitat type (7.7 percent) found within the survey boundary, whereas oyster clumps and mixed SAV beds of *Halophila decipiens* (paddle grass) and *Halodule wrightii* (shoal grass) make up roughly 0.3 percent and 0.2 percent, relatively. Sparse *Ruppia maritima* (widgeon grass) beds were identified in approximately 0.9 acres or 0.3 percent of the survey area. In this case, sparse is a relative term, indicating SAV cover was patchy and/or discontinuous. Approximately 8.2 percent of the 4,343 acres was identified as containing benthic habitat.

Loxahatchee River Estuary

Seven substrate classification types, totaling over 886 acres, exist within the survey boundaries of the Loxahatchee River Estuary (***Figure 4-20***). These substrate classes range from sand to sand/rock, of which sand composes approximately 51 percent of the total substrate within the survey area.

Over 220 acres, or 25.3 percent, of the 886-acre survey area were identified as containing SAV (***Figure 4-21***). The benthic habitat surveys were conducted February through March 2010; therefore, rhizomes were predominant rather than blades. Oyster reefs were the secondary habitat type (1.9 percent) found within the survey boundary. Approximately 27.2 percent of the area was identified as containing benthic habitat.

Lake Worth Lagoon

Eight substrate classification types, totaling over 2,490 acres, exist within the survey boundaries of the Lake Worth Lagoon (***Figure 4-22***). These substrate classes range from thin muck (less than 1.0 foot) to silty sand with sand/shell, of which thin muck composes approximately 31 percent of the total substrate within the survey area, followed by sand and thick muck (greater than 1.0 foot) (30 and 6 percent, relatively).

In surveys conducted in October 2010 and March 2011, SAV was identified within 498 acres, or 14.5 percent, of the 2,619-acre survey area (***Figure 4-23***). Oyster reefs were documented as secondary habitat type (0.3 percent) and totaled 7 acres of the survey area. Approximately 15 percent of the survey area was identified as containing benthic habitat.

Caloosahatchee River Estuary

Twelve substrate classification types, totaling over 22,820 acres, exist within the survey boundaries of Caloosahatchee River Estuary (***Figures 4-24*** through ***4-27***). These substrate classes range from sand to sand/rock, of which sand composes approximately 42 percent of the total substrate within the survey area, followed by silty sand and silty sand with sand/shell (18 and 15 percent, respectively).

In surveys conducted in March–April 2010, SAV was identified within 3,119 acres, or 13.6 percent, of the 22,844-acre survey area (***Figures 4-28*** through ***4-31***). Oyster reefs were documented as secondary habitat type (3.7 percent) and totaled 847 acres of the survey area. Approximately 17.3 percent of the 3,119 acres was identified as containing benthic habitat.

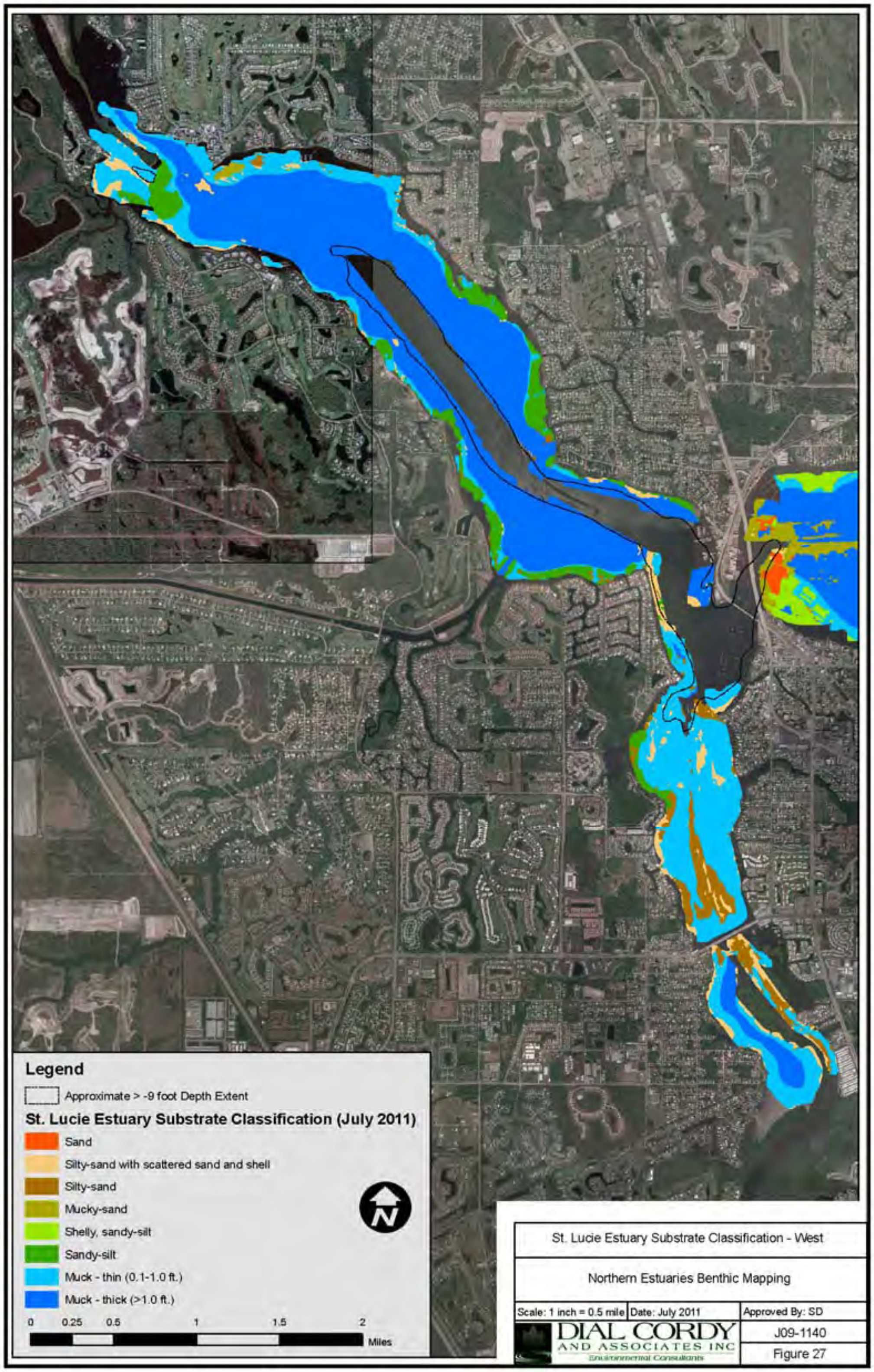


FIGURE 4-16. BENTHIC SUBSTRATE CLASSIFICATION OF THE WESTERN PORTION OF THE ST. LUCIE ESTUARY.

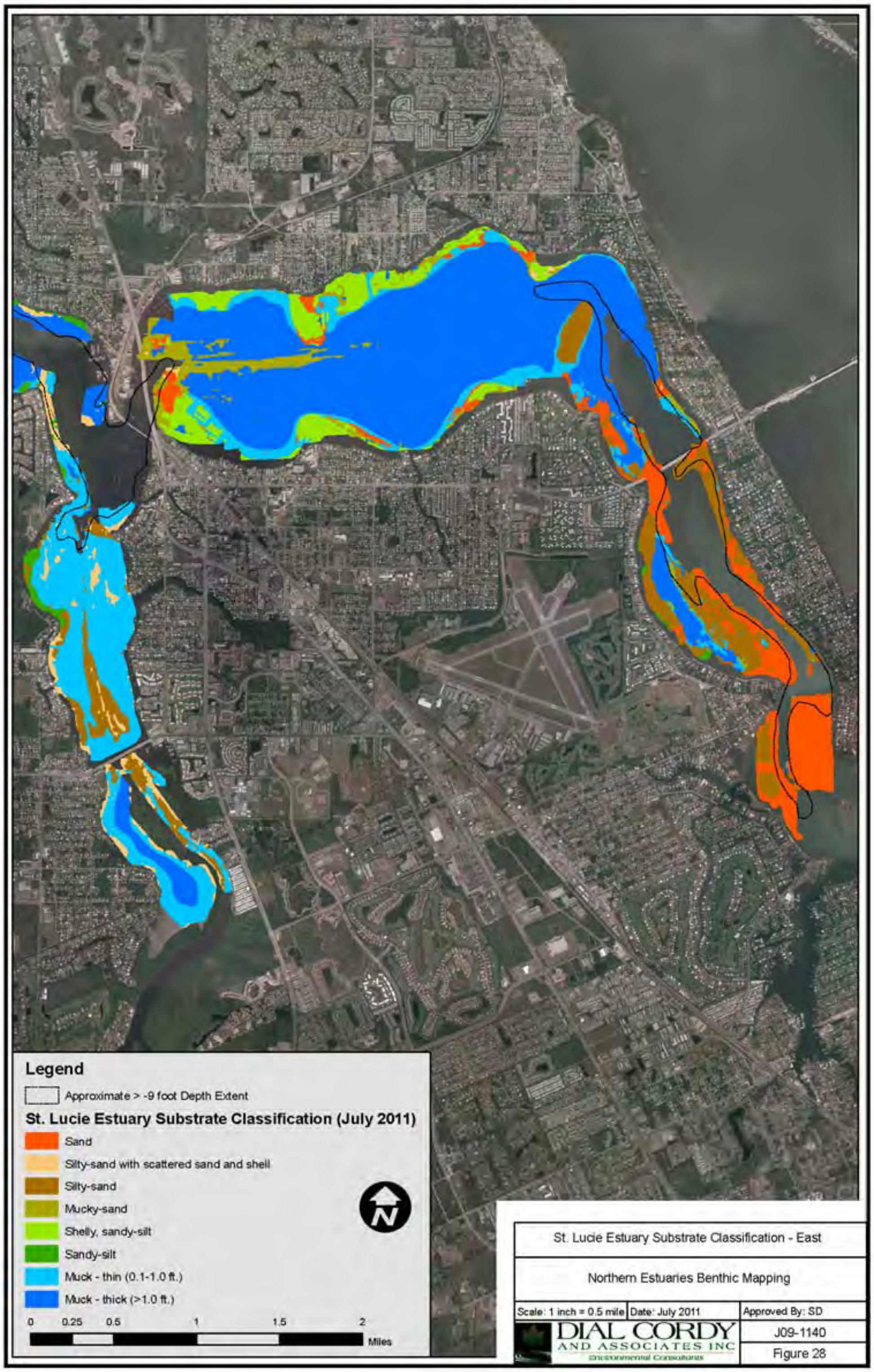


FIGURE 4-17. BENTHIC SUBSTRATE CLASSIFICATION OF THE EASTERN PORTION OF THE ST. LUCIE ESTUARY.

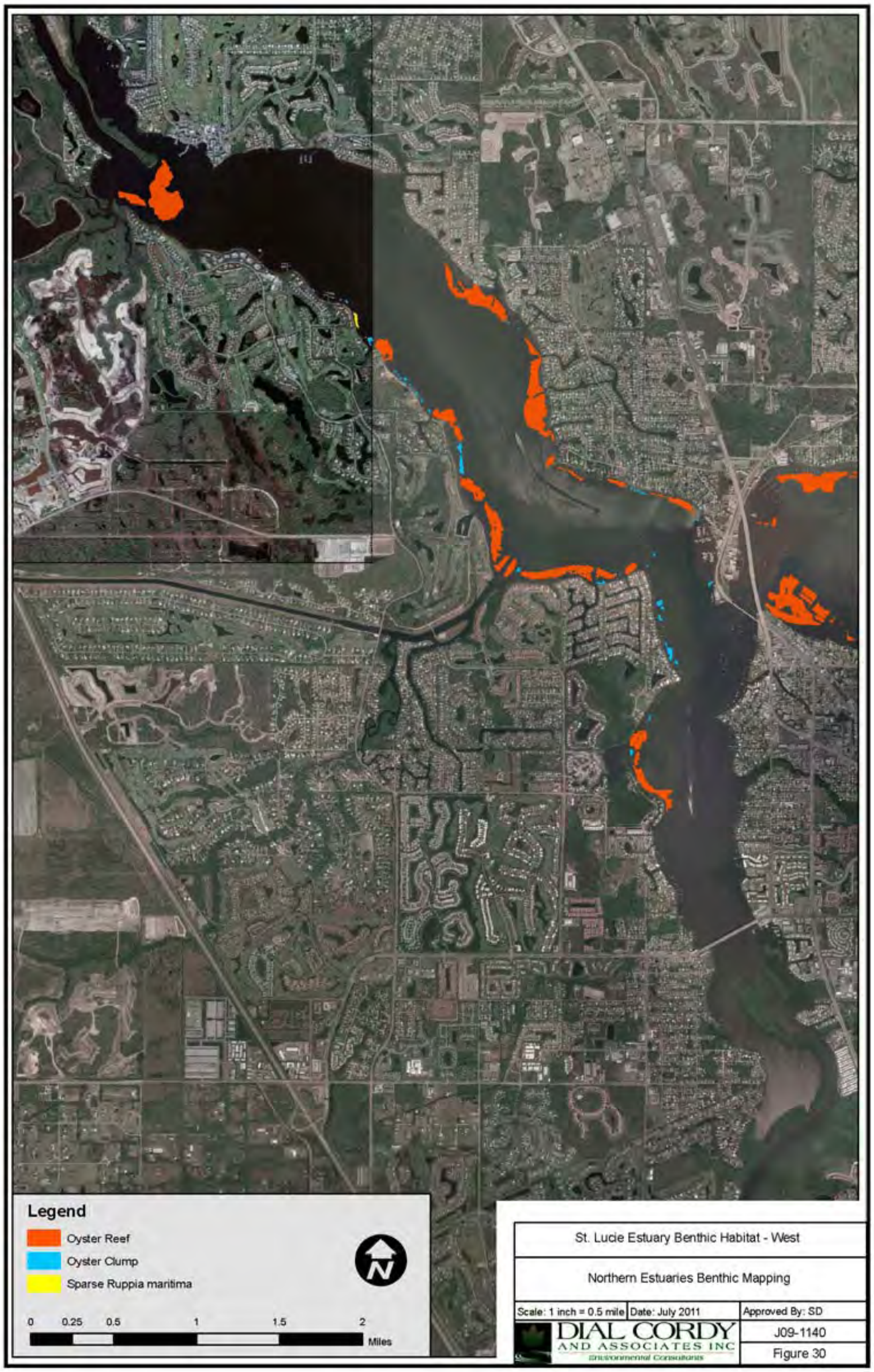


FIGURE 4-18. OYSTER AND SEAGRASS HABITAT WITHIN THE WESTERN PORTION OF THE ST. LUCIE ESTUARY.

FIGURE 4-19. OYSTER AND SEAGRASS HABITAT WITHIN THE EASTERN PORTION OF THE ST. LUCIE ESTUARY.

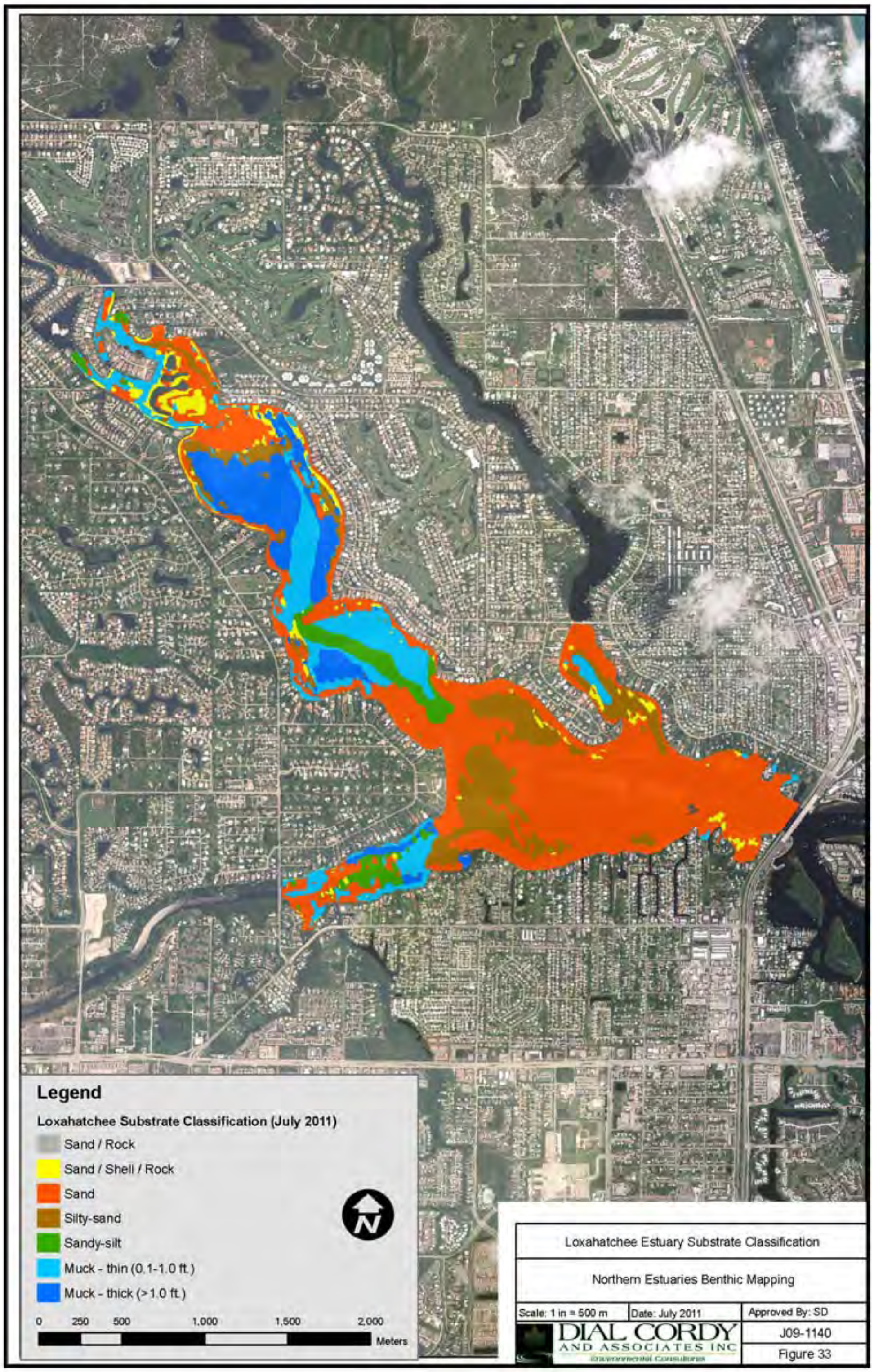


FIGURE 4-20. BENTHIC SUBSTRATE CLASSIFICATION OF THE LOXAHATCHEE RIVER ESTUARY.

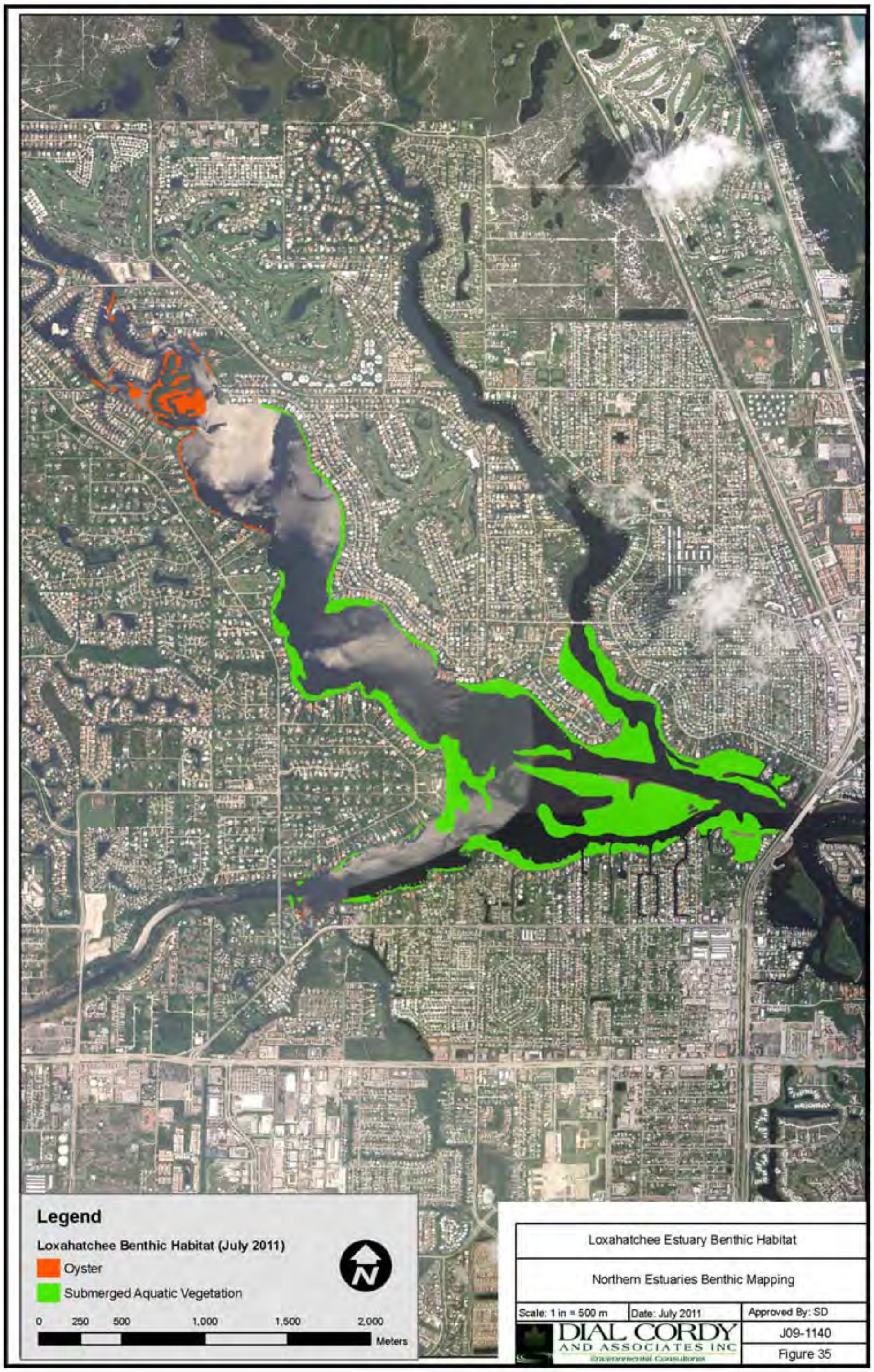


FIGURE 4-21. OYSTER AND SEAGRASS HABITAT WITHIN THE LOXAHATCHEE RIVER ESTUARY.

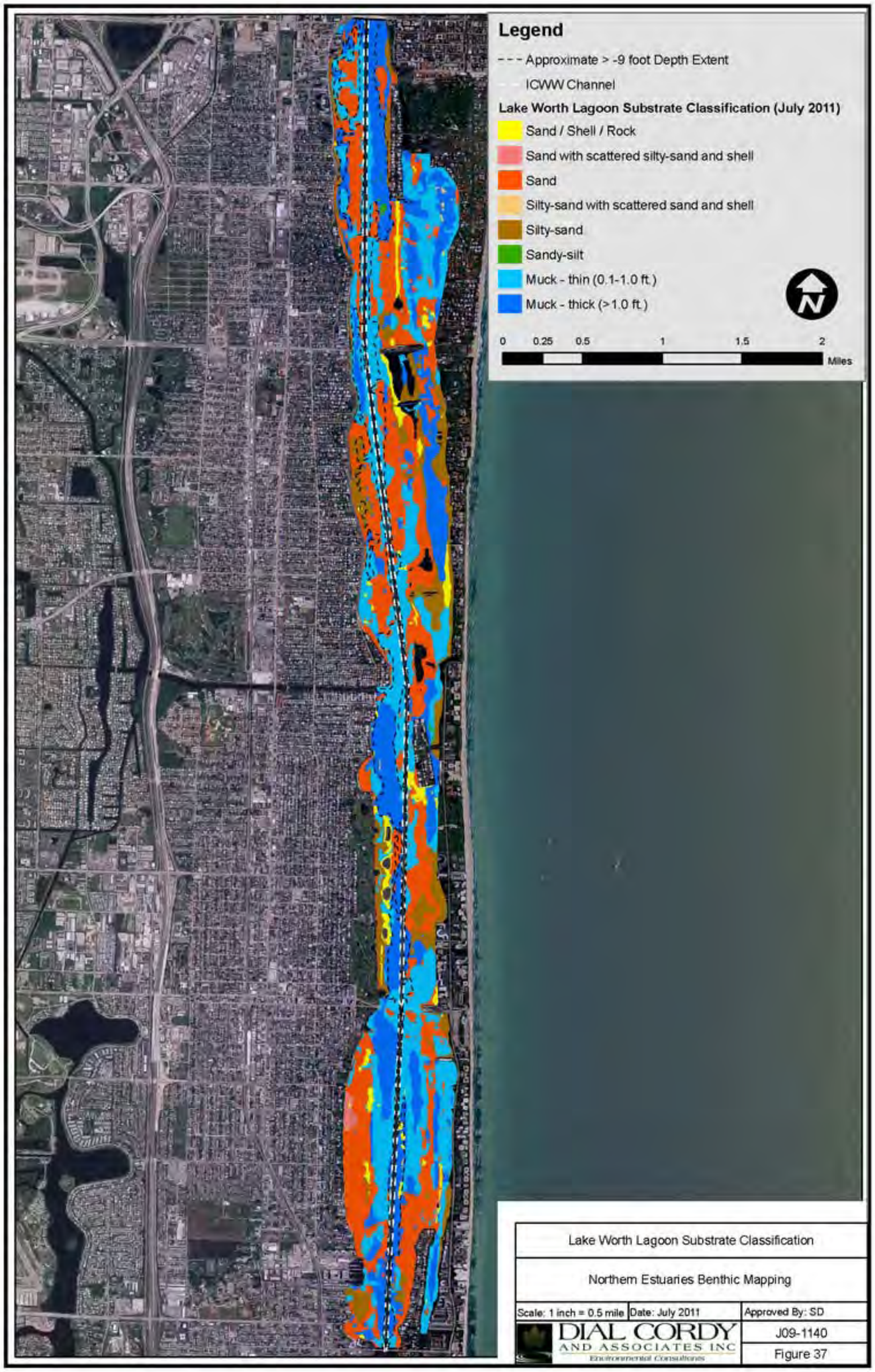


FIGURE 4-22. BENTHIC SUBSTRATE CLASSIFICATION OF LAKE WORTH LAGOON.

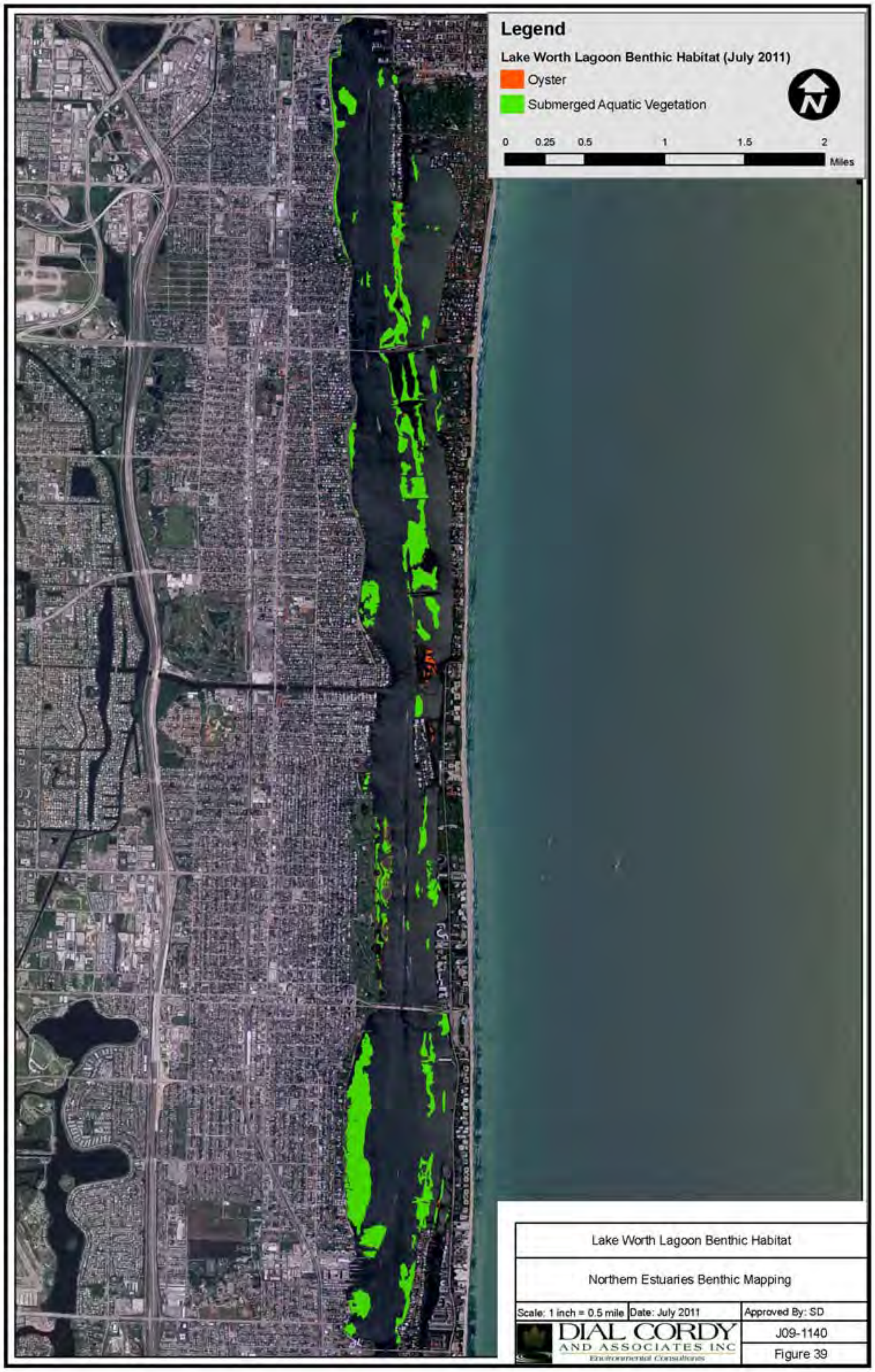


FIGURE 4-23. OYSTER AND SEAGRASS HABITAT WITHIN LAKE WORTH LAGOON.

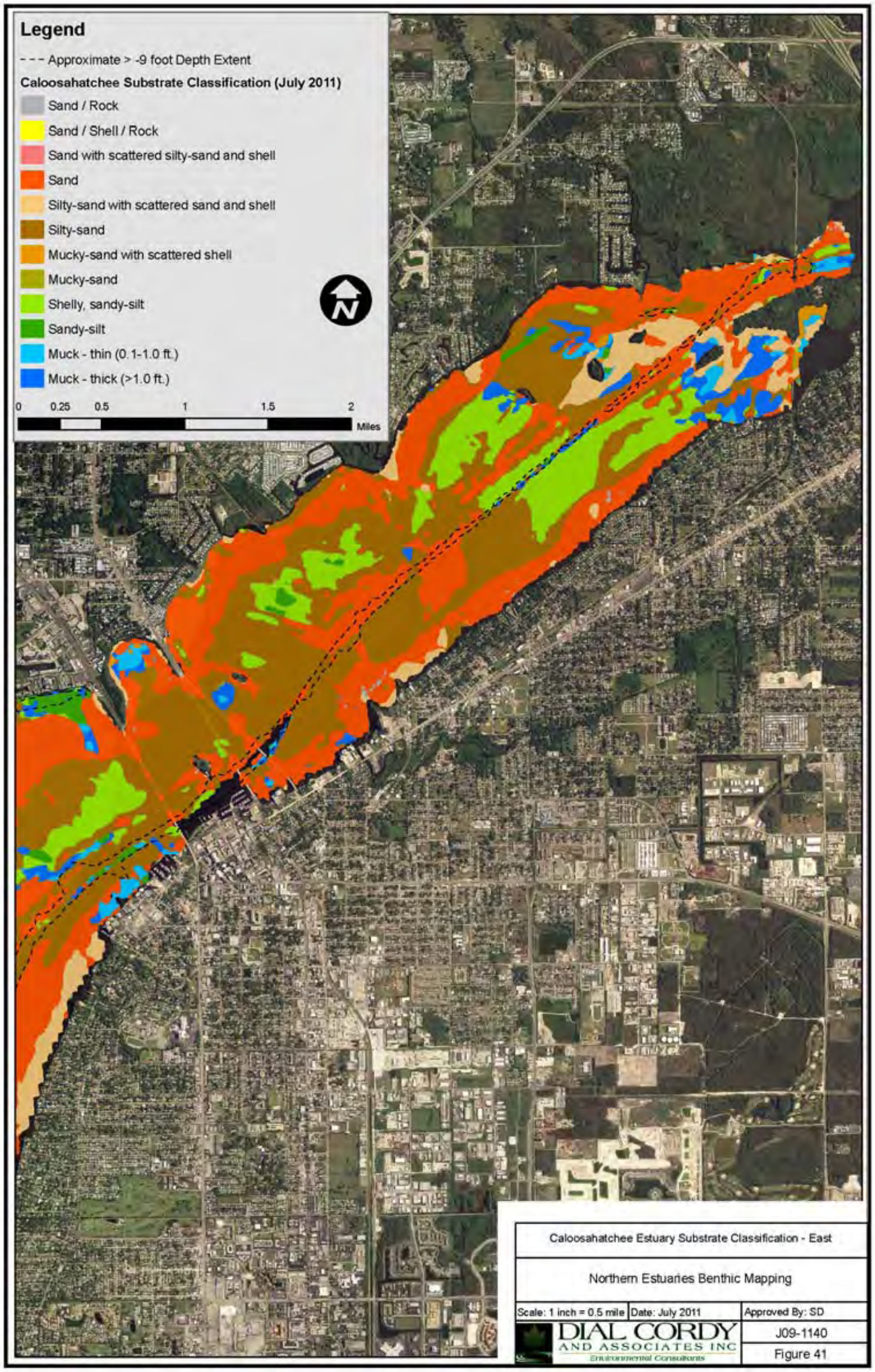


FIGURE 4-24. BENTHIC SUBSTRATE CLASSIFICATION OF THE UPPER PORTION OF THE CALOOSAHATCHEE RIVER ESTUARY.

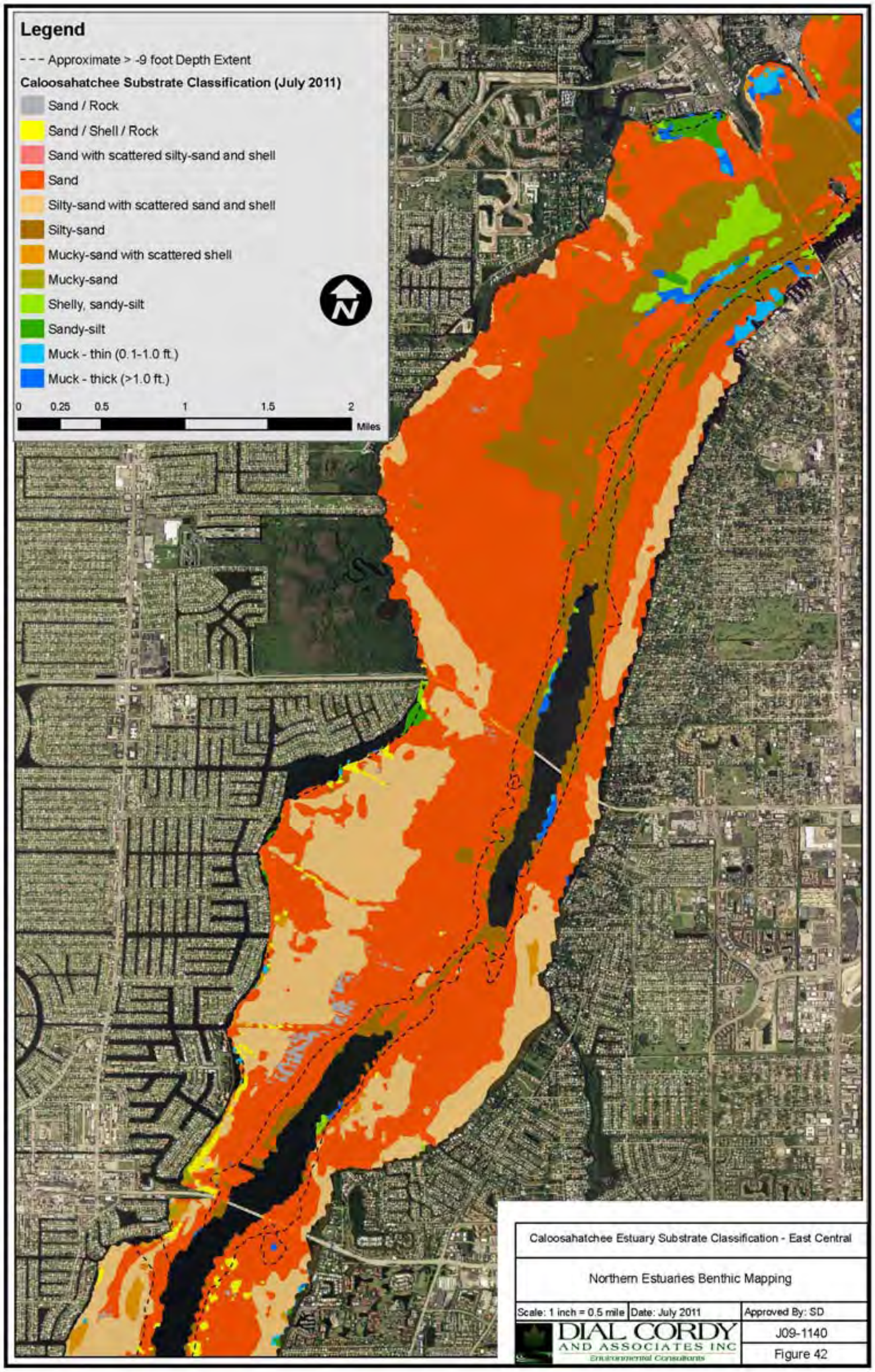


FIGURE 4-25. BENTHIC SUBSTRATE CLASSIFICATION OF THE MIDDLE PORTION OF THE CALOOSAHATCHEE RIVER ESTUARY.

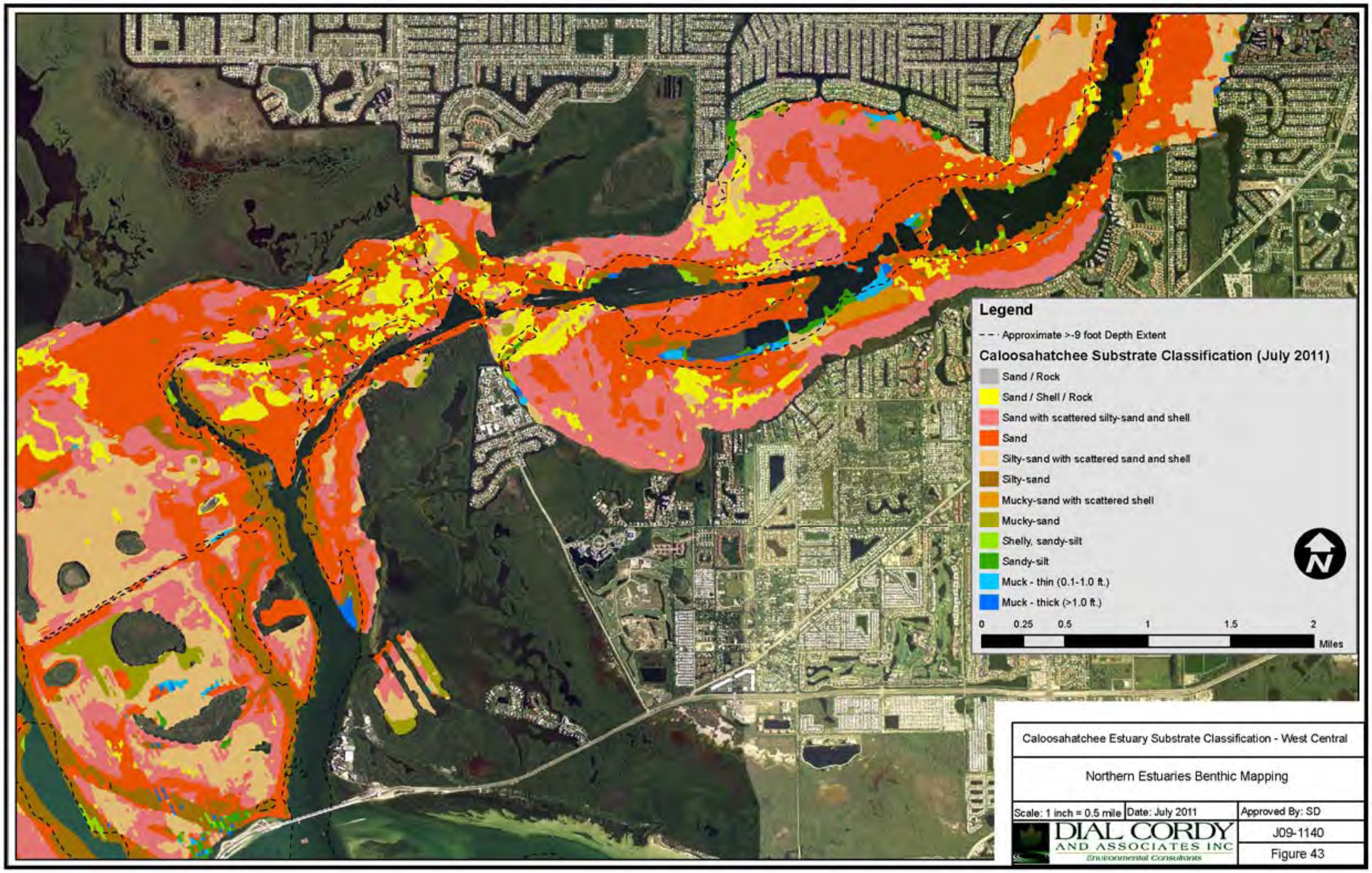


FIGURE 4-26. BENTHIC SUBSTRATE CLASSIFICATION OF THE LOWER PORTION OF THE CALOOSAHATCHEE RIVER ESTUARY.

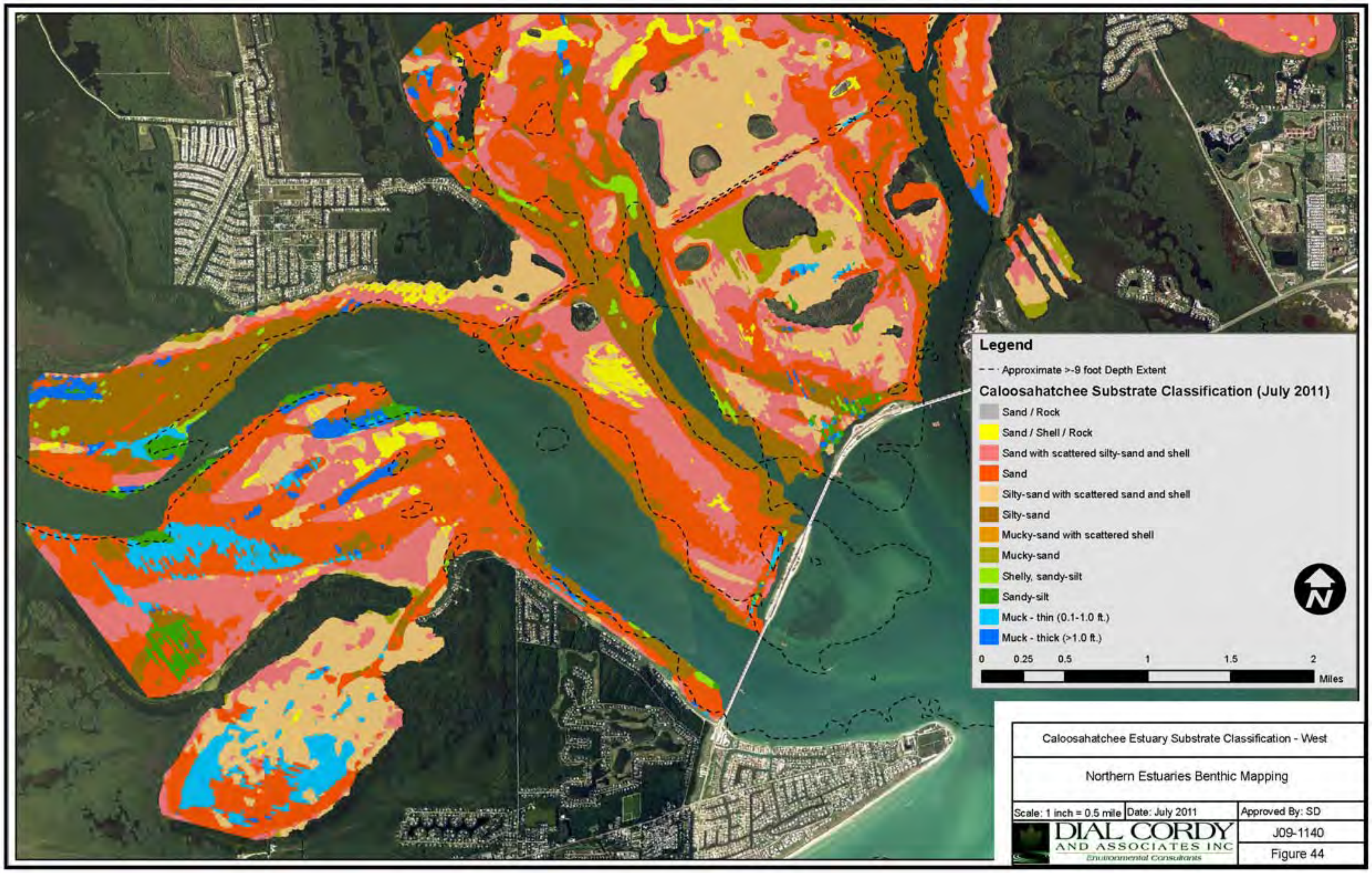


FIGURE 4-27. BENTHIC SUBSTRATE CLASSIFICATION OF THE LOWEST PORTION OF THE CALOOSAHATCHEE RIVER ESTUARY.

FIGURE 4-28. OYSTER AND SEAGRASS HABITAT WITHIN THE UPPER PORTION OF THE CALOOSAHATCHEE RIVER ESTUARY.

FIGURE 4-29. OYSTER AND SEAGRASS HABITAT WITHIN THE MIDDLE PORTION OF THE CALOOSAHATCHEE RIVER ESTUARY.

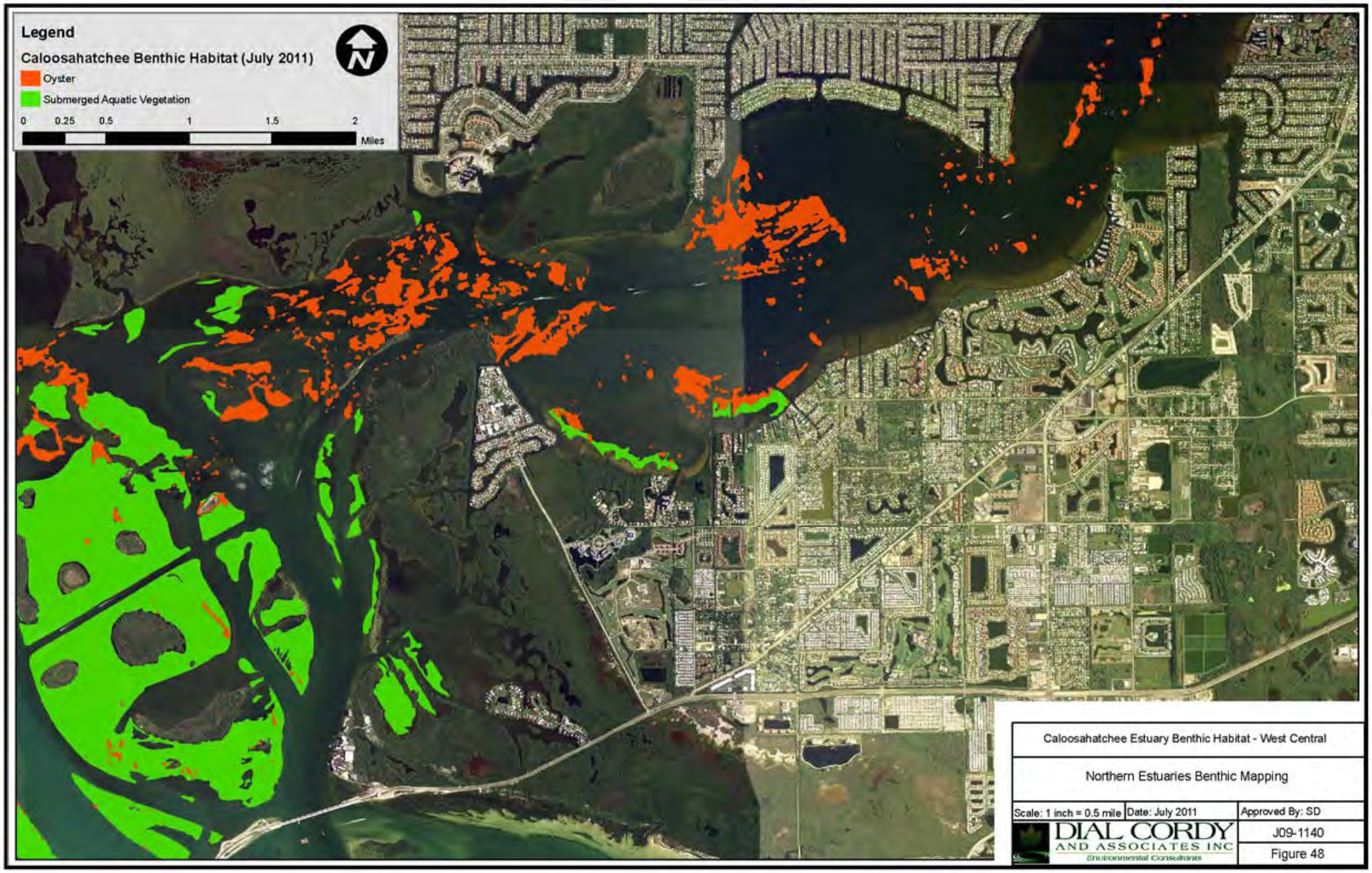


FIGURE 4-30. OYSTER AND SEAGRASS HABITAT WITHIN THE LOWER PORTION OF THE CALOOSAHATCHEE RIVER ESTUARY.

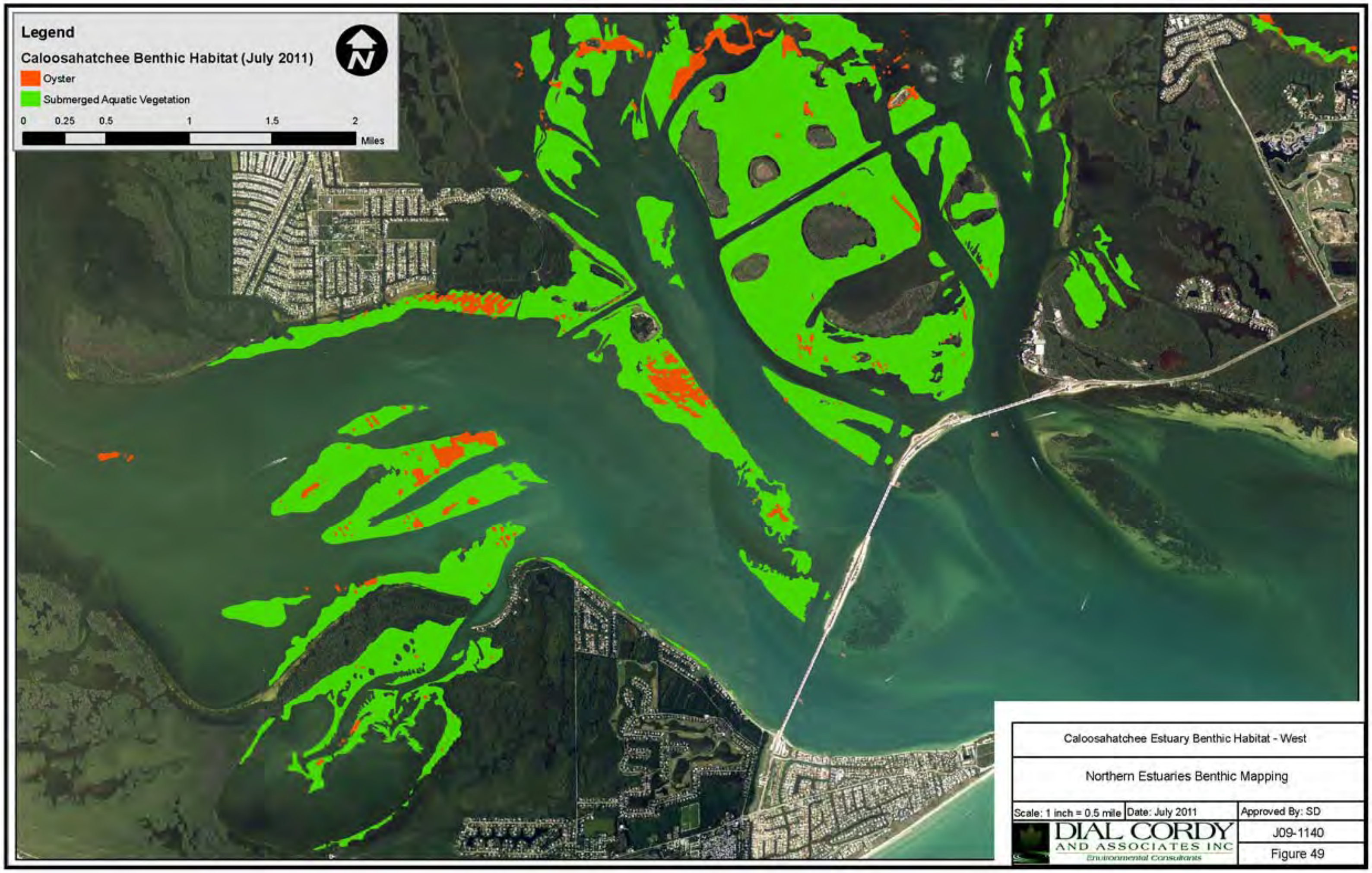


FIGURE 4-31. OYSTER AND SEAGRASS HABITAT WITHIN THE LOWEST PORTION OF THE CALOOSAHATCHEE RIVER ESTUARY.

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Volety, A.K., M. Savarese, G. Tolley, P. Sime, P. Goodman and P. Doering. 2009. Eastern oysters (*Crassostrea virginica*) as an indicator for restoration of Everglades Ecosystems. *Ecological Indicators* 9:S120-S136. DOI:10.1016/j.ecolind.2008.06.005.

CHAPTER 5

GREATER EVERGLADES MODULE

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CHAPTER 5 GREATER EVERGLADES MODULE

INTRODUCTION

For the 2012 System Status Report (SSR), updates are provided for landscape patterns and predator-prey relationships. For additional information on the Greater Everglades see the 2009 SSR (RECOVER, 2010) at http://www.evergladesplan.org/pm/ssr_2009/mod_ge.aspx. A full assessment of the Greater Everglades will be provided in the 2014 SSR.

LANDSCAPE PATTERNS

Introduction

In this section, updates are provided for several aspects of Greater Everglades landscape patterns. These include (1) a discussion of the effectiveness of vegetation classification using satellite data, (2) the status of tree islands in Shark River Slough from 1952 through 2004, (3) tree islands–marsh hydrologic interactions, (4) fire and flooding in the eastern Everglades focusing on the responses to the Mustang Corner fire in 2008, and (5) ridge-slough maintenance and degradation across the landscape. For more information on Greater Everglades landscape patterns, please see http://www.evergladesplan.org/pm/ssr_2009/hc_ge_gelp_results.aspx.

Effectiveness of Greater Everglades Vegetation Classification Using WorldView 2 Satellite Data

In order to map and monitor changes in Greater Everglades vegetation, the use of remote sensing to detect and map Everglades wetland plant communities was evaluated at different scales. Map products were compared, delineated, and resampled at various scales with the intent to quantify and describe the quantitative and qualitative differences between such products.

Methods

Digital Globe's WorldView 2 (WV2) data with a spatial resolution of 2 meters (m) and 30-m Landsat Thematic Mapper data were evaluated for effectiveness in mapping wetland plant communities. Two recursive partitioning algorithms (non-parametric multivariate classification methods)—single tree (cTree) versus multiple tree (randomForest)—were applied to atmospherically corrected bi-seasonal images, and, in the case of WV2 data, local texture variables (variance for a 3-by-3 kernel). Performance of the methods was evaluated utilizing two metrics: (1) model-based accuracy estimates of the classification procedures; and (2) design-based post-classification accuracy estimates of derived maps. To investigate the scalability of plant community maps generated with remote sensing methods, we evaluated scaling using hierarchical thematic aggregation and grid-based versus morphological spatial aggregation by comparing the number of classes detected and percent cover differences. The study area was comprised of three subregions covering ridge and slough landscape in Water Conservation Area (WCA) 3A, and two areas of wet prairie, sawgrass, and tree island mosaic located in WCA 3B and Northeastern Shark River Slough within Everglades National Park (***Figure 5-1***).

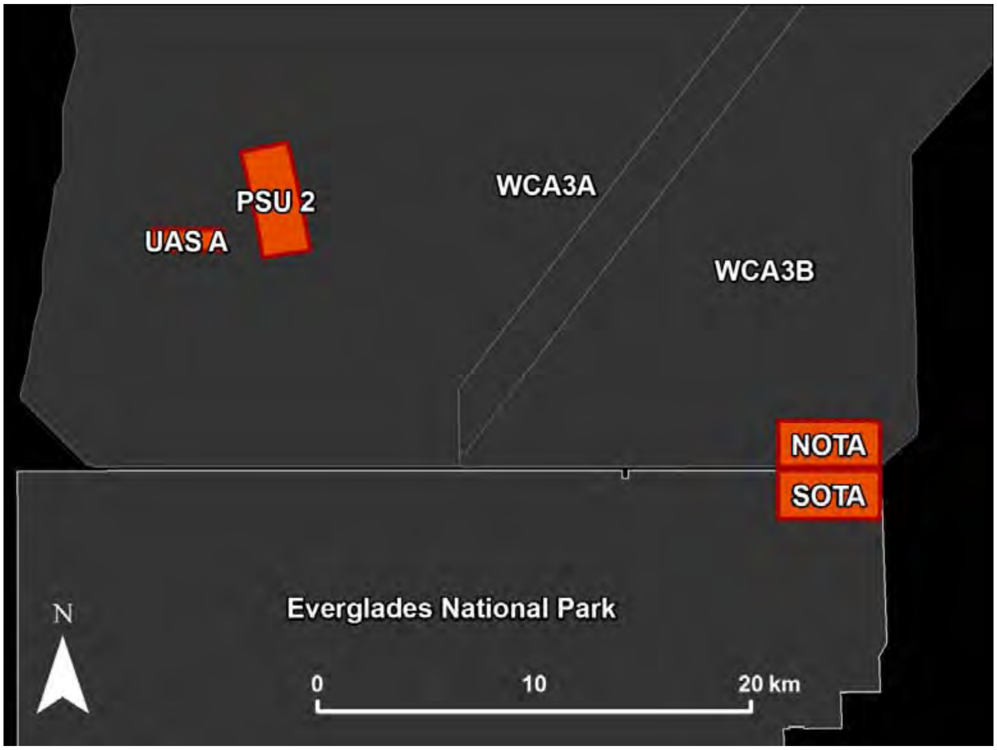

FIGURE 5-1. STUDY AREAS IN WCA 3A (PSU2 AND UAS A), WCA 3B (NOTA), AND EVERGLADES NATIONAL PARK (SOTA).

Results and Conclusion

In general, accuracy was highest when pixels were classified at the community class level using the random forest classification method applied to bi-seasonal imagery including texture variables (***Figure 5-2***, which shows 1 of 3 mapped subareas) and then aggregating to the structural level. Maps derived from WV2 data displayed high overall model-based accuracy of 95.6 percent (Kappa = 92.9 percent) and a design-based accuracy of 90.4 percent (Kappa = 87.45 percent) when classified at the community structural level. Plant community accuracies, which are of interest for conservation and maintenance of landscape pattern, achieved model-based accuracies of 99.6 percent for wet prairies, 99.5 percent for sloughs, and 86.1 to 89.6 percent for tall graminoids, which were primarily sawgrass. In addition to accurately classifying vegetation, the WV2 data provided fine-scale maps of plant communities with high spatial precision of boundaries (2 m) that reflected actual landscape morphology and class distributions. In comparison, Landsat derived maps had a model-based accuracy of 97.2 percent (Kappa = 96.1 percent) and a design-based accuracy of 83.8 percent (Kappa = 68 percent). Landsat derived maps preserved the general landscape morphology seen in the WV2 maps but lacked the degree of patchiness and community interspersion seen in the WV2 images (***Figure 5-3***). Small classes with relatively isolated extents, such as the high heads of tree islands, were lost in Landsat derived maps.

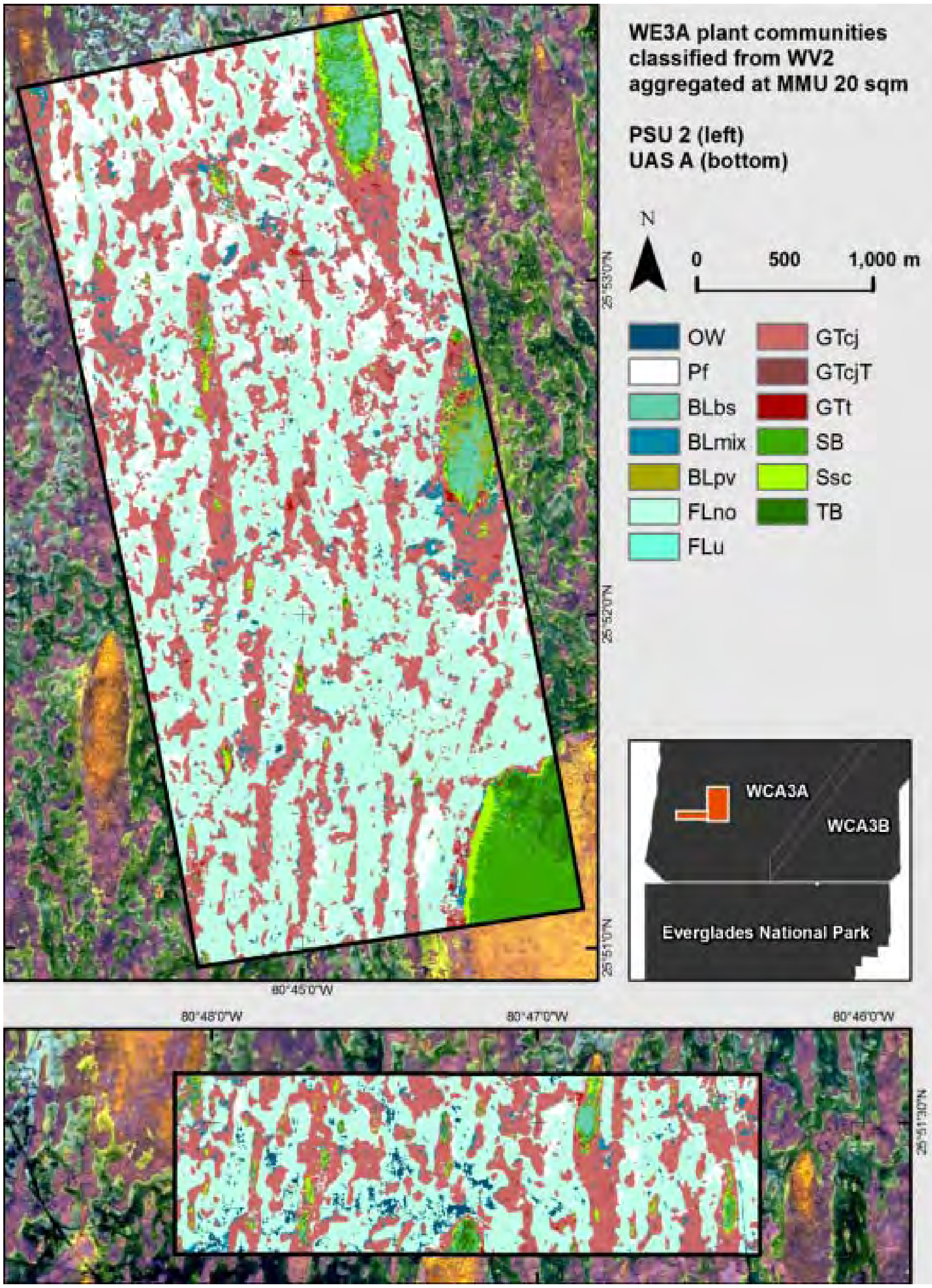

FIGURE 5-2. VEGETATION CLASSIFICATION FROM WV2 AT THE COMMUNITY CLASS LEVEL AND AGGREGATED AT 20 SQUARE METERS (M^2) FOR THE WCA 3A SUBREGIONS.

Classes: OW – Open Water; Pf – Floating Periphyton; BLbs – Broad-Leaved *Blechnum serrulatum*; BLmix – Broad-Leaved Mix; BLpv – Broad-Leaved *Peltandra virginica*; FLno – Floating-Leaved *Nymphaea odorata*; FLu – Floating-Leaved *Utricularia*; GTcj – Graminoid *Cladium jamaicense*; GTcjT – Tall Graminoid *Cladium jamaicense*; GTt – Tall Graminoid *Typha*; SB – Bayhead Shrub; Ssc – Shrub *Salix caroliniana*; and TB – Bayhead Tree.

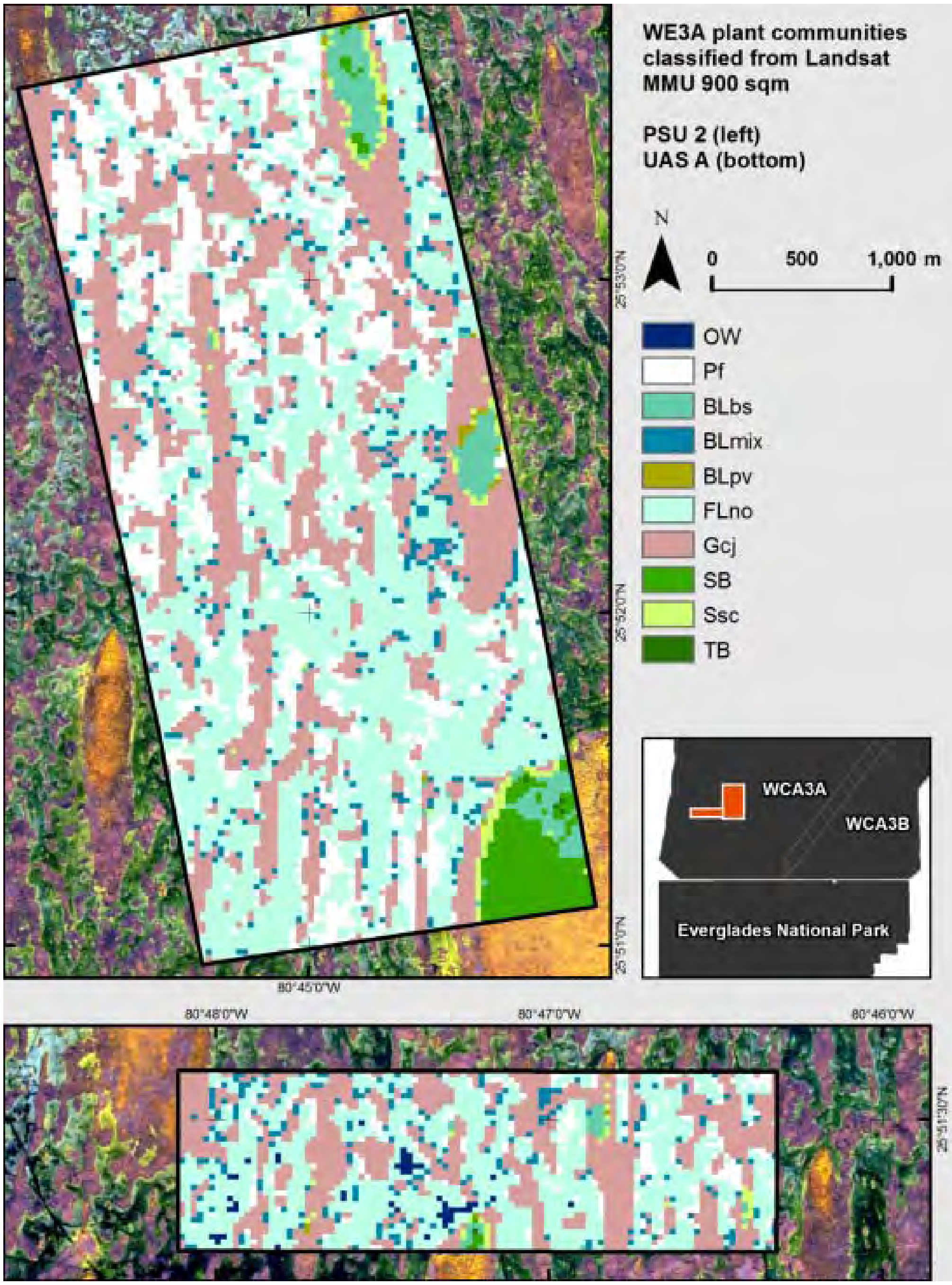

FIGURE 5-3. VEGETATION CLASSIFICATION RESULT FOR LANDSAT DATA FOR THE WCA 3A SUBREGIONS.

Classes: OW – Open Water; Pf – Floating Periphyton; BLbs – Broad-Leaved *Blechnum serrulatum*; BLmix – Broad-Leaved Mix; BLpv – Broad-Leaved *Peltandra virginica*; FLno – Floating-Leaved *Nymphaea odorata*; FLu – Floating-Leaved *Utricularia*; GTcj – Graminoid *Cladium jamaicense*; GTcjT – Tall Graminoid *Cladium jamaicense*; GTt – Tall Graminoid *Typha*; SB – Bayhead Shrub; Ssc – Shrub *Salix caroliniana*; and TB – Bayhead Tree.

Aggregating WV2 pixels to 900 square meters (m^2) (Landsat resolution) using morphological and grid-based aggregation and comparing the aggregate results and Landsat classified maps to WV2 classified map results revealed that differences in percent cover change were minor for wet prairie (-18.2, -17.1, -21.2), slough (2.5, 4.6, -0.7), and tall graminoids (6.3, 6.1, 0.9) in percent for morphological, grid-based and Landsat classified, respectively) (***Table 5-1***). The two classes that displayed most discrepancies were broad-leaved (51.0, -40.3 percent) and tree islands (-16.7, -70.9 percent), where percent change difference was large between Landsat classified classes versus classes morphologically aggregated at 900 m^2 (***Table 5-1***). Grid-based aggregation preserved the location and spatial distribution of large landscape classes better than Landsat classified maps, but compared to morphological aggregation results, the landscape shapes were pixelated (***Figure 5-4***) and some classes at the community class levels were lost entirely (diversity change: morphological = 0 percent, grid-based = -4.8 percent, and classified = -19 percent).

TABLE 5-1. COMPARISON OF AREAL COVERAGE AND PERCENT COVERAGE CHANGES FOR PLANT COMMUNITY STRUCTURE MAPS DERIVED FROM WV2 IMAGES WHEN COMPARED TO MORPHOLOGICAL AND GRID-BASED AGGREGATION RESULTS AT THE RESOLUTION OF LANDSAT DERIVED MAPS (900 M^2).

Reported results are summarized for all three subregions of the study area (see ***Figure 5-1***).

	Area in Square Kilometers				Percent Change Compared to WV2 Classified		
Community Structure	**WV2 Classified & Filtered (20 m^2)**	**Morphological Aggregation (900 m^2)**	**Grid-based Aggregation (900 m^2)**	**Landsat Classified (900 m^2)**	**Morphological Aggregation (900 m^2)**	**Grid-based Aggregation (900 m^2)**	**Landsat Classified (900 m^2)**
Broad Leaf	4.8	2.8	2.9	7.2	-40.3	-38.4	51.0
Tall Graminoids	53.2	56.6	56.5	53.7	6.3	6.1	0.9
Shrub	6.2	6.3	6.3	5.9	1.5	1.5	-4.6
Slough	23.5	24.0	24.5	23.3	2.5	4.6	-0.7
Tree Island	0.4	0.3	0.4	0.1	-16.7	-15.3	-70.9
Wet Prairie	12.0	9.9	9.4	9.8	-17.1	-21.2	-18.2

A promising result of this study is the potential to use the methodology developed here to monitor landscape changes in response to management decisions. WV2 maps preserved the shapes of landscape features at a high precision even when the minimum mapping unit was increased using the morphological aggregation algorithms. Understanding these differential scaling effects for different plant communities allows for a more insightful use of map products that are generated at different resolutions.

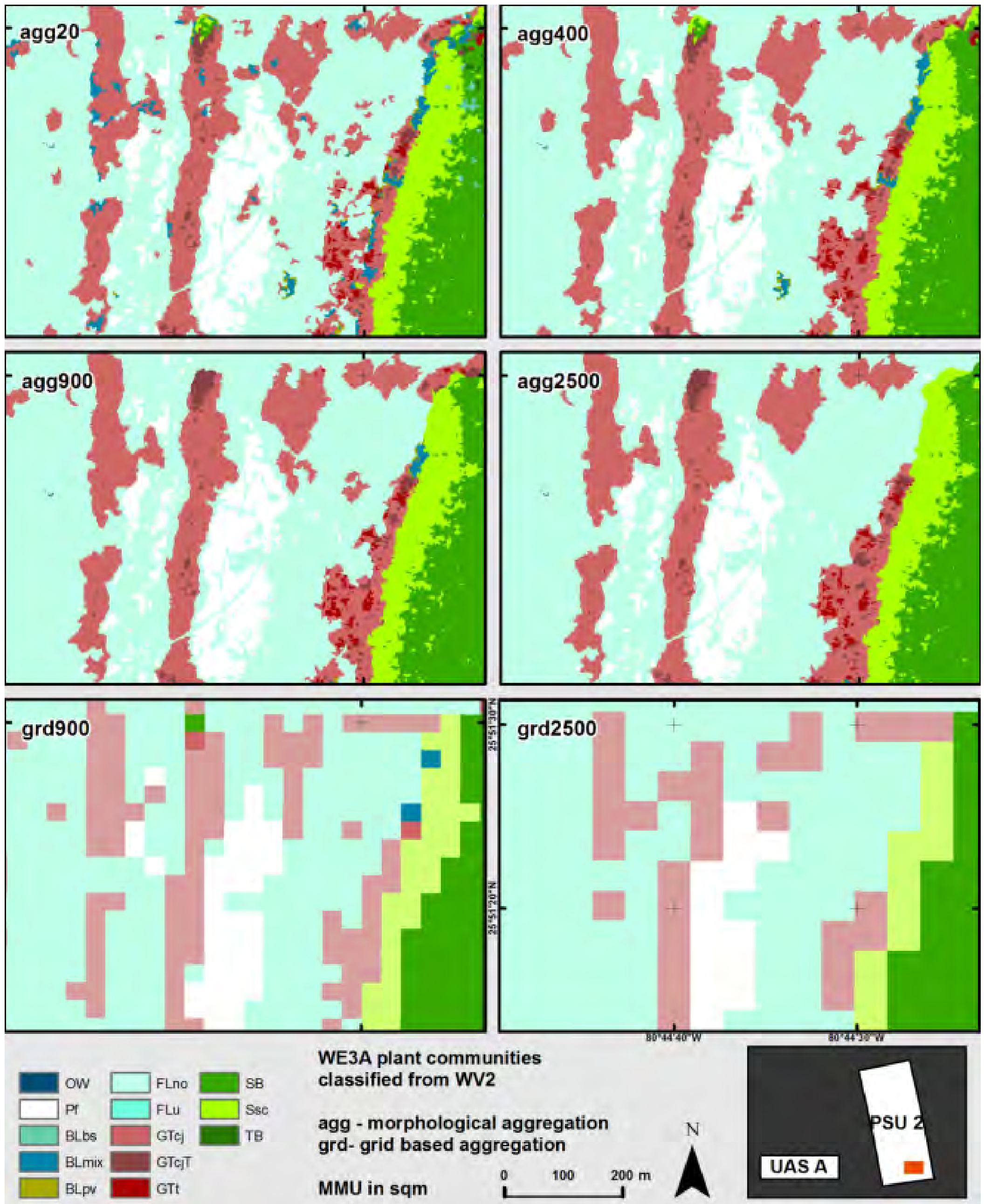

FIGURE 5-4. COMPARISON OF MORPHOLOGICAL AGGREGATION METHOD AT 20, 400, 900, AND 2,500 M^2 AND GRID-BASED AGGREGATION AT 900 M^2 (MMU EQUIVALENT TO LANDSAT PIXELS) AND 2,500 M^2 (MMU EQUIVALENT TO COMPREHENSIVE EVERGLADES RESTORATION PLAN [CERP] GRIDS) IN A WCA 3A SUBREGION.

Classes: OW – Open Water; Pf – Floating Periphyton; BLbs – Broad-Leaved *Blechnum serrulatum*; BLmix – Broad-Leaved Mix; BLpv – Broad-Leaved *Peltandra virginica*; FLno – Floating-Leaved *Nymphaea odorata*; FLu – Floating-Leaved *Utricularia*; GTcj – Graminoid *Cladium jamaicense*; GTcjT – Tall Graminoid *Cladium jamaicense*; GTt – Tall Graminoid *Typha*; SB – Bayhead Shrub; Ssc – Shrub *Salix caroliniana*; and TB – Bayhead Tree.

Areal Coverage of Tree Island Habitat in Shark River Slough 1952–2004

Tree islands were mapped within Shark River Slough within Everglades National Park for each decade from the 1950s through the turn of the century. The mapping was accomplished through stereoscopic analyses of historic aerial photography for the years 1952, 1960/1964, 1973, 1984, 1995, and 2004. The aerial photography consisted of panchromatic and false color infrared film products that were recovered from the archival records of the United States Department of Agriculture, United States Geological Survey, and National Archives. All historic film products were subsequently digitized and geo-referenced to provide a four-dimensional view of the Everglades' landscape, including three dimensions of space and a fourth dimension of time.

Tree islands were defined and mapped from the multi-dimensional imagery in accordance with the following specifications:

- A contiguous area demonstrating 10 percent or greater areal coverage of trees and shrubs.
- The area of trees and shrubs must demonstrate a tapered and compact shape generally indicating the direction of hydrologic flow within the marsh.
- The area of trees and shrubs must not be composed primarily of the invasive exotic melaleuca (*Meleleuca* spp.) species.
- The total area of trees and shrubs must be 1 hectare or greater.

These criteria were specifically designed for the mapping of tree islands, including the head and tail portions of the islands, and were intended to be exclusive of other nonisland woody landscape features such as the expansive regions of Carolina willow (*Salix caroliniana*) and pond apple (*Anonna glabra*) found adjacent to Tamiami Trail and the tidal creek forest communities located at the southernmost end of Shark River Slough.

Results of the mapping demonstrate that tree island habitat, as defined by the mapping criteria, has substantially declined in Shark River Slough and the immediately adjacent wet prairie habitats during the latter half of the twentieth century (***Figures 5-5*** and ***5-6***). The total number of tree islands greater than 1 hectare has declined by 48.4 percent from a population of 961 in 1952 to 496 in 2004. The areal coverage of tree island habitat greater than 1 hectare has declined by 54.5 percent from a total of 5,036.6 hectares in 1952 to 2,291.3 hectares in 2004. The largest single decadal decline appears to occur during the period from 1960/1964 to 1973. During this period of time, 1,095.5 hectares or 23.3 percent of the 1960s era tree island habitat was lost. Each era demonstrates some increase in tree island habitat. On average, 162.9 hectares of island habitat was added per decade. However, modest regional increases during the period did not outpace declining habitat elsewhere in Shark River Slough. In addition, increases in tree island habitat appear to be primarily related to the expansion of Carolina willow and cypress (*Taxodium* spp.) species while declining habitat appears to be primarily associated with bayhead communities.

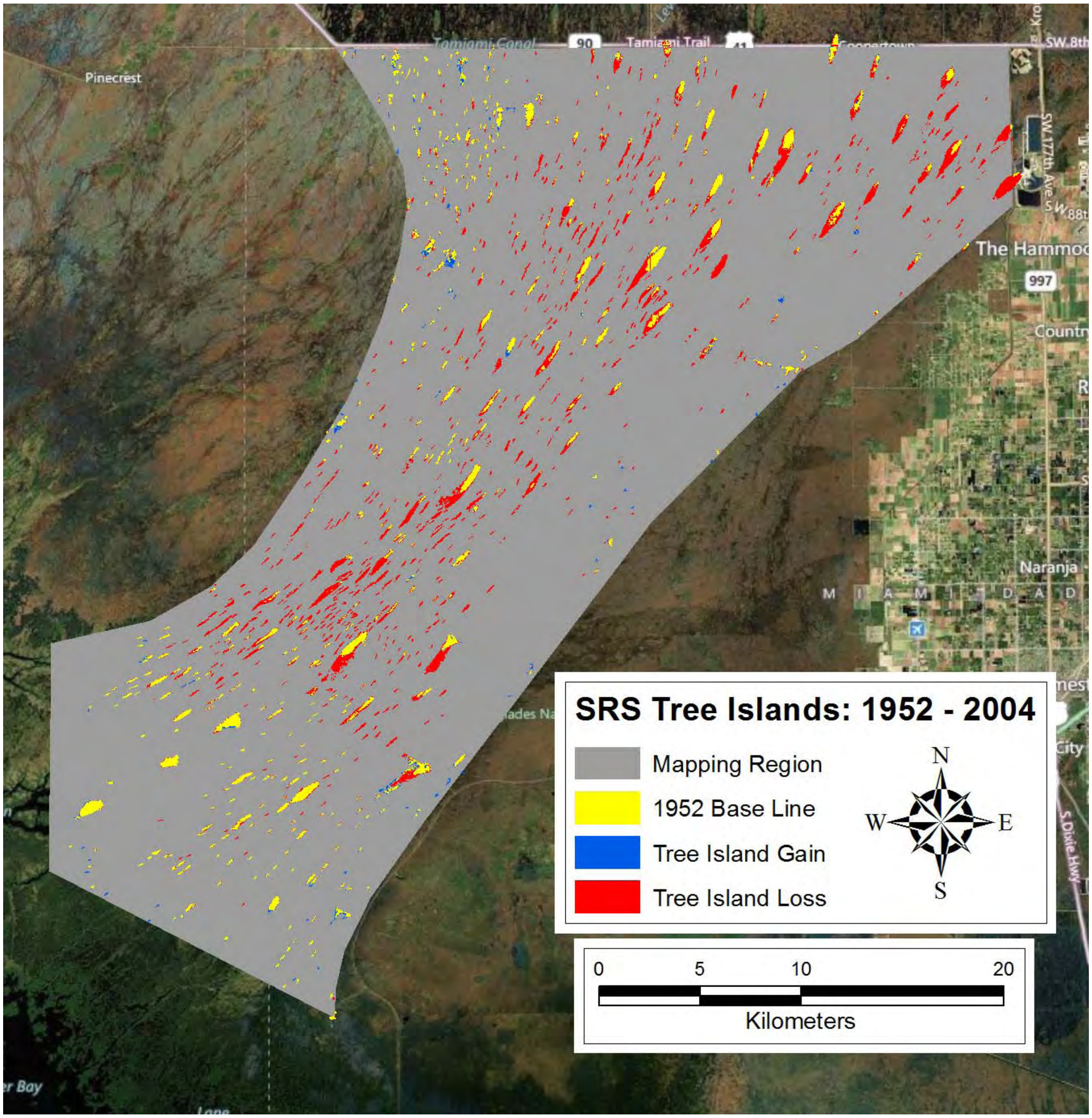

FIGURE 5-5. TREE ISLANDS WITHIN SHARK RIVER SLOUGH FOR THE PERIOD FROM 1952 THROUGH 2004.

Grey regions of the map indicate the extents of the tree island mapping and the locations for which no tree islands were recorded for the period. Yellow regions of the map indicate islands that were present in 1952 and remain on the landscape in 2004. Blue regions of the map indicate an expansion of tree island communities over the period. Red regions of the map indicate lost tree island habitat during the period.

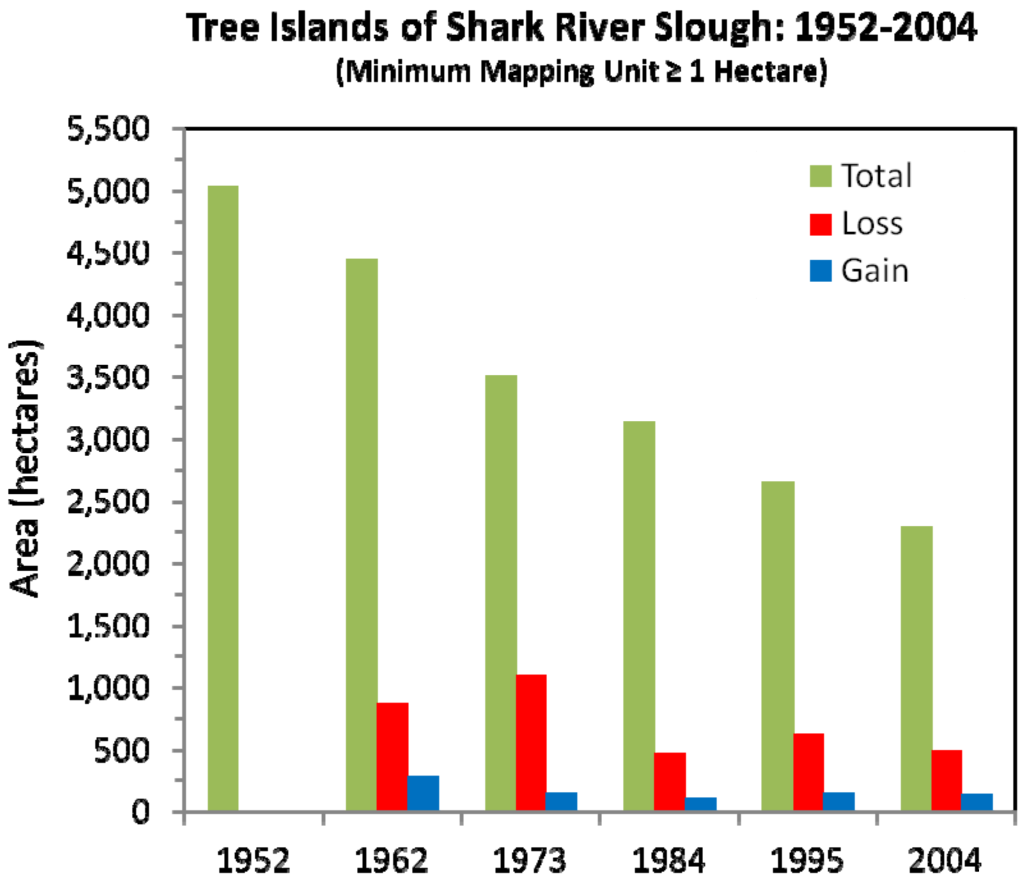

FIGURE 5-6. BAR GRAPH SHOWING THE CUMULATIVE AREA (GREEN), DECLINE (RED), AND EXPANSION (BLUE) OF TREE ISLAND HABITAT IN EACH OF THE MAPPING YEARS FROM 1952 THROUGH 2004.

The 1952 era mapping only shows the cumulative area because this era was used as the baseline condition for the analysis. The 1960s era data was compiled from aerial photography acquired in 1960 and 1964 and is presented here as the average year of 1962.

Regression modeling of the mapping data indicates that further declines in tree islands within Shark River Slough can be expected (***Figure 5-7***). By 2020, the model predicts an additional decline of 19 percent to a new population of approximately 400 tree islands greater than 1 hectare. The cumulative area of tree island habitat is expected to decline an additional 21 percent by 2020 to approximately 1,800 hectares. Some evidence speaking to the cause of the decline and to the succession of tree island habitats during this period is contained within the historic aerial photography. For example, there is ample evidence within the photography demonstrating the impacts of fire on specific tree islands. The historic photography also contains information regarding the quality of the tree island habitat (e.g., canopy height, tree density, and perhaps island type). Documentation of this additional information is necessary to better understand how and why tree islands have changed over the last 50 years and what might be in store for their future.

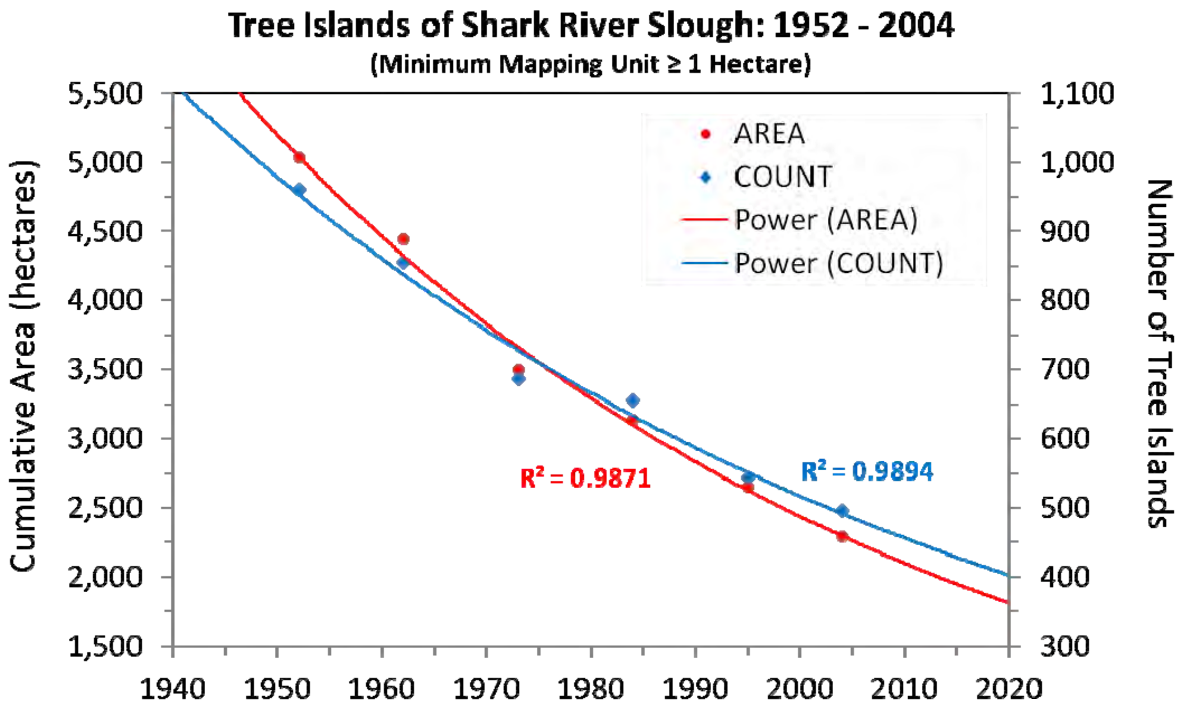

FIGURE 5-7. REGRESSION ANALYSIS OF THE RESULTS OF THE HISTORIC TREE ISLAND MAPPING INDICATES A GOOD FIT OF THE MODEL TO BOTH THE POPULATION AND AREAL COVERAGE DATA.

The total population of tree islands 1 hectare and larger is plotted as blue diamonds, is modeled by the blue regression line, and references the right-side vertical axis. The cumulative area of tree islands is plotted as red circles, modeled by the red regression line, and references the left-side vertical axis.

Tree Islands and Surrounding Marsh Eco-Hydrologic Relationship

Restoration of degraded tree islands and protection of intact tree islands are among the goals for restoring the Everglades ridge and slough ecosystem. Current restoration plans estimate changes in hydrology, including water depth, frequency, and timing of inundation, over portions of the ridge and slough ecosystem including a large number of tree islands (Sklar and van der Valk, 2002). Predicting the effects of changes in water depth and hydroperiod on tree island species composition, hydroperiod, and spatial extent, requires spatial data on topographic differences across a broad spectrum of the ridge and slough ecosystem.

Methods

To predict how changes in tree island elevation are likely to affect the depth, extent, and duration of tree island inundation and plant species composition, the field methodology calls for measuring topographic differences across a broad spectrum of tree islands and their surrounding ridge-slough ecosystem in order to estimate the effects of proposed hydrologic changes on tree islands located in WCA 3A. Predicting the effects of changes in water depth and inundation frequency on tree islands cannot be accomplished until the spatial height distribution of tree islands and their elevation relative to their surrounding marsh are better known. The processes that drive such interactions and feedbacks must be understood and quantified to ensure that management strategies are designed to conserve both the extent and spatial distribution of tree islands across the Everglades landscape.

The overall analyses presented here combine biotic and abiotic data collected at 40 tree islands throughout WCA 3A (***Figure 5-8***). The relationship between environmental parameters and plant community composition was quantified by using nonmetric multidimesional scaling (NMDS) ordination. This analysis simplifies the multiple factors that govern species distribution to a small number of independent ordination axes. The significant ordination axes are then related to measured environmental variables to identify the strongest environmental gradients that may govern species distribution. Thus NMDS explores the relationship between abiotic factors and plant community composition and investigates how the relationship between environmental factors and plant communities varies among different regions of the central Everglades.

Results and Discussion

The distribution of plant species in the NMDS species ordination space was consistent with the typical community associations found in sloughs, ridges, and tree islands of the Greater Everglades ecosystem. As reported in previous studies (Furedi and Volin, 2006; Allen and Volin, 2008), hydroperiod and other measures of hydrologic conditions were the environmental variables most significantly correlated with the ordination axes (***Figure 5-9***). Soil thickness was the only environmental variables that was significantly correlated (tau = 0.233) with axis 2. The three axes in ***Figure 5-9*** explained 57 percent of the total variation in species composition; since they are orthogonal, this suggests that soil depth is, in part, an indirect measure of an environmental gradient other than hydrology. Consistent with this finding, analyses of similar data by other authors (Givnish et al., 2008) have suggested that a combination of hydrological and nutrient gradients may be an important determinant of plant species distributions in the central Everglades.

NMDS ordination of the species data from the head plots of the 40 islands produced two significant axes, both of which were significantly correlated with hydrologic conditions and soil depth. Carolina willow was the plant species most strongly correlated with the axes of the species ordination space. NMDS ordination of environmental data from tree island heads (i.e., hydrology, soil thickness, ground surface slope, and rock surface slope) revealed interesting relationships between the environmental space and the distribution of plant species (***Figure 5-10***). Carolina willow and toothed midsorus fern (*Blechnum serrulatum*) were the two species most strongly correlated with both of the significant environmental ordination axes. Soil thickness and measures of hydrology were strongly correlated with both of the ordination axes. The strong positive correlation between hydroperiod and soil thickness could indicate that peat accumulation, along with lack of flow, may lead to a flattening of the topography in regions that do not experience regular dry downs.

The results of these analyses suggest that the processes that currently drive the interactions and feedbacks among environmental variables and plant communities may differ among regions within the central Everglades. These processes must be understood and quantified to ensure that management strategies are designed to conserve the extent and spatial distribution of tree islands across the entire landscape of the central Everglades.

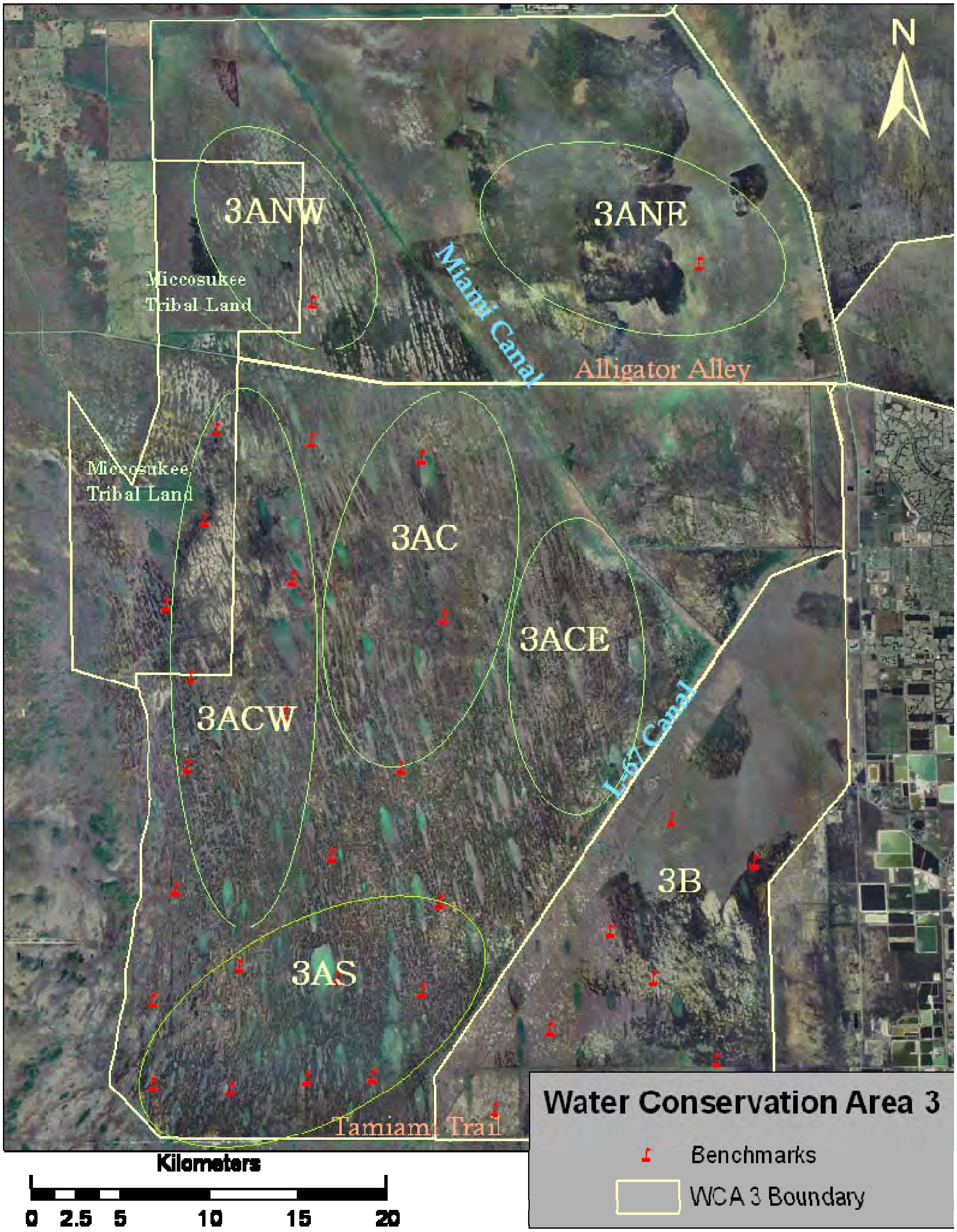

FIGURE 5-8. MAP OF THE STUDY AREA WITHIN WCA 3A WITH REGIONS OUTLINED BY GREEN OVALS.

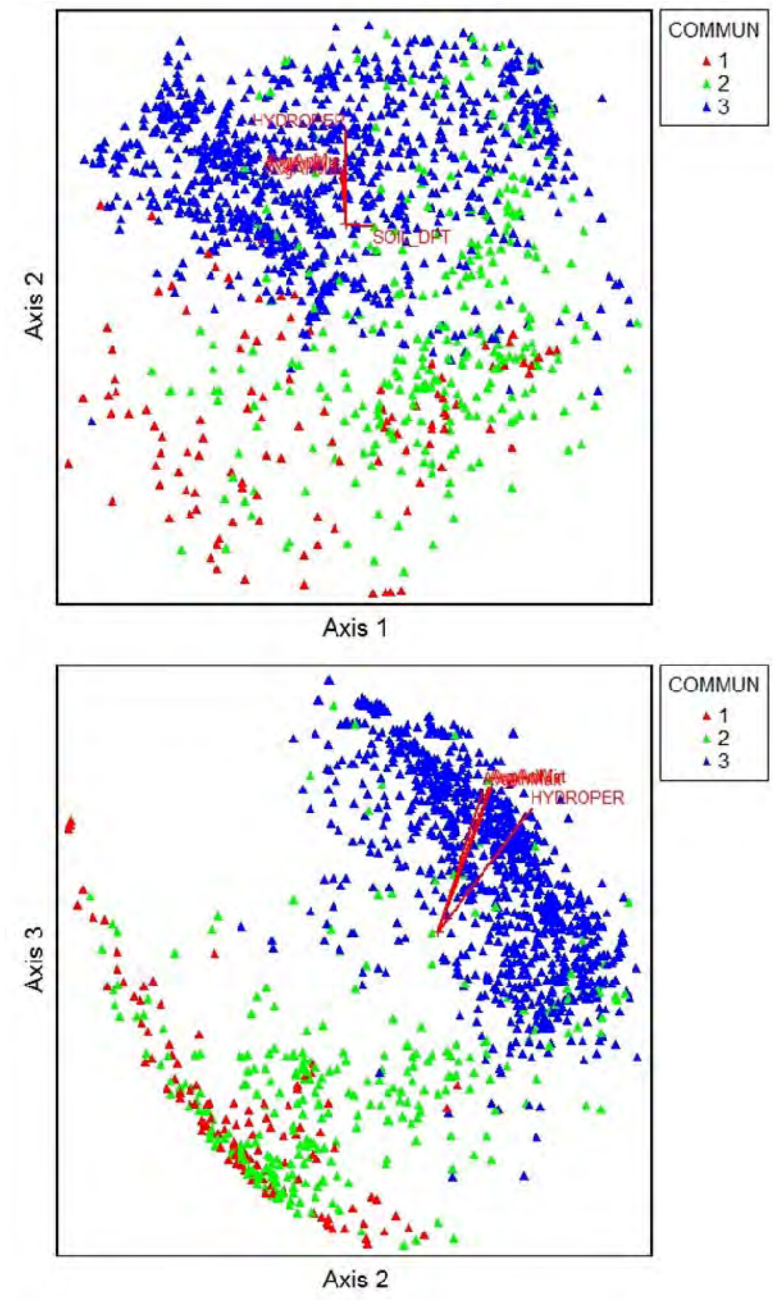

FIGURE 5-9. NMDS ORDINATION OF THE PERCENT COVER OF PLANT SPECIES FOR 1,416 SAMPLE POINTS ON 40 TREE ISLAND AND SURROUNDING SLOUGHS, INCLUDING DATA COLLECTED AT RANDOM POINTS THAT WERE USED IN PREVIOUS STUDIES FOR THE VALIDATION OF TOPOGRAPHIC MODELS.

The strength and direction of the bi-plot vectors indicate the correlations between environmental factors and the score on the three principal axes. The x- and y-components of each environmental vector are the Spearman correlation coefficients (r) between the environmental factor and the axes. Plot types are color coded as indicated in the legend as (1) tree island head and near-tails, (2) randomly located points, and (3) surrounding sloughs.

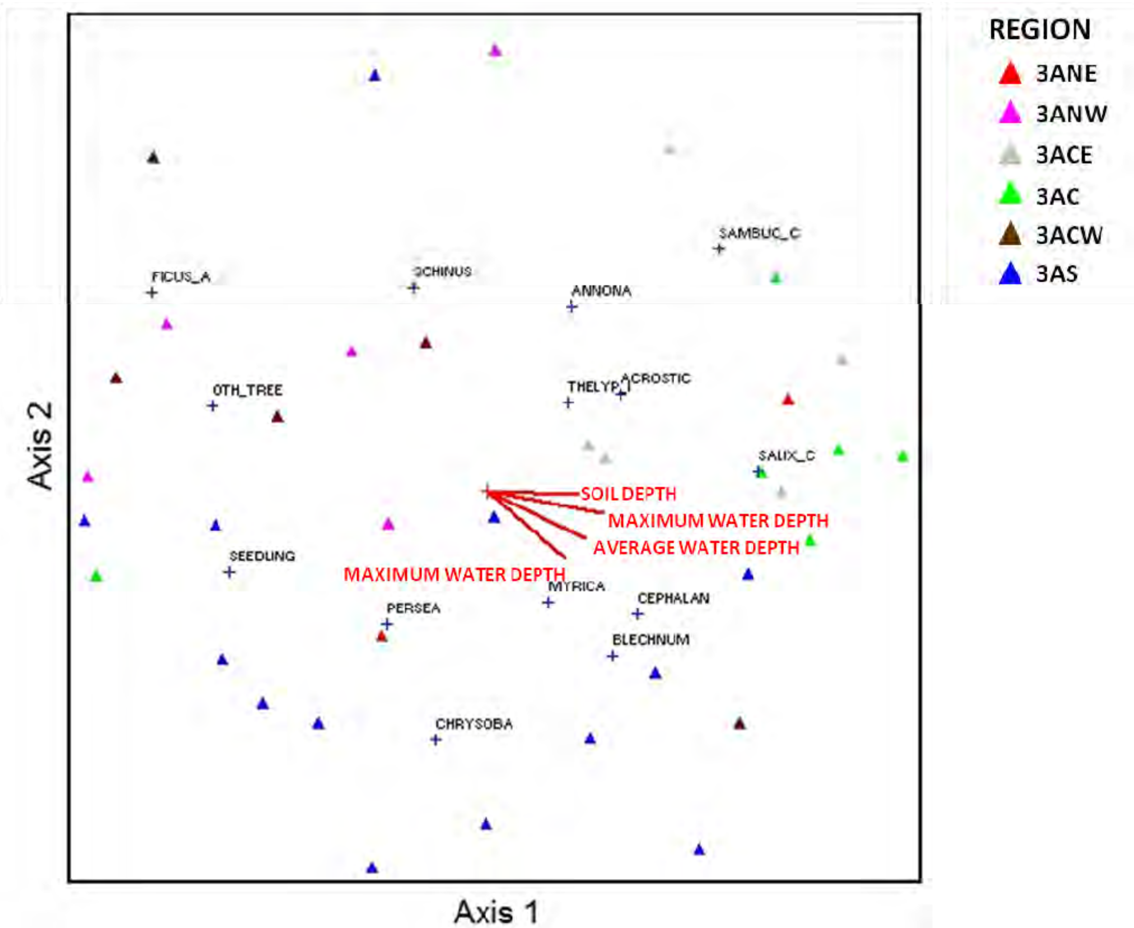

FIGURE 5-10. NMDS ORDINATION OF PERCENT COVER OF PLANT SPECIES ON TREE ISLAND PEAKS, SHOWING THE DISTRIBUTION OF PLANT SPECIES AND THE STRENGTH AND DIRECTION OF CORRELATIONS GREATER THAN 0.2 BETWEEN ENVIRONMENTAL FACTORS AND THE SCORE ON THE TWO PRINCIPAL AXES.

The location of island head plots in the ordination space is coded by region as indicated in the legend. The x- and y-components of each environmental vector correspond to the Spearman correlation coefficients (r) between the environmental factor and the axes.

Fire and Flooding in the East Everglades: Responses of Tree Islands to the Mustang Corner Fire

Forested tree patches or tree islands are an integral component of the Everglades. They are prominent features in both the short hydroperiod marl prairie grasslands and long hydroperiod ridge and slough wetlands of the Everglades (***Figure 5-11***). Within these two distinct hydrologic regions, tree islands add structure and bio-topographic relief to an otherwise physiographically limited landscape. More importantly, however, they provide a network of refuges for forest dwelling plants and animals and perform important biodiversity and nutrient cycling functions (Gaines et al., 2002; Jayachandran et al., 2004; Hanan and Ross, 2009).

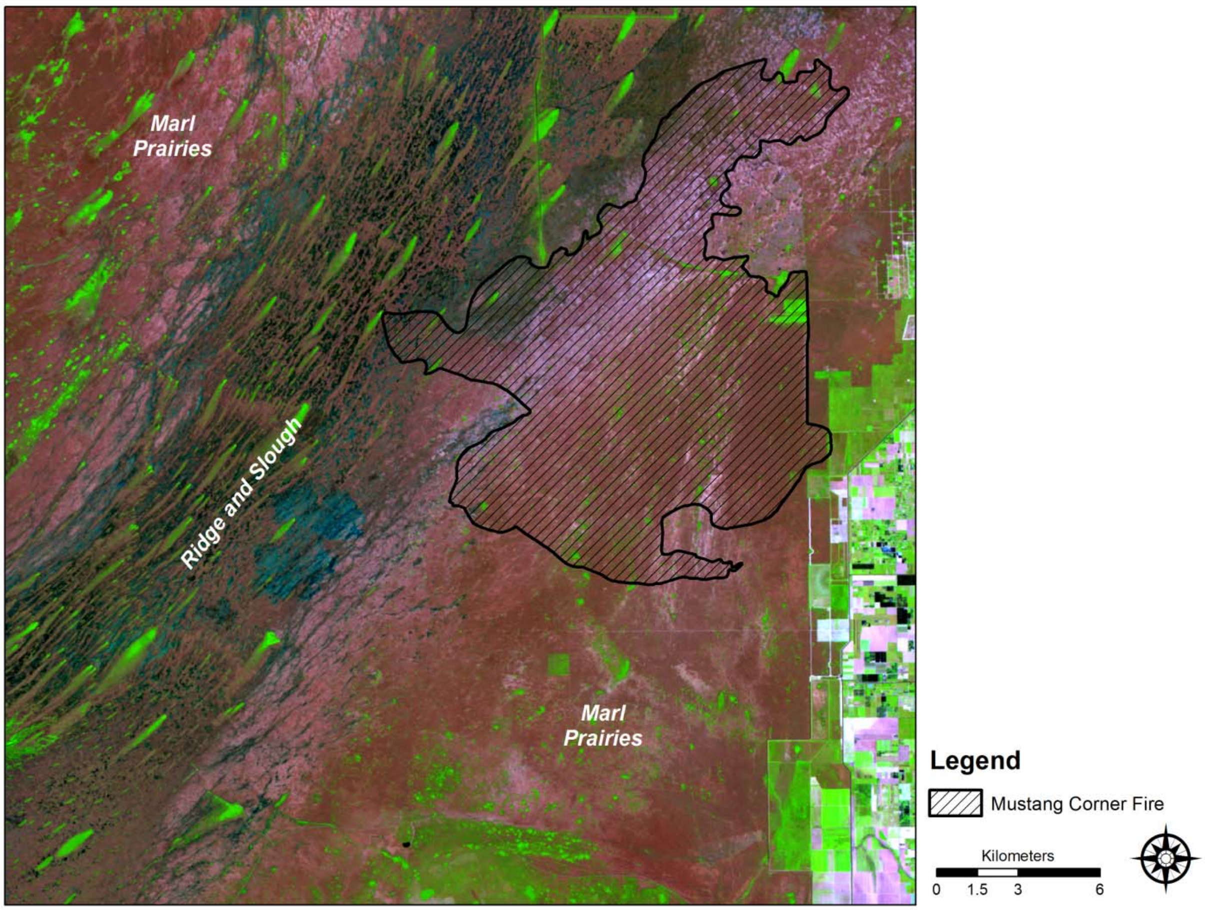

FIGURE 5-11. MUSTANG CORNER FIRE INCIDENT BOUNDARY WITHIN EVERGLADES NATIONAL PARK.

Within the marl prairie grasslands, the combined effects of fires and flooding usually lead to very significant changes in community structure, sometimes resulting in shifts to an alternative stable state (Sah et al., 2012). Tree islands are no exception and are highly susceptible to the synergistic effects of severe fires and post-fire flooding. Depending on fire severity and post-fire hydroperiod, these effects may vary spatially and temporally throughout the landscape, creating a patchy post-fire mosaic of tree islands with different successional states (***Figure 5-12***).

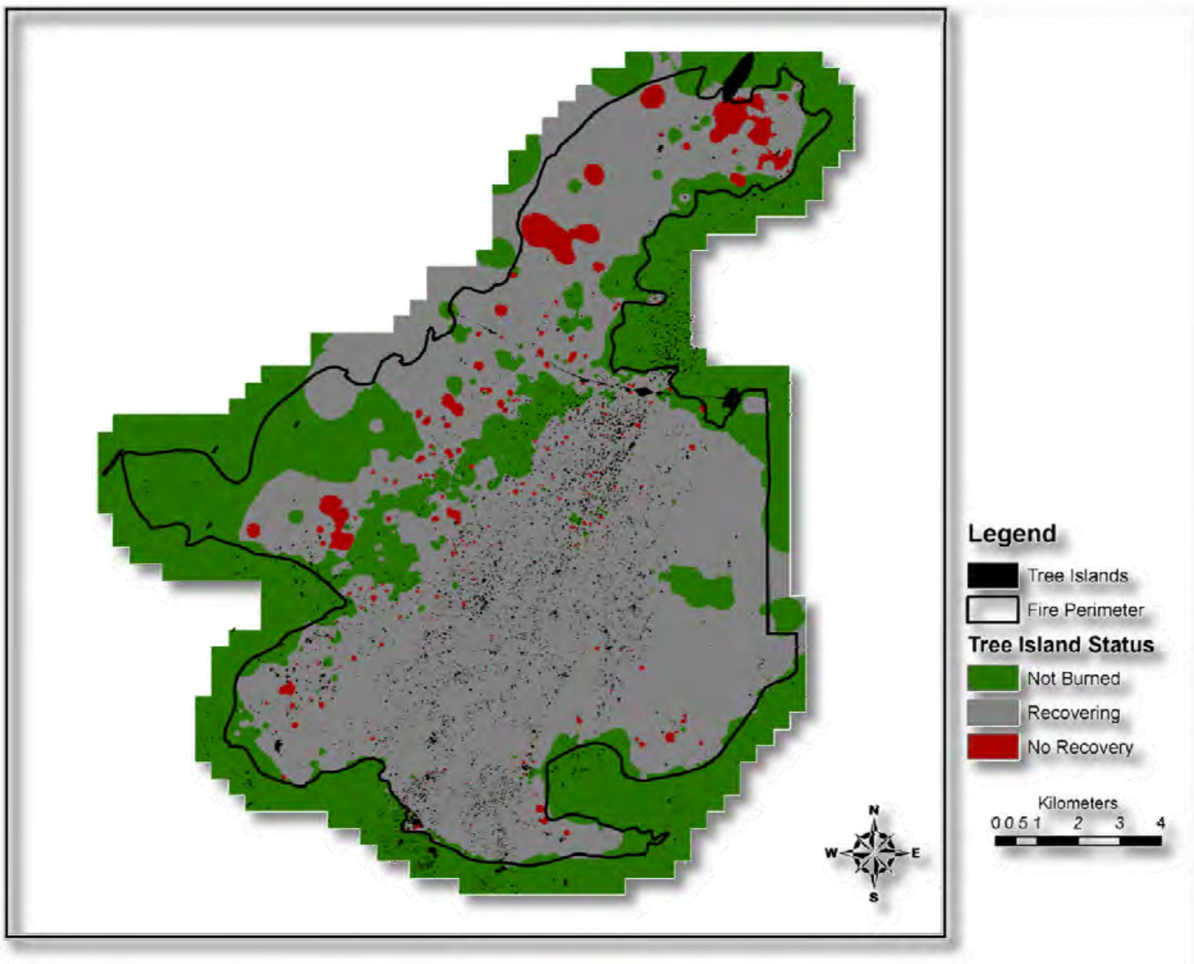

FIGURE 5-12. THREE-YEAR POST-FIRE MOSAIC OF TREE ISLANDS STATUS OR SUCCESSIONAL STATE FOLLOWING THE MUSTANG CORNER FIRE IN 2008.

Furthermore, severe fires and post-fire flooding may limit the establishment and development of new tree islands within this landscape and may ultimately contribute to their contraction or loss (Hofstetter and Hilsenbeck, 1980; Lockwood et al., 2003; Hanan et al., 2010). The many rock platforms or skeleton islands that are present within this landscape (***Figure 5-13***) are undoubtedly the result of such interactions (Hofstetter and Hilsenbeck, 1980).

Through the use of four predictor variables—marsh water table elevation, post-fire hydroperiod, and tree island size and shape—and multiple logistic regression analysis, the probability of tree islands burning and recovering following the Mustang Corner fire in Everglades National Park in May–June 2008 was examined. The analysis showed that there is a direct relationship between pre- and post-fire hydrology and tree island post-fire burn status and recovery. More specifically, the elevation of the marsh water table at the time of the fire appears to be the most important parameter determining the severity of fire in tree islands (***Table 5-2***). This finding is consistent with that of Craighead (1984) who found that a water table elevation at or above -0.7 meter (m) below the surface, tended to exclude fires from hardwood hammocks while values less than or equal to -0.7 m below the surface lead to severe hardwood hammock fires.

FIGURE 5-13. SPARSELY VEGETATED ROCK OUTCROP (SKELETON ISLAND).

TABLE 5-2. COEFFICIENTS OF THE MULTIPLE LOGISTIC REGRESSION OF TREE ISLAND POST-FIRE BURNED STATUS, NOT BURNED VERSUS BURNED IN 2008.

Variable	Coefficient(ß)	Standard Error	Wald Statistic	Significance	Exp(ß)
Intercept	2.019	0.423	22.753	< 0.001	7.527
Water Table (m)	-5.075	0.202	628.545	< 0.001	0.006
Circularity Ratio	-4.046	0.472	73.420	< 0.001	0.018
Tree Island Log (Area)	-0.395	0.048	66.753	< 0.001	0.674

Furthermore, in the post-fire recovery phase, both tree island size and hydroperiod during the first year after the fire played important roles in determining the probability of recovery of burned tree islands (***Table 5-3***). It is unclear what role tree island size plays in the recovery process, but post-fire flooding of the tree island environment is likely to lead to anoxia among basal and belowground apical meristems and hinder resprouting from belowground parts. Our data show that water management both during and after fire can lead to tree island contraction or loss, with significant repercussions on the overall ecological health of the Everglades.

TABLE 5-3. COEFFICIENTS OF THE MULTIPLE LOGISTIC REGRESSION OF TREE ISLAND POST-FIRE RECOVERY STATUS, NOT RECOVERING VERSUS RECOVERING IN 2011.

Variable	Coefficient(ß)	Standard Error	Wald Statistic	Significance	Exp(ß)
Intercept	-2.041	0.575	12.576	< 0.001	0.130
Tree Island Log (Area)	1.379	0.096	207.492	< 0.001	3.969
Hydroperiod (Days)	-0.007	0.001	36.651	< 0.001	0.993
Circularity Ratio	-1.890	0.631	8.964	0.003	0.151

Mechanisms of Ridge-Slough Maintenance and Degradation in the Greater Everglades

The ridge-slough patterned landscape mosaic is one of the most charismatic and functionally critical features of the central and southern Everglades. Hydrologic modification has altered the extent and quality of the patterning. This has made the protection of those areas where pattern is still relatively well conserved a priority, and focused attention on the hydrologic restoration necessary to restore degraded patterning. This section summarizes two important findings regarding the ridge-slough landscape. The first pertains to the soil organic matter budget, and results that suggest that hydrologic modification has dramatically altered both the magnitude and ridge-slough difference in soil respiration. The second pertains to the important links between conservation of landscape pattern and regional hydrology.

Soil Respiration in the Ridge-Slough Landscape

In the Everglades, soil elevation and landscape patterning occur because of the accumulation of organic matter into peat soils. We have monitored soil respiration, a key component of the peat budget, in sites spanning a hydrologic gradient from too dry (WCA3AN) to too wet (southern WCA3AS), including the best conserved portions of the patterned landscape (***Figure 5-14***). Measurements of soil respiration have been made over a three-year period from 2009 through 2011 (***Figure 5-15***). During this time, hydrologic condition in the Everglades varied from extremely dry to extremely wet, suggesting that the measurements over this short period span the range of extant hydrologic variation.

There were two primary findings. First, there were no community differences (i.e., ridge versus slough) in the relationship between water depth and soil respiration. This means that the soils underlying both communities appear equal in carbon quality. Moreover, there was no apparent temperature effect, suggesting that water level is the primary driver of soil respiration variation (***Figure 5-15***). We note that these measurements pool 549 observations from four blocks sampled bi-monthly for three years.

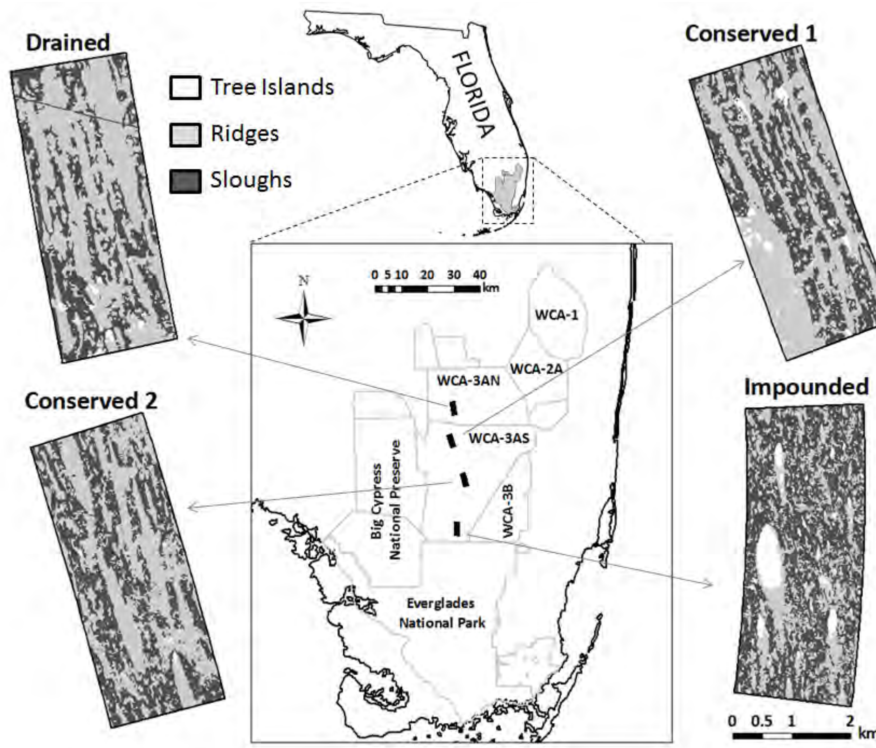

FIGURE 5-14. LOCATIONS OF SOIL RESPIRATION MEASUREMENTS SPANNING A GRADIENT OF HYDROLOGIC CONDITION WITHIN WCA 3A.

Locations were selected from Monitoring Assessment Plan (MAP) primary sampling units (PSUs). Vegetation polygons are from the South Florida Water Management District for 1995.
Note: km – kilometers.

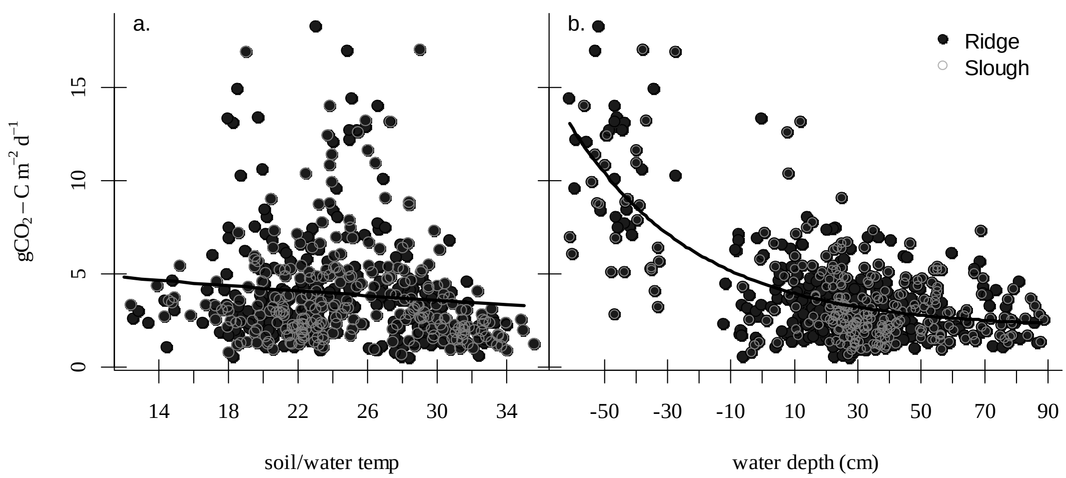

FIGURE 5-15. MEASURED SOIL RESPIRATION (IN GRAMS OF CARBON PER M^2 PER DAY [GCO_2-$CM^{-2}D^{-1}$]) VERSUS (A) TEMPERATURE AND (B) WATER DEPTH (IN CENTIMETERS [CM]) FOR RIDGES AND SLOUGHS.

No significant community-level effect was observed for either relationship, so one line (respiration versus water depth) was fit. The temperature effect was weakly statistically significant ($p < 0.05$). The water depth effect was highly significant ($p < 0.001$).

This first result does not mean, however, that soil respiration from the two communities are equal because sloughs are generally a lower elevation. Consequently, they are generally under greater depth of water, and thus exhibit slightly lower respiration over all. An 11-year estimate of soil respiration as a function of soil elevation indicates that higher elevation soils respire more on an annual average because they are exposed more often (see black line in ***Figure 5-16***). Also shown in the figure are measured soil elevations at the sites, showing a strongly bi-modal distribution at the two conserved sites, with the two modes representing ridges (high elevation mode) and sloughs (low elevation mode), and unimodal distributions at the two hydrologically modified sites (both drainage and impoundment). The median soil elevation for ridges (dashed black lines) and sloughs (dashed grey lines) can be used to compare soil respiration values. The results suggest that respiration rates are uniformly high in the drained sites, with extremely small differences between ridges and sloughs, uniformly low in the impounded sites, also with small ridge-slough differences, and intermediate levels in the two conserved sites, with much more marked ridge-slough differences. This suggests that hydrologic modification has altered the fundamental process of soil respiration, which is likely integral to the maintenance of soil elevation separation between ridges and sloughs. This also supports the widely held contention that the central part of WCA3AS supports the least impaired ridge-slough landscape, tentatively providing a reference condition for hydrologic restoration.

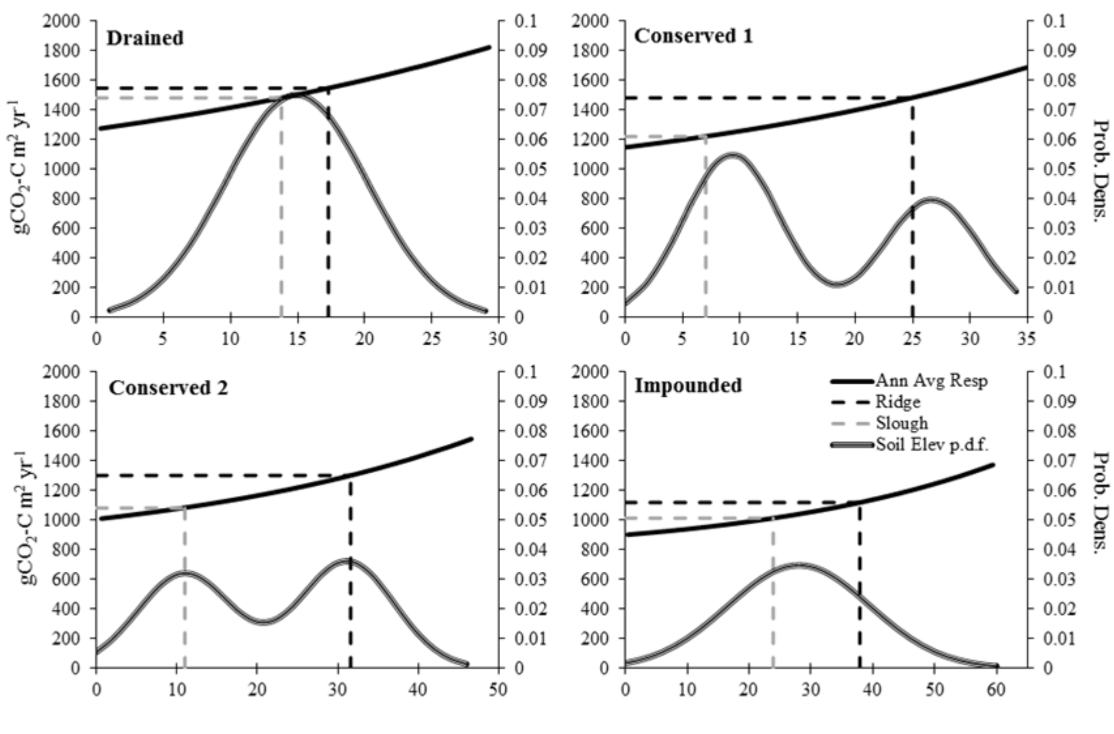

FIGURE 5-16. SUMMARY OF ESTIMATED ANNUAL SOIL RESPIRATION RATES OVER 11 YEARS (2000–2011) AT FOUR SITES SPANNING A GRADIENT OF HYDROLOGIC CONDITION.

The underlying model for soil respiration was derived from 549 field measurements of soil respiration. The soil elevation distribution is from Watts et al. (2010).

Landscape Pattern Affects Regional Hydrology

The development and maintenance of the ridge-slough patterning remains an area of some uncertainty, with implications for hydrologic restoration targets. One hypothesis holds that the configuration of the landscape exerts strong controls on hydrologic behavior, specifically the ability of the landscape to shed water, thus affecting hydroperiod. Using state-of-the-art hydrologic simulation models after the Surface-Water Integrated Flow and Transport in Two Dimensions (SWIFT2D) (Schaffranek, 2004), these effects have been explored.

One of the sentinel features of the ridge slough landscape is the elongation of the patches (individual ridges and sloughs) in the direction of historical flow. The degree of elongation has an important impact on the hydrologic connectivity of the landscape, with water passage through the landscape made easier when the deeper water slough habitats are connected in the direction of flow. One measure of that elongation is *anisotropy*, which has low values (near 1) when the patches are not elongated, and values approaching 6 in the minimally impacted ridge-slough landscape. The model was employed to test the effect of patch elongation on hydroperiod. The process, summarized in ***Figure 5-17***, is to start with measured water levels over a 20-year period in a well conserved part of the Everglades landscape; these yield mean water depth and hydroperiod (annual duration of ponded water) for that landscape. From this water level record, we used the model to estimate the water flow (since levels are well measured, flows are not). This same flow was applied to 120 synthetic landscapes (constructed to resemble the geostatistical properties of the Everglades, but with variation in anisotropy) using the hydrologic simulation model, and the resulting mean water levels and hydroperiods were extracted for each. The process required an intermediate step of constructing a unique "rating curve" for each landscape that links flow and water level given the configuration and hydrologic connectivity of the patches. More details can be found in Kaplan et al. (2012).

The results are summarized in ***Figure 5-18***. They suggest two critically important features of the relationship between pattern anisotropy and hydrology. First, as anisotropy increases, the percentage of time that the ridges are dry also increases. These differences are large. In the reference landscape, the fraction of each year that ridges are dry is approximately 15 percent. We observed similar values for synthetic landscapes with high anisotropy, but much lower values for less anisotropic landscapes (***Figure 5-18b***). Since regular drawdowns are thought to be critically important to the maintenance of ridges, and the probability of a drawdown is near zero for landscapes that have lost anisotropic patches (that is, anisotropy values approach one) this finding suggests that the configuration of the landscape exerts substantial control on regional hydrology. Another way of saying this is that the difference in ridge hydroperiod between the reference landscape and a synthetic landscape with anisotropy of one is over 40 days, a significant change for the ecology of ridges (***Figure 5-18d***).

A second important finding is that these effects are largest in dry years (***Figure 5-18c***). During wet years, ridges in all landscapes are wet most of the year, and landscape configuration differences exert minor influence on hydroperiod. However, in drier years (specifically in years when ridges in the reference landscape were dry for longer), the effect of landscape configuration is paramount. The expected hydroperiod in landscapes where anisotropy is one are lengthened by as much as 100 days. This suggests that periods of low stage, which are critical for maintenance of the habitats in the Everglades, are lost as pattern is degraded.

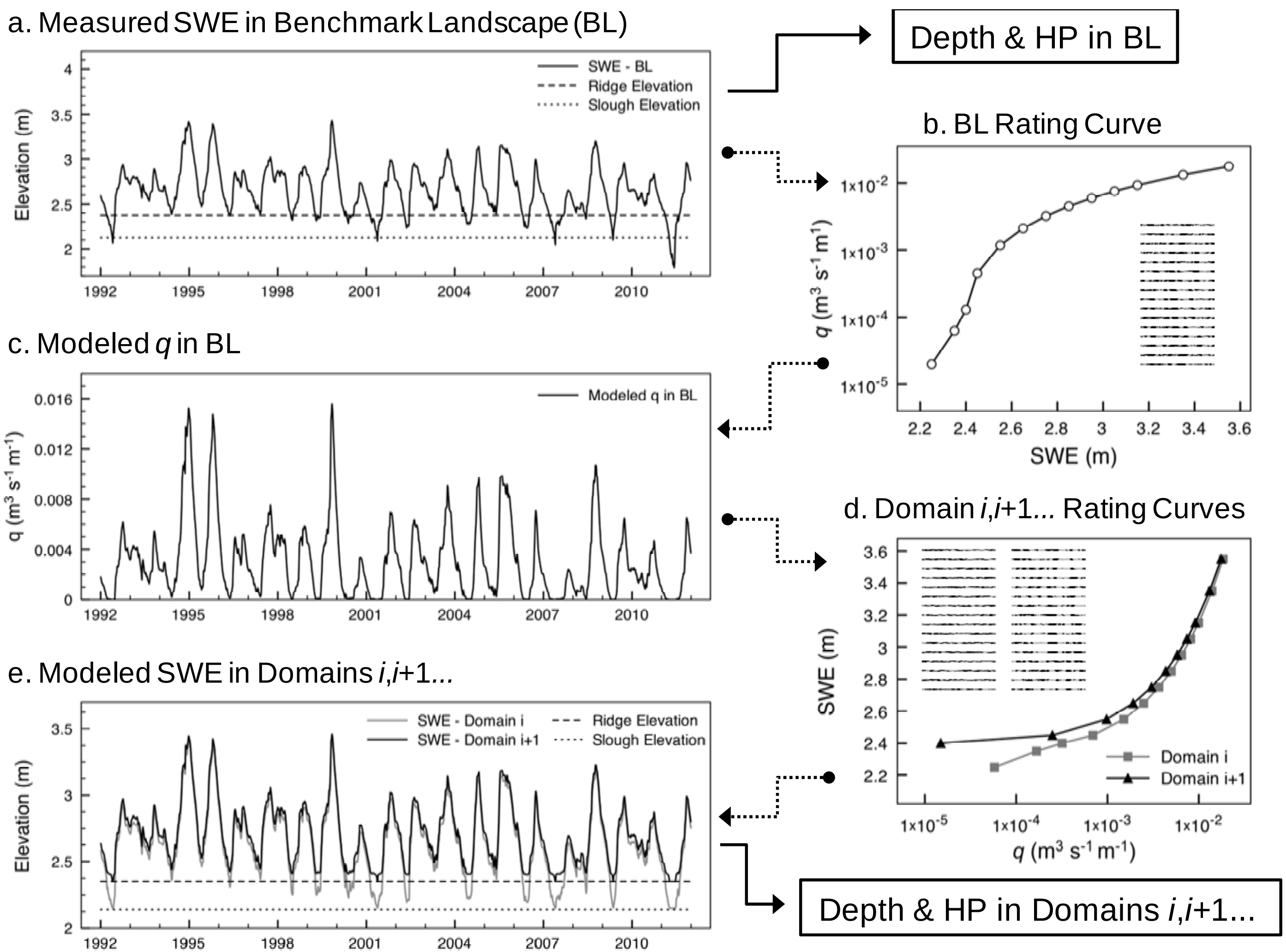

FIGURE 5-17. METHOD FOR EVALUATING HYDROLOGIC EFFECTS OF PATCH ANISOTROPY.

First, surface water elevation (SWE) data (a) were used to calculate depth and hydroperiod (HP) in a benchmark landscape (BL) in the Everglades. Next, a rating curve relating SWE to discharge competence (q) in the BL (b) was used to estimate q in the BL (c). q is reported in cubic meters per second per meter ($m^3s^{-1}m^{-1}$) Rating curves for synthetic domains (d) were used to predict SWE time series (e), flooding depths, and hydroperiod in all domains.

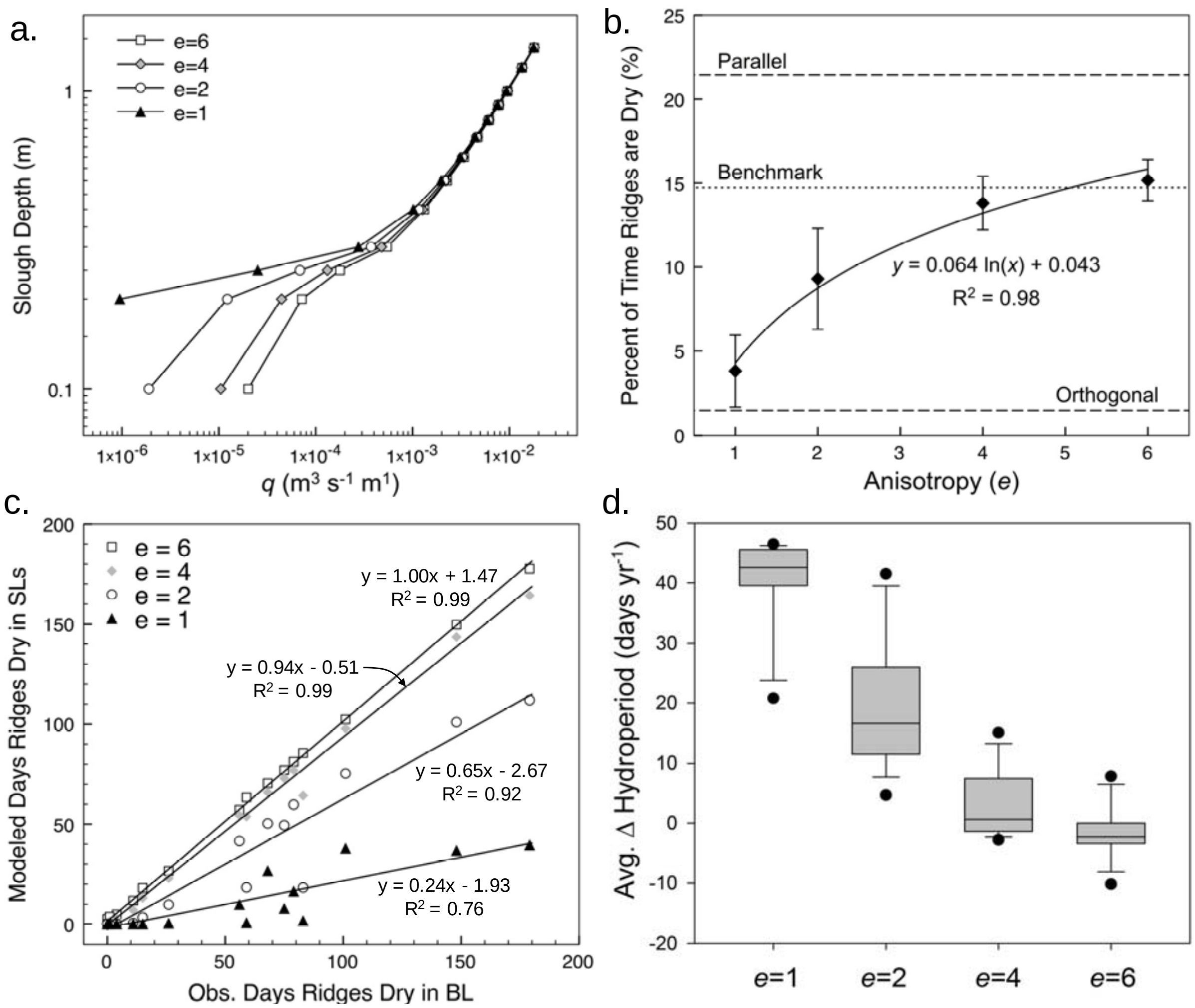

FIGURE 5-18. MODEL RESULTS.

(a) Landscape rating curves illustrating average discharge competence (q) in domains with different anisotropy (e) values at depths of 0.1–1.4 m. (b) The proportion of time ridges were exposed as a function of e. Error bars denote standard deviation. (c) The yearly number of days ridges were exposed in the benchmark landscape (BL) versus the average number of days ridges were exposed in simulated landscapes (SL) with different e-values. (d) Box plots showing average yearly changes in hydroperiod relative to the BL (Δ hydroperiod) as a function of e. Symbols denote the 95 percent confidence interval.

This analysis broadly suggests that the loss of pattern exerts important controls on regional hydrology, and that potential feedbacks between pattern and hydrology may be the basis of pattern generation.

PREDATOR-PREY RELATIONSHIPS

Three aspects of the predator-prey relationships are discussed in this section: (1) long-term fish dynamics at the Everglades marsh-mangrove ecotone, (2) use of fish monitoring data for evaluation modeling of wading bird prey, and (3) trophic linkage of wading birds, hydrology, and wet and dry season aquatic fauna. In the 2009 System Status Report (SSR) (RECOVER, 2010), the first item was discussed under the Everglades Coastal Wetlands section, which can be viewed at http://www.evergladesplan.org/pm/ssr_2009/hc_ge_egcw_results.aspx. The remaining two items were discussed under the Greater Everglades Wading Bird Nesting in Relation to Aquatic Fauna Forage Base (Predator-Prey) section, which can be viewed at http://www.evergladesplan.org/pm/ssr_2009/hc_ge_pred_prey_results.aspx. A more detailed assessment of predator-prey relationships will be provided in the 2014 SSR.

Long-term Fish Dynamics at the Everglades Marsh-Mangrove Ecotone

Natural hydrologic regimes and how water is managed play a prevalent role on the structure and dynamics of aquatic communities. Since 2004, spatiotemporal dynamics in the Everglades fish community at the marsh-mangrove ecotone have been examined (***Figure 5-19***). The focus has been in understanding how both freshwater and estuarine fishes, including species of important recreational value, respond to variation in hydrological conditions and extent of marsh inundation, primarily driven by upstream freshwater inflows into the estuary. The approach has been to examine the effects of hydrology on fishes at multiple ecological scales along the marsh-mangrove boundary (***Figure 5-20***). The links between temporal (both seasonal and yearly) hydrological variation and patterns of fish abundance and distribution, trophic ecology of key mesoconsumers, and recreational fisheries are reported.

Headwaters of the Shark River in southwestern Everglades National Park (***Figure 5-19***) are inhabited by a diverse and dynamic fish community composed of transient freshwater species, resident estuarine species, and transient marine taxa. In the dry season, fish abundance in mangrove creeks increases markedly as upstream marshes dry and marsh fishes enter the estuary. This increase in the freshwater taxa, both small-bodied prey and larger predatory taxa, is accompanied by increases in the abundance of estuarine predators, dominated by snook, particularly at the headwater sites (closest to marshes, ***Figure 5-21***). Marsh water level is thus a key predictor of total fish abundance at these headwater sites (***Figure 5-22***).

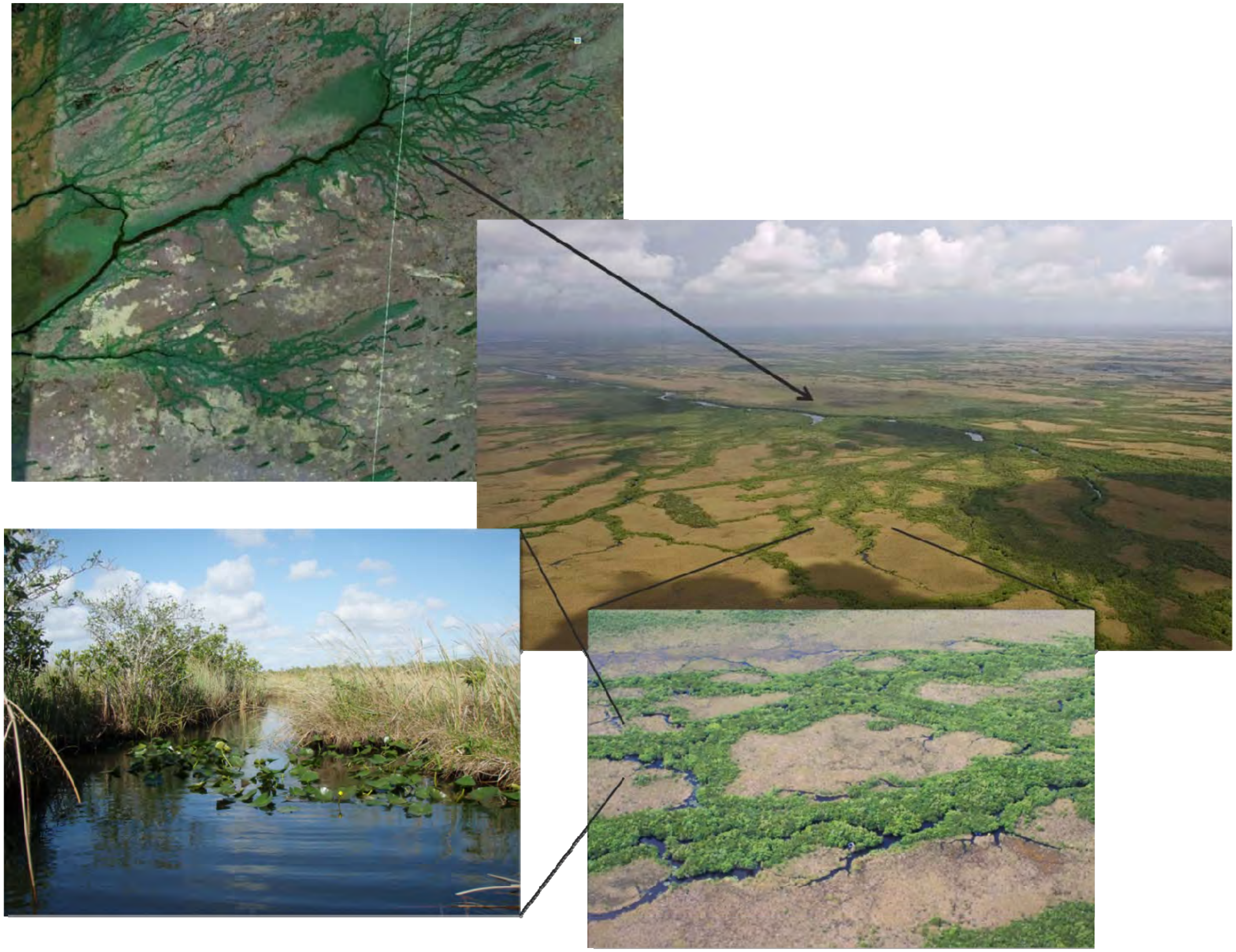

FIGURE 5-19. IMAGES AT MULTIPLE SCALES OF MANGROVE CREEKS AT THE MARSH-MANGROVE ECOTONE IN THE SHARK RIVER SLOUGH – SHARK RIVER ESTUARY INTERFACE WITHIN EVERGLADES NATIONAL PARK

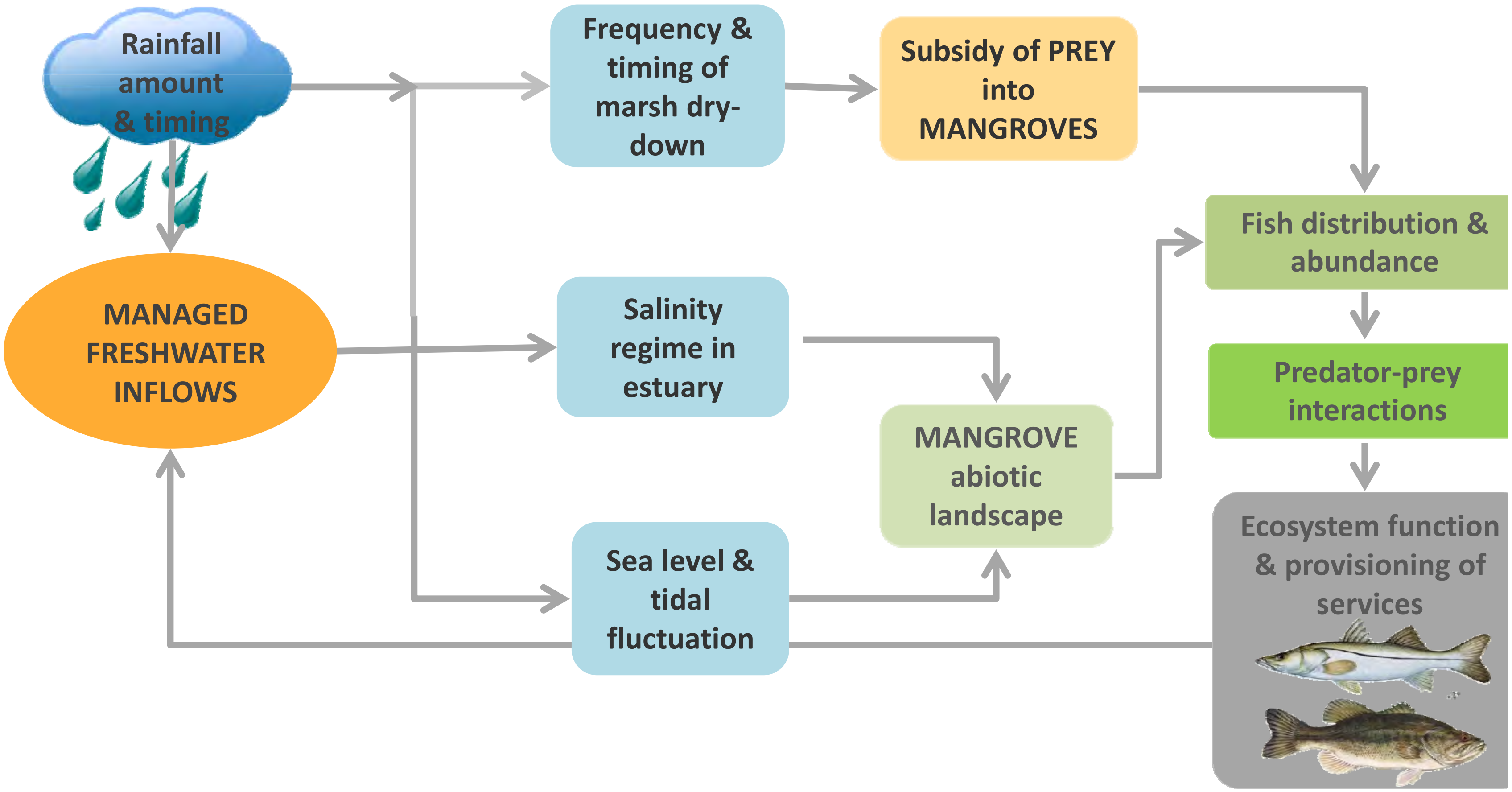

FIGURE 5-20. CONCEPTUAL FRAMEWORK DEVELOPED BASED ON THE PAST 8 YEARS OF MONITORING, SHOWING THE KEY FACTORS INFLUENCING THE ABUNDANCE AND DISTRIBUTION OF FISHES IN ECOTONAL HABITATS IN THE SOUTHWESTERN EVERGLADES.

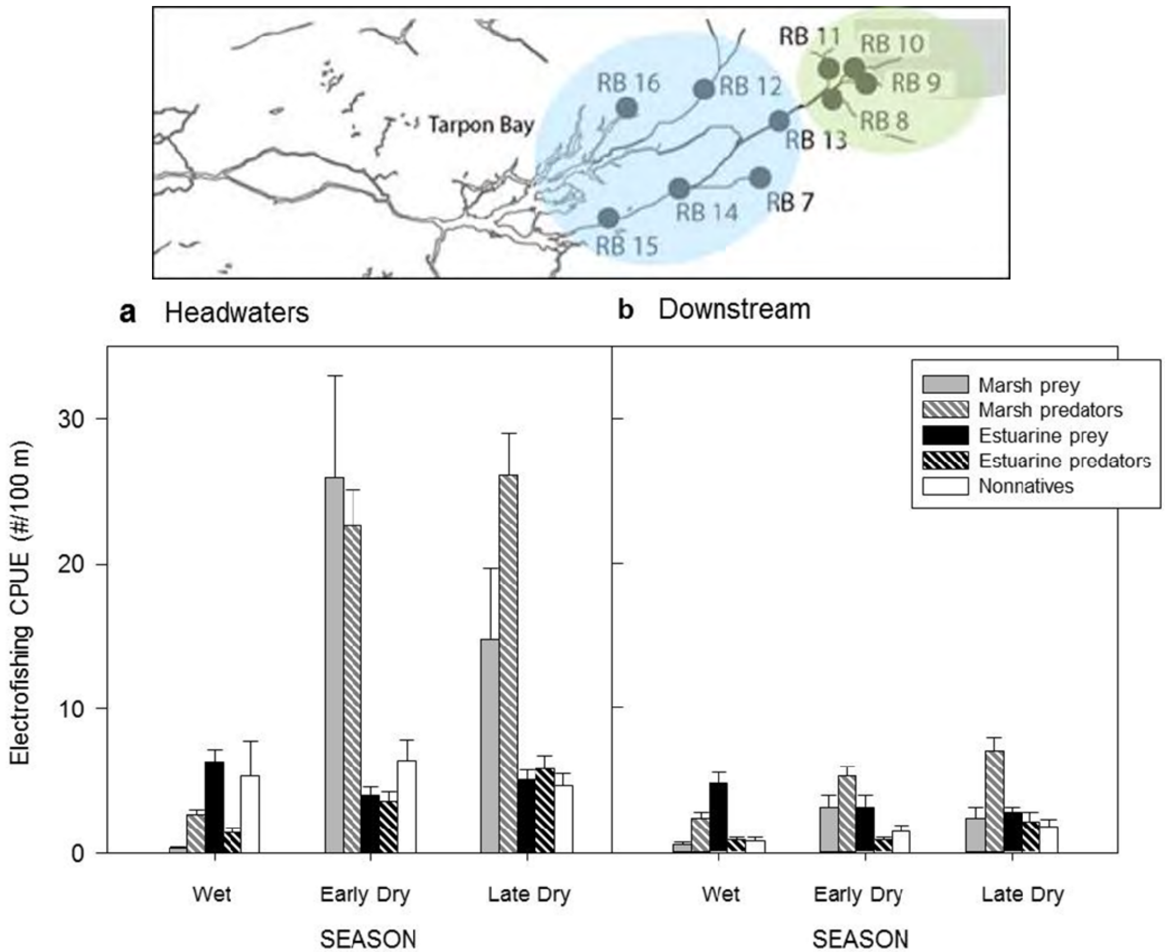

FIGURE 5-21. SEASONALITY IN ELECTROFISHING CATCHES IN CATCH PER UNIT EFFORT (CPUE [NUMBER OF FISH PER 100 METERS OF CREEK SHORELINE] ± STANDARD ERROR [SE]) ACROSS FUNCTIONAL GROUPS FOR ALL YEARS OF SAMPLING: FRESHWATER PREY, FRESHWATER PREDATORS, ESTUARINE/MARINE PREY, ESTUARINE/MARINE PREDATORS AND NONNATIVE TAXA (A) AT THE HEADWATERS (SHADED GREEN IN MAP INSERT), AND (B) DOWNSTREAM CREEK SITES (SHADED BLUE IN MAP INSERT).

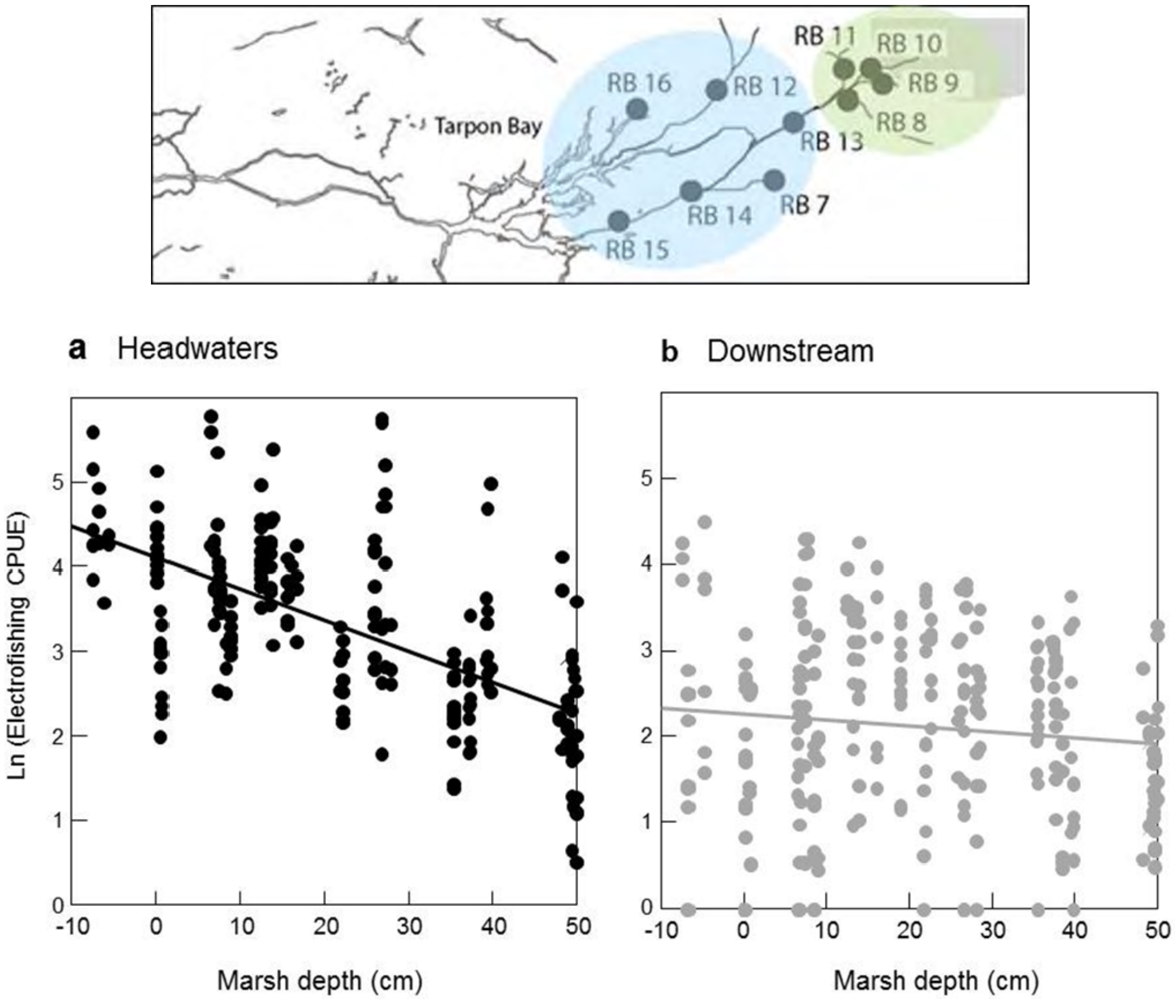

FIGURE 5-22. RELATIONSHIPS BETWEEN ELECTROFISHING CPUE (ALL TAXA COMBINED) AND MARSH WATER LEVELS (USGS SH1 STATION), SHOWN SEPARATELY FOR (A) HEADWATER (SHADED GREEN IN MAP INSERT) AND (B) DOWNSTREAM SITES (SHADED BLUE IN MAP INSERT).

Food web dynamics can be good metrics of anthropogenic impacts on ecosystem processes, and of the responses to restoration efforts, since they integrate large spatiotemporal scales and reflect both structural and functional effects. The 2011 study of diets shows that consumers in creeks, both the freshwater (largemouth bass [*Micropterus salmoides*] and bowfin [*Amia calva*]) and estuarine species (snook [*Centropomus* spp.]) feed almost exclusively on marsh prey. As marshes dry, freshwater fishes move into the estuary, creating a short-lived pulse of prey and a resource subsidy for estuarine snook (***Figure 5-23***). Marsh prey are three to six times more abundant than estuarine prey in the dry season at headwater sites (***Figure 5-21***).

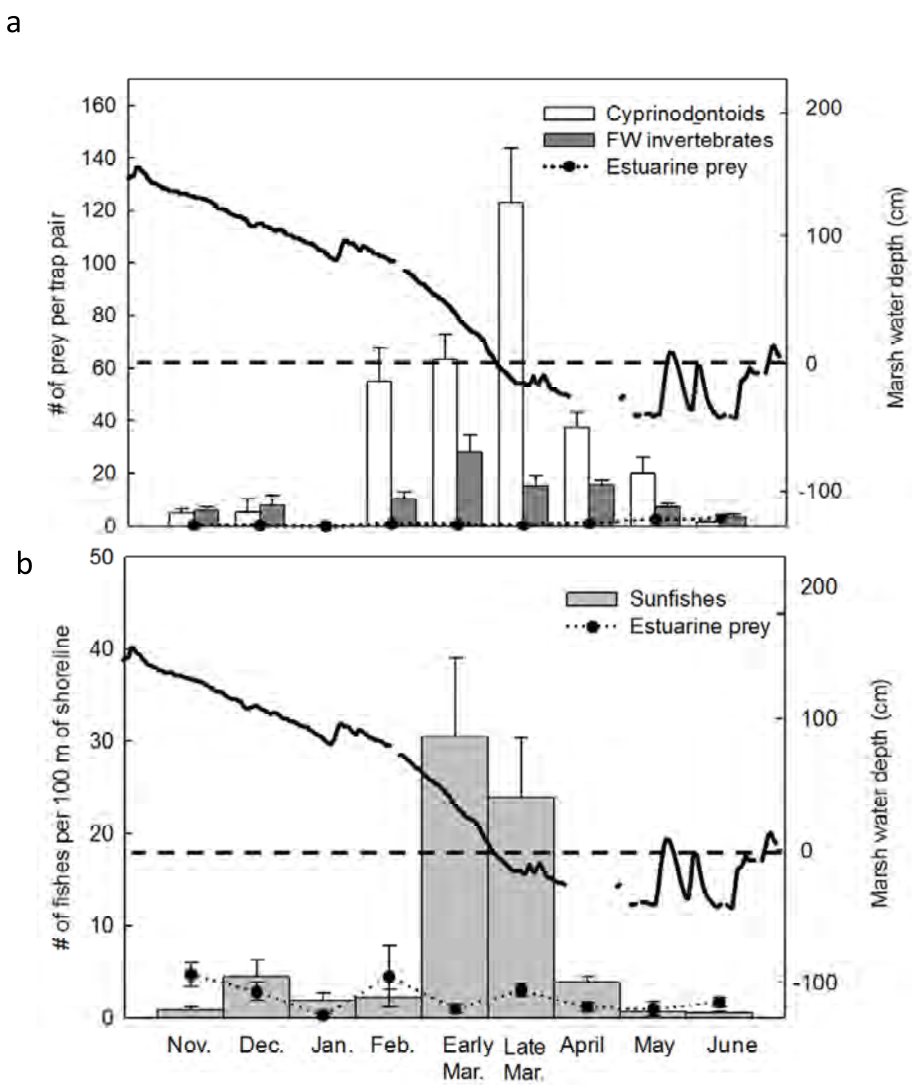

FIGURE 5-23. VARIATION IN PREY ABUNDANCE ACROSS PREY GROUPS: CYPRINODONTOIDS (WHITE BARS) AND INVERTEBRATES (GRAY BARS) CAUGHT IN (A) MINNOW TRAPS AND (B) FOR SUNFISHES CAUGHT VIA ELECTROFISHING.

The solid black line shows marsh water depth (United States Geological Survey hydrostation SH1) over the period of sampling and the dashed line indicates complete marsh drying.

Total consumption of marsh prey in the upper estuary triples upon marsh drying, with 41 percent of marsh prey biomass eaten by the freshwater bass and bowfin, and 59 percent consumed by estuarine snook (***Figure 5-24***). Body condition gains (an index of overall fish health), of similar magnitude were seen in snook and largemouth bass, suggesting that both consumer types, freshwater and estuarine, benefit from the marsh prey subsidy. However, these subsidized populations of consumers, may be restricted to the headwaters, where the ratio of marsh prey to estuarine prey and total prey abundance far exceeds ratios and abundance downstream. Ongoing dietary work aims at examining the spatial extent of marsh subsidies downstream, particularly for snook.

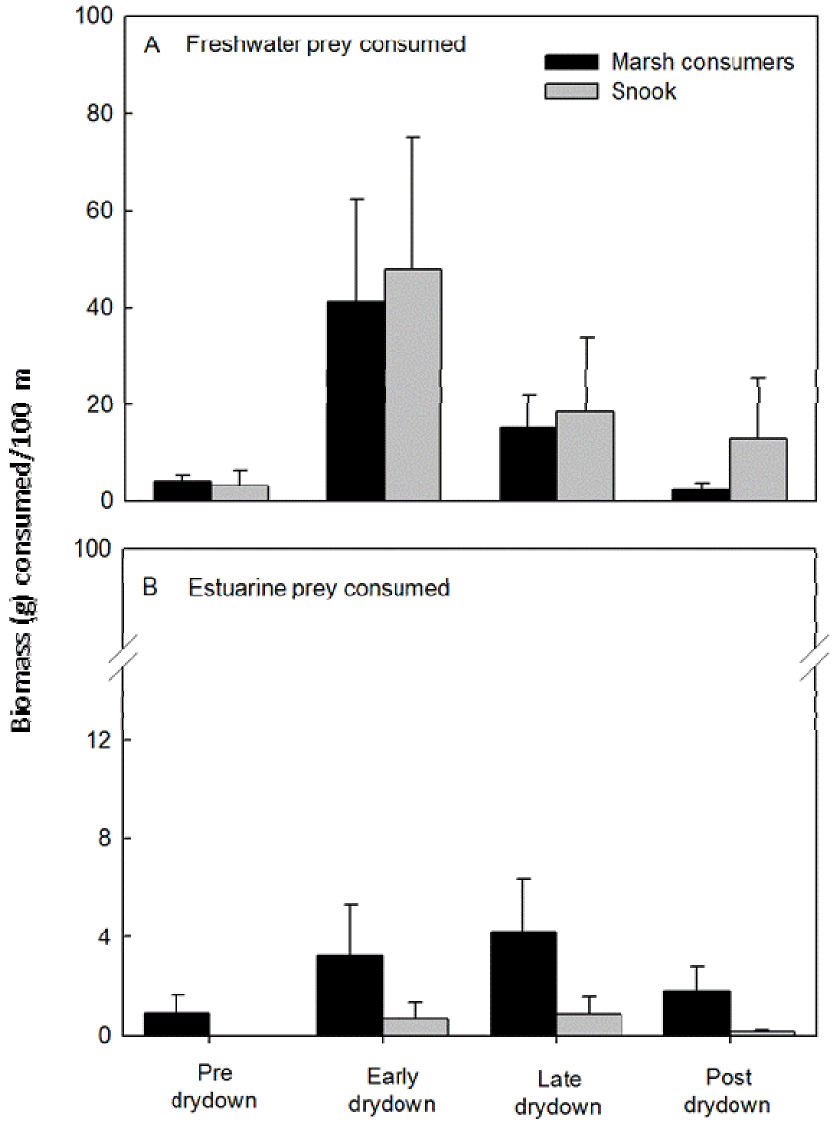

FIGURE 5-24. AVERAGE BIOMASS OF (A) FRESHWATER PREY AND (B) ESTUARINE PREY CONSUMED PER 100 M OF MANGROVE CREEK SHORELINE BY BASS AND BOWFIN (BLACK BARS) AND SNOOK (GREY BAR) ACROSS HYDROLOGIC STAGES.

Long-term monitoring of dynamics at these sites has allowed detection of the structuring effects of other drivers, such as extreme climatic events. The 2010 cold event caused significant mortality across Everglades fauna and flora, and at sites, species affected included estuarine and nonnative fishes, both of tropical origin (***Figure 5-25***). While estuarine prey appear to have recovered from the cold snap, snook and nonnatives show no recovery, which has led to the continued closure of the snook fishery for 2012, a multimillion dollar industry in Florida. The monitoring provided the only fisheries-independent population estimates for snook in Everglades National Park. With projected increases in extreme temperature events as a result of climate change, subtropical regions may undergo drastic community shifts and diversity loss, with implications for the provisioning of ecosystem services.

Seasonal inundation of upstream marshes may play an important role in provisioning its world-renowned recreational fishery, but little is known about how the dynamics of freshwater inflows and how the extent of marsh inundation interacts with Everglades estuarine fisheries production. The importance of wet season amplitude (annual peak marsh water height) and duration of drydown (days marshes dried per year) of upstream marshes in driving catch rates of largemouth bass and snook were examed. Angler records from a local fishing club, from 1992 to 2012, were used. These anglers exclusively fish the upper Shark River in a tournament style setting, and do not alter fishing practices based on catches of either species, likely because these tactics work equally well for both species. These data were validated by comparing angler catches to the 2004–2012 electrofishing data (***Figure 5-26***). Angler and electrofishing catches track well for bass, but not snook. Results suggest previous year's marsh dynamics, particularly the duration of marsh dry down, significantly influenced bass and snook catches, but in different ways and with time lags. Bass angler catches were negatively correlated to the severity of marsh drying in the previous year, while snook catches were positively linked to days marshes were dry two years prior (***Figure 5-27***). Previous work on marshes and current work in the estuary show that following a prolonged dry season, the abundance of bass and other freshwater species significantly decreases likely due to high mortality. For instance, catches of freshwater taxa decreased by almost two-thirds between the 2011 and 2012 dry seasons as a result of the 2011 drought (***Figure 5-25b***). In the year following prolonged marsh drying, angler catches of bass are then low and thus the negative relationship between the length of marsh drying and bass catches the following year (***Figure 5-27***). As the numbers of bass decrease in the marsh, prey, including those that pulse into estuary, experience a release from predation. This release means that two years following a drought, bass are still in low numbers, but marsh prey are in high numbers, potentially driving a positive relationship between the length of marsh drying and snook angler catches two years later (***Figure 5-27***). Thus, in years following a severe dry season, it is expected that subsidies to snook will increase, increasing snook numbers in the upper estuaries, which is reflected in higher angler catch rates. Lags in the positive effect of marsh predator release and the prey's own recovery from drydown likely explain why it takes two years for snook catches to increase post drydown. Evidence of this potential mechanism will hopefully bee seen post-2011 drought.

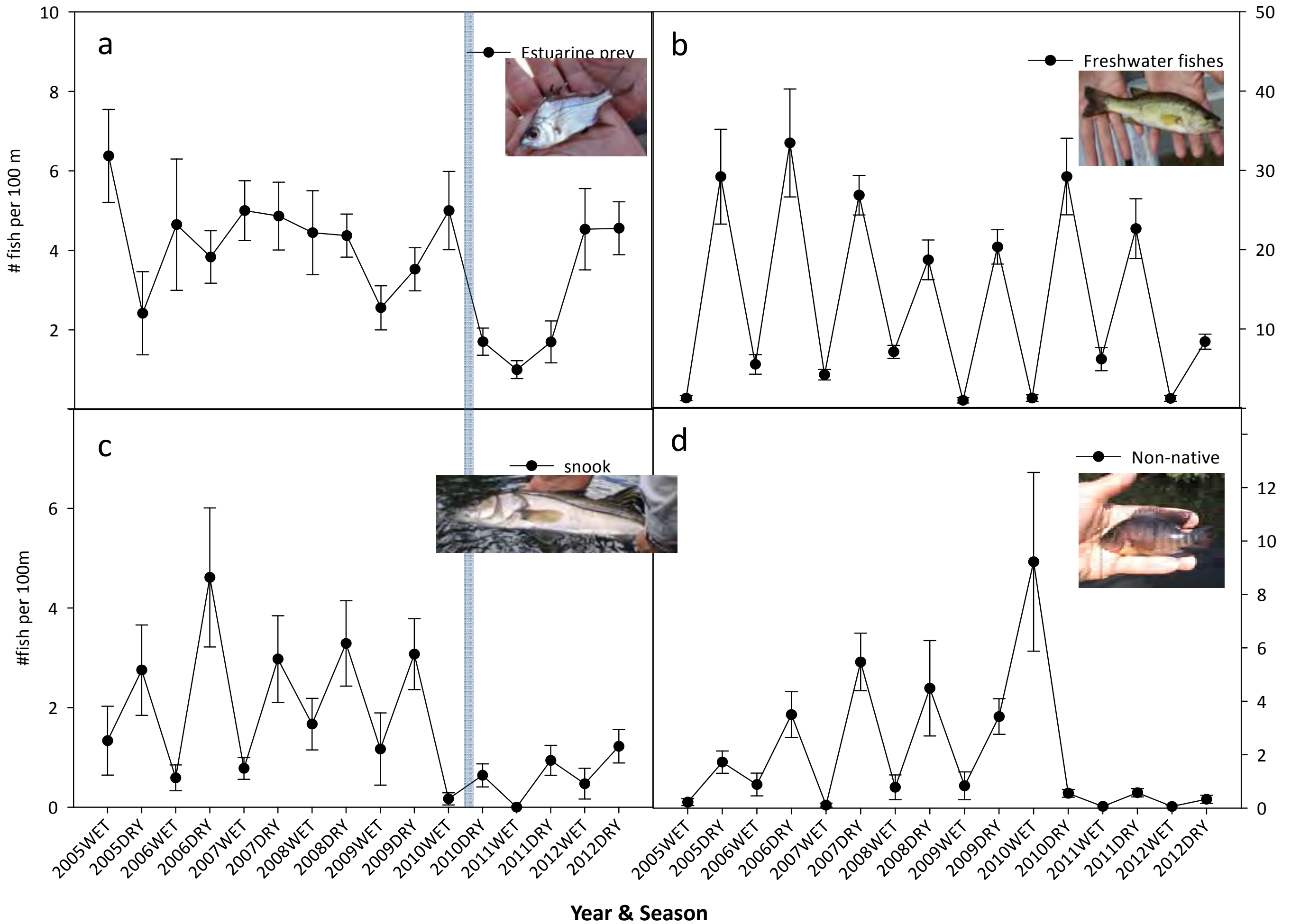

FIGURE 5-25. SEASONAL AND YEARLY ABUNDANCE OF (A) ESTUARINE PREY, (B) FRESHWATER MARSH FISHES (BOTH PREDATORS AND PREY), (C) SNOOK, AND (D) NONNATIVE TAXA ACROSS ALL SAMPLED CREEKS.

Wet season samples correspond to November–December, while dry season samples aggregate early (February–March) and late dry (April–May) samples. The timing of the 2010 cold snap is shown by the blue line.

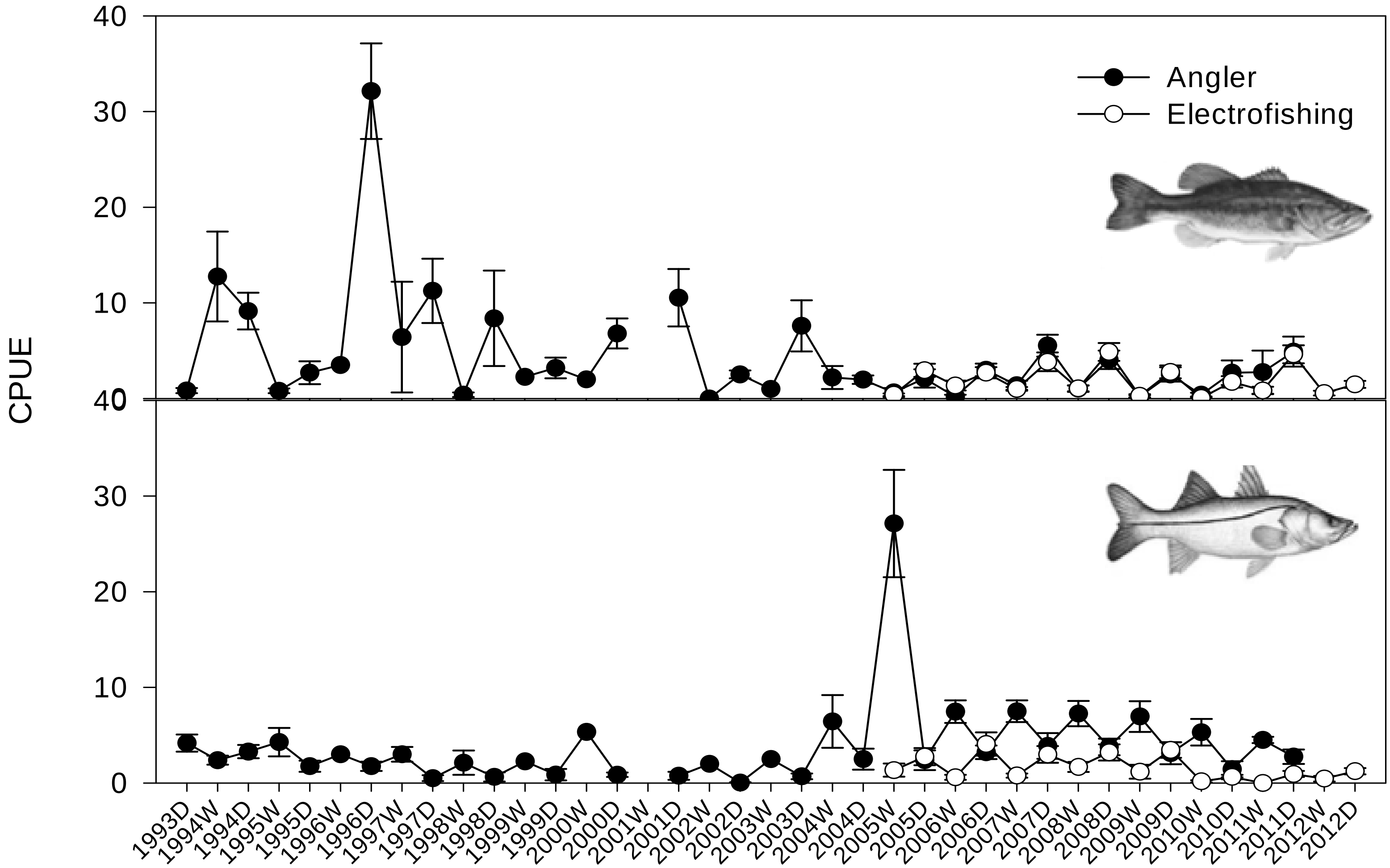

FIGURE 5-26. SEASONAL VARIATION IN CPUE (NUMBER OF FISH PER 100 M OF MANGROVE SHORELINE) VIA ELECTROFISHING AND ANGLER (NUMBER OF FISH CAUGHT PER PERSON PER DAY) OF (A) LARGEMOUTH BASS AND (B) SNOOK BETWEEN 1993 AND 2012.

Wet season samples (July–December) are denoted by W and dry season samples (January–June) by D.

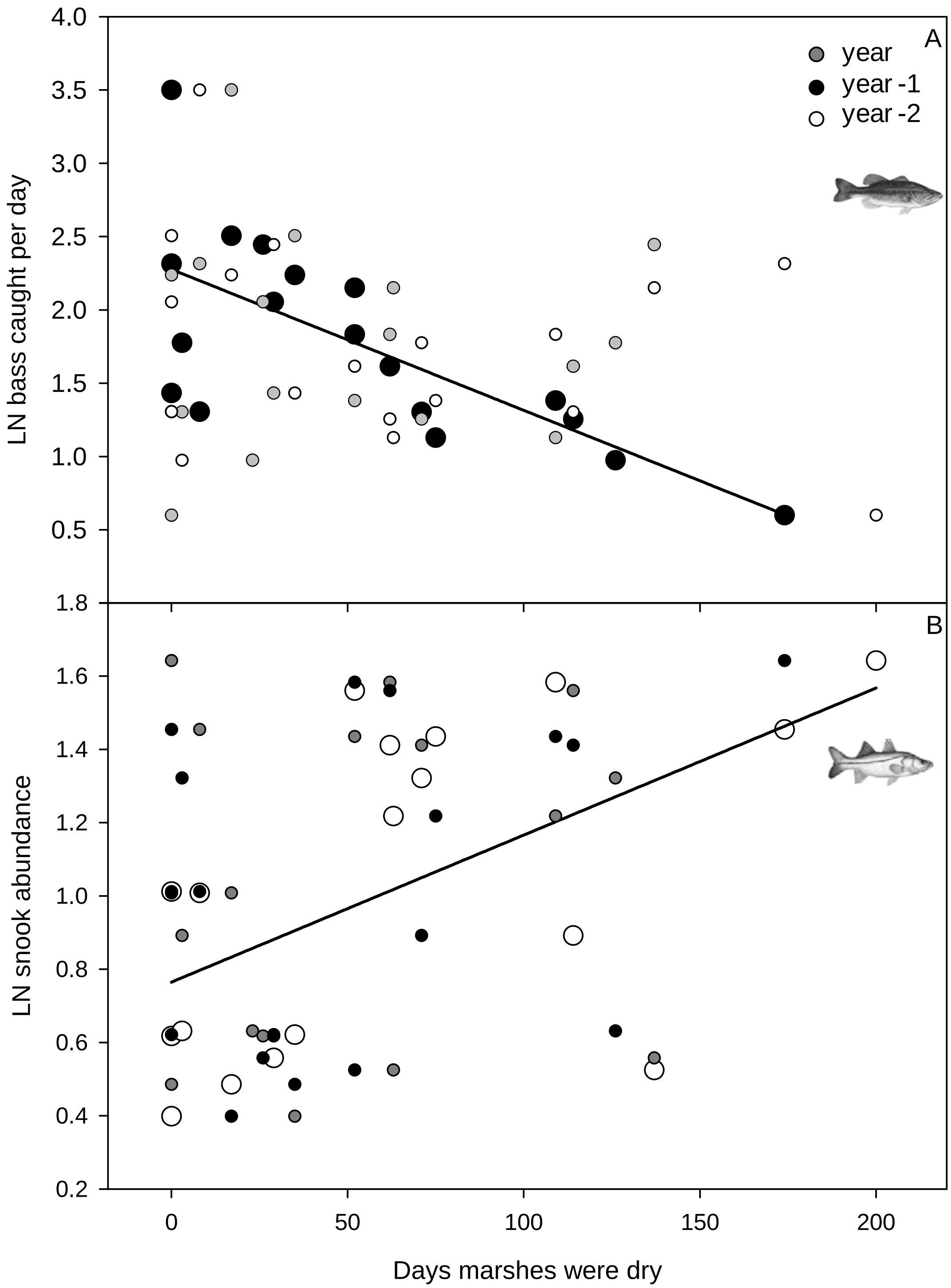

FIGURE 5-27. SCATTER PLOTS COMPARING (A) LARGEMOUTH BASS AND (B) SNOOK CATCHES WITH DAYS MARSHES WERE DRY DURING THE YEAR FISH WERE CAUGHT (GREY), THE PREVIOUS YEAR (BLACK) AND TWO YEAR PRIOR (WHITE).

The time period with the best fit is indicated by the larger circles and is fitted with the regression line.

Use of Fish Monitoring Data for Evaluation Modeling of Wading Bird Prey

Background

Restoration of historical hydrological patterns of the Everglades is a primary goal of the Comprehensive Everglades Restoration Plan (CERP), though exact historical patterns are not known and are logically unattainable because of peat loss and development inside the footprint of the historical ecosystem. Altered hydroperiods resulting from land use changes have caused precipitous declines in faunal elements throughout the Everglades and recovery of aspects of the historical hydrology is seen as the most apparent route to regaining some of the productivity.

RECOVER (2004) proposed a Trophic Hypothesis as the basis of management to restore the abundance and spatial pattern of nesting of wading birds by focusing on recovering their foraging conditions (see also Trexler and Goss, 2009). A desired result of restored hydroperiods is to increase densities of small fishes and invertebrates throughout the Everglades, but especially in the southern Everglades where rookeries historically supported the most nests. Because small fishes are the most abundant vertebrates in the Everglades and are consumed by apex predators, the Trophic Hypothesis predicts that an increase in density of small fish will benefit higher trophic-level predators such as wading birds, reptiles, and larger fish that depend on them as a food source.

Models were developed from long-term monitoring data to provide a comparison of projected small fish density under Existing Conditions hydrology to one possible restoration hydrology, CERP0. The CERP0 model is a projection of proposed restoration conditions approved in the Water Resources Development Act of 2000 and it provides an additional 300,000 acre-feet per year of water deliveries into the Everglades. This water represents 60 percent of the regulatory releases from Lake Okeechobee currently diverted into the St. Lucie and Caloosahatchee estuaries (http://modeling.cerpzone.org/pmviewer/ModelRunInfo.do?modelrunID=55).

Models

Densities of small fishes (less than 8 centimeters [cm]) are highly dependent on variation in hydroperiod. Based on time series data, Trexler and Goss (2009) parameterized a logistic model to predict small fish densities based on the time between drying events (days since dry [DSD]) (see also Donalson et al., 2010). The habitat is considered dry when average daily depth drops below 5 cm. At this depth, sediment and organic material impedes small fish movements and water conditions become increasingly anoxic leading to fish mortality. Despite using only a single independent variable, these logistic models commonly explain the majority of the variation in density of small Everglades fishes (60–70 percent). Because of variation in landscape features and hydrology within different regions of the Everglades, logistic models were fit to data from three primary regions: Water Conservation Areas (WCAs) 3A and 3B, Shark River Slough, and Taylor Slough (***Equation 5-1***, ***Table 5-2***).

$$\text{LOG(TOTFISH + 1)} = \frac{\text{K}}{\left[1+\left({(\text{K}-\text{Y0})}/{\text{Y0}}\right)e^{(-\text{r}*DSD)}\right]}$$ **Equation 1**

Where,

r = growth constant
K = asymptotic density
Y0 = Y intercept
DSD = days since dry
TOTFISH = total small-sized fish density (number of individuals) per square meter (m^2)

TABLE 5-2. SMALL-SIZED FISH DENSITY LOGISTIC REGRESSION EQUATION PARAMETERS PER MONITORING REGION.

	Monitoring Region		
Equation Parameter	**WCA 3A & WCA 3B**	**Shark Slough**	**Taylor Slough**
K	2.901	2.757	2.625
r	0.097	0.006	0.003
Y0	0.300	1.486	1.08

Source: Donalson et al., 2010

The objective of this project was to evaluate how two different hydrology scenarios (Existing Conditions and CERP0) would affect small fish densities throughout the Everglades using rainfall observed over a 36-year time period (1965–2000). CERP0 models hydrology resulting from an effort to restore aspects of historical hydroperiods by removing some anthropogenic barriers to flow (e.g., canals and levees).

Methods

Using the logistic equations and parameters in ***Table 5-1***, the average densities per square meters per day (/m^2/day) of small fish at each primary sampling unit (PSU) were estimated. A generalized recursive tessellated grid was used to select 146 PSUs distributed over the Greater Everglades landscape (Stevens and Olsen, 2003). These sites were selected because hydrological output generated from the 2-mile by 2-mile models could be adjusted to local topography using MAP in situ water depth measurements assuming a flat plane in the model cell. Also, MAP data provides observations of fish density at these sites that are used to evaluate model predictions.

The Existing Conditions and CERP0 models were run on a 2-mile by 2-mile grid, which is too large to capture important ecological features such as Taylor Slough. Pseudo-topography was created by determining the difference in observed water depth at the CERP MAP study sites visited in 2005 and water depth estimated at the same locations by the Everglades Depth Estimation Network (EDEN; http://sofia.usgs.gov/eden/). EDEN is run on a 400-meter (m) by 400-m grid. This correction was then used to adjust the 2-mile by 2-mile depths for 2000 to the EDEN depths that year at the PSU coordinates. This two-step process gave us a depth offset for the study PSUs to create relief within the simulated hydrology. The 36-year time series of water depth for cells with CERP MAP sampling sites were taken, the daily depths for each MAP site offset were adjusted, and the DSD for each day in the time series was calculated. These DSD values were then transformed to a fish density time series for each PSU for both the Existing Conditions and CERP0 scenarios.

Because these models compute log(density), the results wer back-transformed to yield fish densities in units of number of individuals per m^2 for the PSU. The average daily fish density/m^2 was then calculated for each of 10 landscape units that are enclosed by levees, canals, and/or mangrove creeks. The Shark River Slough model was used for regions in WCA 2A, WCA 2B, and the Arthur R. Marshall Loxahatchee National Wildlife Refuge. The model for Taylor Slough was also used for regions in the oligohaline zone, Lostman's River, and Southern Marl Prairies. Densities for WCA 3A and WCA 3B were computed using the model parameters developed for those areas.

The cumulative difference in predicted daily fish density/m^2 between the CERP0 and Existing Conditions models was calculated [sum(CERP0 fish density – existing fish density)] for each region to summarize differences. CERP0 provides additional water deliveries of 300,000 acre-feet per year across the redline and into the Everglades that result from CERP0.

Model Output

The following model results are reported:

- Time series plots comparing cumulative DSD between Existing Conditions and CERP0 models for each region (***Figure 5-28***)
- Time series plots of cumulative difference in predicted daily average fish density/m^2 between Existing Conditions and CERP0 models for each region (***Figure 5-29***)
- Maps of spatial distributions of predicted daily average fish density/m^2 across the regions for the Existing Condition model, CERP0 model, and the difference between the models (***Figures 5-30*** and ***5-31***)

Spatial data from these models can be reported in two ways. The first is to report bubble plots at the sites where data are collected for the MAP with sizes proportional to the difference in density between the two models (***Figure 5-30***). Because the scale of the increases in fish densities is so much bigger than the scale of decreases, sites were color-coded differently for increases and decreases. The second report uses kriging to smooth the differences among PSU estimates to make a smoothly colored map of densities and differences. In this map, kriging was contrained to within areas enclosed by levees and canals in the current ecosystem under the notion that fish cannot cross such boundaries; therefore, data from either side should not be used in a common regression model (***Figure 5-31***).

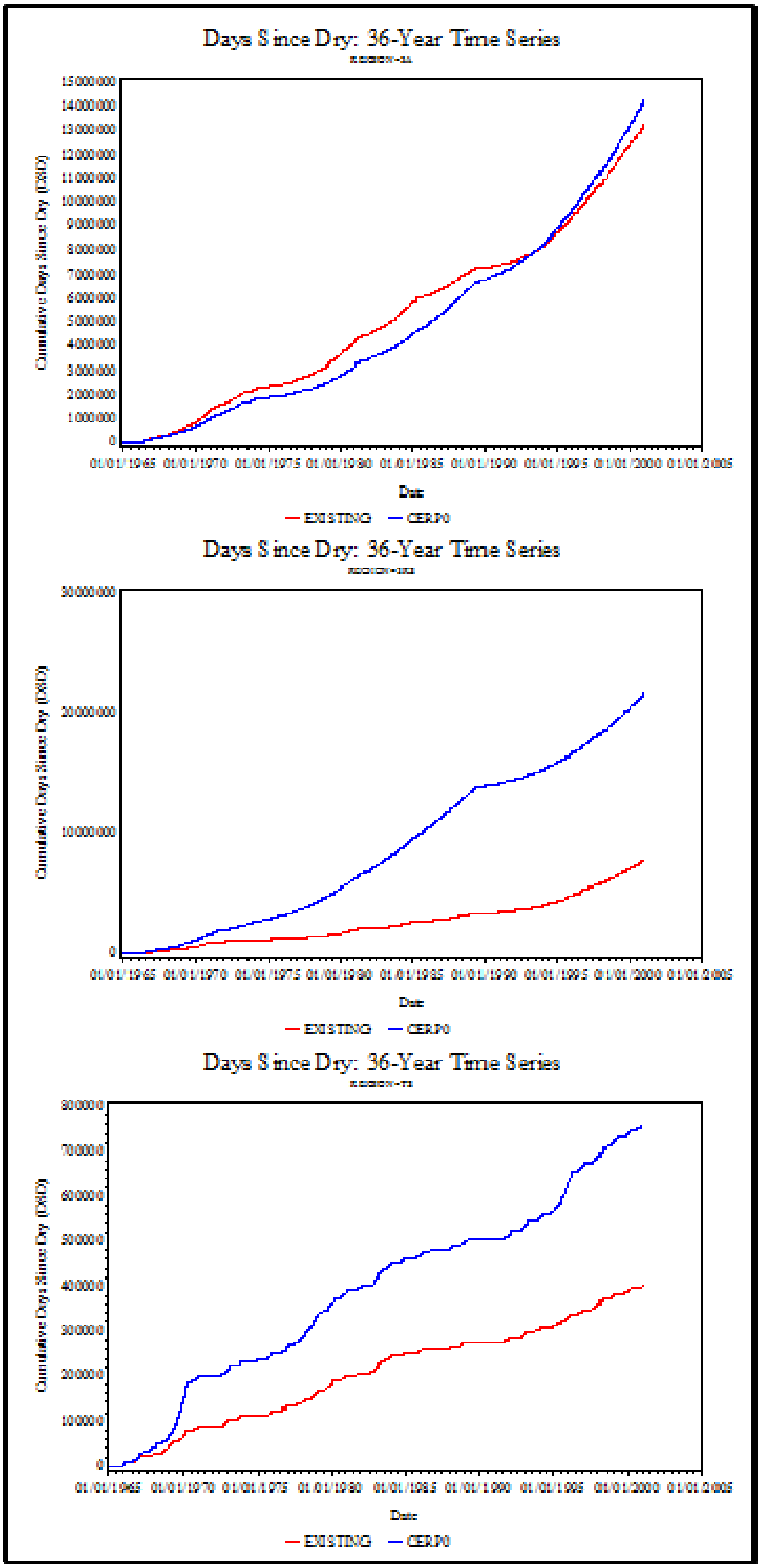

FIGURE 5-28. COMPARISON OF CUMULATIVE DSD SIMULATED FROM EXISTING CONDITIONS AND CERP0 MODELS FOR WCA 3A, SHARK RIVER SLOUGH, AND TAYLOR SLOUGH.

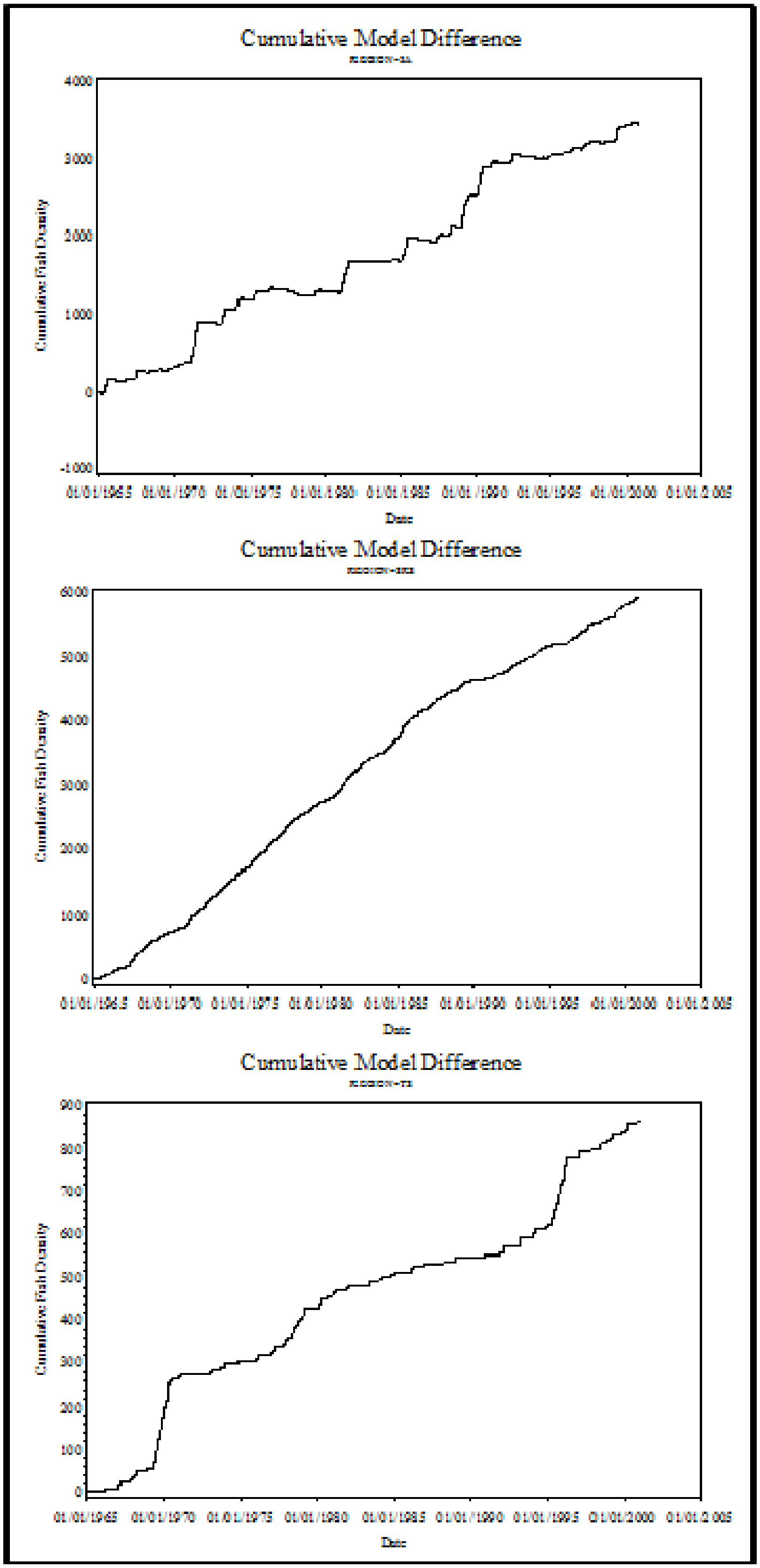

FIGURE 5-29. COMPARISON OF DIFFERENCE IN FISH DENSITY PREDICTED BY EXISTING CONDITIONS AND CERP0 MODELS FOR WCA 3A, SHARK RIVER SLOUGH, AND TAYLOR SLOUGH .

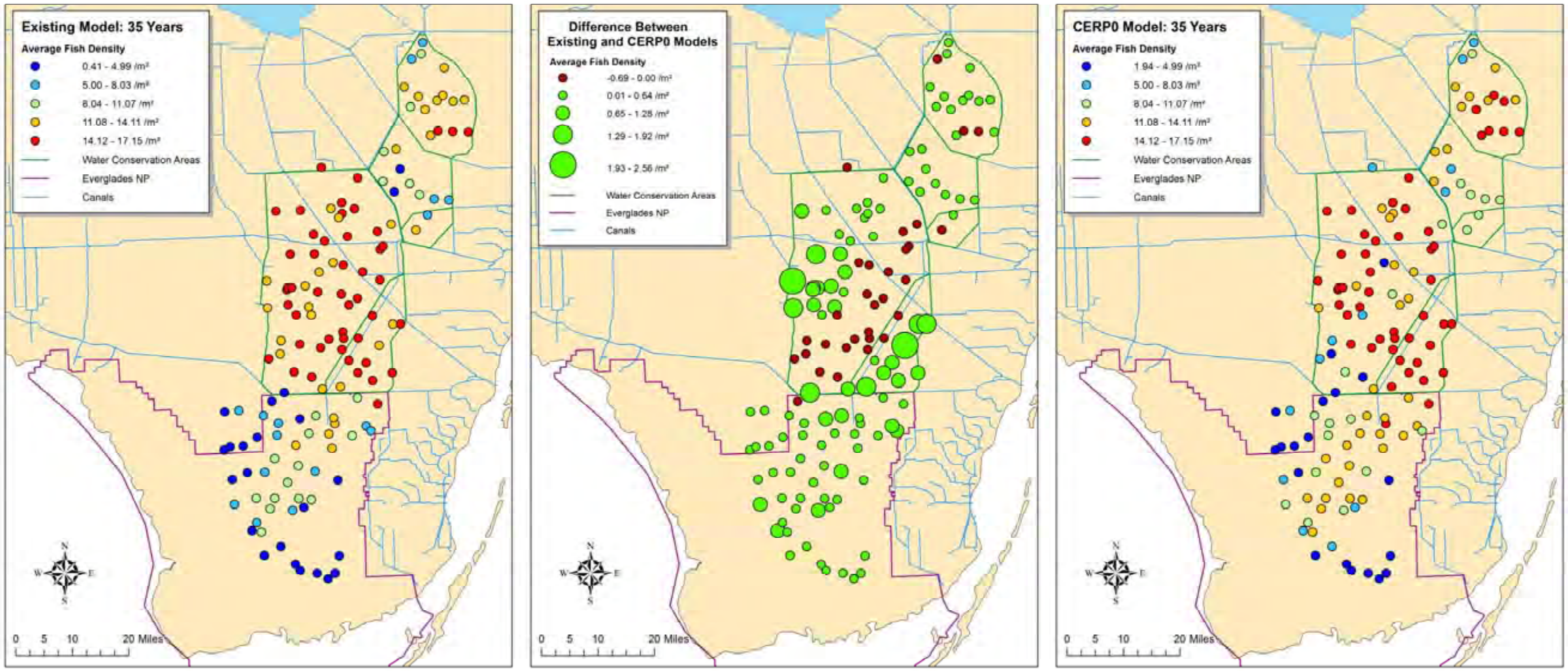

FIGURE 5-30. AVERAGE DAILY FISH DENSITY OVER A 35-YEAR TIME PERIOD (1965–2000) PREDICTED BY EXISTING CONDITIONS AND CERP0 MODELS (PSU FISH DENSITY BUBBLE PLOT MODEL REPRESENTATION).

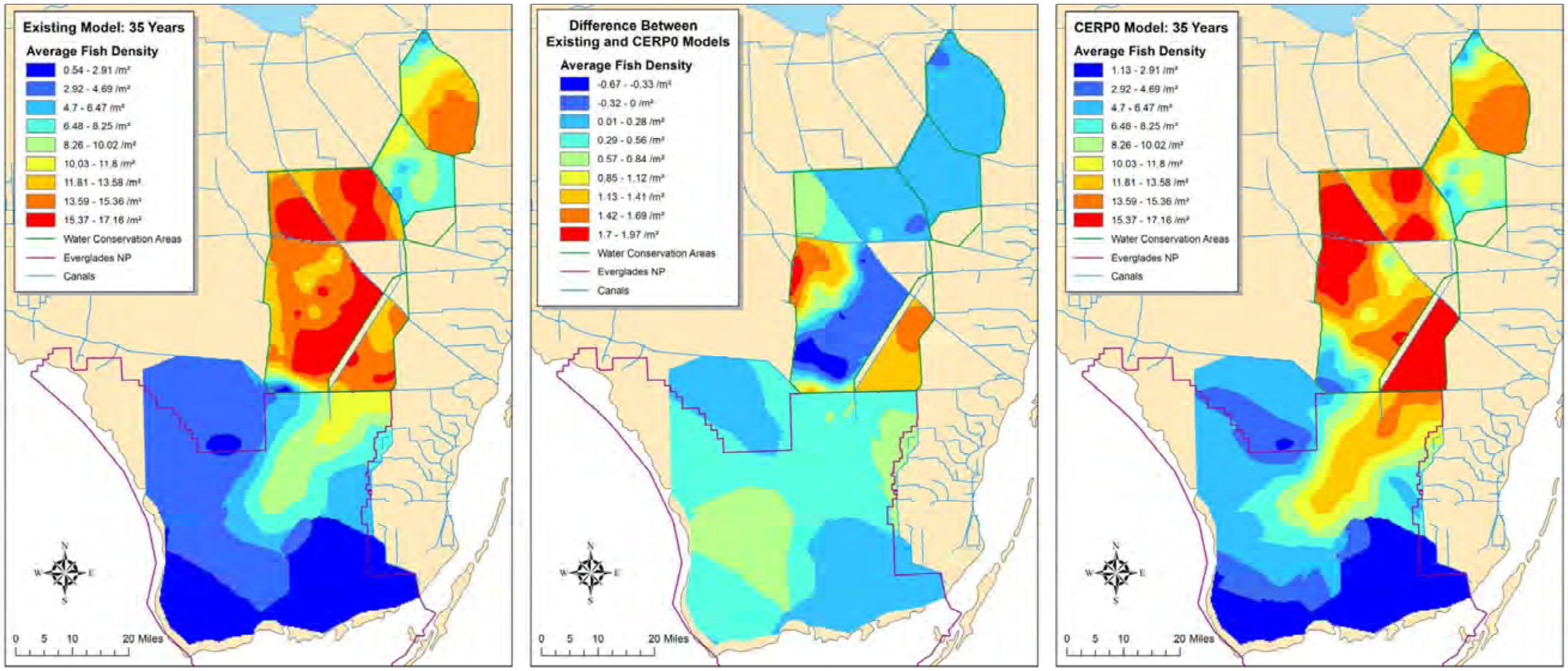

FIGURE 5-31. AVERAGE DAILY FISH DENSITY OVER A 35-YEAR TIME PERIOD (1965–2000) PREDICTED BY EXISTING CONDITIONS AND CERP0 MODELS (KRIGED FISH DENSITIES WITH BARRIERS TO FISH DISPERSAL).

Results

In all regions, increased water delivery in the CERP0 model predicted fewer drying events than the Existing Conditions model, leading to greater DSD (***Figure 5-28***) and higher daily fish density/m² (***Figure 5-29***) throughout the 36-year time series. Though the average increase in densities of small fishes appears small (0.65–1.28/m² in the PSUs in Shark River Slough and 0.01–0.64/m² in Taylor Slough), these differences represent large numbers of fishes because of the large areas involved (***Figure 5-30***). These increases in daily average small fish density/m² translate to substantially higher biomass of small fishes when concentrated into drying pools in the dry season, when bird feeding is most critical to support growing chicks. Based on the Trophic Hypothesis, this increase in food resources should promote increases in abundances of many Everglades species (e.g., wading birds, alligators, and large fish).

The largest gains in daily average fish density were predicted for PSUs in WCA 3B and the western portion of WCA 3A. In these areas, fish densities often increased in excess of 0.65/m² up to 2.56/m² (***Figure 5-30***). Scaled up in space and time this translates to a very large increase in biomass. In contrast, the eastern portion of WCA 3A was predicted to decrease in fish densities by up to -0.69/m² (***Figure 5-30***). This area has been maintained at unnaturally high water levels with sustained periods of inundation, so restoration to historical hydroperiod would be consistent with a small decrease in small fish densities in this area.

Conclusion

The increased fish densities predicted for CERP0 relative to the Existing Conditions hydrology throughout most regions of the Everglades supports this scenario as a change in the direction targeted for CERP implementation. This increased fish production should lead to increased abundance of higher vertebrates that are food limited, including wading birds, alligators, and large fish.

Trophic Linkage of Wading Birds, Hydrology, and Wet and Dry Season Aquatic Fauna

Restoring historical abundance and spatial patterns of nesting wading birds is an important goal for the CERP. The Trophic Hypothesis of the CERP MAP states that (1) wading bird nesting in the modern Everglades is limited by prey availability, (2) prey production is determined by hydrological variation, and (3) historical hydrological variation fostered increased prey production in the southern Everglades, thus supporting large colonies of nesting birds (***Figure 5-32***). The first six years of MAP monitoring have generated data to evaluate and update the Trophic Hypothesis, with the goal of creating predictive models that provide real-time advice to water managers on operations that could facilitate prey production and support wading bird nesting. To accomplish this, a deeper understanding was needed of prey availability that links wet season production of aquatic fauna to the physical processes that redistribute those animals into drying pools. The MAP integrated dry season and wet season fauna sampling is the first study to quantify the constituent parts of prey availability in a way that allows for predictions of how high quality prey patches are created that link wading bird foraging and hydrologic conditions driven by water managers.

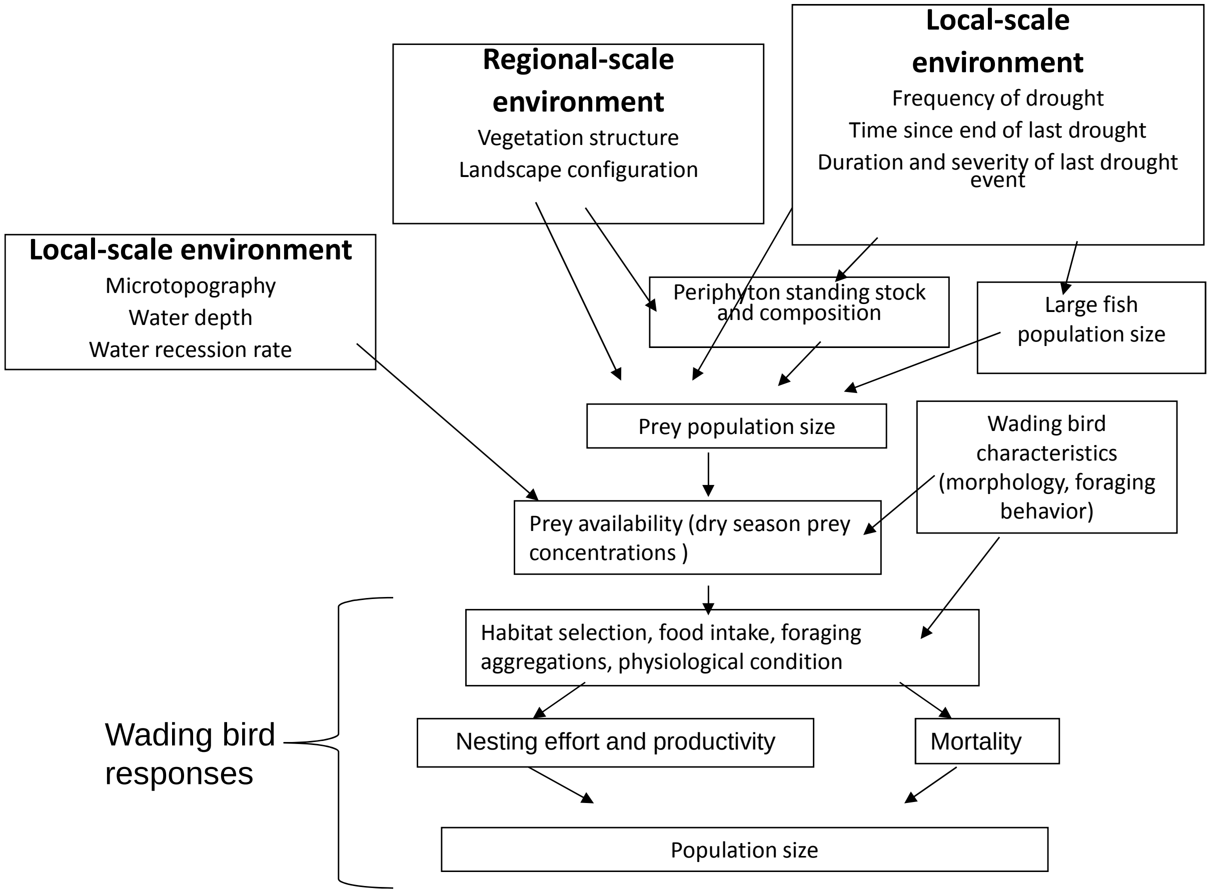

FIGURE 5-32. A CONCEPTUAL MODEL ILLUSTRATING THE CERP MAP TROPHIC HYPOTHESIS.

Everglades wading birds consume fish and aquatic macroinvertebrates (primarily crayfish). Nesting success depends on wading bird foraging success during the dry season (January through May); however, the wet season (June through December) is important for the production of prey even though few birds are present. Fish and macroinvertebrates wre sampled during the wet season to capture spatial and interannual patterns of wading bird prey production, and again during the dry season to determine how this production is made available in concentrated patches (***Figure 5-33***). The results have confirmed that the density of fish and large invertebrates in pools on the trailing edge of the seasonally drying marsh is considerably higher than densities at the same time of year in deeper water (***Figure 5-34***), illustrating the importance of the physical processes that redistribute prey into drying pools. Comparisons of individual fish species densities between drying pools and deeper areas show that drying pools where wading birds forage have a higher proportion of flagfish (*Jordanella floridae*) and marsh killifish (*Fundulus confluentus*) (***Table 5-3***), two species that grow to sizes preferred by wading birds.

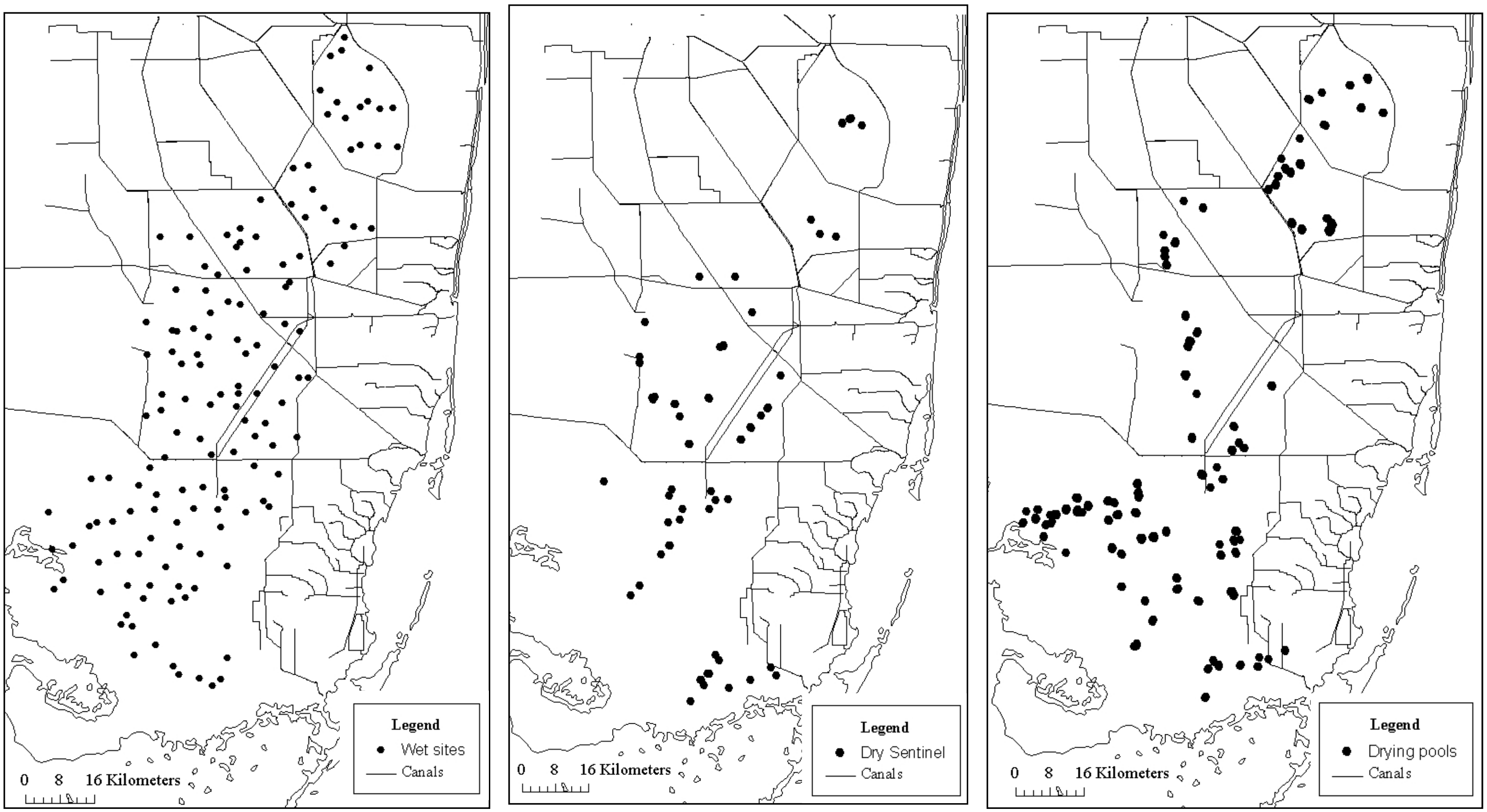

FIGURE 5-33. LOCATION OF WET SEASON AND DRY SEASON STUDY SITES.

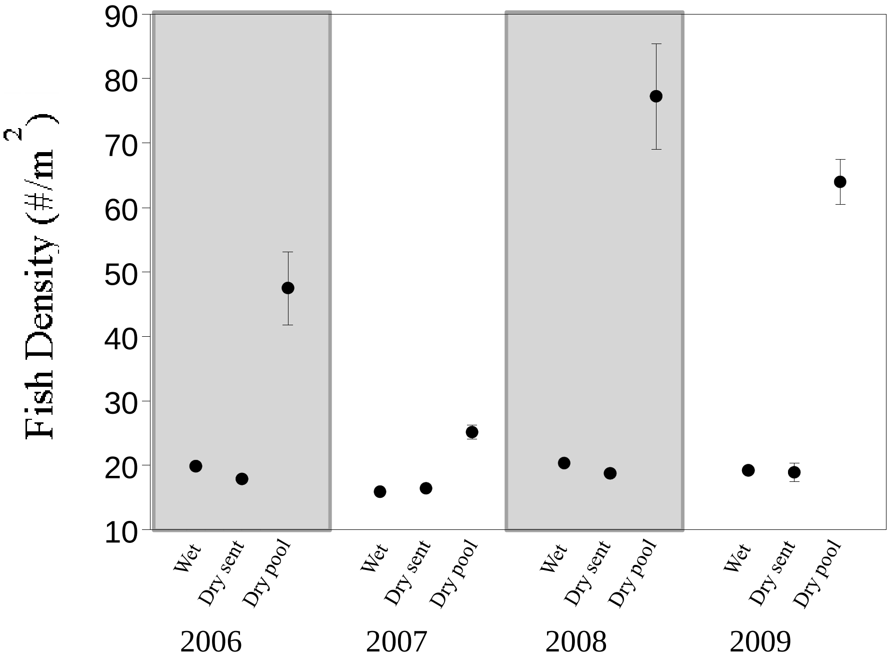

FIGURE 5-34. DENSITY IN NUMBER PER SQUARE METER (#/M^2) OF FISH DURING THE WET SEASON, THE DRY SEASON IN FLOODED SENTINEL SITES, AND THE DRY SEASON IN DRYING POOLS.

TABLE 5-3. SPECIES COMPOSITION AT WET SEASON SITES, FLOODED DRY SEASON SENTINEL SITES, AND DRY SEASON POOLS.

Relative abundance (%) is reported.

Common Name	Scientific Name	Wet season (%)	Dry Season Sentinel (%)	Dry Season Pool (%)
Eastern mosquitofish	*Gambusia holbrooki*	26.6	13.0	20.8
Flagfish	*Jordanella floridae*	14.7	17.6	30.9
Bluefin killifish	*Lucania goodei*	9.3	10.4	6.6
Sailfin molly	*Poecilia latipinna*	5.9	10.4	5.8
Marsh killifish	*Fundulus confluentus*	9.2	5.7	9.3
Golden topminnow	*Fundulus chrysotus*	10.2	13.3	7.7
Least killifish	*Heterandria formosa*	9.5	2.8	6.3
Dollar sunfish	*Lepomis marginatus*	1.7	7.5	1.7
Everglades pygmy sunfish	*Elassoma evergladei*	2.6	5.5	4.2
Spotted sunfish	*Lepomis puctatus*	1.67	2.9	3.2

The fish portion of "prey" biomass was highest when the variability in microtopography was high, the rate of receding water was high, vegetation density was low, and the biomass of fish in the preceding wet season was high (***Figure 5-35a–c***). The positive effect of water recession rate was strongest when wet season biomass was high and likewise, the positive effect of wet season biomass was strongest when water level recession rate was high. The crayfish portion of "prey" biomass differed from fish in that crayfish biomass was positively related to vegetation density and negatively related to flocculent thickness. In addition, crayfish biomass (but not fish) was affected positively by water depth at the trap site and negatively by day since last drydown (***Figure 5-36a-f***).

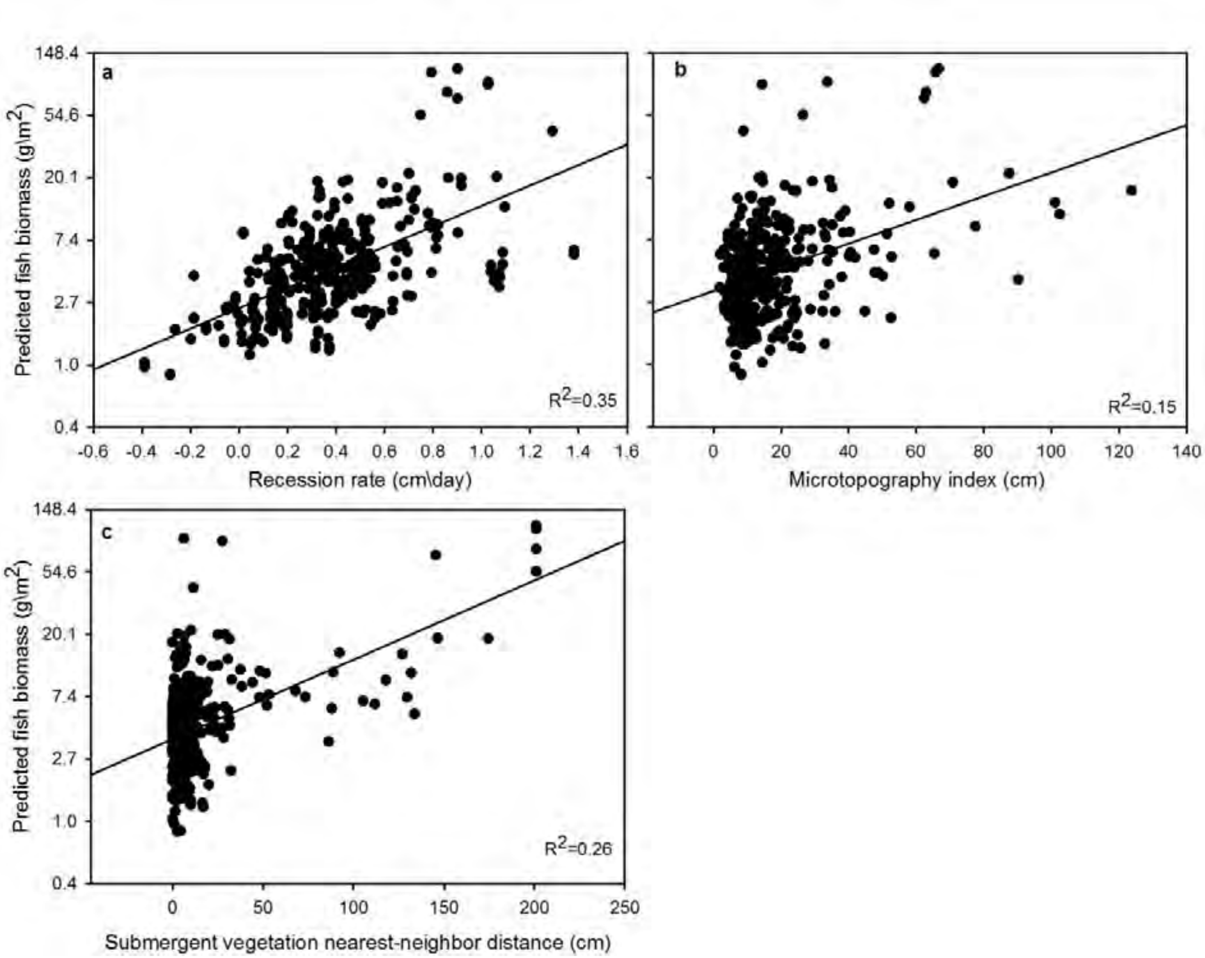

FIGURE 5-35. MODEL-AVERAGED PREDICTED VALUES OF FISH BIOMASS IN GRAMS PER SQUARE METER (G\M^2) PLOTTED AGAINST (A) OBSERVED RECESSION RATE, (B) MICROTOPOGRAPHY INDEX AND, (C) SUBMERGED VEGETATION NEAREST-NEIGHBOR DISTANCE.

All panels are plotted on log scale.

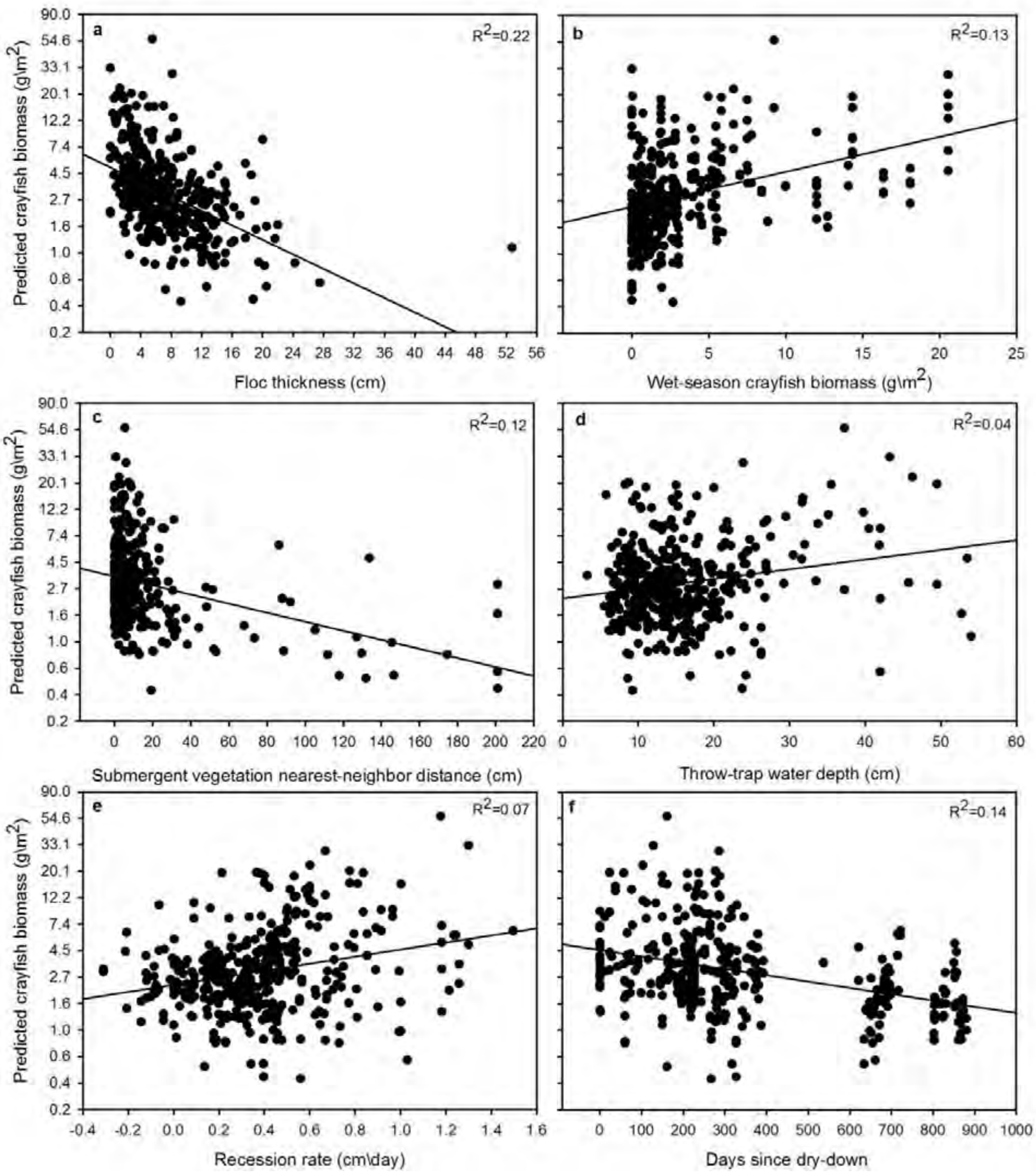

FIGURE 5-36. MODEL-AVERAGED PREDICTED VALUES OF DRY SEASON CRAYFISH BIOMASS PLOTTED AGAINST OBSERVED (A) FLOCK THICKNESS, (B) WET SEASON CRAYFISH BIOMASS, (C) SUBMERGED VEGETATION NEAREST-NEIGHBOR DISTANCE, (D) THROW TRAP WATER DEPTH, (E) RECESSION RATE, AND (F) DAYS SINCE LAST DRY-DOWN.

All panels are plotted on log scale.

An important test of the Trophic Hypothesis is whether the integrated wet and dry season prey data can be used to predict wading bird nesting. This study shows that wet season prey biomass is not related to nesting in a direct way (***Figure 5-37a***); however, the models confirm the Trophic Hypothesis by showing that wet season prey density is a key component of dry season prey availability, which is directly related to wading bird nesting (***Figure 5-37b***). This is a striking confirmation of the Trophic Hypothesis, even with so few years of MAP sampling. Interannual variation is the key to showing the linkages hypothesized by the Trophic Hypothesis, so in spite of large within year efforts, only a multiyear effort can develop the models needed to guide management. These results (***Figure 5-37***) also illustrate why previous attempts to relate fish to wading bird nesting were unsuccessful. Past work failed to account for the mechanism that turned wet season production into high quality prey patches that, in turn, support nesting. This work also illustrates how the hypothesis structured design of the MAP can be used to reveal ecological 'surprises' that lead to a deeper understanding of the ecosystem response to hydrologic changes. For example, in 2009 dry season prey density was only moderately high, but nesting effort was very high. This data pointed to a new landscape-scale mechanism by which prey concentrations become available to wading birds. If confirmed with additional years of MAP data, such insights will improve the ability to link the hydrologic changes brought about by CERP implementation with wading bird nesting. Furthermore, this effort is producing models that can be used to evaluate water recession rates in real-time and project their likely impact on foraging success and nesting in the same year. Such real-time models can guide water managers as they make daily decisions about operations of the Everglades water distribution system.

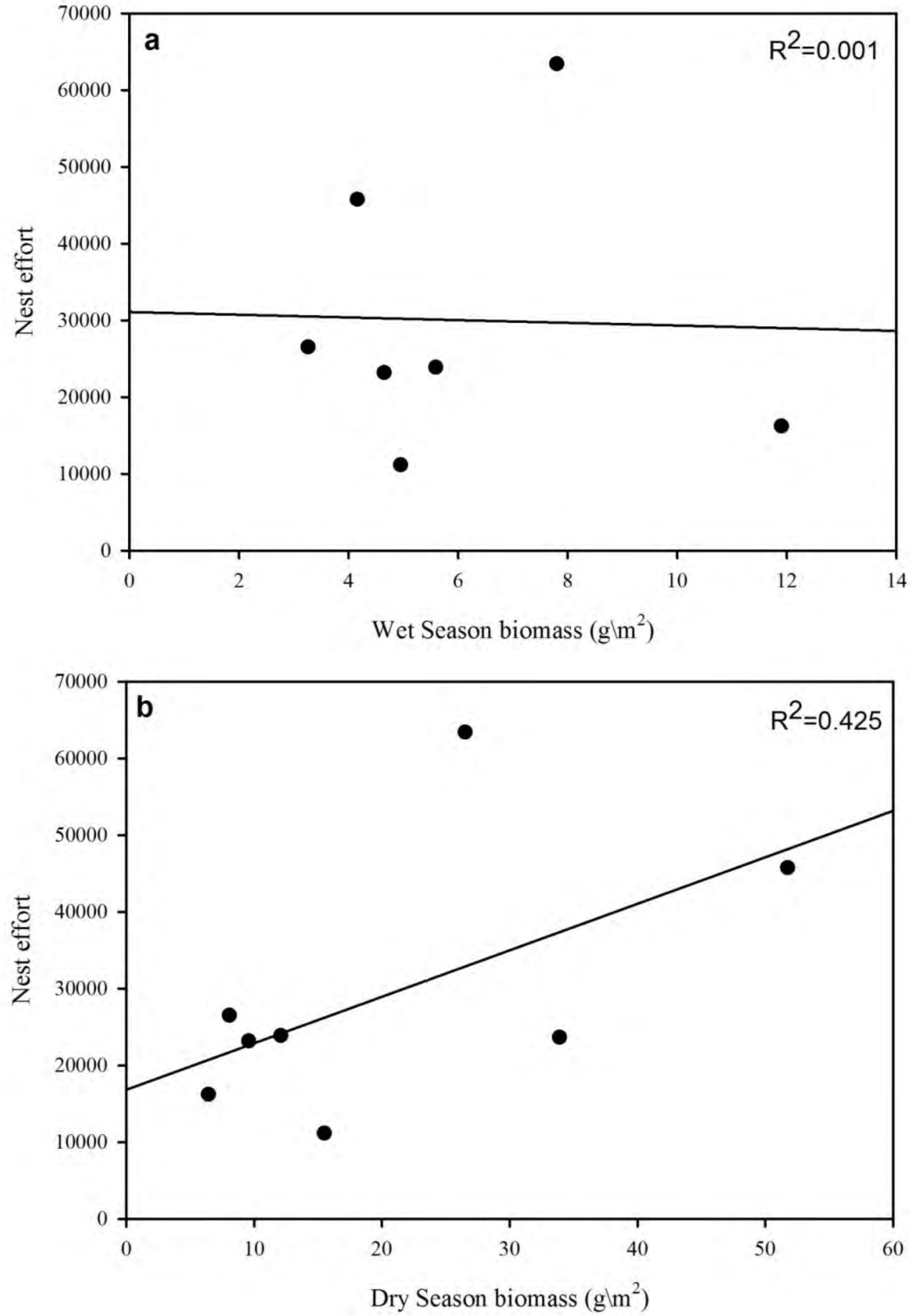

FIGURE 5-37. THE RELATIONSHIP BETWEEN WADING BIRD NESTING EFFORT AND THE DENSITY OF FISH DURING (A) THE WET SEASON AND (B) IN DRYING POOLS DURING THE DRY SEASON.

Wading bird nest effort is pooled across wood stork (Mycteria americana), great egret (*Ardea alba*), white ibis (*Eudocimus albus*), and snowy egret (*Egretta thula*) nesting numbers/estimates from 2005–2012.

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CHAPTER 6

SOUTHERN COASTAL SYSTEMS

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CHAPTER 6 SOUTHERN COASTAL SYSTEMS MODULE

INTRODUCTION

This section provides an update on work that has been done to further assessments within the Southern Coastal Systems (SCS) region including performance measure and model development for salinity, sportfish, and seagrass. Brief updates on several indicators, including algal blooms, pink shrimp, and roseate spoonbills are also provided in this section.

For more information on the SCS, see the *2009 System Status Report* (SSR) (RECOVER, 2010; http://www.evergladesplan.org/pm/ssr_2009/ssr_main.aspx). The 2009 assessment of the SCS region can be accessed directly at http://www.evergladesplan.org/pm/ssr_2009/mod_scs.aspx.

SALINITY

Introduction

The importance of salinity as an indicator for ecosystem health in Florida's southern estuaries cannot be overstated. The 2009 SSR highlighted salinity as the most important physical parameter for determining species and community composition in coastal waters, and the physical parameter most likely to be affected by Comprehensive Everglades Restoration Plan (CERP) implementation in the SCS region. Salinity is the linchpin to attaining ecological restoration in these estuaries, and it is critically tied to virtually all ecological indicators and performance measures in the region. More information on salinity in the SCS salinity can be found on the SCS Salinity page of the 2009 SSR available at http://www.evergladesplan.org/pm/ssr_2009/hc_scs_salinity_results.aspx.

This section provides updates on progress made towards developing salinity predictive and assessment tools and setting restoration targets for the estuaries of the SCS, which include Biscayne Bay, Florida Bay and the estuaries along the southwestern coast of Florida.

Salinity Restoration Target Setting for Southern Biscayne Bay

This section briefly describes the progress made on developing salinity predictive tools and setting salinity restoration targets for southern Biscayne Bay since the 2009 SSR was published. On February 1–2, 2011, the Restoration Coordination and Verification Program (RECOVER) SCS Regional Coordinators convened an Interim Salinity Goal/Target Setting Workshop to determine approaches for setting salinity targets in Florida's southern estuaries. One of the objectives of this meeting was to select a tool(s) that would facilitate setting interim salinity targets in southern Biscayne Bay. Southern Biscayne Bay is the area represented between Shoal Point (just south of Matheson Hammock Park) and Mangrove Point (adjacent to the Arsenicker Keys) (***Figure 6-1***).

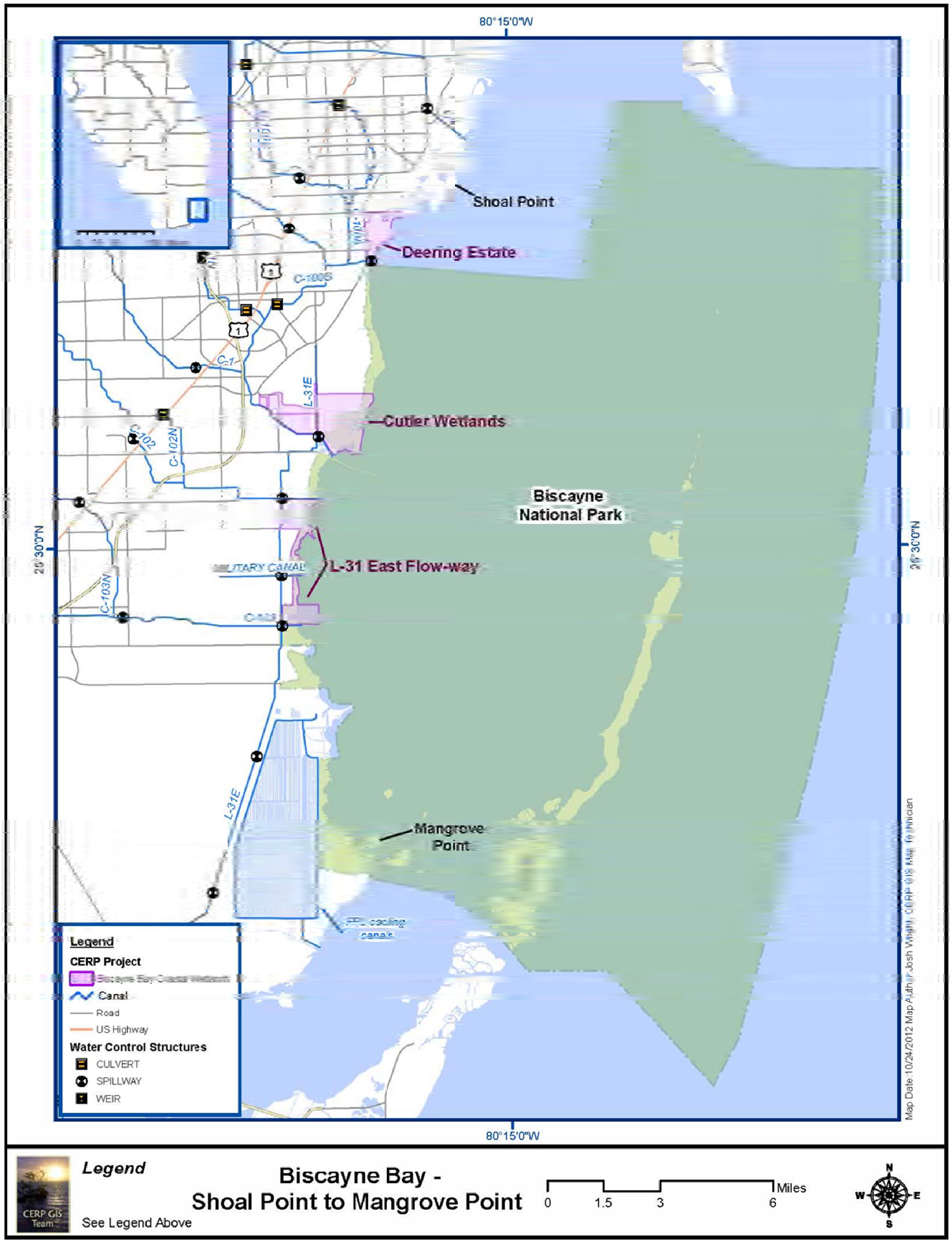

FIGURE 6-1. MAP SHOWING SOUTHERN BISCAYNE BAY.

Agricultural and urban development of the Biscayne Bay watershed substantially altered the upland hydrology and, consequently, changed salinity patterns in Biscayne Bay. Insufficient information exists on pre-development upland hydrology and salinity patterns in Biscayne Bay to definitively set a restoration salinity target. To work around the lack of historic hydrologic information, historic or natural salinity conditions can be estimated using mathematical simulations (e.g., hydrodynamic models). Of the hydrodynamic tools currently available for Biscayne Bay, the team consensus during the February 2011 workshop was to use the Biscayne Bay Simulation Model (BBSM) and/or the Biscayne Bay Coastal Wetlands (BBCW) Adaptive Hydraulics (AdH) Model. Both models have been well documented and applied. More information on the BBSM can be found in Wang et al. (2003). Use of the AdH model would require adaptation of the existing BBCW TABS-MDS model that was previously developed for simulating salinity in the south central area of Biscayne Bay and utilized to determine the final accepted design for the CERP BBCW Project.

The TABS-MDS platform is no longer supported and is what drove the requirement to adapt the BBCW TABS-MDS model to the AdH platform. Subsequent team discussion, and the lack of technical support available for the BBSM, resulted in the decision to use the AdH model as the predictive tool for Biscayne Bay.

In mid-2011, a southern Biscayne Bay target-setting technical subteam was formed that included the SCS Regional Coordinators and other representatives from the United States Army Corps of Engineers, South Florida Water Management District (SFWMD), and the National Park Service to finalize the transfer of the BBCW TABS-MDS model to AdH and develop restoration target-setting scenarios (described below) for input to the AdH model.

Uncertainty exists regarding which upstream hydrologic models available to the SCS can provide realistic pre-drainage or “natural” western boundary conditions for the AdH model. To address this, the subteam opted to run five independent target-setting scenarios (i.e., boundary conditions) through the AdH model. The CERP existing condition baseline planning scenario (CERP2000) will also be run for comparison against the target-setting scenarios. The larger team assembled for the 2011 workshop will be presented with these scenarios and will decide which one will be used to set the salinity target for southern Biscayne Bay. The restoration target-setting scenarios are as follows:

- **Scenerio 1 (NSM) –** SFWMD Natural System Model version 4.6.2 (NSM) output along the western shoreline of Biscayne Bay (for more information on the NSM see (http://www.sfwmd.gov/portal/page/portal/xweb%20-%20release%202/natural%20system%20model)
- **Scenerio 2 (NSM-ALT) –** NSM flow (i.e., Scenario 1 flow volumes and timing) directed through historic river and creek locations (i.e., flow directed to fit a natural South Florida creek hydrograph)
- **Scenerio 3 (NSRSM) –** Natural System Regional Simulation Model (NSRSM) output along the western shoreline (for more information on the NSRSM see https://my.sfwmd.gov/portal/page/portal/common/pdf/splash/natsys_regmodel.pdf)

- **Scenerio 4 (NSRSM-ALT) –** NSRSM flow (i.e., Scenario 3 volumes and timing) directed through historic river and creek locations (i.e., flow directed to fit a natural South Florida creek hydrograph)
- **Scenerio 5 (MECB) –** Modified Existing Condition Baseline (MECB) using existing flow volumes directed through historic river and creek locations with natural timing

Scenario 1

The NSM presumably should simulate a "natural" or pre-development hydrological regime with recent climatic conditions. NSM output is readily available and it incorporates a realistic groundwater component, but it possesses some short-comings including the following:

- Substantially less flow to south central Biscayne Bay than the existing condition
- Stream hydrographs do not simulate a "natural" pattern
- Stream locations are in the wrong places

Due to the short-comings listed above, NSM-based hydrological patterns are not anticipated to be similar to a realistic "restored" condition. For detailed documentation on NSM shortcomings see *Modeling Support for Salinity Restoration Target Development for Southern Biscayne Bay* (Alleman et al., 2012), which is available from the 2012 SSR Southern Coastal Systems Salinity page: http://www.evergladesplan.org/pm/ssr_2012/hc_scs_salinity_results_2012.aspx.

Scenario 2

NSM-ALT was developed to address the distribution problem observed with NSM by redirecting NSM flows through historic river and creek systems. Historic flow paths were determined using historic charts, maps, aerial photographs and written accounts to identify the size and location of creeks. This scenario is does not address the NSM flow volume and timing problems.

Scenarios 3 and 4

NSRSM has been in development by the SFWMD and has recently become available for use by RECOVER. An examination of the NSRSM output along the southeastern edge of the model domain (adjacent to Biscayne Bay) shows volumes greater than NSM flows, but less than existing flows. As with NSM, the NSRSM stream hydrographs do not appear to simulate a natural pattern for South Florida undisturbed creek systems. The NSRSM stream locations also appear to be in the wrong locations. As with NSM, the target setting subteam developed NSRSM-ALT to address the distribution problem observed with NSRSM, but not flow volume and timing problems.

Scenario 5

MECB was developed as an alternative to NSM and RSNSM scenarios to address the concerns with those scenarios described above. One major difference between this scenario and the NSM and RSNSM scenarios is that the MECB scenario uses existing freshwater flow volumes, instead of simulated "natural" or historic freshwater flow volumes. The subteam believes that the existing flow volumes more accurately represent historic volumes, than the NSM or NSRSM estimates, which are substantially less than existing flows. The MECB approach includes the following:

- Total freshwater flow volumes that presently exit the major conveyance canal system in southern Biscayne Bay would be used as input to the AdH model. The advantages of using existing flows is that the volumes are well documented over at least 29 years, individual years can be selected based upon a range of climatic conditions, and sets the restoration target within a reasonable range of attainment.

- The annual pattern of daily flow would be modified to match a natural stream flow pattern appropriate for the size of each outlet creek to the bay.

- Freshwater outflow to the bay would be redirected through historic river and creek systems. Historic flow paths were determined using historic charts, maps, aerial photographs and written accounts to identify the size and location of creeks.

For a more in-depth description of the MECB scenario, see *Modeling Support for Salinity Restoration Target Development for Southern Biscayne Bay* (Allemann et al., 2012), which is available from the 2012 SSR Southern Coastal Systems Salinity page: http://www.evergladesplan.org/pm/ssr_2012/hc_scs_salinity_results_2012.aspx.

Both the AdH model development and generation of restoration target scenarios will be complete in fall 2012. The output from this effort will be used to refine the existing SCS Salinity Performance Measure for the central and southern Biscayne Bay regions: http://www.evergladesplan.org/pm/recover/recover_docs/perf_measures/010709_se_salinity.pdf.

Revisions to Florida Bay Salinity Performance Measure

The RECOVER SCS Subteam has recently completed a major revision of the Florida Bay salinity performance measure. This revision was deemed necessary during assessments conducted for the 2009 SSR revealed significant flaws and conflicting targets in the previous version of the performance measure. Unlike most performance measures used by RECOVER, the revised salinity measure for Florida Bay can be used for both assessing existing and previous conditions using monitoring data from the bay, as well as evaluating CERP alternatives. The performance measure was approved for use in June 2012. The performance measure is being used in scenario screening and to evaluate alternatives developed for the Central Everglades Planning Project. This section describes the revised performance measure and shows examples of its use. A detailed description of the performance measure, including goals, targets, metrics, reporting, uncertainty, and future needs is available online at the following webpage: http://www.evergladesplan.org/pm/recover/recover_docs/perf_measures/062812_rec_pm_scs_salinity_flbay.pdf .

Salinity Restoration Targets

Salinity targets for the performance measure (here called "paleo-adjusted NSM salinity targets") are derived using simulated historical hydrologic conditions with the NSM Version 4.6.2 (SFWMD and IMC, 2005) and multiple linear regression (MLR) statistical models to estimate salinity response at all Marine Monitoring Network (MMN) stations in Florida Bay (Marshall et al., 2011). The NSM salinity time series values at each MMN station are then adjusted based on paleo-salinity information provided by United States Geological Survey (USGS) studies in Florida Bay (Marshall et al., 2009; Marshall and Wingard, 2012; Wingard et al., 2007a; Wingard et al., 2010; Wingard and Hudley, 2011). These adjustments provide a more accurate pre-water management salinity condition than the unadjusted NSM provides. The paleo-adjusted NSM salinity targets are generally consistent with the former salinity target envelopes described in the previous version of this performance measure, which were based on salinity optima and preferences of plant and animal species common to historical (i.e., desired) communities in the various basins (Pattillo et al., 1997), as well as best professional judgment. For the previous version of the performance measure, see http://www.evergladesplan.org/pm/recover/perf_se.aspx

Figure 6-2 shows the locations of all MMN stations in Florida Bay for which paleo-adjusted NSM salinity targets are available. The figure also shows "zones of similarity," which have been defined by recent studies showing that Florida Bay can be divided into six zones based upon water quality/salinity characteristics (Briceno and Boyer, 2010). Performance measure evaluations/assessments for individual MMN stations can be conveniently rolled up into these zones to provide a "big picture" view of conditions in the bay.

Performance Measure Metrics

The performance measure is comprised of three separate, but interrelated, metrics: regime, offset and high salinity. For each metric, either simulations of CERP alternatives (evaluations) or monitoring data (assessments) are compared against the targets. Each metric is appraised on a monthly and seasonal basis (wet season = June through November; dry season = December through May) at each MMN station.

Regime Metric – This metric examines the central tendency of salinity distributions by comparing the overlap between the mid-ranges of the target and the observed or predicted (CERP alternative) time series. The mid-range is defined as the salinity range between the 25th and 75th percentiles. Results are presented as ribbon plots and each site is scored as a percentage of the observed data or alternative simulation values that fall within the target mid-range. Users of the performance measure are at liberty to assess any data period of interest from one year to several.

Offset Metric – This metric provides a measure of the magnitude that the observed data or predicted (CERP alternative) output may deviate from the target. It is determined by calculating the absolute value of the difference between the target monthly (or seasonal) salinity mean and the observed (or predicted) monthly (or seasonal) salinity mean.

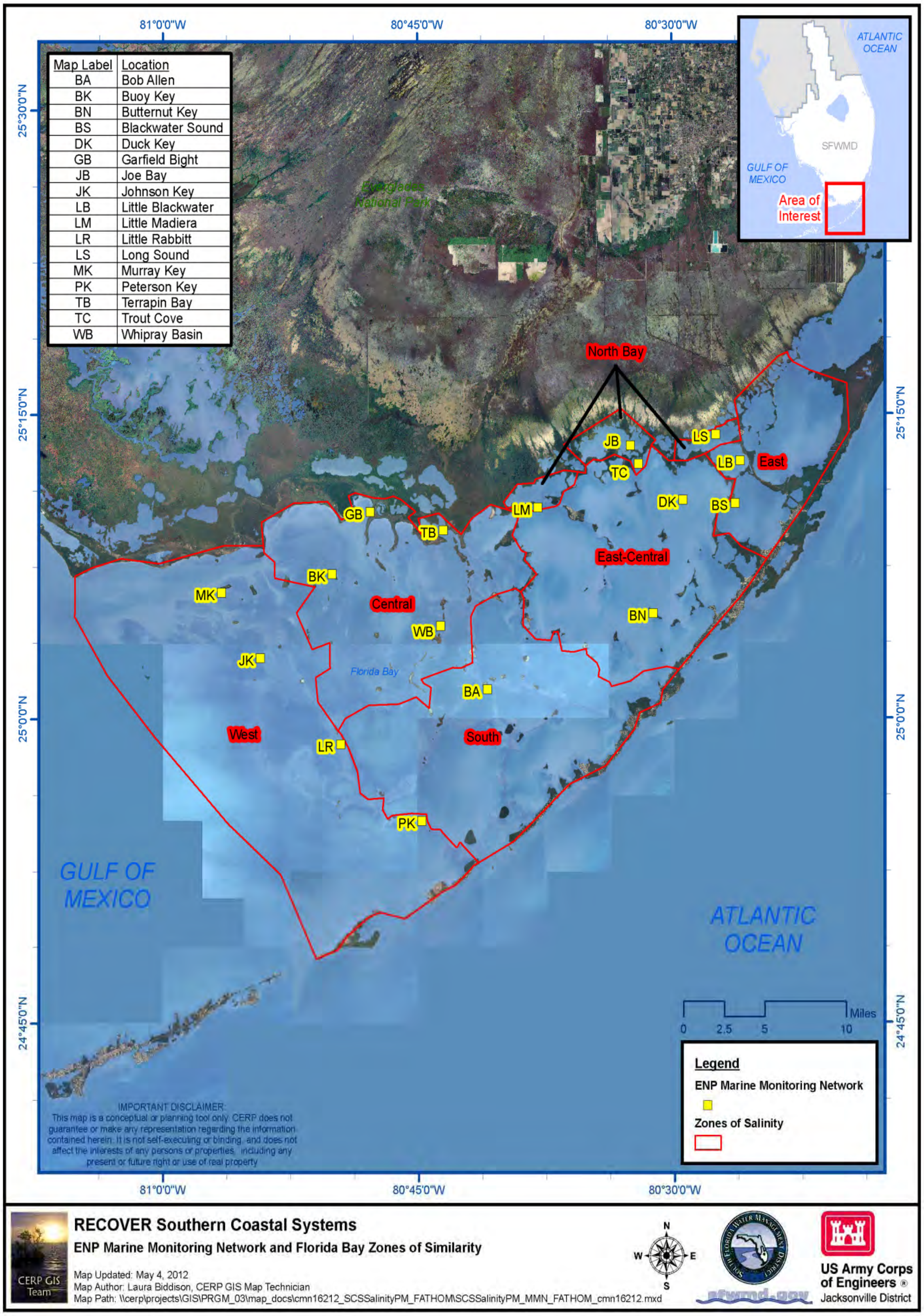

FIGURE 6-2. MAP SHOWING MMN STATIONS AND ZONES OF SIMILARITY.

High Salinity Metric – This metric focuses on the exceedences (in days) of the observed or predicted data above a high-salinity threshold. The high-salinity threshold is defined as the 90th percentile value of the 36-year period of record of the paleo-adjusted NSM. Target exceedences are then calculated on a monthly and seasonal basis by determining the number of days in the month (or season) in the paleo-adjusted NSM data that exceeds the threshold. For assessment purposes, the number of days in a given month or season in the observed data for the year(s) of interest exceeds the 90th percentile target value is determined. The metric score is then calculated by dividing the number of days of the exceedence target by the number of days of exceedence in the observed data. The same procedure is used for evaluating CERP alternatives.

Examples of Use

Figure 6-3 shows results of the metrics as applied to observed salinity data from Whipray Basin in 2003. The gray ribbon represents the target mid-range and the orange ribbon represents the mid-range of the observed data. The darker orange ribbon shows the overlap area. The target mid-range distribution is significantly wider than the 2003 observed data distribution because the target is an average distribution of a 36-year record versus only one year of observed data. For 2003, the regime overlap score during the wet season is 0.13, which is less than during the dry season (0.37). Monthly scores for all metrics are shown just above the x-axis. For 2003, the mean offset during the wet season (4.51 pratical salinity units [psu]) is larger than the offset during the dry season (2.24 psu). The ideal condition (i.e., desired) is a mean offset score of 0.0. For the high salinity metric, the months of February–June and November–December scored a maximum of 1.0, meaning that there was no appreciable concern with high salinities in Whipray Basin during that time period. The months of January, August, and September exhibited scores of 0.10 to 0.12, indicating a significant high salinity problem during those months.

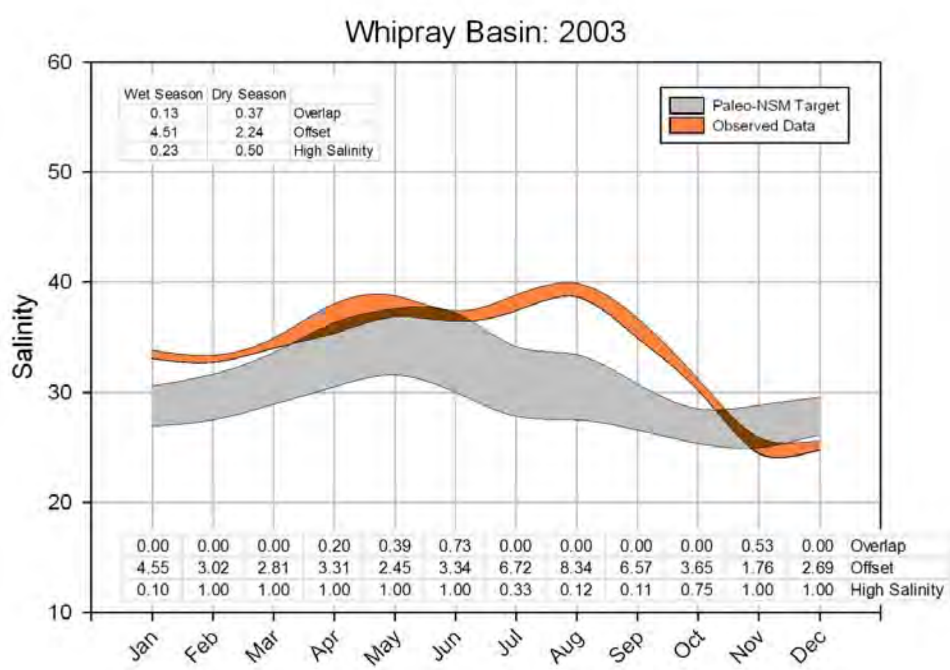

FIGURE 6-3. A GRAPHICAL DISPLAY OF THE PERFORMANCE MEASURE METRICS APPLIED TO 2003 OBSERVED DATA FOR WHIPRAY BASIN.

Figure 6-4 shows an example of the metrics as used for CERP alternative evaluations. The left panel shows 2050B3 (i.e., future without CERP) compared to the target for Whipray Basin. The right panel shows CERP0 (i.e., future with CERP) versus the target for Whipray Basin. Note that the future with CERP provides noticeable improvement for all three metrics during both the wet and dry seasons compared to the future without CERP.

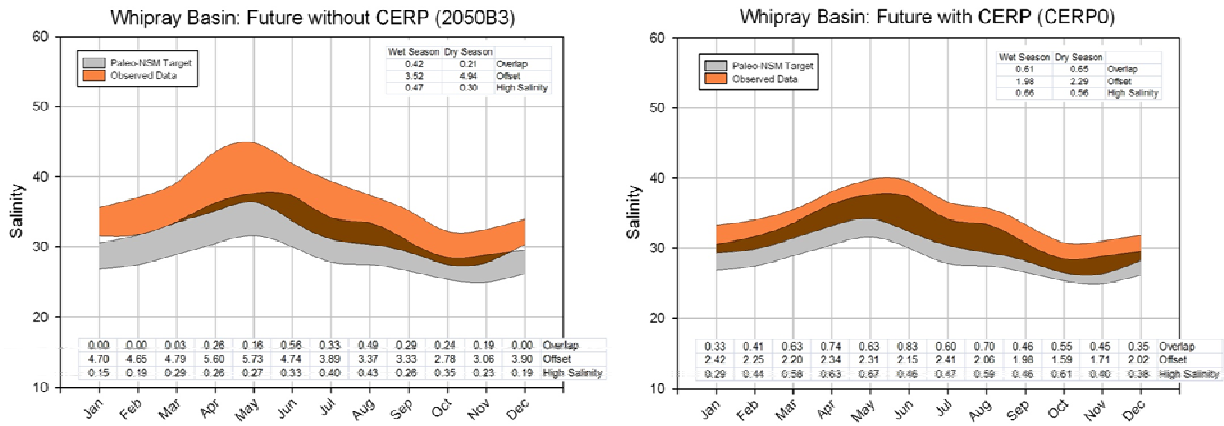

FIGURE 6-4. A GRAPHICAL DISPLAY OF THE PERFORMANCE MEASURE METRICS APPLIED TO CERP ALTERNATIVES.

Metric Reporting

Information from the three metrics will be used to evaluate an alternative or assess a period of observed data compared to the target using a "stoplight report card" approach. This approach is a common format for displaying high-level, highly aggregated information to scientists and resource managers (Harwell et al., 1999; Doren et al., 2009). A red stoplight color indicates substantial deviations from restoration targets creating severe negative conditions that merit action. Yellow indicates the current condition does not meet restoration targets and merits attention. Green indicates good conditions and restoration goals or trends toward those goals have been reached.

For the regime overlap and high salinity metrics, the stoplight scale shown in ***Table 6-1*** will be used. Those two metrics are normalized to a 0–1 scale and threshold values to determine stoplight colors are adopted from Lorenz et al. (2009) for scores relative to a target, with each color category comprising one third of the 0–1 range.

TABLE 6-1. STOPLIGHT SCALE FOR THE FLORIDA BAY SALINITY PERFORMANCE MEASURE.

Score Regime Overlap and High-salinity Metrics	Stoplight Evaluation
<0.33	Red
0.33–0.67	Yellow
>0.67	Green

Stoplight colors for the mean offset metric are determined by comparing the mean and 90 percent confidence limit (90%CL) of the target with the assessment or evaluation data (see example in ***Figure 6-5*** below). The red threshold is defined by the mean and 90%CL of the paleo-adjusted NSM salinity for the 1989–1990 time period (NSM-dry). The 1989–1990 period was an extremely dry two years resulting in very high, harmful salinities in Florida Bay. It is highly likely that salinities would have been high during this time even under pre-drainage conditions resulting in severe negative conditions for flora and fauna. The green threshold is defined by the mean and 90%CL of the full period of record paleo-adjusted NSM salinity time series. If the assessment period data mean (or evaluation scenario mean) falls above the NSM-dry condition mean, the stoplight color is red. If the assessment data (or evaluation scenario) mean falls below the full period of record paleo-adjusted NSM target mean, the condition is green. If the assessment data (or evaluation scenario) mean falls between the target and NSM-dry means, the 90%CLs determine the stoplight color (if no overlap, the condition is yellow). If the 90%CL of the assessment period (or evaluation scenario) overlaps the 90%CL of the restoration target, the condition is green. Conversely, if the 90%CL of the assessment period (or evaluation alternative) overlaps the 90%CL of the NSM-dry, the condition is red. In the example in ***Figure 6-5***, the year 2001 in Whipray Basin is a red condition because the 90%CL of the observed data overlaps the 90%CL of the NSM-dry condition. A green stoplight condition existed for 2002 because the 90^{th} percentile of the observed data overlaps the 90^{th} percentile of the restoration target.

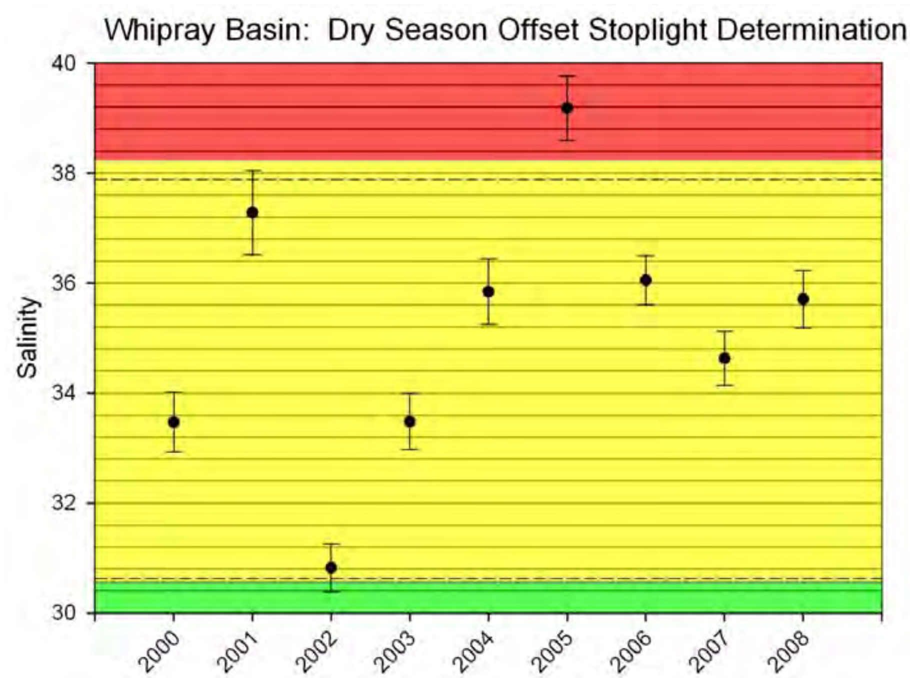

FIGURE 6-5. A GRAPHICAL DISPLAY OF HOW THE MEAN OFFSET METRIC STOPLIGHT COLOR IS DETERMINED.

The red, yellow and green areas represent the salinity range encompassed by the stoplight color for Whipray Basin. The dashed lines represent the 90%CLs above the green target mean and below the red condition. The circles represent the mean dry season salinity for a given year in Whipray Basin. The whiskers represent the 90%CL around the means of the assessment data.

The overall seasonal stoplight values can be obtained by aggregating individual metric stoplight values. This is determined by re-assigning a numeric value to the stoplight colors—red = 0, yellow = 0.5, and green = 1. The seasonal stoplight value is then calculated by taking the arithmetic mean of the three performance measure metrics for each MMN station and applying the mean to the stoplight scale above (i.e., the scale for regime and high salinity stoplights) to obtain the overall stoplight condition (Lorenz et al., 2009). For example, according to ***Table 6-2***, the Murray Key assessment for 2003 dry season resulted in yellow scores for two metrics and a green score for one metric. Using the stoplight color assignments described above, this results in an overall stoplight score of 0.66 [$(0.5 + 0.5 + 1.0) \div 3 = 0.66$] or the color value of yellow.

TABLE 6-2. SUMMARY OF METRIC SCORES AND STOPLIGHT EVALUATION FOR EACH MMN STATION WITHIN FLORIDA BAY FOR 2003 (A RELATIVELY WET YEAR) AND AVERAGES OF THE SCORES WITHIN EACH MAJOR BAY ZONE.

Open circles represent red condition, half-empty circles represent yellow, and closed circles represent green. MMN stations have been grouped according to zones as determined by Briceno and Boyer (2010) and zone averages (the mean of MMN station values within each zone) have been calculated.

	Dry Season				Wet Season			
MMN Station	Mid-range Overlap	Mean Offset	High Salinity	Overall Stoplight Score	Mid-range Overlap	Mean Offset	High Salinity	Overall Stoplight Score
Joe Bay (JB)	○ Red	○ Red	○ Red	○ Red	● Green	● Green	● Green	● Green
Little Madeira Bay (LM)	◑ Yellow	◑ Yellow	○ Red	◑ Yellow	● Green	● Green	● Green	● Green
Long Sound (LS)	○ Red	◑ Yellow	○ Red	○ Red	● Green	● Green	● Green	● Green
Trout Cove (TC)	○ Red	○ Red	○ Red	○ Red	◑ Yellow	● Green	● Green	● Green
North Bay average	Red	Red	Red	Red	● Green	● Green	● Green	● Green
Blackwater Sound (BS)	○ Red	◑ Yellow	○ Red	○ Red	◑ Yellow	◑ Yellow	● Green	◑ Yellow
Little Blackwater Sound (LB)	○ Red	○ Red	○ Red	○ Red	● Green	◑ Yellow	● Green	● Green
East average	Red	Red	Red	Red	● Green	◑ Yellow	● Green	● Green
Butternut Key (BN)	○ Red	◑ Yellow	○ Red	○ Red	○ Red	◑ Yellow	○ Red	○ Red
Duck Key (DK)	○ Red	◑ Yellow	◑ Yellow	◑ Yellow	○ Red	◑ Yellow	○ Red	○ Red
East-central	Red	◑ Yellow	Red	Red	Red	◑ Yellow	Red	Red
Buoy Key (BK)	● Green	◑ Yellow	● Green	● Green	● Green	◑ Yellow	◑ Yellow	◑ Yellow
Garfield Bight (GB)	◑ Yellow	◑ Yellow	◑ Yellow	◑ Yellow	● Green	◑ Yellow	● Green	● Green
Terrapin Bay (TB)	◑ Yellow	◑ Yellow	◑ Yellow	◑ Yellow	● Green	● Green	● Green	● Green
Whipray Basin (WB)	◑ Yellow	◑ Yellow	◑ Yellow	◑ Yellow	○ Red	◑ Yellow	○ Red	○ Red
Central average	◑ Yellow	◑ Yellow	◑ Yellow	◑ Yellow	● Green	◑ Yellow	◑ Yellow	◑ Yellow
Bob Allen Key (BA)	○ Red	◑ Yellow	● Green	◑ Yellow	○ Red	◑ Yellow	○ Red	○ Red
South average	Red	◑ Yellow	● Green	◑ Yellow	Red	◑ Yellow	Red	Red
Johnson Key (JK)	● Green	◑ Yellow	● Green	● Green	○ Red	○ Red	○ Red	○ Red
Little Rabbit Key (LR)	● Green	● Green	● Green	● Green	○ Red	○ Red	○ Red	○ Red
Murray Key (MK)	◑ Yellow	◑ Yellow	● Green	◑ Yellow	○ Red	◑ Yellow	○ Red	○ Red
Peterson Key (PK)	○ Red	◑ Yellow	○ Red	○ Red	○ Red	◑ Yellow	○ Red	○ Red
West average	◑ Yellow	◑ Yellow	● Green	◑ Yellow	Red	Red	Red	Red
Taylor River (TR)	● Green	◑ Yellow	◑ Yellow	● Green	● Green	● Green	● Green	● Green

An example of aggregated metrics taken from an assessment of 2003 conditions at all MMN stations is shown in ***Table 6-2***. ***Figure 6-6*** shows how the seasonal aggregated stoplight scores can be rolled up to show a spatial representation of average conditions in the six zones of similarity for the wet season. The colors on the maps represent the overall seasonal stoplight score for the basin average taken from ***Table 6-2***. The symbols on the map represents the overall seasonal stoplight score for the MMN station taken from ***Table 6-2*** (wet season only).

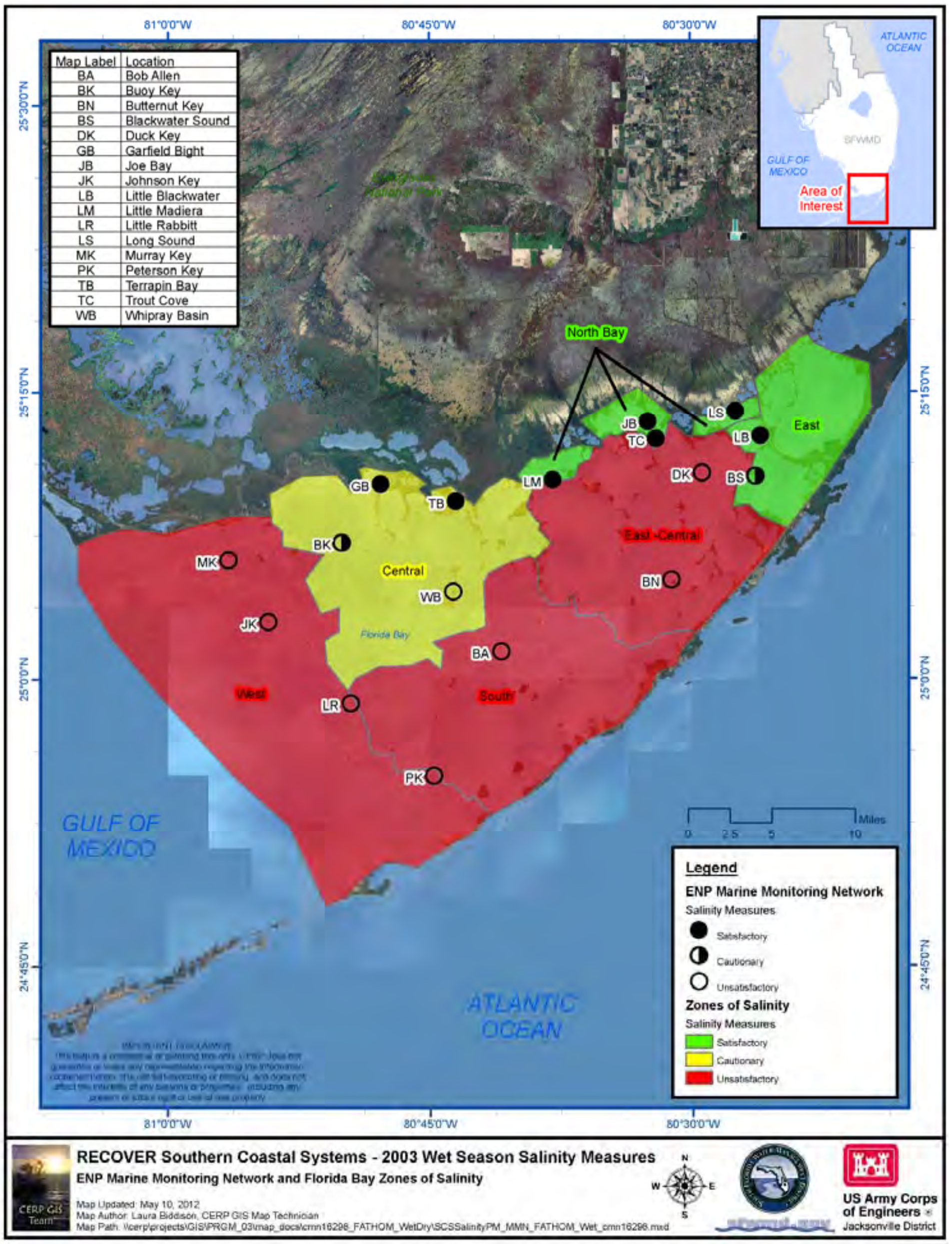

FIGURE 6-6. SPATIAL REPRESENTATION OF ZONE AVERAGES FROM TABLE 6-2 FOR THE 2003 WET SEASON IN FLORIDA BAY.

The symbols represent the overall stoplight score for the station (open circles represent red condition, half-empty circles represent yellow, and closed circles represent green).

Wrap-up

The revised salinity performance measure for Florida Bay described above is a significant improvement over its predecessor and represents an important step forward by RECOVER's SCS Team. The metrics of the performance measure are applicable to most, if not all, estuarine systems and RECOVER anticipates utilizing these metrics in other estuaries of the SCS as modeling tools become avilable to set targets and accurately simulate CERP alternatives in these regions.

Empirical Tools for Simulating Salinity for Everglades National Park Estuaries

This section provides a thumbnail from Marshall et al. (2011).

Salinity in a shallow estuary is affected by upland freshwater inputs (i.e., surface runoff, stream/canal flows, and groundwater), atmospheric processes (i.e., precipitation and evaporation), marine connectivity, and wind patterns. In Everglades National Park, the unique Everglades ecosystem exists as an interconnected system of freshwater, brackish water, and saltwater marshes, mangroves, and open water. For this effort, a coastal aquifer conceptual model of the Everglades hydrologic system was used with traditional correlation and regression hydrologic techniques to create a series of MLR salinity models from observed hydrologic, marine, and weather data. The 37 Everglades National Park MLR salinity models cover all of the estuarine areas of the park and produce daily salinity simulations at each MMN station (***Figure 6-7***). These models are capable of estimating 65–80 percent of the daily variability in salinity depending upon the model (***Figure 6-8***). The root mean squared error is typically about 2–4 psu (***Figure 6-9***), and there is little bias in the predictions. However, the absolute error of a model prediction in the nearshore embayments and the mangrove zone of Florida Bay may be relatively large for a particular daily simulation during the seasonal transitions. Comparisons show that the models group regionally by similar independent variables and salinity regimes. The MLR salinity models have approximately the same expected range of simulation accuracy and error as higher spatial resolution salinity models.

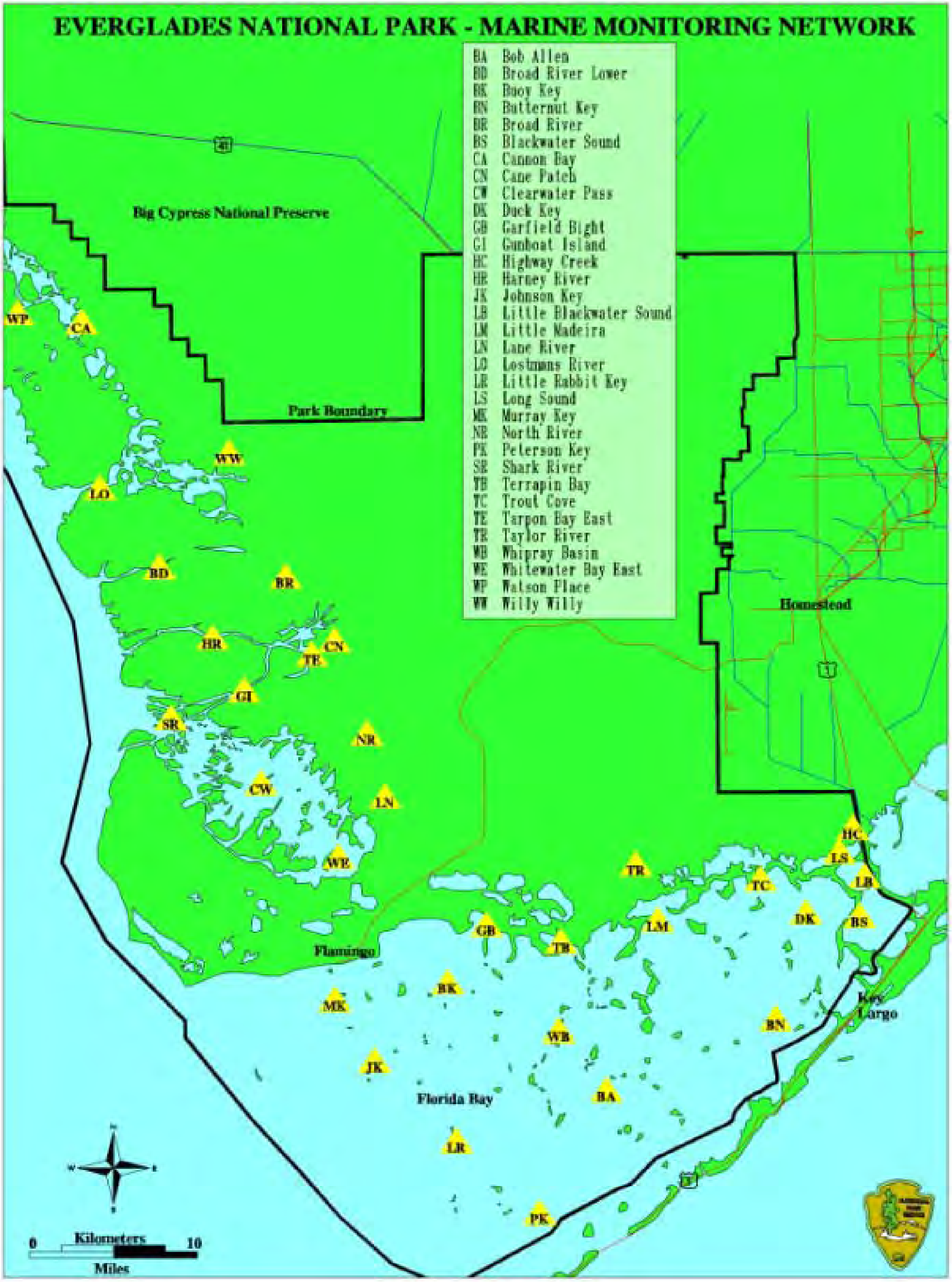

FIGURE 6-7. LOCATIONS OF EVERGLADES NATIONAL PARK MMN STATIONS AND MLR SALINITY MODELS.

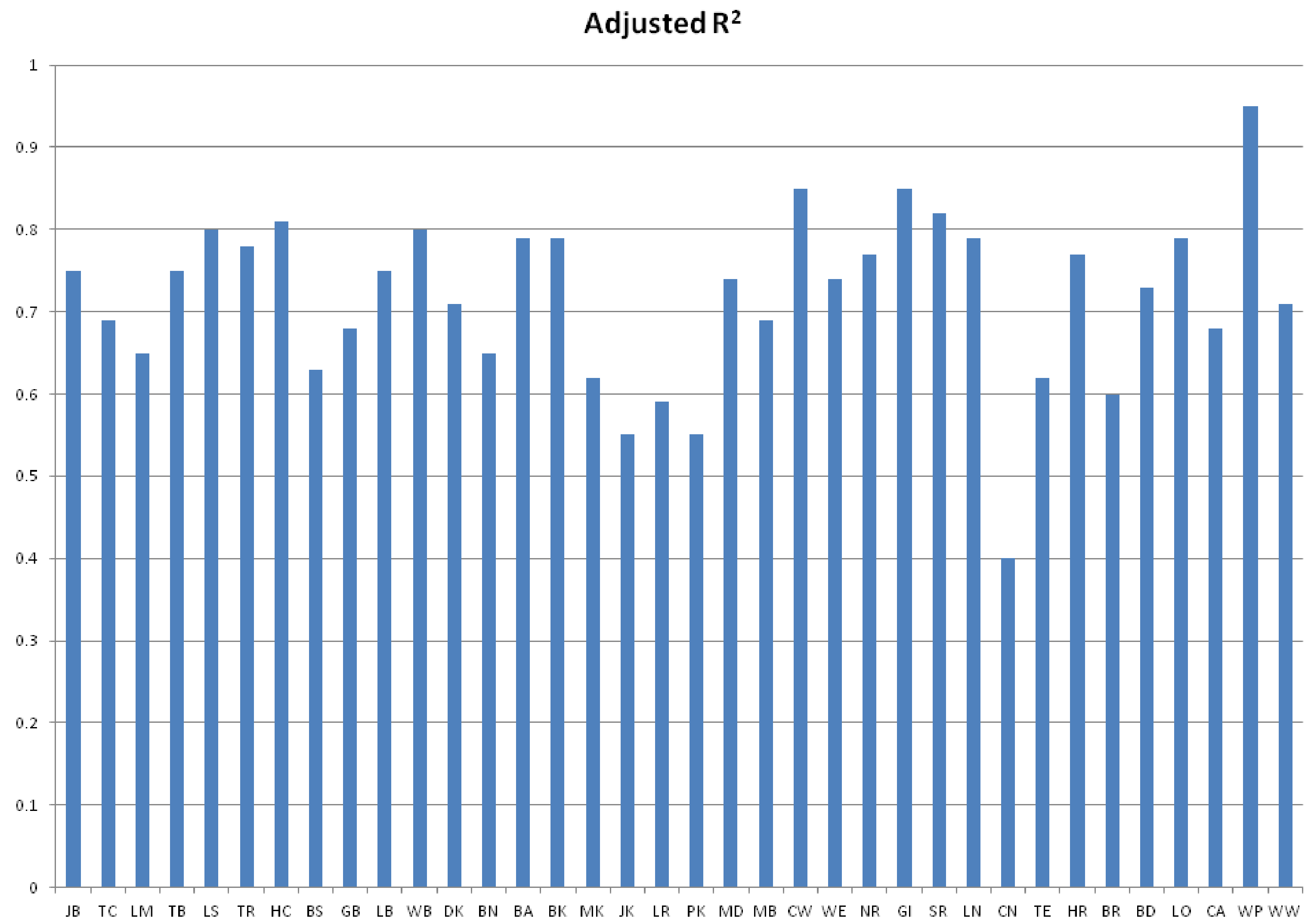

FIGURE 6-8. COMPARISON OF R^2 VALUES FOR THE 37 MLR SALINITY MODELS.

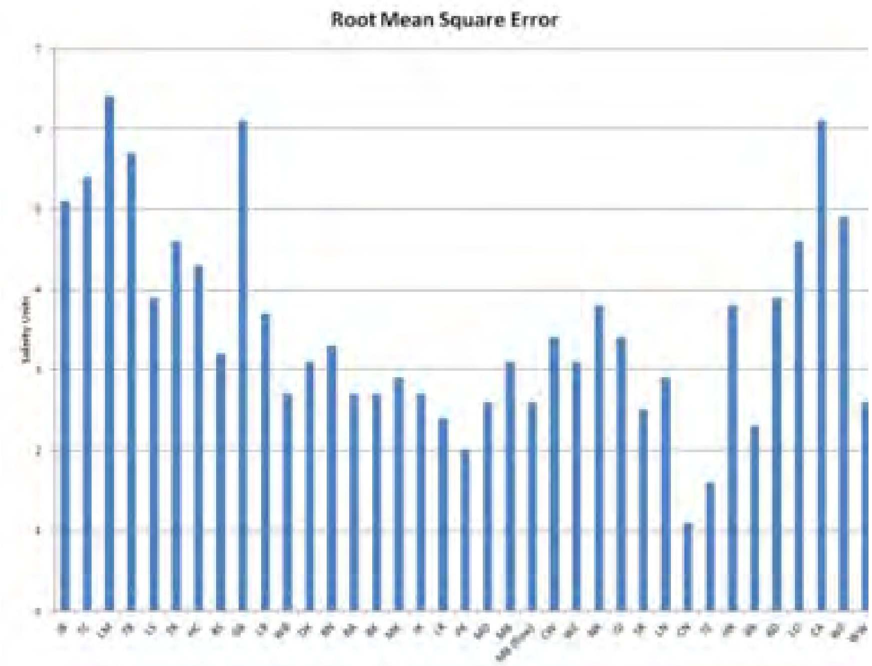

FIGURE 6-9. COMPARISON OF ROOT MEAN SQUARE ERROR VALUES FOR THE 37 MLR SALINITY MODELS.

South Florida Salinity and Hydrology Models Review

This section is a thumbnail from Marshall and Nuttle (2011).

The hydrology and salinity models being used for Everglades restoration were compared for use and performance with RECOVER performance measure evaluations. Criteria for this comparison included portability, validity, fidelity, focus, ease of use, and temporal/spatial coverage. Each model was scored for each criterion on a 1 to 5 scale with 5 being the highest score (excellent). The widest ranges of scores were for portability and ease-of-use reflecting the constraints of model sophistication (***Table 6-3***). The narrowest range of scores was associated with validity—most of these models have withstood the test of use and have been developed, reviewed and updated to a point of application-ready acceptance.

In general, the most complex models are the least portable, are rated lowest for ease of use, and did not score as high on validity compared to the models that are less complex. The most complex models are the South Florida Water Management Model (SFWMM), Regional Simulation Model (RSM), Flow and Transport in a Linked Overland-Aquifer Density Dependent System (FTLOADDS), Environmental Fluid Dynamics Code (EFDC) Florida Bay, Wang et al. (2003) Biscayne Bay, and TABS-MDS Biscayne Bay. The less complex models are linear regression models for stage and flow, MLR salinity models, FATHOM Florida Bay (a dynamic spatially explicit mass balance model), Four Box Model Florida Bay, Biscayne Bay Box Model). Temporal coverage was best for the regression models because they are daily time step models and can be run for the longest periods of time. For spatial coverage, none of the models covers the full domain of the South Florida coastal system but most model domains cover the region(s) of focus (e.g., Florida Bay, Biscayne Bay, etc.).

The least expensive models to employ are the least sophisticated statistical models and box models. The use of grid-domain freshwater models covering a large region such as the spatial domain of the SFWMM and RSM will always be more costly to run than the freshwater ecosystem statistical and box models by a substantial amount. However, there are important transport, exchange, and circulation questions in the connected Everglades freshwater and estuarine system that require a very high level of resolution, justifying the use and cost of more sophisticated models.

TABLE 6-3. SUMMARY OF SCORING FOR SOUTH FLORIDA HYDROLOGY AND SALINITY MODELS USING THE MODEL EVALUATION CRITERIA.

Score is from 1 = poor to 5 = excellent. No scores are provided for the category of model focus because all of the models satisfy the requirement that output be relevant to ecosystem attributes.

Model	Parameters Simulated	Portability	Validity	Fidelity	Focus	Ease of Use	Temporal Coverage	Spatial Coverage
Linear regression models for stage	stage	3	4	2	-	5	5	3
PHAST (simulates multi-component, reactive solute transport in three-dimensional saturated groundwater flow systems)	flow	2	4	2	-	5	4	2
South Florida Water Management Model (SFWMM)	stage, flow	3	4	4	-	4	4	4
Regional Simulation Model (RSM)	stage, flow	1	5	4	-	1	5	4
Multiple linear regression (MLR) model for salinity	salinity	5	5	2	-	5	5	3
Four Box Florida Bay	salinity	2	5	3	-	4	4	3
Biscayne Bay Box Model	salinity	3	5	3	-	4	4	3
FATHOM Florida Bay (a dynamic, spatially explicit, mass balance model)	salinity	4	5	4	-	4	4	3
Application of the Flow and Transport in a Linked Overland-Aquifer Density Dependent System (FTLOADDS) to the following models: - Tides and Inflows in the Mangroves of the Everglades Model (TIME) - Biscayne Southern Everglades Coastal Transport Model (BISECT) - Ten Thousand Islands Model (TTI)	stage, flow, salinity	3	4	5	-	3	3	4
Environmental Fluid Dynamics Code (EFDC) for Florida Bay	salinity	1	4	5	-	2	2.5	3
Wang et al. (2003) Biscayne Bay	salinity	3	4	4	-	3	2.5	3
TABS-MDS Biscayne Bay (a finite element hydrodynamic model) (formerly RMA10)	salinity	1	4	5	-	1	2.5	3

Recent Paleoecology-Linear Regression Model Research in Southern Coastal Systems

This section summarizes research conducted by F.E. Marshall (Cetacean Logic Foundation, New Smyrna Beach, Florida) and G. Lynn Wingard (USGS, Reston, Virginia).

Understanding natural hydrologic conditions in the Greater Everglades ecosystem prior to drainage modification is essential to the ongoing large-scale restoration of this system. Paleoecologic data collected from sediment cores can provide a snapshot of the conditions that existed in different parts of the ecosystem over the last century. For management to develop performance measures and targets, however, it is necessary to determine how the components of the system are connected. For example, how much freshwater flow is necessary to produce pre-drainage salinity patterns in Florida Bay?

To answer these questions, a three-phase method has been developed that couples paleoecologic data on historical salinity conditions in the estuaries to freshwater flow and stage data from upstream wetlands (Marshall et al., 2009; Marshall and Wingard, 2012). Phase one estimates historical salinity conditions from radiometrically-dated sediment cores (Wingard et al., 2007b) collected in the estuaries. The remains of animals in the cores are identified, counted, and compared to data on salinity tolerances of living animals (USGS, 2012). Average salinity values from the modern data set are weighted by the abundance of that species in each sample, and a cumulative weighted average salinity is produced for each 2-centimeter core segment (Wingard and Hudley, 2012). The paleosalinity estimates from about 1900 (prior to drainage modification) are the phase one output.

Phase two develops statistical models that relate freshwater flow and stage in the Everglades wetlands, and wind and tide in the estuaries, to salinity in the estuaries. These models are based on 14 to over 50 years of data collected at monitoring sites in the Everglades wetlands and downstream estuaries. These statistical equations predict salinity in the estuaries based on stage and flow in the wetlands using observed wind and tide data, and vice versa. Phase three couples the paleosalinity estimates with the salinity models, by inserting the paleosalinity values from circa 1900 into the equations and solving for flow and stage. Climate data from 1965 to 2000 (similar to climate conditions for circa 1900) are used for the models. The phase three output predicts what the historical flow and stage in the Everglades wetlands would have been from 1965 to 2000 without drainage modification in order to produce the salinities indicated by the analyses of the cores. This approach has been applied to five sediment cores in Florida Bay. The results show a “wetter Everglades” prior to twentieth century water management practices. When these pre-drainage conditions are replicated for the 1965 to 2000 climate, stage in the Everglades is from 0.6 to 1.2 feet higher than the observed post-drainage conditions, depending upon location (***Figure 6-10***). For the same period, flow into Shark River Slough at Tamiami Trail was about 1,500 cubic feet per second (cfs) higher and at Taylor Slough Bridge about 120 cfs higher than existing flows (***Figure 6-11***). The resulting salinity in Florida Bay for 1965 to 2000 period averaged 12 psu lower in the nearshore transition zones and about 3 psu lower on the western margin of the bay near the Gulf of Mexico connection (***Figure 6-12***). These results are being used by RECOVER’s SCS Sub-team to develop performance measures and targets for salinity in the estuaries for use by managers to guide restoration of the Greater Everglades ecosystem.

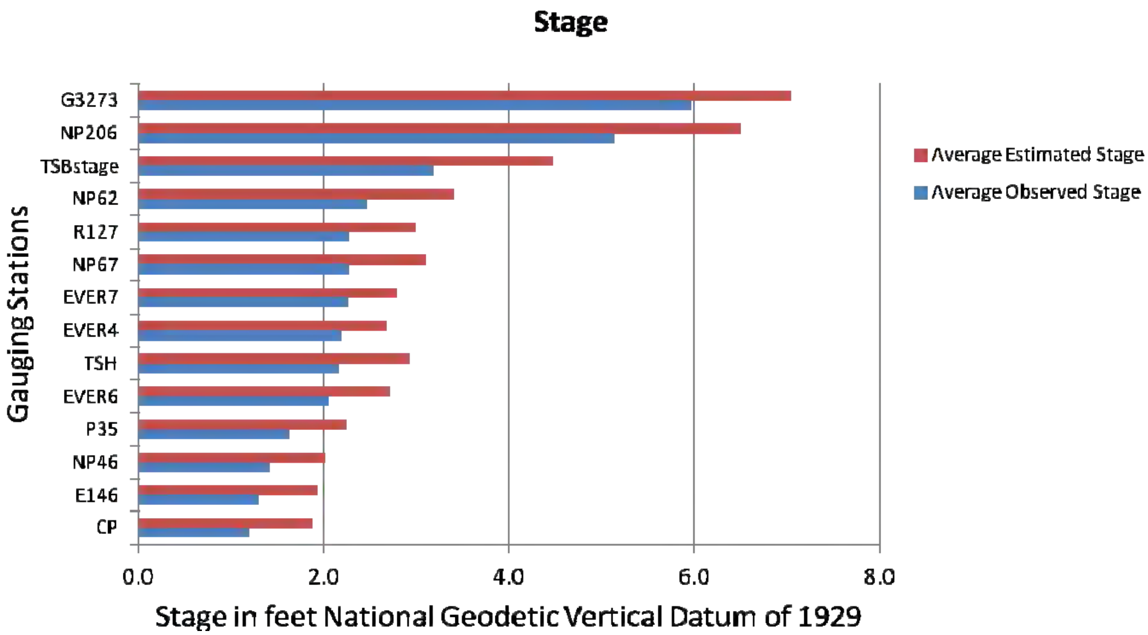

FIGURE 6-10. AVERAGE STAGE ESTIMATES FOR 1965 TO 2000 CLIMATE CONDITIONS WITHOUT HYDROLOGIC MODIFICATION BASED ON ANALYSES OF FIVE CORES COMPARED TO AVERAGE STAGE OBSERVED AT WATER GAUGING STATIONS IN THE EVERGLADES WETLANDS.

See Marshall and Wingard (2012) for data and details. Estimated stage without drainage modification is higher at every station compared to observed modern stage.

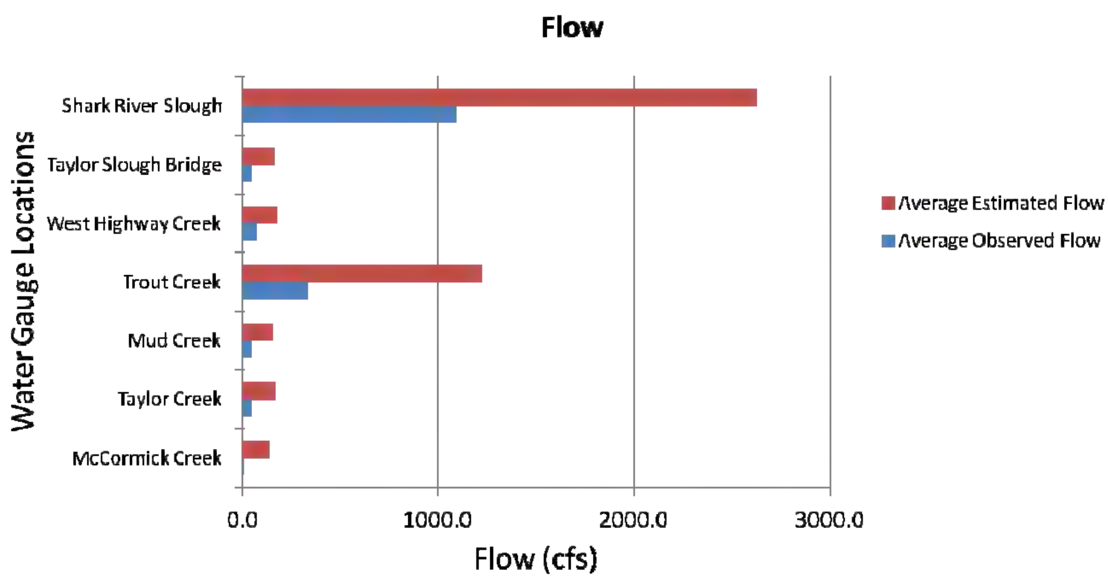

FIGURE 6-11. AVERAGE FLOW ESTIMATES FOR 1965 TO 2000 CLIMATE CONDITIONS WITHOUT HYDROLOGIC MODIFICATION BASED ON ANALYSES OF FIVE CORES COMPARED TO AVERAGE FLOW OBSERVED AT WATER GAUGING STATIONS IN THE EVERGLADES WETLANDS.

See Marshall and Wingard (2012) for data and details. Estimated flow without drainage modification is higher at every station compared to observed modern flow.

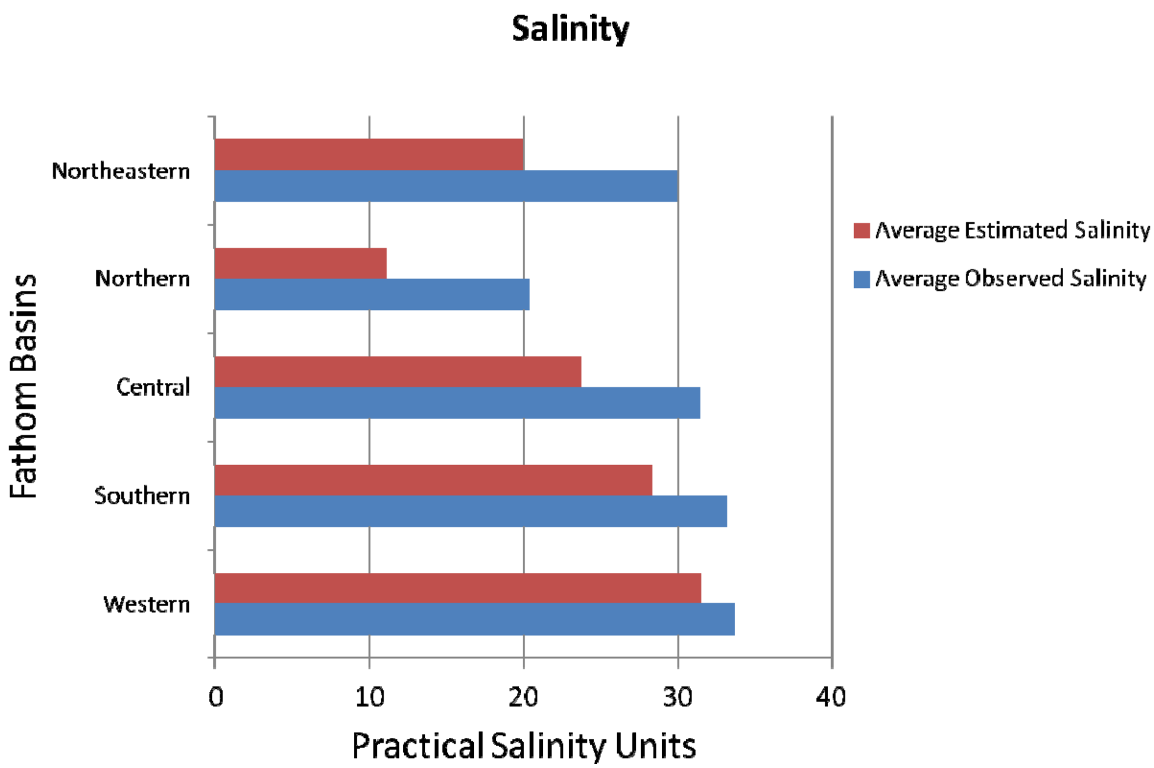

FIGURE 6-12. AVERAGE SALINITY ESTIMATES FOR 1965 TO 2000 CLIMATE CONDITIONS WITHOUT HYDROLOGIC MODIFICATION BASED ON ANALYSES OF FIVE CORES COMPARED TO AVERAGE SALINITY OBSERVED AT WATER MONITORING STATIONS AGGREGATED FOR EACH MAJOR ZONE IN FLORIDA BAY.

See Marshall and Wingard (2012) for data and details. Pre-drainage salinity estimates are lower in every zone compared to observed modern salinities.

ALGAL BLOOMS

During the 2010–2011 reporting period, no severe algal blooms were observed in the estuaries of the SCS region. However, the strength of this assessment was decreased because coastal water quality monitoring programs used to develop the algal bloom indicator (as chlorophyll *a*) were altered due to funding cuts during the reporting period. Bias introduced by changing both number and location of monitoring stations required a significant new effort to adjust the stoplight threshold limits. For example, offshore sites of the Southwest Florida Shelf were eliminated in 2010 and these stations typically have lower chlorophyll concentrations than inshore stations. Using inshore results in 2010 and 2011 with thresholds derived from long-term combined inshore and offshore values, scores for the Southwest Florida Shelf would have been red in 2010 and 2011. For this report, the threshold had to be recalculated using only the remaining (nearshore) stations in the section and the offshore section is listed as nonreporting due to this lack of data (black). No long-term trends in the algal bloom indicator were observed.

A two-year prospectus is not provided here because past blooms have been related to major disturbance events, such as runoff pulses and wind/wave impacts of hurricanes, and nutrient releases from seagrass die-off events. Such events are not reliably forecast. In two subregions with CERP projects being implemented—northeastern Florida Bay and southern Biscayne Bay—water quality degradation reflected by this indicator is not expected to occur.

More information on algal blooms and other water quality indicators within the SCS can be found on the 2009 SSR Water Quality Results page, which can be viewed at the following website: http://www.evergladesplan.org/pm/ssr_2009/hc_scs_wq_results.aspx.

SUBMERGED AQUATIC VEGETATION

Introduction

This section provides a status of submerged aquatic vegetation (SAV) in Florida Bay. It also provides an update on modeling and new science available for the Southern Coastal Systems (SCS) SAV. More information on SCS SAV can be found in the 2009 SSR (RECOVER, 2010). SCS SAV results from the 2009 SSR can be viewed online at the following website: http://www.evergladesplan.org/pm/ssr_2009/hc_scs_sav_results.aspx.

Florida Bay Stoplight Indicator

The status of SAV habitat in Florida Bay and the Everglades coastal wetland transition zone is characterized by a stoplight indicator. Indicator results are based on annual surveys in representative basins of this large (approximately 2,000 square kilometers) estuary. The overall (composite) indicator showed that SAV in Water Year (WY) 2011 (May 1, 2010–April 30, 2011) remained unchanged since WY 2009, with a fair (yellow) status in Florida Bay's nearshore northern zone and its southern zone, near the Florida Keys, and good (green) status in the northeastern, central and western zones.

The SAV indicator is composed of four components of community attributes: (1) the spatial extent of seagrass, which can be useful in detecting seagrass die-off and recovery, (2) the density of seagrass cover where it occurs, (3) the species diversity of the seagrass community, and (4) the frequency of occurrence of restoration target species. The first two attributes are aggregated in an Abundance Index and the second two attributes are aggregated in a Species Index. These two indexes are combined in the Composite SAV Indicator, which reports the overall status of SAV.

The yellow Composite SAV Indicator status in the nearshore northern zone (the transition zone between the bay and southern Everglades) represents a status of fair for all four underlying component indexes over the past three years. This area showed an improvement in the Species Index compared to previous years, which in part may be a consequence of improved water management via C-111 South Dade Project operations along Everglades National Park's eastern boundary. The green status through the main body of the bay from northeastern basins westward to the Gulf of Mexico incorporates a variety of SAV attributes, most notably an improvement in the Abundance Index over the past few years. This improvement is due to the recovery of seagrass communities after several hurricanes and phytoplankton (micro-algal) blooms caused seagrass die-off in the 2005–2008 period. In the southern zone, little recovery has occurred following this period, which has been reflected in red Abundance Index values for several years, yielding yellow Composite SAV Index scores in WY2010 and WY2011. Despite baywide incidents of high salinity in the past three years, no large-scale die-off events have been observed in any zone. It is anticipated that increases in freshwater flows to the bay through restoration efforts should result in improvements in SAV habitat and improved indicator scores.

Models

RECOVER is tasked with creation of predictive tools (models) to support regional performance measure development/refinement, systemwide planning activities, and adaptive management activities. These models are a combination of the best available science with mathematical and/or spatial modeling techniques. Since the 2009 SSR, seagrass models have been developed for Florida Bay (numerical model) and Biscayne Bay (spatial model).

Florida Bay Seagrass Community Model

The Florida Bay Seagrass Community Model (SEACOM) was developed by scientists at the SFWMD. SEACOM is a numerical model that simulates the effects of environmental parameters such as water column and sediment porewater nutrients, temperature, salinity, organic matter, hydrogen sulfide, and sediment depth on the viability, productivity, and distribution of three seagrass species—turtle grass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*), and widgeon grass (*Ruppia maritima*)—in Florida Bay. A conceptual model showing these parameters and interactions is provided in ***Figure 6-13***. More information on SEACOM is available in other publications:

Model Results:

Madden, C.J. and A.A. McDonald. 2009. A Modeling Study of Alternate Stable States in the Florida Bay Ecosystem: A Synthesis of Models to Simulate Benthic-Pelagic Coupling. In *American Society of Limnology and Oceanography Aquatic Sciences Meeting 2009, A Cruise Through Nice Waters*, 25–30 January 2009, Nice, France. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_seacom_mod_results.pdf.

Restoration Scenarios:

McDonald, A.A., C.J. Madden and F.E. Marshall, III. 2011. Projected Effects of Everglades Restoration on Florida Bay Seagrass Communities. 2011 Coastal and Estuarine Research Federation Conference, Daytona Beach, FL. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_seacom_sceneri os.pdf.

Model Description:

Madden, C.J. In press. Use of models in ecosystem-based management of the southern Everglades and Florida Bay, Florida. In J.W. Day, Jr. and A. Yañez-Arancibia (eds.), *The Gulf of Mexico: Its Origins, Waters, Biota and Human Impacts; Volume 5 Ecosystem Based Management*. Harte Research Institute for Gulf of Mexico Studies, Texas A&M University–Corpus Christi, Texas A&M University Press, College Station, TX.

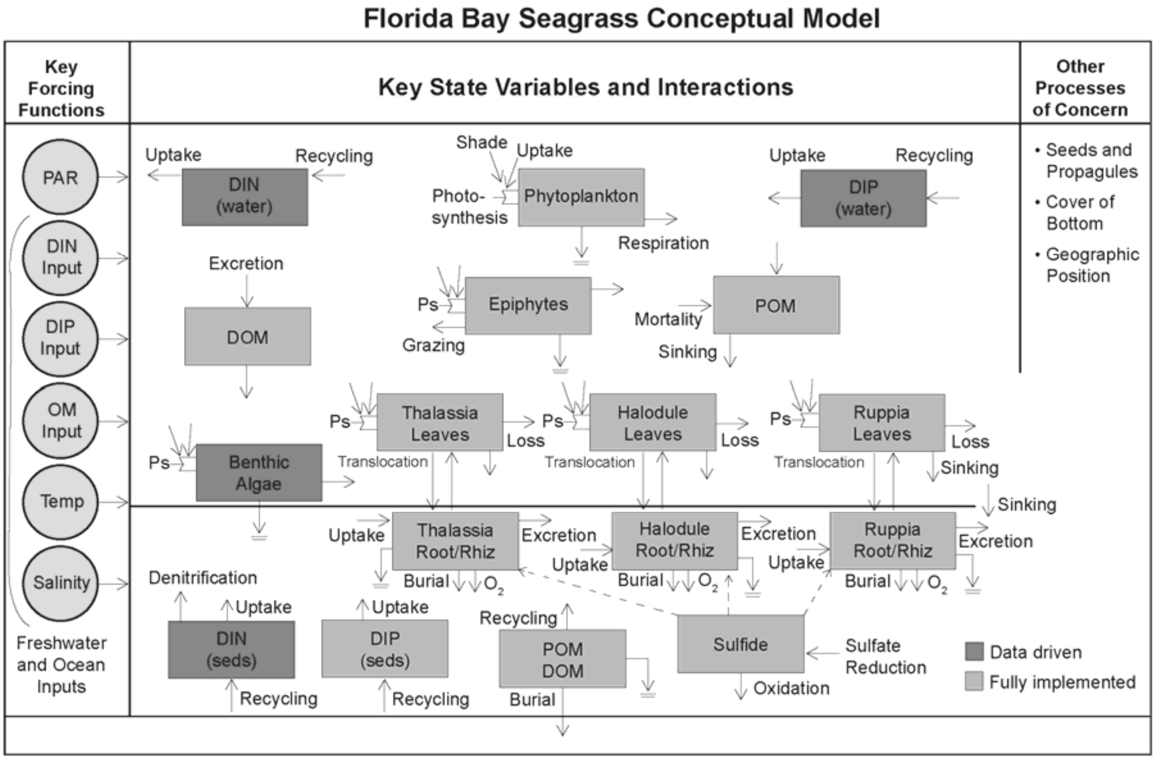

FIGURE 6-13. FLORIDA BAY SEAGRASS CONCEPTUAL MODEL.

Key: DIN – dissolved inorganic nitrogen, DIP – dissolved inorganic phosphorus, DOM – dissolved organic matter, O_2 – dioxygen, OM – organic matter, PAR – photosynthetically-active radiation, POM – particulate organic matter, Ps – photosynthesis, and Temp – temperature.

Technical Documentation:

Madden, C.J. and A.A. McDonald. 2010. Seagrass Ecosystem Assessment and Community Organization Model (SEACOM), A Seagrass Model for Florida Bay: Examination of Fresh Water Effects on Seagrass Ecological Processes, Community Dynamics and Seagrass Die-off. South Florida Water Management District, West Palm Beach, FL. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_seacom_documentation.pdf.

For more information on SEACOM contact Christopher J. Madden at cmadden@sfwmd.gov.

Biscayne Bay Habitat Suitability Model

A habitat suitability model was developed by scientists from the University of Miami, Rosenstiel School of Marine and Atmospheric Sciences. This model was specifically developed for turtle grass (*Thalassia testudinum*) and shoal grass (*Halodule wrightii*) within Biscayne Bay. Monitoring information collected by the CERP Monitoring and Assessment Plan (MAP) and the ecological niche factor analysis (ENFA) statistical approach were combined to generate suitability maps for the two seagrass species. A conceptual model of for Biscayne Bay seagrass habitat suitability is provided in ***Figure 6-14***.

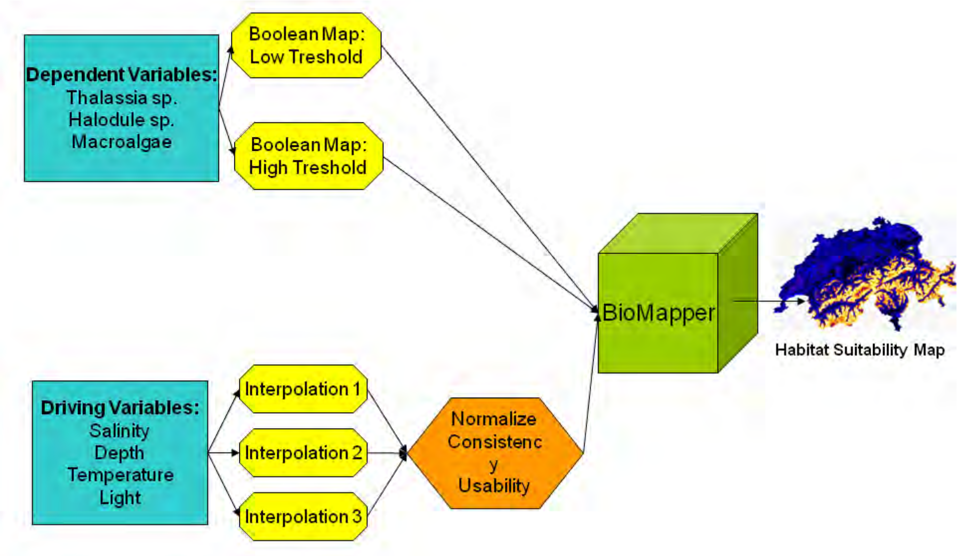

FIGURE 6-14. A CONCEPTUAL MODEL FOR BISCAYNE BAY SEAGRASS HABITAT SUITABILITY.

This habitat suitability model was used to evaluate the effects of a restoration scenario of increased freshwater flow to the bay resulting in a lowering of salinity. Results can be found in Santos and Lirman (2012):

Santos, R.O. and D. Lirman. 2012. Using habitat suitability models to predict changes in seagrass distribution caused by water management practices. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1-9.

For more information on this model, contact Diego Lirman at dlirman@rsmas.miami.edu.

New Science

The network of SAV scientists working in the SCS region, some of which are directly supporting the CERP MAP, have published several journal articles and reports since the 2009 SSR documenting new scientific information for the SCS. These publications, in reverse order by date of publication, are as follows:

Collado-Vides, L., S. Blair, C. Avila, D. Lirman, W. Anderson, J. Boyer, P. Sweeney and S. Leser. 2012. An Evaluation of the Expansion of the *Anadyomene* Complex Bloom in Biscayne Bay. A Study of Their Nutrient and Stable Isotope Content. Final Report to the Biscayne Bay Aquatic Preserve, Florida Department of Environmental Protection, Miami, FL. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_new_sci_1.pdf.

Hall, M.O. and M.J. Durako. 2012. South Florida Fisheries Habitat Assessment Program (FHAP-SF). Annual Report 1 to the South Florida Water Management District, West Palm Beach, FL. FWC/FWRI File Code: F4046-11-I2. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_new_sci_2.pdf.

Durako, M.J. 2012. Using PAM fluorometry for landscape-level assessment of *Thalassia testudinum*: Can diurnal variation in photochemical efficiency be used as an ecoindicator of seagrass health? *Ecological Indicators* 18:243-251. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_new_sci_3.pdf.

Durako, M.J. 2012. In 1987 a large area of turtle grass died in Florida Bay. Pages 278–279 in W.L. Kruczynski and P.J. Fletcher (eds.), *Tropical Connections: South Florida's Marine Environment*, IAN Press, University of Maryland Center for Environmental Studies, Cambridge, MD.

Hall, M.O. 2012. Seagrass communities in Florida Bay changed after the die-off. Pages 281–282 in W.L. Kruczynski and P.J. Fletcher (eds.), *Tropical Connections: South Florida's Marine Environment*, IAN Press, University of Maryland Center for Environmental Studies, Cambridge, MD.

Collado-Vides, L., W. Anderson, S. Blair, C. Avila, D. Lirman and T. Thyberg. 2011. Macroalgae as Indicators of Nutrient Conditions in Biscayne Bay: A Study of Nutrient and Stable Isotope Content on the Green Macroalgae Complex *Anadyomene stellata – A. pavonina*. Final Report to the Biscayne Bay Aquatic Preserve, Florida Department of Environmental Protection, Miami, FL. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_new_sci_4.pdf.

Collado-Vides, L., V. Mazzei, T. Thyberg and D. Lirman. 2011. Spatio-temporal patterns and nutrient status of macroalgae in a heavily managed region of Biscayne Bay, Florida, USA. *Botanica Marina* 54:377-390.

Santos, R.O., D. Lirman and J.E. Serafy. 2011. Quantifying freshwater-induced fragmentation of submerged aquatic vegetation communities using a multi-scale landscape ecology approach. *Marine Ecology Progress Series* 427:233-246.

Durako, M.J. and K.M. Chartrand. 2008. Changes in spectral reflectance in response to salinity variation in *Siderastrea radians* from Florida Bay, Florida USA. Pages 607-610 in ReefBase Project, *Proceedings of the 11th International Coral Reef Symposium, Fort Lauderdale, FL, 7–11 July 2008*, WorldFishCenter, Penang, Malaysia. Volume 1:614-617 (Session number 17). Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_new_sci_5.pdf.

Chartrand, K.M., M.J. Durako and J.E. Blum. 2009. Effect of hypo-salinity on the photophysiology of *Siderastrea radians*. *Marine Biology* 156:1691-1702. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_new_sci_6.pdf.

Chartrand, K.M. and M.J. Durako. 2009. Distribution and photobiology of *Siderastrea radians* and *Thalassia testudinum* in Florida Bay, FL USA. *Bulletin of Marine Science* 84(2):153-166. Available at http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/hc_scs_sav_new_sci_7.pdf.

NEARSHORE FAUNAL COMMUNITIES

Introduction

The 2009 SSR provided assessments on several nearshore faunal communities within the SCS estuaries. These communities included Biscayne Bay mangrove fish, Florida Bay juvenile sportfish (mainly spotted seatrout [*Cynoscion nebulosus*]), Biscayne Bay alongshore epifauna communities including pink shrimp (*Farfantepenaeus duorarum*), and seagrass-associated fish, crab and shrimp within all of the SCS estuaries through the Fish and Invertebrate Assessment Network (FIAN). More information on each of these communities can be found on the 2009 SSR Nearshore Faunal Communities Results page, which can be found online at http://www.evergladesplan.org/pm/ssr_2009/hc_scs_fauna_results.aspx.

A partial update of nearshore faunal communities is provided in this section. A brief status of pink shrimp is provided, followed by a discussion of using habitat suitability models in the development of performance measures for sportfish in Florida Bay.

Pink Shrimp

The 2010 and 2011 status of pink shrimp in 19 nursery locations in three southern coastal regions was determined by the FIAN. Status for 2012 is not available because funding for this project was terminated. Status was determined in relation to a base of the first five FIAN years, 2005–2009, using as indicators an abundance index and delta-density in the months of annually greatest abundance (September and October). By comparison to the five-year base, 2010 and 2011 were poor (red) or neutral (yellow) years for pink shrimp in most locations.

In Biscayne Bay, pink shrimp status was poor or neutral in all but one location (Manatee Bay in 2010) in both 2010 and 2011. The regional overview pink shrimp status for Biscayne Bay was poor for both 2010 and 2011. The seven-year (2005–2011) trend in Biscayne Bay, although downward, was not significant for any location.

In Florida Bay, pink shrimp status was poor in three out of eight locations in 2010, neutral in four locations, and good in one location (Whipray Basin). The 2010 Florida Bay regional overview pink shrimp status was poor. In 2011, pink shrimp status remained good in Whipray Basin and improved from poor to good in two other locations in Florida Bay. Pink shrimp status declined from neutral to poor in Johnson Key Basin, the nursery location where juvenile shrimp are most abundant in South Florida. The 2011 regional overview pink shrimp status in Florida Bay was neutral, as was the seven-year trend.

Along the southwestern Florida coast, pink shrimp status was good only in Lostmans River in 2010. It was poor in Ponce de Leon Bay in both 2010 and 2011 and in Oyster Bay in 2011. The overview pink shrimp status for this area was neutral for 2010 and poor for 2011. A significant seven-year downward trend was noted in Oyster Bay. Otherwise, the trends in this region, although downward, were not significant.

The overall seven-year trend in the southern coastal regions, although not significant, is negative in all but one location, suggesting a coastal-wide influence. Loss of funding prevents determination of current and future status.

Using Habitat Suitability Models to Develop a Quantitative Restoration Performance Measure for Sportfish in Florida Bay

Introduction

The current performance measure for sportfish in Florida Bay anticipates an increase in distribution, growth, and survival of juvenile spotted seatrout in north-central and western Florida Bay as a result of improving salinity conditions due to CERP implementation. This performance measure is qualitative and does not answer many important questions, such as what is the expected increase in abundance of spotted seatrout. The performance measure must answer this question and be quantitative to allow for the assessment and evaluation of restoration against a desired condition for fish in Florida Bay.

The use of juvenile spotted seatrout as an indicator of the fish community in Florida Bay is well justified. Spotted seatrout are an important recreational sportfish in the bay and spend their entire life history within the bay. The use of juveniles in the indicator minimizes the impact of confounding factors that can be more pronounced in the adult population, such as changes in fishery regulations. Spotted seatrout are an established indicator of estuarine health (Bortone, 2003) and their distribution has been documented to vary in response to salinity patterns within Florida Bay (Thayer et al., 1999). Specifically, the current salinity regime often has persistent high-magnitude hypersalinity events in the central portion of Florida Bay. When this hypersaline water is present, juvenile spotted seatrout are largely absent from this region. One of the interim goals of Everglades restoration is to mitigate these hypersalinity events in Florida Bay. If hypersalinity is reduced, habitat suitability for juvenile spotted seatrout will likely increase. However, there is no knowledge of the pre-drainage spotted seatrout community in Florida Bay; thus, performance measures must be developed from data collected in a degraded system. To accomplish this, habitat suitability index (HSI) models are being developed that can be used to estimate the area of suitable habitat if the system had not been altered and compare it to the currently observed area of suitable habitat for spotted seatrout. Once developed, these models will become the core of a quantitative performance measure for spotted seatrout in Florida Bay.

Methods

The HSI models under development calculate the area of habitat suitable for juvenile spotted seatrout from SAV and water quality parameters. In the initial formulation, the water quality component is the main focus because CERP implementation will result in changes to salinity regimes in Florida Bay, which are a parameter of the water quality component. These changes in salinity will also affect SAV distribution. However, in order to examine the effect on spotted seatrout of expected changes in SAV within the CERP context, we must first have a reliable, predictive model to estimate the SAV distribution throughout Florida Bay after CERP is implemented. Once a reliable SAV model is available, the models and thus the performance measure will be able to predict changes in suitable habitat for spotted seatrout due to both changes in salinity and changes in SAV distributions. The performance measure will examine the area of suitable habitat under current conditions with respect to the area of suitable habitat predicted from the NSM. The area of suitable habitat expected from the NSM will be used to set restoration targets that the CERP can aim to achieve.

Two distinct methods are being used to develop two compatible and comparable HSI models. The first was developed using classical techniques (Coyne and Christensen, 1997) following a similar approach that was applied to model juvenile spotted seatrout in Tampa Bay (Clark et al., 2003). Specifically, the HSI was developed following the range-mean method (Rubec et al., 1999) using the data from 2004 through 2010 (the first seven years for which there is data), leaving 2011 data for validation (the last year for which there is a full data set). A species occurrence matrix was developed to assess how juvenile spotted seatrout frequency of occurrence varied in response to all environmental parameters. Turbidity, temperature, and salinity were used as parameters for the water quality component. Spatial coverage and density of three species of seagrass—turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and shoal grass (*Halodule wrightii*)— were used as parameters for the SAV component. This matrix was first used to determine biologically relevant ranges for each parameter by defining areas where the cumulative frequency of juvenile spotted seatrout increased linearly with the environmental parameter (***Figures 6-15*** and ***6-16***). The suitability index for each biologically relevant range was calculated by dividing the observed frequency of occurrence for that range by the maximum frequency of occurrence for any biologically relevant range for that environmental parameter. This yielded suitability index scores for all environmental parameters that vary from 0 to 1. For example, the right panel of ***Figure 6-15*** shows the plot of cumulative frequency of occurrence against salinity. There are five biologically relevant ranges for salinity as determined by the five ranges with a linear response in cumulative frequency to salinity shown in the right panel. The frequency of occurrence for each of these five ranges was then calculated and divided by the highest frequency of occurrence for any of the ranges. For example, the range from a salinity of 32 to 39 had the highest frequency of occurrence at 0.255 and received an SI = 1 (0.255/0.255); however, the range from a salinity of 40 to 52 had a frequency of occurrence of 0.145 and an SI = 0.57 (0.145/0.255).

The water quality component of the HSI model is derived by aggregating the relationships of temperature, salinity, and turbidity with juvenile spotted seatrout frequency of occurrence. An index with a maximum of 1 is calculated for each of the three water quality parameters based on the ratio of the observed frequency of occurrence for a given range of that variable over the maximum observed frequency of occurrence for any range of that variable. The geometric mean of all three indices is calculated to give an overall water quality HSI score from zero to one. This model was able to explain 77 percent of the variance in spotted seatrout frequency of occurrence (***Figure 6-17***). The distribution of the water quality scores was examined in relation to the abundance and frequency of occurrence of juvenile spotted seatrout. This led to the delineation of ranges in the HSI water quality model that defined “not suitable”, “poor”, “moderate”, “good”, and “optimal habitat” for juvenile spotted seatrout based on the best professional judgment interpretation of these results (***Table 6-4***).

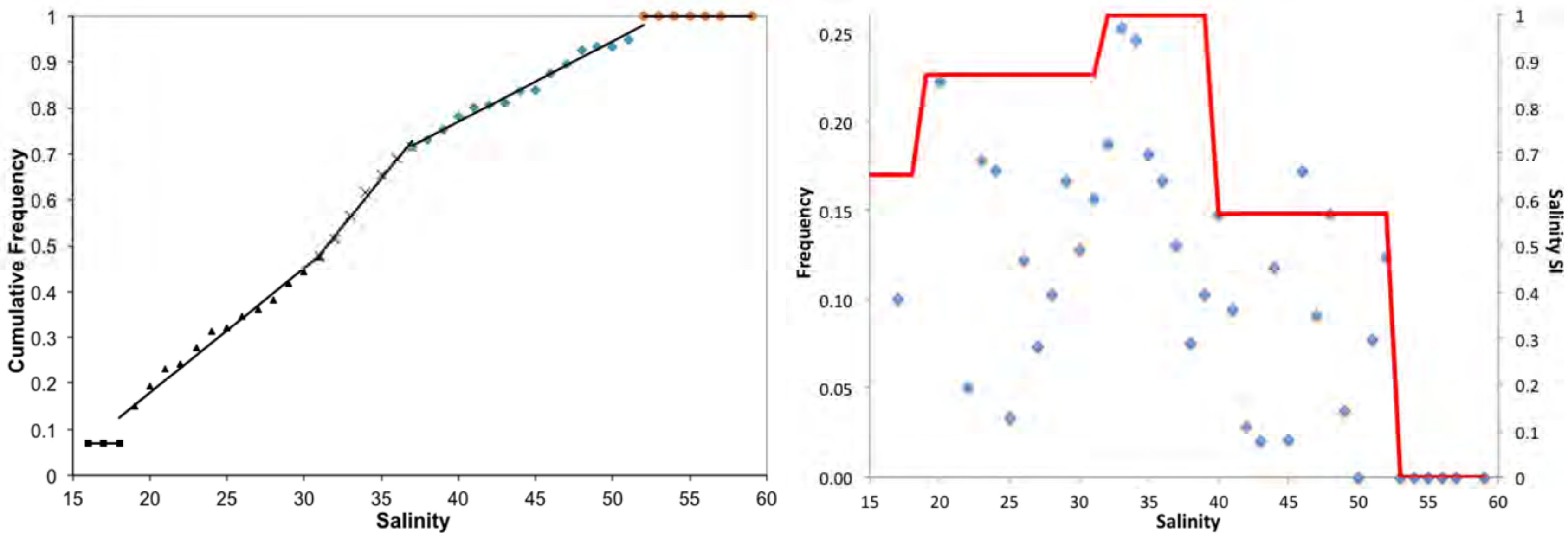

FIGURE 6-15. CUMULATIVE FREQUENCY, FREQUENCY OF OCCURRENCE, AND HABITAT SUITABILITY OF JUVENILE SPOTTED SEATROUT VERSUS SALINITY.

On the right is a plot of cumulative frequency for juvenile spotted seatrout and salinity. The lines depict the biologically relevant areas defined as areas in which the cumulative frequency increases linearly with salinity. On the left is a plot of the frequency of occurrence of juvenile spotted seatrout for each salinity bin (blue diamonds) and a red line showing the salinity suitability index score across the observed salinity range, which are constant within the biologically relevant range.

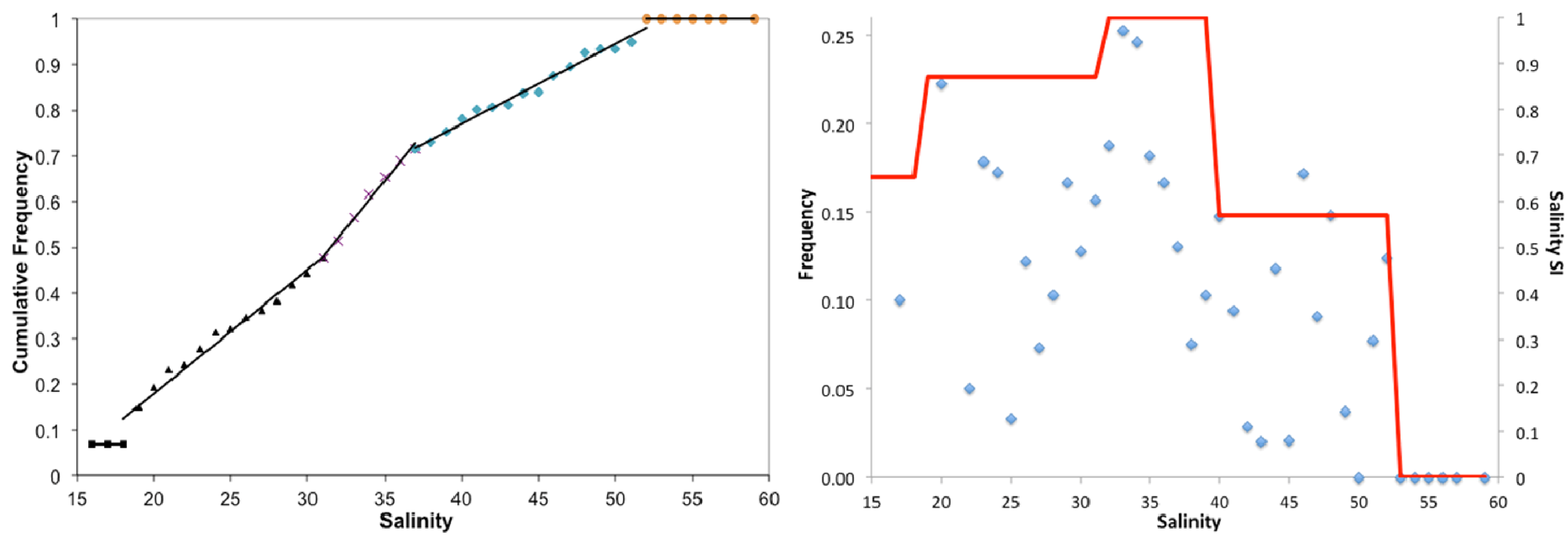

FIGURE 6-16. CUMULATIVE FREQUENCY, FREQUENCY OF OCCURRENCE, AND HABITAT SUITABILITY OF JUVENILE SPOTTED SEATROUT VERSUS TEMPERATURE.

On the right is a plot of cumulative frequency for juvenile spotted seatrout and temperature. The lines depict the biologically relevant areas. On the left is a plot of the frequency of occurrence of juvenile spotted seatrout for each temperature bin (blue diamonds) and a red line showing the temperature suitability index score across the observed temperature range, which are constant within the biologically relevant range.

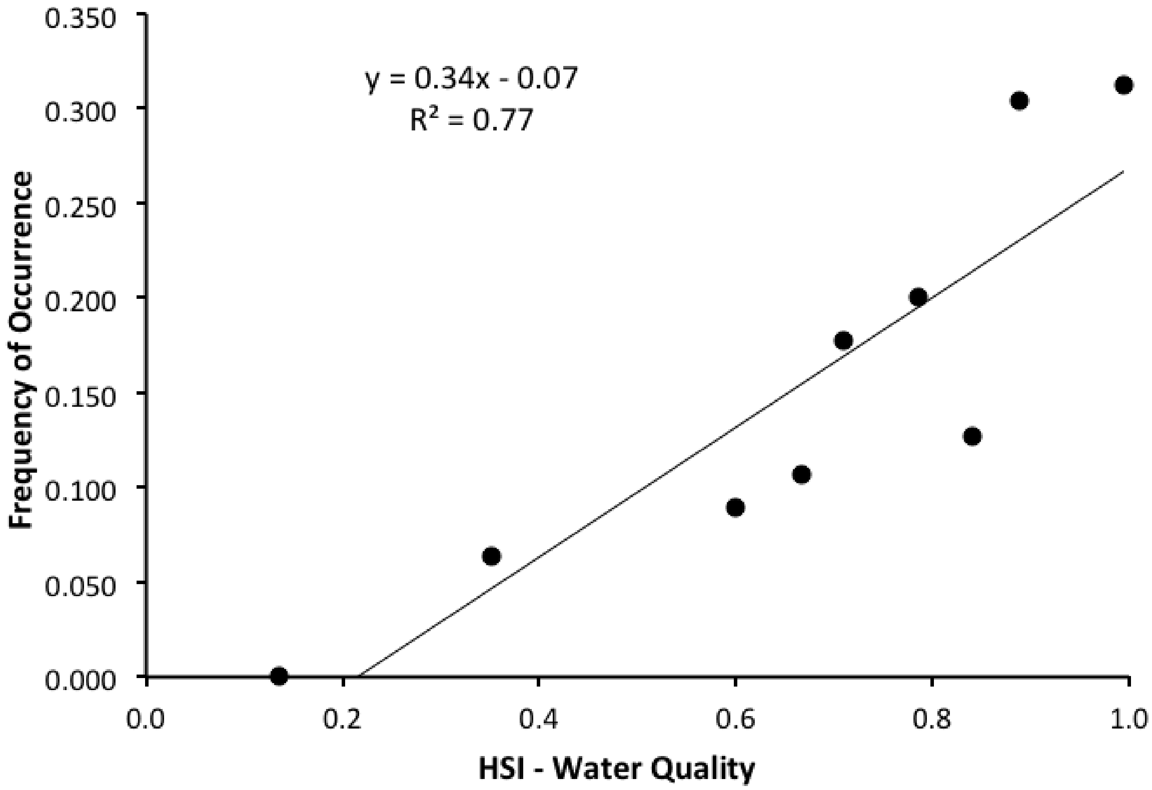

FIGURE 6-17. LINEAR REGRESSION OF FREQUENCY OF OCCURRENCE ON THE WATER QUALITY COMPONENT OF THE HSI MODEL.

TABLE 6-4. DELINEATION OF THE RANGES IN HSI SCORES INTO NOT SUITABLE, POOR, MODERATE, GOOD, AND OPTIMAL HABITAT BASED ON THE FREQUENCY OF OCCURRENCE AND ABUNDANCE OF JUVENILE SPOTTED SEATROUT.

HSI Water Quality	n	Frequency of Occurrence	Abundance (# $1000m^{-2}$)	Class
0-0.21	105	0.000	0.000	Not Suitable
0.24-0.49	156	0.064	0.665	Poor
0.60-0.68	724	0.093	0.564	Moderate
0.71-0.84	736	0.167	0.875	Good
0.88-1.00	452	0.305	2.369	Optimal

Note: # 1000m-2 – number per 1,000 square meters, n – sample size.

The second HSI model is being developed via multiple logistic regressions. There are two multiple logistic regressions that make up the model, one for water quality and one for SAV, making it directly compatible with the classically developed HSI described above. The probability of observing juvenile spotted seatrout, which corresponds to a value between zero and one, is calculated separately from the water quality and SAV parameters. The use of logistic regression offers two main advantages. First, it is a continuous model where the data does not have to be binned like in the classical technique, which reduces the amount of information going into the model. Second, the multiple regressions allow all of the water quality and SAV components to be considered in concert rather than in isolation as is done using the range-mean method. Calculating the probability of observing juvenile spotted seatrout with all of the parameters at once reduces the influence of factors that may co-vary such as temperature and salinity, which are known to co-vary in Florida Bay (Kelble et al., 2007). This results in a model that more accurately reflects the true relationship between environmental parameters and the juvenile spotted seatrout population.

The logistic regression was calculated using all data collected from 2004 through 2010, leaving 2011 data out for model validation. For water quality, we examined the potential effects of sediment depth, water depth, turbidity, salinity, and temperature on the probability of juvenile spotted seatrout occurrence. However, only salinity and temperature were found to contribute significantly to the logistic regression HSI for water quality and both variables showed a hyperbolic relationship (***Figure 6-18***).

Both HSI models corroborate each other's findings with respect to water quality. For salinity, both show the best range for juvenile spotted seatrout to be from 20 to near oceanic values of 36 with significant decreases in habitat suitability as salinity increases from 36 through 50 and very poor conditions when the salinity is greater than 50 (***Figures 6-15*** and ***6-18***). This is similar to salinity preferences that have previously been reported for juvenile spotted seatrout. The preferred temperature range is much narrower than salinity in both models with the optimal conditions being from about 25 degrees Celsius (^{o}C) to just above 30 ^{o}C and significant declines indicating poor habitat for temperatures less than about 23 ^{o}C (***Figures 6-16*** and ***6-18***). The corroboration between models gives us confidence that the HSI models are performing well and accurately reflect the true relationship between environmental parameters and juvenile spotted seatrout.

The next step in developing a quantitative performance measure is to validate these models against the 2011 data, select the one which performs the best, and use this HSI model to examine and quantify the gains in juvenile spotted seatrout habitat expected from CERP implementation. We have begun to do this by using output from the NSM that simulates stage height in the Everglades under pre-drainage conditions. These stage heights are then input into multiple linear regression models that link stage height to salinity at ten stations within Florida Bay (Marshall et al., 2011). Output salinity is then adjusted using paleo-ecological information to estimate what the natural salinities would have been in Florida Bay from 1962 through 2002 (Marshall et al., 2009; Marshall and Wingard, 2012). Since this period of record for the NSM does not overlap with our observations we had to find years that would likely have similar salinity patterns. These years were identified by correlating monthly rainfall patterns for the year of interest and the preceding six months. At least one match was found in the 30-year NSM record for every year from 2004 through 2010. After identifying years with similar patterns, the HSI model was run on the current observational data and on the NSM values.

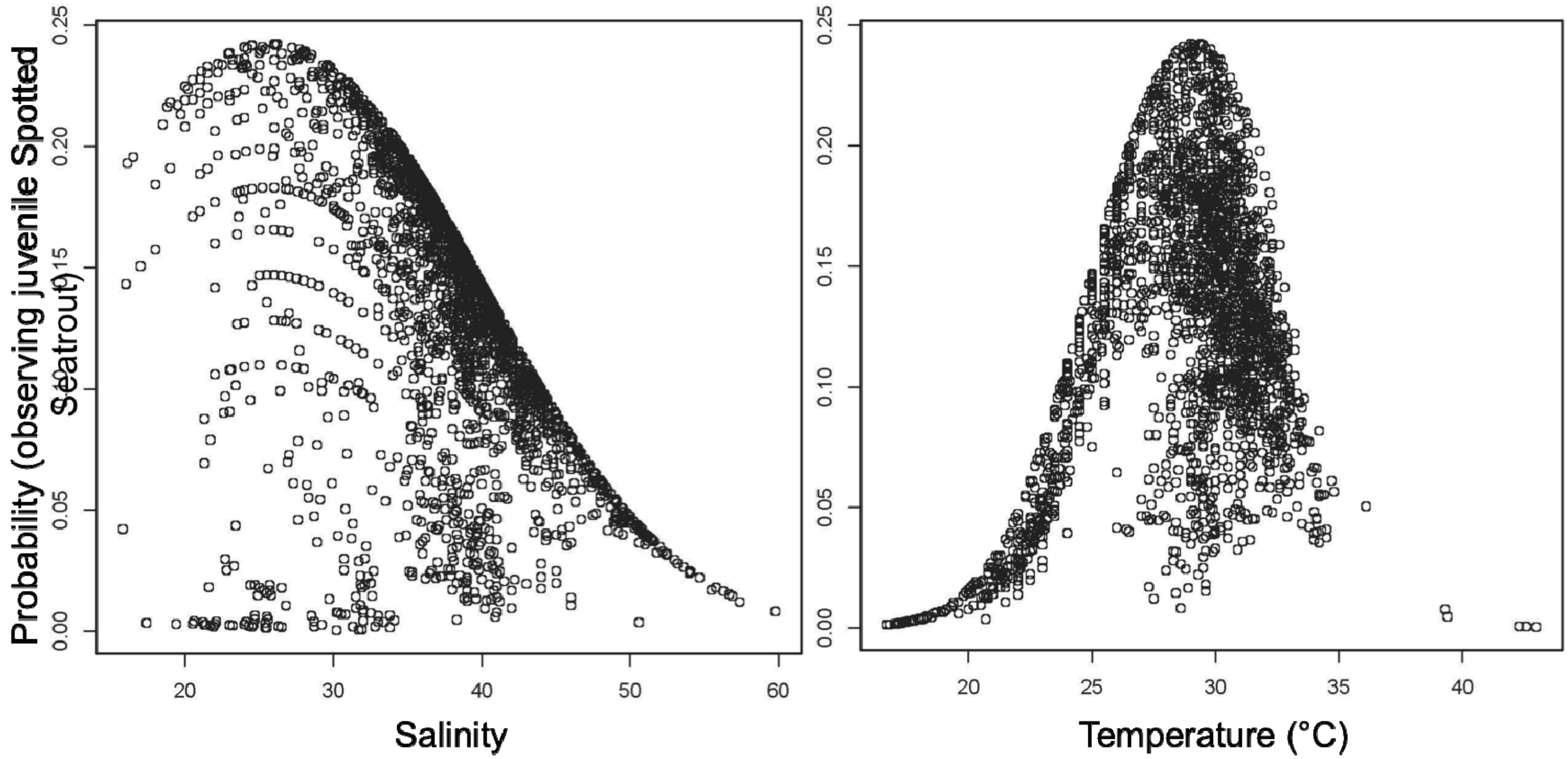

FIGURE 6-18. RESULTS FROM THE HSI MODEL DEVELOPED USING LOGISTIC REGRESSION SHOWS THE HYPERBOLIC RELATIONSHIP BETWEEN THE PROBABILITY OF OBSERVING JUVENILE SPOTTED SEATROUT AND SALINITY OR TEMPERATURE.

(Note: ºC – degrees Celsius.)

For example, 2009 rainfall was well-correlated with 1975 rainfall, so the HSI was calculated from the observational data collected in August 2009 and for the NSM salinities of August 1975. This allows us to estimate the distribution of juvenile spotted seatrout habitat that would have been observed if anthropogenic drainage had not occurred. In other words, the area of suitable habitat under a full restoration scenario corresponds to that calculated from the NSM. The output shows that if CERP implementation restores Florida Bay to natural conditions there would be a dramatic increase in the areal extent of good and optimal habitat for juvenile seatrout (***Figure 6-19***).

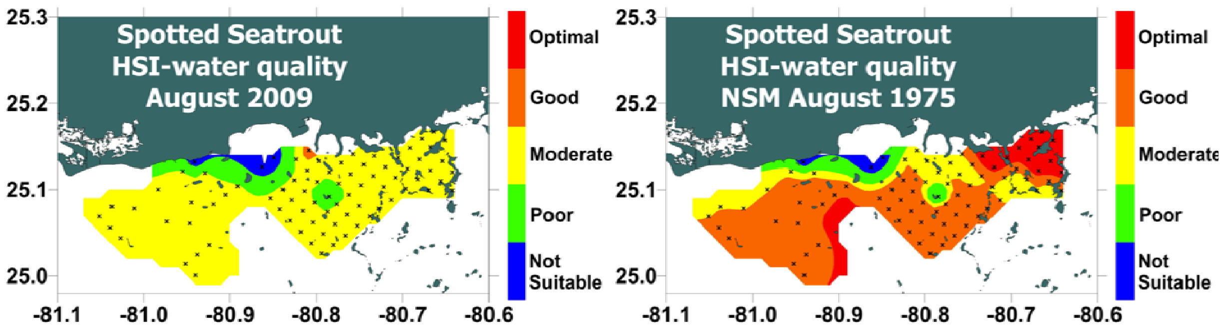

FIGURE 6-19. SPATIAL DISTRIBUTION OF HABITAT QUALITY FOR SPOTTED SEATROUT CALCULATED FROM OBSERVATIONS IN AUGUST 2009 (LEFT PANEL) AND FROM THE NSM OUTPUT IN AUGUST 1975 (RIGHT PANEL).

Note that the color scheme for optimal, good, etc. differs from what was used in ***Table 6-1***.

Wrap up

The HSIs described above represent significant progress in the development of a fish performance measure for Florida Bay since the 2009 SSR. It is anticipated that the further development, and possible completion, of this fish performance measure will be a high priority task for the RECOVER SCS Team for Fiscal Year 2013, resulting in a significantly improved seatrout performance measure for use in the 2014 SSR.

ROSEATE SPOONBILLS

The condition of roseate spoonbills in northeastern (NE) Florida Bay appears to be improving while the condition of those in northwestern (NW) Florida Bay is declining.

Nesting success in NE Florida Bay has improved greatly in recent years, probably due to favorable climatic conditions and to communication between the principle investigator (Dr. Jerry Lorenz) and operations managers at the SFWMD during nesting season. This communication results in fewer unnecessary disruptions in flow patterns to the foraging grounds in NE Florida Bay, leading to better foraging opportunities resulting in greater nesting success.

The chicks that have fledged over this seven-year period of high production are now coming into sexual maturity and may reverse the declining trend in nest numbers in NE Florida Bay. For the first time in over a decade, nest numbers increased (from 87 in 2011 to 186 in 2012). In addition, a long dormant colony just north of Florida Bay (Madeira Hammock Colony) was discovered to be active in 2011 by aerial reconnaissance. Although nest numbers cannot be counted from the air, nesting activity is readily identifiable. The colony is remote and extremely difficult to access. Efforts to access the colony failed in 2011, but this year a passable route was found and two surveys were made. An additional 164 nests were estimated with a high degree of nesting success. A good percentage of the observed adults were birds that were marked as hatchlings in Florida Bay colonies, indicating that this colony is part of the NE Florida Bay population.

In contrast, nest numbers in NW Florida Bay have declined to the point of having a yellow score for the first time in over 25 years starting in 2010. By 2011, they declined to being nearly scored in the red (140 nests counted; the red threshold is 130). Furthermore, there were three consecutive years of failed nesting from 2010 to 2012. This has only happened once before during an exceptionally wet set of years (1996–1998). Since 1984, there have only been eight years in which NW Florida Bay colonies have failed (including 1996–1998) prior to 2010. The cause for the decline in NW Florida Bay is not known, but two highly speculative reasons can be put forth. One is that much more nest predation from crows has been observed over the last few years. This generally occurs in relatively close proximity to the Flamingo Visitor Center where crows have ample subsidies from human carelessness: crows regularly raid unattended human food parcels and trash. This also has been observed to be more frequent in recent years. The second possibility is that the Homestead and East Cape canals have degraded the interior wetlands of Cape Sable (the primary foraging grounds of NW Florida Bay birds) to the point that they are no longer as productive in prey base fishes. These canals have since been plugged but a third canal, Raulerson Brothers Canal, has become an uncontrolled tidal canal continuing the degradation started by the Homestead and East Cape canals.

For additional information on roseate spoonbills, see the Everglades Coastal Wetlands Results page of the 2009 SSR (RECOVER, 2010) available online at the following website: http://www.evergladesplan.org/pm/ssr_2009/hc_ge_egcw_results.aspx.

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