Chapter 6: Everglades Research and Evaluation

Edited by Fred Sklar and Thomas Dreschel

SUMMARY

The studies and findings discussed in this chapter are presented within four main fields: (1) wildlife ecology, (2) plant ecology, (3) ecosystem ecology, and (4) landscape patterns and ecology. Programs of study are based on the short-term operational needs and long-term restoration goals of the South Florida Water Management District (District or SFWMD), including large-scale and regional hydrologic needs in relation to regulation schedules, permitting, Everglades Forever Act (Section 373.4592, Florida Statutes) mandates, and the Comprehensive Everglades Restoration Plan (CERP). This chapter summarizes Water Year 2014 (WY2014) (May 1, 2013–April 30, 2014) hydrology in the Everglades Protection Area (EPA), followed by an overview of key Everglades studies on wildlife, plants, the ecosystem, and landscapes (**Table 6-1**).

HYDROLOGY

In general, rainfall for the entire region hovered around the historical average and was slightly less than last year. The amount of rain in the EPA for WY2014 was 2 to 9 inches less than last year, but still a few inches above the average historical conditions, except in Everglades National Park (ENP), which was slightly below the historical average.

In ENP, the rainfall was 4.4 inches less (8.0 percent) than the historical average, and 7.7 inches less (13.2 percent) than last year. Water Conservation Area (WCA)-1 and WCA-2 experienced the smallest deviations from the historical average. Rainfall in WCA-1 and WCA-2 was only 2 inches (3 percent) above the historical average and 8.9 inches (14.2 percent) less than last year. The rainfall in WCA-3 was only 2.7 inches more (5.3 percent) than the historical average and was only 2.1 inches more (3.7 percent) than last year.

WILDLIFE ECOLOGY

Nesting effort was relatively suppressed for most species of wading bird during 2014. An estimated 25,529 wading bird nests were initiated in the Everglades during the 2014 nesting season. This nesting effort is 29 percent lower than the decadal average (35,483 nests) and 65 percent lower than 2009, which was the best nesting year on record in the Everglades since the 1940s.

The Loxahatchee Impoundment Landscape Assessment (LILA) facility continues to be an effective, living laboratory for evaluating fish, crayfish, wading bird, and hydrology interactions. This year, a LILA study is described in which tagged fish are tracked across habitat types with changing hydrology.

A third wildlife study examines the potential for applying remote sensing applications (high resolution digital imagery) to vegetation and wildlife monitoring and research. Based on results of

early testing, the technique will be useful for gathering quick-response, multiple-use data for monitoring SFWMD assets, structures, effectiveness of the Stormwater Treatment Areas (STAs), and the effects of water management decisions on restoration. This data is appropriate for monitoring ecological and operational targets (levee inspections, exotic vegetation assessment, STA vegetation health, etc.), and can be considered a valuable source of data.

PLANT ECOLOGY

The two plant projects discussed in this chapter focus on hydrologic impacts and restoration goals. This year, a LILA study assesses the potential for deploying saplings in peat bags for the purpose of restoring degraded tree islands. Initial observation following a year-long study are promising, pond apple saplings grow and produce an extensive root system.

In a second study, characteristics of tree growth and production are compared between regions of a conserved and degraded tree island in the Everglades. The results indicate that litterfall production is an ecological process that is strongly influenced by several environmental parameters, such as hydrology, soil nutrients, air temperature, rainfall, and wind, that operate over large spatial and temporal scales. Results from this study confirm previous reporting in which current hydrological conditions of high water level, low water flow, and impounded conditions need to be restored to the historical conditions of moderate water levels and flow, to restore the structure and function of degraded tree islands.

ECOSYSTEM ECOLOGY

Two ecosystem-scale projects are reported in this chapter. First, an update on Active Marsh Improvement—a project designed to provide a better understanding of the effect of physical removal of cattail using herbicides— is provided. This study demonstrated that the lower rate, 0.21 kilogram acid equivalent per hectare (kg ae ha^{-1}), would not be recommended to manage cattail in similar nutrient enriched conditions. In contrast, the higher rate, 0.28 kg ae ha^{-1}, was effective and maintained its maximum effectiveness for 21 months after treatment (MAT), but showed signs of declining efficacy at 24 MAT. Overall, these results confirm imazamox to be a viable tool to manage ridge and slough habitat patterning within the Everglades.

The second project describes monitoring and research being conducted in Florida Bay. Water quality in Florida Bay (eastern, central and western regions), Whitewater Bay to the west, and Barnes Sound in Biscayne Bay to the east and other southern coastal systems has been monitored since 1991 (WY1992) to ensure that District operations and projects protect and restore the ecosystem to the extent possible. As reported in the *2014 South Florida Environmental Report–Volume I*, annual averages of all parameters analyzed (chlorophyll a, total dissolved phosphorus, total dissolved nitrogen, total organic carbon, dissolved inorganic nitrogen, and turbidity) were similar between WY2012 and WY2013 and continue to be similar during WY2014.

Analysis of synoptic survey results shows that surface water conditions across much of northeastern Florida Bay are correlated with discharge through the western creeks (Taylor River and Mud Creek). The western creeks have particular importance because ongoing restoration efforts are expected to increase their water deliveries. In addition, the robust relationship between Taylor River discharge and near-shore salinity suggests that it is an appropriate sentinel monitoring site for tracking trends and conditions of northeastern Florida Bay.

Studies are being conducted to determine the factors influencing *Ruppia maritima* presence and abundance throughout the mangrove ecotone in Florida Bay. *R. maritima* is a desired benthic vascular plant that provides shelter and food for numerous birds, invertebrates and fish, creates quality habitat and increases higher trophic level productivity in Florida Bay. *R. maritima* is an explicit restoration target for expansion in CERP performance measures and is the valued

ecosystem component by which the effectiveness of the Florida Bay Minimum Flows and Levels rule is assessed.

The SEACOM is a seagrass community ecological simulation model of Florida Bay. The model was used in support of the Restoration Coordination and Verification (RECOVER) efforts to predict potential trajectories of seagrass biomass and species composition under historical salinity conditions simulated by the Natural Systems Model, the existing condition baseline, the future without project model and Central Everglades Planning Project (CEPP) implementation of restoration flows to Florida Bay [Alternative 4R2 (Alt 4R2)].

LANDSCAPE

Three projects are described that involve the evaluation of landscape-level changes. The first project involves evaluating methods for mapping cattail expansion within the Everglades. Mapping the extent and spread of cattail invasion and loss of sawgrass in a timely manner is important for restoration and water management decisions, but has been difficult due to the spectral similarity and similar growth forms of the species. In this study, combining ecological theory—the invasion ecology of a species—together with a combination of advanced remote sensing techniques permitted us to automatically classify two similar communities to acceptable (75–89 percent) accuracy that could not be differentiated by pixel-based techniques in the past. Changes in cattail coverage can be rapidly mapped—completing a classification within one day—as opposed to previous manual classifications that can take months to years to complete.

In the second landscape project, an update to the Decomp Physical Model (DPM) effort is provided. The DPM examines the impacts of restoring flow between WCA-3A and WCA-3B. To reproduce pre-drainage flow conditions, new structures were built for the experiment, including 10 gated culverts on the L-67A levee, a 3,000-foot gap in the L-67C levee, and three 1,000-foot canal backfill treatments in the adjacent canal. With a combined discharge capacity of 750 cubic feet per second, the culverts generated water velocities as high as 4.5 centimeters per second. This report describes the sediment, total phosphorus and fish dynamics, providing synthesis examples of ridge and slough and marsh-to-canal dynamics.

The third landscape project provides a description of workshops held to discuss the ecological significance of an unstationary future climate on south Florida, particularly on the restoration of the Everglades. The major results of the first technical meeting in 2013 were that increased temperature and decreased rainfall could pose very serious challenges to the goals of Everglades restoration and water supply, particularly in the freshwater wetlands (WCA-1, WCA-2, and WCA-3). Sea level rise might affect ENP and coastal systems through replacement of freshwater ecosystems with marine ecosystems and displace coastal mangrove forests inland.

Table 6-1. Water Year 2014 (WY2014) (May 1, 2013–April 30, 2014) Everglades research findings in relation to operational mandates.[1]

Project	Findings	Mandates[1]
Hydrology		
Hydrologic Patterns for WY2014	Rainfall for WY2014 hovered around the historical average. Dry season recession rates began much earlier than typical and were an important cue for wading birds to start nesting. Early foraging and nesting was disturbed, but not eliminated, by a major reversal in January. Central Water Conservation Area-3A (WCA-3A) did not experience a dry season reversal and had excellent hydrology in support of wading birds.	ROS MFL
Wildlife Ecology		
Wading Bird Nesting Patterns	Nesting effort was relatively suppressed for most species of wading bird during 2014. Numbers of great egret and white ibis nests were reduced compared to recent years. The smaller *Egretta* herons, which have exhibited a consistent decline in nest numbers in recent years, had another relatively poor nesting season. These declines in *Egretta* herons do not appear to be due to changes in the distribution of nesting and instead appears to reflect a general reduction in overall nesting effort in the Everglades. Roseate spoonbills also exhibited relatively reduced nesting effort in 2014. In Florida Bay, spoonbill nesting effort was less than half that of recent years.	ROS CERP MFL FEIM
Habitat Preferences of Tagged Fish in the Loxahatchee Impoundment Landscape Assessment (LILA)	Findings show that reflooding events such as reversals can cause important distributional changes in prey fishes, promoting use of newly available habitats and thereby reducing densities in alligator holes, as well as in sloughs where wading birds typically forage. Reflooding events may then lower slough prey densities as prey move to ridges, and where due to the high sawgrass density, wading birds foraging may be less likely and less successful.	CERP MFL ROS
Capturing Digital Aerial Imagery for Vegetation and Wildlife Monitoring Data	The feasibility of affixing a Unmanned Aerial Systems payload (camera, GPS, inertial navigation system, etc.) to a South Florida Water Management Bell 407 helicopter was evaluated. This would provide for flexible altitude requirements, the ability to change targets with short notice, and allowing entrance into the Class B airspace without special permission.	CERP MFL ROS

[1]**Mandates**

CERP	Comprehensive Everglades Restoration Plan
EFA	Everglades Forever Act, Section 373.4592, Florida Statute (F.S.)
FEIM	Florida Everglades Improvement and Management
LTP	Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area
MFL	Minimum Flows and Levels, Section 373.042, F.S., Chapter 40E-8, Florida Administrative Code
ROS	Regulation and Operational Schedules

Table 6-1. Continued.

Projects	Findings	Mandates[1]
Plant Ecology		
Deploying Tree Saplings in Peat Bags as a Potential Restoration Technique: A Pilot Study	A conceptual approach for creating artificial floating islands is being tested. Commercially available peat bags were used to support one or two tree saplings until they can become established near the ghost tree island head and provide a seed source for further recruitment. To do this, the saplings are planted into the bags which are then floated onto the site, punctured and tethered in place using PVC poles.	CERP EFA ROS
Litterfall and Tree Growth Dynamics in a Pristine Tree Island and a Degraded Tree Island in WCA 3-A	This study compares forest structure, growth rate, species contribution to leaf fall, and litterfall between a pristine and a degraded tree island. It is hypothesized that soil saturation and poor soil nutrient conditions have a negative effect on the structure and function of tree islands. The results indicate that litterfall production is strongly influenced by several environmental parameters, such as hydrology, soil nutrients, air temperature, rainfall, and wind, that operate over large spatial and temporal scales.	CERP EFA ROS
Ecosystem Ecology		
Active Marsh Improvement Project – Slough Study	Twenty-four months after treatment (MAT), analysis of plant responses in the Active Marsh Improvement – Slough Project, demonstrated that only the higher rate of herbicide application resulted in decreased cattail percent cover compared to controls, suggesting the lower rate will not maintain effective treatment long-term. However, even the higher rate showed evidence of increased cattail growth at 24 compared to 21 MAT, suggesting reapplication, or spot treatment, may be necessary in these high nutrient areas.	LTP ROS
Florida Bay Update	Hydrologic patterns, water quality and macrophyte coverage in Florida Bay showed little long-term change from the previous two years. The results of synoptic, high resolution water quality measurements linked discharge with the water quality of the bay. In addition, a submerged aquatic vegetation model indicated improved conditions with the implementation of increased freshwater flows expected from the Central Everglades Planning Project.	CERP MFL ROS

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Table 6-1. Continued.

Projects	Findings	Mandates[1]
Landscape		
Tracking Transitions from Sawgrass-Dominated Landscape to Cattail-Dominated Landscape	This study investigated the ability to automatically classify two similar vegetative communities using ecological theory and remote sensing techniques by classifying three years of Landsat imagery by texture and spectral characteristics, assessing their accuracy, and comparing the results to previous high-resolution, hand-delineated maps.	CERP EFA ROS MFL
Reintroducing Sheetflow to the Ridge and Slough Landscape – Findings from the First High Flow Event in the Decomp Physical Model (DPM)	During the first flow event, water velocities high enough to erode sediments and increase sediment transport up to twentyfold higher than baseline, pre-flow estimates were achieved. Greater transport in sloughs than ridges does indicate the greater erosion of slough sediments, an important first step in restoring microtopography. Importantly, particulates and water total phosphorus did not increase, suggesting particle recapture is sufficient to maintain low TP conditions even while flowing. Results from fish sampling suggest there has been no loss of fishing habitat with the partial or complete fills.	CERP MFL ROS
Climate Change Simulation Workshops: 2013 & 2014	Climatic and sea level change might pose challenges to south Florida water supply, flood control, and environmental restoration over the next century. These challenges surpass the ability of any one agency or governmental unit to address. The District is participating in regional and national efforts to begin planning for sea level rise in South Florida.	CERP MFL ROS

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HYDROLOGIC PATTERNS FOR WATER YEAR 2014

Fred Sklar

In general, rainfall for the entire region hovered around the historical average and was slightly less than last year (**Table 6-2**). The amount of rain in the Everglades Protection Area (EPA) for Water Year 2014 (WY2014) (May 1, 2013–April 30, 2014) was 2 to 9 inches less than last year, but still a few inches above the average historical conditions, except in Everglades National Park (ENP), which was slightly below the historical average. In ENP, the rainfall was 4.4 inches less (8.0 percent) than the historical average, and 7.7 inches less (13.2 percent) than last year. Water Conservation Area (WCA)-1 and WCA-2 experienced the smallest deviations from the historical average. Rainfall in WCA-1 and WCA-2 was only 2 inches (3 percent) above the historical average and 8.9 inches (14.2 percent) less than last year. The rainfall in WCA-3 was only 2.7 inches more (5.3 percent) than the historical average and was only 2.1 inches more (3.7 percent) than last year.

Table 6-2. Average, minimum, and maximum stage [feet National Geodetic Vertical Datum of 1929 (ft NGVD)] and total annual rainfall (inches) for Water Year 2014 (WY2014) (May 1, 2013–April 30, 2014) in comparison to historical stage and rainfall for the Water Conservation Areas (WCAs) and Everglades National Park (ENP).[1] (Average depths calculated by subtracting elevation from stage.)

Area	WY2014 Rainfall	Historical Rainfall	WY2014 Stage Mean (ft NGVD) (min; max)	Historical Stage Mean (ft NGVD) (min; max)	Elevation (ft NGVD)
WCA-1	53.92	51.96	16.31 (15.07; 16.83)	15.66 (10.0; 18.16)	15.1
WCA-2	53.92	51.96	12.69 (11.63; 14.19)	12.52 (9.33; 15.64)	11.2
WCA-3	54.10	51.37	10.23 (8.98; 11.59)	9.59 (4.78; 12.79)	8.2
ENP	50.08	55.22	6.63 (5.80; 7.26)	6.0 (2.01; 8.08)	5.1

[1]See Chapter 2 of this volume for a more detailed description of rain, stage, inflows, outflows, and historical databases.

The small amount of above-average rainfall in all three WCAs translated into a small and proportional increase in mean stage in each WCA (**Table 6-2**). A similar proportional change in the average stage of the ENP did not occur. Despite the fact that the ENP had less rain than the historical average and less rain than last year, it had a higher stage than the historical average [6.63 feet National Geodetic Vertical Datum of 1929 (ft NGVD) versus 6.0 ft NGVD, respectively) and it had a higher stage than last year (6.63 ft NGVD versus 6.52 ft NGVD, respectively). This may have been due to a significantly wetter dry season in WY2014 than last year and on average. During the dry season (i.e., winter), evapotranspiration is lower than during the wet season; therefore, more water is available throughout the area. This combined with active water management [an Everglades Restoration Transition Plan (ERTP) schedule] to move water south as much as possible, lead to higher than predicted stages for ENP.

The following hydropattern figures highlight the average stage changes in each of the WCAs for the last three years in relation to the recent historical averages, flooding tolerances for tree islands, drought tolerances for wetland peat, and recession rates and depths that support both nesting initiation and foraging success by wading birds. These indices are used by the South Florida Water Management District (District or SFWMD) to facilitate weekly operational discussions and decisions. Tree island flooding tolerances are considered exceeded when depths on the islands are greater than 2-2.5 feet for more than 120 days (Wu et al., 2002). Drought tolerances are considered exceeded when water levels are greater than 1 foot below ground for more than 30 days, i.e., the criteria for Minimum Flows and Levels (MFL) in the Everglades (SFWMD, 2014b). **Figures 6-1** through **6-7** show the ground elevations in the WCAs as being essentially the same as the threshold for peat conservation. We use the concept of peat conservation to indicate what is needed to restore a hydrologic environment that will prevent soil oxidation of the ridges and tree islands. The drought tolerance concept is a peat fire potential index and as such does not capture this restoration criteria.

The wading bird nesting period is divided into three simple categories (red, yellow, and green) based upon foraging observations in the Everglades (Gawlik, 2002). A red label indicates poor conditions due to recession rates that are too fast (greater than 0.6 foot per week) or too slow (less than 0.04 foot per week for more than two weeks). A red label is also given when the

average depth change for the week is positive rather than negative. A yellow label indicates fair conditions due poor foraging depths (i.e., depths greater than 1.5 feet), or slow recession rate of 0.04 foot for a week, or rapid recessions between 0.17 foot and 0.6 foot per week. A green/"good" label is assigned when water depth decreased between 0.05 foot and 0.16 foot per week and water depths are optimum for foraging by the wading birds (i.e., between 0.1 and 1.5 feet).

WATER CONSERVATION AREA 1

The water levels in WCA-1 at the start of WY2014 were abnormally high. In April and May of 2013, the lack of a receding stage stopped the wading birds from foraging and may have given their prey (small fish) an opportunity to rebound from the drought of WY2012. What is interesting about the WCA-1 stage in WY2014 is the relative flatness of the entire year. Depths hovered around 1 to 1.5 feet from May 2013 until March 2014. There was a slight wet season peak in October when depths reach about 1.75 feet, after which, recession rates were excellent and cued the wading birds to nest earlier than average. Unfortunately, there were two reversals in the dry season in WY2014 causing the birds to start and re-start nesting, and reducing the potential for high nesting success in WCA-1.

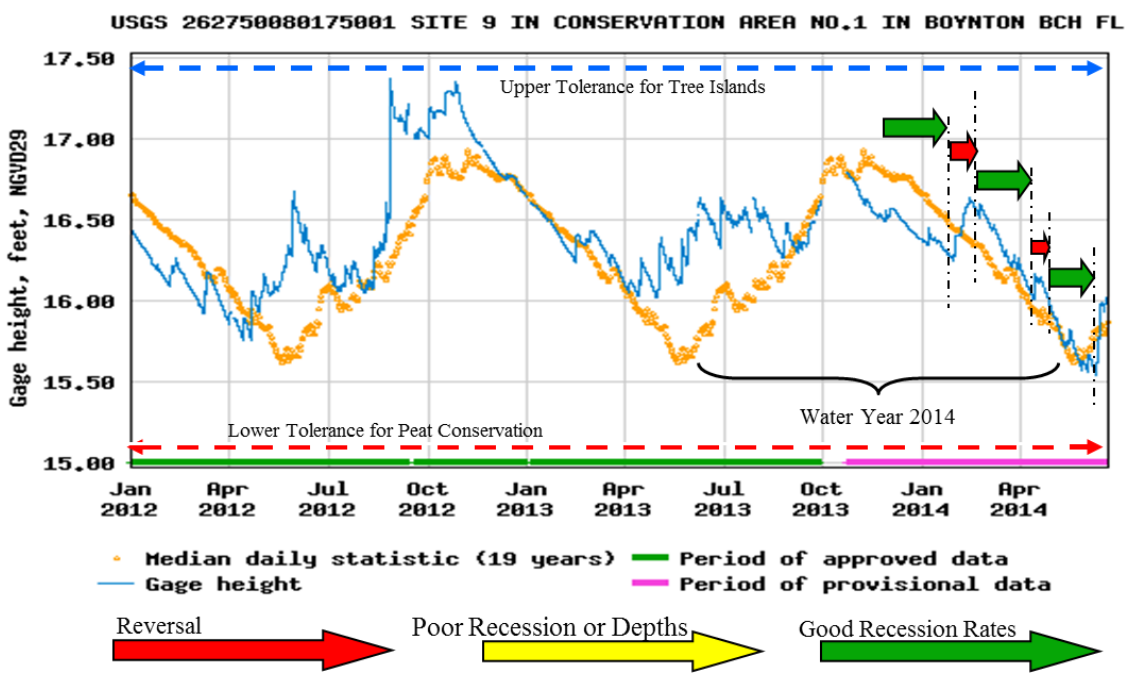

Figure 6-1. Hydrology in Water Conservation Area (WCA)-1 in relation to the 19-year median stage, as well as indices for tree island flooding, peat conservation, and wading bird foraging. [Note NGVD29 – National Geodetic Vertical Datum of 1929, USGS – United States Geological Survey.)

WATER CONSERVATION AREA 2A AND 2B

It is common for the stage levels during the wet season to briefly exceed the upper flood tolerance for tree islands in WCA-2A, as it did this year (**Figure 6-2**). Although one month is not considered enough time to cause any long lasting tree island damage (Wu et al., 2002), it is believed that tree islands may require some dry periods for survival (Heisler et al., 2002). Two out of the last four years have seen wet season water depths below the upper tolerances for tree islands; good for the remaining islands, and possibly a period of rejuvenation for the "ghost" islands that need restoration. Future efforts to restore WCA-2A tree islands will require a closer examination of the Dynamic Equilibrium Hypothesis (i.e., peat accumulation is a balance between plant productivity and soil respiration) to see if this kind of hydropattern can enhance the return of woody species to these marshes.

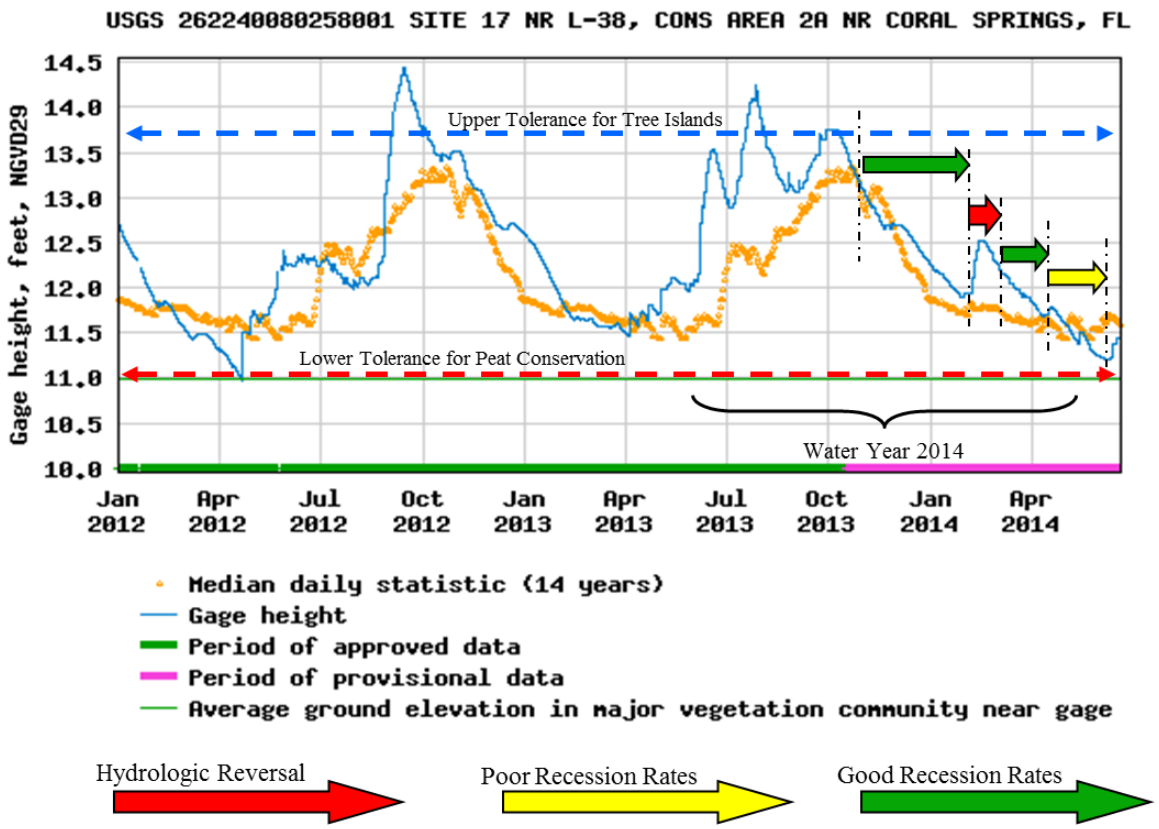

Figure 6-2. Hydrology in WCA-2A in relation to the recent 14-year average, with indices for tree islands, peat conservation, and wading bird foraging.

In WY2013, WCA-2A good recession rates were long lived, followed by a rapid and early return of the WY2014 wet season (**Figure 6-2**). This rehydration rate during the wet season created a good environment for prey rebound. Recession rates were excellent starting in November and cued the wading birds to nest earlier than average. No nesting was observed; lack of tree islands in WCA-2A and WCA-2B makes these regions unsuitable for nesting. Unfortunately, as in WCA-1, there was a large reversal due to high rainfall in January and February that fostered a nesting re-start. Good foraging recessions and depths began again in March and lasted until some small reversals occurred in April and May. In general, WCA-2A was a good foraging location in WY2014 because (1) the rehydration in WY2013 allowed bird prey to rebound and (2) the WY2014 hydrology created a relatively long foraging period of March to June. The 2012 to 2014 hydrograph (**Figure 6-2**) for this section of the WCA continues to suggest a long-term trend of above average foraging.

WCA-2B tends to be utilized by wading birds only during large-scale droughts because it tends to stay deeper for longer periods than the rest of the EPA. This was true in WY2009 when dry season water levels went below ground for most of the EPA, and the wading birds moved to WCA-2B. It was not true in WY2014 because foraging was good throughout the Everglades and because water depths in WCA-2B remained above 2 feet from June 2013 until May 2014 (**Figure 6-3**). Unlike many previous years, there was a short period in WY2014 (April, May and June) when recession rates and water depths in WCA-2B were excellent for foraging by wading birds. Despite these good conditions, there was no evidence of foraging behavior in WCA-2B.

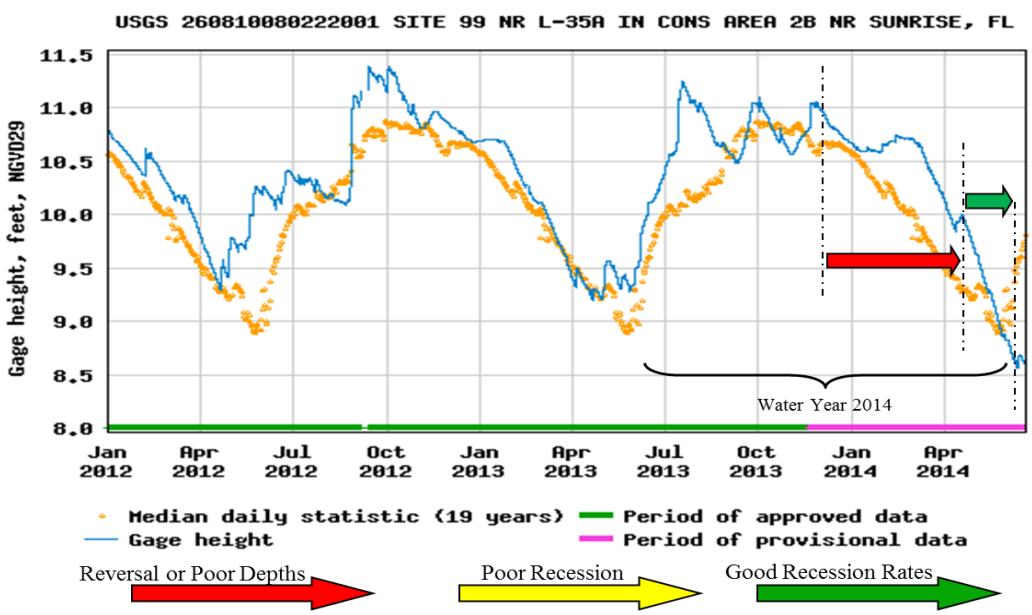

Figure 6-3. Hydrology in WCA-2B (gage 99) in relation to the recent 19-year average with indices for tree islands, peat conservation, and wading bird foraging. WCA-2B does not show ground elevation or tree island tolerance because WCA-2B acts more like a reservoir where water depths are consistently too deep for tree islands and the peat conservation index is never reached.

WATER CONSERVATION AREA 3A

The stage changes in the northeastern region of WCA-3A (gage 63) was almost an exact replica of WY2013. Like WY2013, the WY2014 wetseason began early, rose quickly, stayed above average for most of the wet season and exceeded the tolerance of tree islands for some 100 days (**Figure 6-4**).One hundred days are not considered enough time to cause any long lasting tree island damage (Wu et al., 2002). Unlike WY2013, the dry season started very early in WY2014. Recession rates were excellent starting in November—good for wood storks (*Mycteria americana*)—and optimum depths started to appear around January. Recession rates and depths cued foraging and nesting in December 2013 and might have resulted in an extended nesting season in northern WCA-3A if it were not for the big January–February reversal (evident from rainfall gages in the region but not evident in **Figure 6-4** due to missing data). Instead, this mid-dry season reversal caused the prey base to disperse causing foraging to decline and some birds to abandon their nest (Cook, in prep), while others delayed nesting. In general, northern WCA-3A hydrology was below optimum but had enough "green" periods to support a moderate recruitment from the always prolific Alley North Colony. Of particular interest is the return of roseate spoonbills (*Platalea ajaja*), a species that typically nests in the coastal habitats of Florida Bay, and their incorporation into the Alley North Colony for the last three years.

The 2012 to 2014 hydrograph (**Figure 6-4**) for this northern section of the WCA suggests a long-term trend of average foraging and nesting. For the last three years, the hydrograph during the dry season was typified by green arrows.

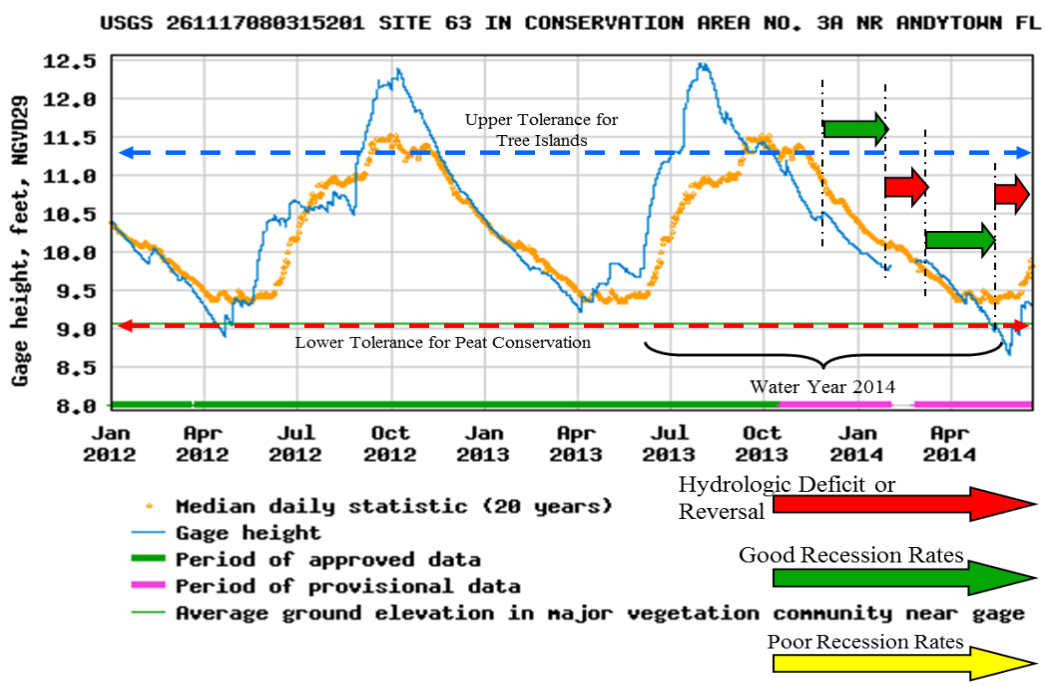

Figure 6-4. Hydrology in northeastern WCA-3A (gage 63) in relation to the recent 20-year average with indices for tree islands, peat conservation, and wading bird foraging.

The hydrologic pattern in central WCA-3A (gage 64) (**Figure 6-5**) was almost exactly the same as that in northeastern WCA-3A described above, except there was no large reversal in January–February and water depths never went below the lower tolerance for peat conservation. This central region of WCA-3A had the best foraging, for the longest period of time, than any other region of the EPA. At first glance it would appear that the WY2013 and WY2014 nesting season were the same. However two major factors made WY2013 a poorer environment for wading birds foraging and nesting than WY2014: (1) poor prey rejuvenation due to an extended WY2011 drought, and (2) a shorter foraging season due to higher water depths in December and May than in WY2014. Average-to-large flocks of wading birds were observed following the receding drydown fronts in central WCA-3A during WY2014. The 2012 to 2014 hydrograph for this section of the WCA suggests a long-term trend of above average foraging and nesting. For the last three years, the hydrograph has had large green arrows for extended periods of time during the dry season.

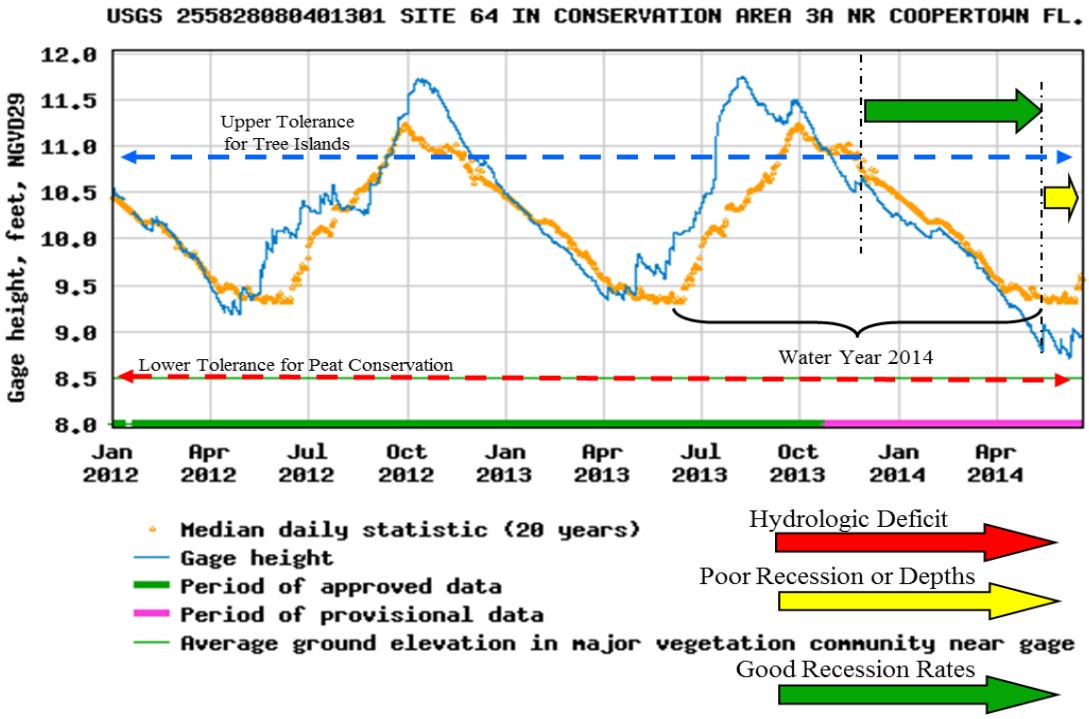

Figure 6-5. Hydrology in central WCA-3A (gage 64) in relation to the recent 20-year average with indices for tree islands, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 3B

For the last three years, in WCA-3B, water levels have been falling at an almost steady perfect 0.10 foot per week during the dry season (**Figure 6-6**). Last year's foraging activity during the dry season was reported to be relatively high, but it was limited by the quick return of the wet season in May. This year, the typical steady recession rate for WCA-3B was punctuated by a couple of relatively small, but significant reversals. The word "relatively" is used for WCA-3B because there are few sloughs in WCA-3B and, as a result, the amount of foraging habitat is very limited. Water depths and recession rates are often good for foraging by wading birds in WCA-3B, but foraging is very limited due to the lack of sloughs, and in WY2014, limited by the reversals. Data are limited in this region, but it is possible that the extended foraging season (April, May and June 2014) helped to counteract the negative influence of the two reversals in WCA-3B. The dry season in WCA-3B ended in April in WY2013, thereby making the foraging season very limited and causing wading birds in colonies just south of WCA-3B, in ENP, to abandon their nests at above average rates. This year, the colonies south of WCA-3B are expected to have higher nesting success than they had last year.

The 2012 to 2014 hydrograph for this section of the WCA indicates that the last two years were good for tree islands and good for wading bird foraging. WY2014 was better than WY2013, which was better than WY2012 (probably) because aquatic prey densities have been getting better and the extent of the foraging period has been increasing.

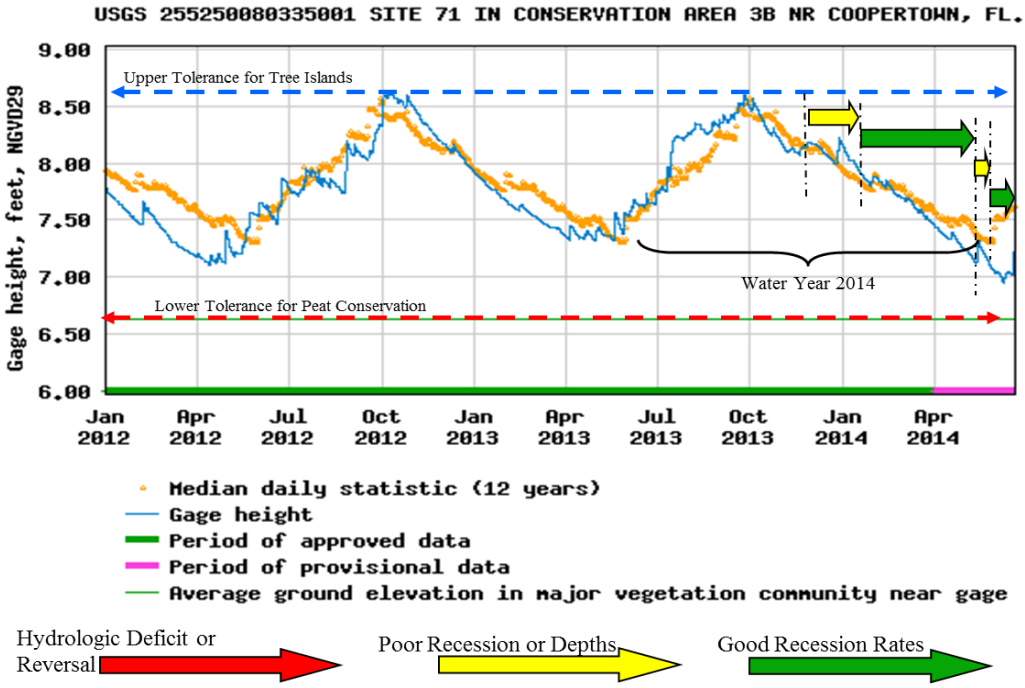

Figure 6-6. Hydrology in central WCA-3B (gage 71) in relation to the recent 12-year average and indices for tree islands, peat conservation, and wading bird foraging.

NORTHEAST SHARK RIVER SLOUGH

Last year (WY2013), the wet season was relatively wet, and dry season recession rates were very good up until May. This hydrology suggests that Northeast Shark River Slough (NE-SRS) was optimal in WY2013 for foraging wading birds because the aquatic prey had a year to return to pre-drought condition and because the nesting period was not cut short. The reasons why large flocks of birds are not usually found in NE-SRS are not completely clear, but this may be due to the dense vegetation, the limited amount of slough, and a legacy of fires and very dry conditions. This year (WY2014), the hydrology did not support an extended foraging period due to poor recession rates (**Figure 6-7**). Water levels stayed flat in NE-SRS for some 10 months. Good recessions were observed in April and May of WY2014; by June depths went below ground. Local colonies likely needed to foraging further south in the ENP or up north in WCA-3 to have a reasonably good nesting season. Previous South Florida Environmental Reports (SFERs) reporting on the hydrology of NE-SRS suggest a long-term trend of suboptimum foraging and nesting. The WY 2014 hydrograph for this section of ENP suggests that the foraging and nesting hydrology has not improved (**Figure 6-7**).

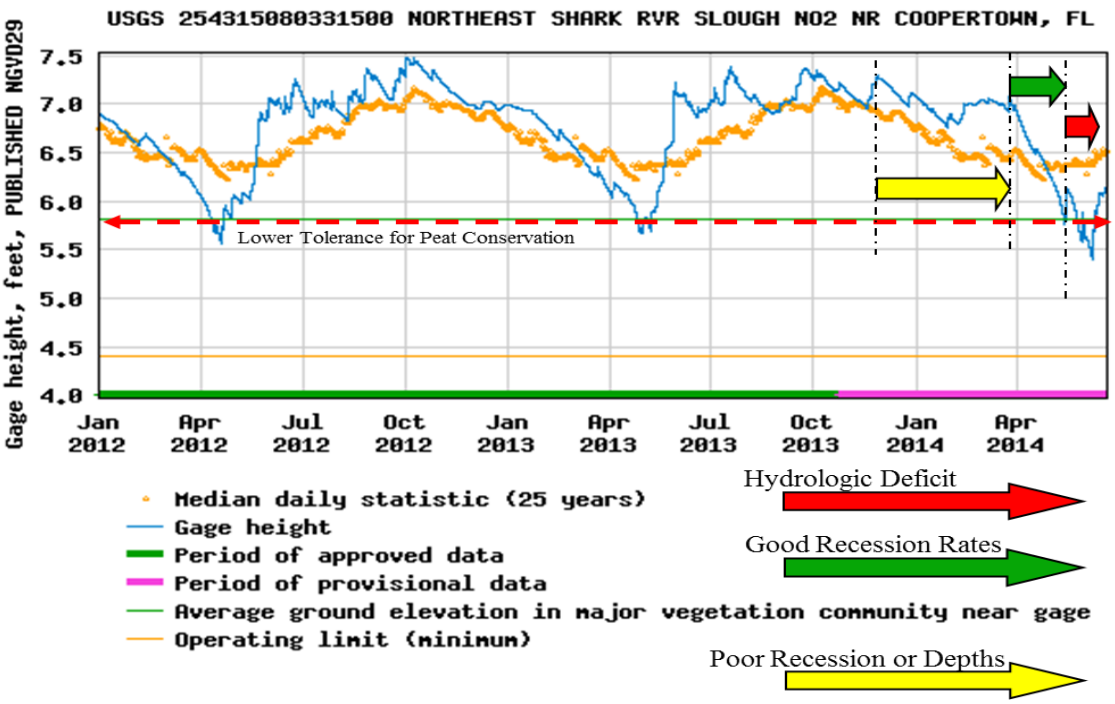

Figure 6-7. Hydrology in Northeast Shark River Slough in relation to the recent 25-year average with indices for tree islands, peat conservation, and wading bird foraging. The NE Shark River Slough has a unique operational limit indicating extreme fire potential, which is why there is a large gap below the ground elevation height.

FLORIDA BAY HYDROLOGY

Amanda McDonald

The District is part of a multi-agency partnership that maintains a long-term monitoring network throughout the southern Everglades and Florida Bay to provide a continuous record of salinity and its associated hydrologic inputs for the Florida Bay watershed. These data are used in support of District operations, in developing and monitoring Comprehensive Everglades Restoration Plan (CERP) performance measures, in assessing effectiveness of MFL criteria, and supporting calibration and verification of hydrologic models.

Methods

Salinity, rainfall, water elevation, and flow are monitored at instrumented platforms with salinity and rainfall reported every hour and flows measured every 15 minutes. Rainfall and most salinity platforms are maintained by ENP and are located to allow determination of upstream to downstream effects (**Figure 6-8**). Flow has been measured by the United States Geological Survey (USGS) at five creeks discharging into Florida Bay since WY1997. For the purposes of this assessment, data from WY 2001 through WY 2014 are examined to coincide with the installation and operations of S-332D, which was a significant change to the management of the South Dade Conveyance System and water deliveries toward Florida Bay.

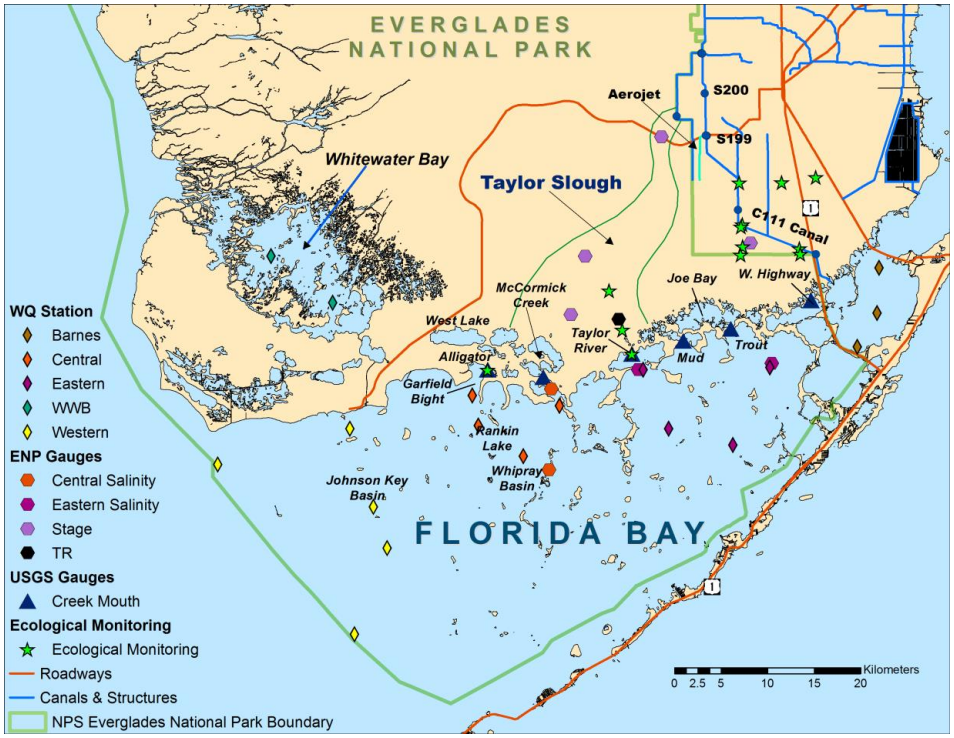

Figure 6-8. Sampling points within Florida Bay and southern Everglades showing areas influenced by water management operations from Whitewater Bay in the west to Barnes Sound in the east. Environmental parameters are monitored by the South Florida Water Management District (SFWMD or District), United States Geological Survey (USGS), and Everglades National Park (ENP or Park).

Results

Similar to WY2013, WY2014 started out wetter than average with the month of May receiving at least twice as much rain as the historical average (WY2001–WY2012). Above average rainfall in the early part of the wet season led to above average water levels and flows and below average salinities in Florida Bay. In addition, more rain fell over Taylor Slough than over the C-111 Basin (the area bounded to the north and east by the C-111 canal and to the west by the Aerojet Canal). While radar rainfall estimates indicate that both regions historically receive an average of 45 to 45.5 inches of rainfall per year, Taylor Slough received 49.7 inches (4.2 inches above average) in WY2014 and the C-111 basin received 42.7 inches (2.4 inches below average). This mimicked the expected water distribution due to operations of the C-111 Spreader Canal Western Features Project.

Above average rains in the beginning of the water year also translated into above average flows in the beginning of the water year (**Figure 6-9**) making this the second year in a row where abnormally high rainfall at the end of the previous dry season has led to lower than average salinity conditions downstream to start the water year (**Figure 6-10**). In addition, the persistent high water levels and low salinity from WY2013 provided a buffer for WY2014 when below average rainfall in the latter half of the wet season caused water level recession and salinity increases. The water year ended with near average salinities in Florida Bay and rapidly rising salinities in the mangrove ecotone.

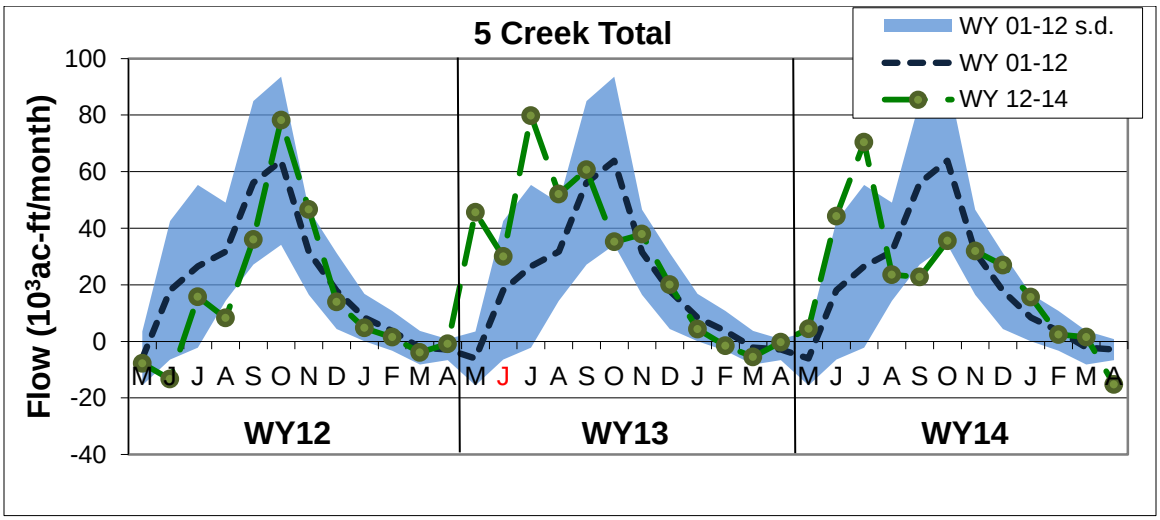

Figure 6-9. Monthly cumulative discharge to Florida Bay through five creeks in WY2012–WY2014 (WY12-14 in the legend), compared to monthly discharge mean (WY01-12) and standard deviation envelope (WY01-12 s.d) for WY2001–WY2012. The red "J" on the x-axis marks the month of June in WY2013 when the C-111 Spreader Canal Western Features began operations. Data are supplied courtesy of the USGS.

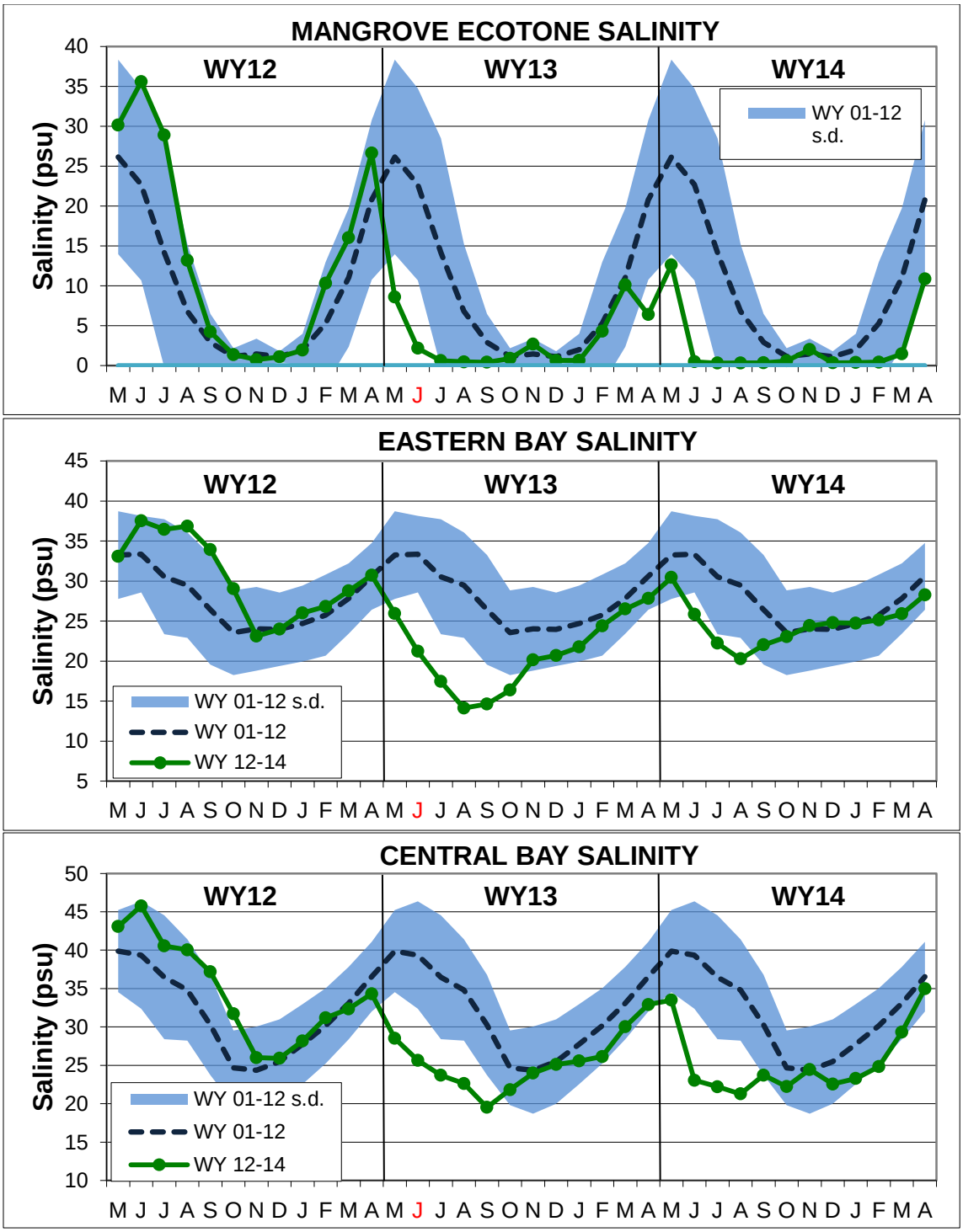

Figure 6-10. Mean monthly salinity values in the mangrove ecotone at the ENP-Taylor River platform (top), eastern Florida Bay (middle), and central Florida Bay (bottom) in WY2012–WY2014 (WY 12-14 in the legend), compared to monthly means (WY01-12) and standard deviation (WY 01-12 s.d) for WY2001–WY2012. The eastern and central bay salinity values are averaged between 2 continuous monitoring platforms within each region. The red "J" marks when the C-111 Spreader Canal Western Features began operations.

Relevance to Water Management

Above average water levels persisted throughout most of WY2014 in the wetlands of Taylor Slough as a result of wet hydrologic conditions at the end of WY2013 and the beginning of WY 2014. Above average rainfall in November and water deliveries through the South Dade Conveyance System after three months of below average rainfall helped to maintain elevated water levels in the wetlands of the Florida Bay watershed and buffer increasing salinities downstream into the dry season. Operations of the C-111 Spreader Canal Western Features Project (now in the second year of operation) may have also contributed to the above average water levels that persisted through WY2013–WY2014. However, the above average water levels and below average salinity began one to two months prior to operations of the S-199 and S-200 pumps, making determination of the relative contributions of the project and climatic variability difficult.

Dry conditions at the end of the water year caused water levels to dip below average for the first time in two years. Daily average salinities in Florida Bay were above average at the end of the water year and continued to increase. Flows to Florida Bay were negligible in April 2014 allowing prolonged wind-driven flow reversals, which pushed saline water upstream. As a result, salinities in the mangrove ecotone were rapidly rising during April. The 30-day moving average salinity at the TR site, which is monitored for the Florida Bay MFL, increased above the 30 threshold on June 24, 2014, and remained above the threshold until July 13, 2014. A violation of the MFL is defined as exceedances of the 30 threshold in back-to-back years twice in a 10-year period. The last back-to-back years with exceedances were 2008 and 2009. Therefore, if 2015 also experiences an exceedance of the MFL threshold, the Florida Bay MFL will be violated.

WILDLIFE ECOLOGY

Large populations of colonially nesting wading birds (order Pelecaniformes: egrets, ibises, herons, spoonbills; and order Ciconiiformes: storks) were a common and a defining feature of the predrainage Everglades. Long-term records of their nesting stretch back to the early part of the last century, and some clear reproductive responses to anthropogenic alterations have been established. These include the following:

- A marked decline in the nesting populations of several species, particularly the tactile foraging species
- A movement of colonies from the over-drained estuarine region to the more ponded interior marshes
- A marked decrease in the frequency of exceptionally large aggregations of nesting white ibises
- Delayed nest initiations of wood storks by a few months (from November/December to February/March), resulting in reduced nestling survival

These responses appear to be consistent with mechanisms that involve foraging and specifically the role that hydrology plays on the production and vulnerability to predation of aquatic prey animals (see Frederick et al., 2009 and references within).

The District currently focuses its wildlife research toward gaining a better understanding of the links among hydrology, aquatic prey availability, and wading bird foraging and reproduction. These relationships have been formalized in the Trophic Hypothesis, a conceptual ecological model that provides the underlying scientific framework for District wildlife research (http://www.evergladesplan.org/pm/ssr_2012/ssr_2012_pdfs/2012_ssr_full_web.pdf). This research has improved both the District's capacity to effectively manage the system and ability to

predict future restoration scenarios. This utility of the research stems not only from an improved knowledge of how key ecological drivers affect wading bird reproduction, but also from the recasting of these data into practical spatially explicit tools to predict foraging and nesting responses to physical and biological processes in real time and space. This section (1) summarizes wading bird nesting effort and success in the Everglades and Florida Bay during the WY2014 breeding season, (2) describes a study that examines inter-habitat movements of remotely tagged fish in response to water-level changes in the Loxahatchee Impoundment Landscape Assessment (LILA) area, and (3) reports on a study examining the potential for applying remote sensing applications (high resolution digital imagery) to vegetation and wading bird monitoring and research.

WADING BIRD MONITORING

Mark Cook

Wading birds are excellent indicators of wetland ecosystem health and have a central role in the CERP. Nesting figures for CERP performance measures are restricted to colonies in the Greater Everglades Region, i.e., the WCAs and ENP, for the following five species:

- great egret (*Casmerodius albus*)
- snowy egret (*Egretta thula*)
- tricolored heron (*Egretta tricolor*)
- white ibis (*Eudocimus albus*)
- wood stork (*Mycteria americana*)

The timing of breeding, number of nests, and location of nesting colonies within the Everglades are used as CERP targets to evaluate the progress of the Everglades restoration effort. In addition to CERP, wading birds are of special interest to the public and play a prominent role in adaptive protocols, MFL criteria, and day-to-day operations of the District.

Recovery of pre-drainage (1930–1940) wading bird nesting patterns was evaluated using the two independent sets of measures. CERP Restoration Coordination & Verification (RECOVER) established three performance measures (www.evergladesplan.org/pm/recover), which include the three-year running average number of nesting pairs of the five key wading bird species, timing of wood stork nesting, and proportion of the wading bird population that nests in the marsh-coastal ecotone (Ogden et al., 1994). In addition, the South Florida Ecosystem Task Force developed two additional measures for their annual stoplight reports: the ratio of visual to tactile wading bird species breeding in the Everglades, and the frequency of exceptionally large white ibis nesting events (Frederick et al., 2009):

- Increase and maintain the total number of pairs of nesting birds in mainland colonies to a minimum of 4,000 pairs of great egrets, 10,000–20,000 combined pairs of snowy egrets and tricolored herons, 10,000–25,000 pairs of white ibises, and 1,500–2,500 pairs of wood storks.
- Shift in timing of nesting in mainland colonies to more closely match pre-drainage conditions. Specific recovery objectives would be for wood storks to initiate nesting no later than January in most years and for ibis, egrets, and herons to initiate nesting in February–March in most years.

- Return of major wood stork, great egret, white ibis and small Egretta nesting colonies from the Everglades to the coastal areas and the freshwater ecotone of the mangrove estuary of Florida Bay and the Gulf of Mexico.
- Reestablish historical distribution of wood stork nesting colonies in the Big Cypress Basin and in the region of mainland mangrove forests downstream from the Shark River Slough and Taylor Slough basins. Increase the proportion of birds that nest in the southern ridge and slough marsh-mangrove ecotone to greater than 50 percent of the total for the entire Greater Everglades.
- For wood storks, restore productivity for all colonies combined to greater than 1.5 chicks per nest.
- Return to an interval between exceptional white ibis nesting events (< 2.5 years), defined as greater than 70th percentile of annual nest numbers for the period of record.

Summary of Nesting Year 2014

The information reported in this section represents a compilation of data collected by the District, University of Florida, ENP, and Audubon of Florida. The population counts include all wading bird species (except cattle egret, *Bubulcus ibis*) nesting throughout the Greater Everglades region (WCAs, ENP and Florida Bay), and the period covered is the nesting season from January–July 2014. Note that counts do not include estimates of precision due to the challenges of estimating detection bias at the landscape scale, although progress is being made in this respect (e.g., Fredrick et al., 2003; Williams et al., 2011). Further details on independent sampling methods are presented in Cook (in prep).

During the 2014 nesting season, an estimated 25,529 wading bird nests were initiated in the WCAs and ENP. This nesting effort is 29 percent lower than the decadal average (35,483 nests) and 65 percent lower than the banner year 2009 when a record high of 73,096 nests was recorded in the Everglades.

Nesting effort was relatively suppressed for most species of wading bird during 2014 (**Figure 6-11**). Numbers of great egret and white ibis nests were reduced compared to recent years, down 24 and 18 percent, respectively, from the ten-year average, and down 33 and 18 percent from the five-year average. The smaller *Egretta* herons, which have exhibited a consistent decline in nest numbers in recent years, had another relatively poor nesting season: nesting effort was reduced 68 percent for the snowy egret relative to the ten-year average, while only 11 nests (both species combined) were detected for tricolored heron and little blue heron (*Egretta caerulea*). These declines in *Egretta* herons do not appear to be due to changes in the distribution of nesting and instead appears to reflect a general reduction in overall nesting effort in the Everglades. Roseate spoonbills also exhibited relatively reduced nesting effort in 2014. In Florida Bay, spoonbill nesting effort (126 nests total) was less than half that of recent years (e.g., 367 nests in 2013) and only a third of the long-term average (mean since 1984 is 479 nests). While primarily a coastal species, the spoonbill has for the past three years nested in relatively large numbers (> 200 nests) at inland colonies in northern WCA-3A and ENP. This year, nest numbers were reduced to normal for the inland colonies (50 nests total). The only exception to the general pattern of reduced nesting in 2014 was for the wood stork, which had a relatively average year for nest initiations with 1,735 nests. This represents a 33 percent improvement relative to the 10-year average but is 14 percent lower than the five-year average.

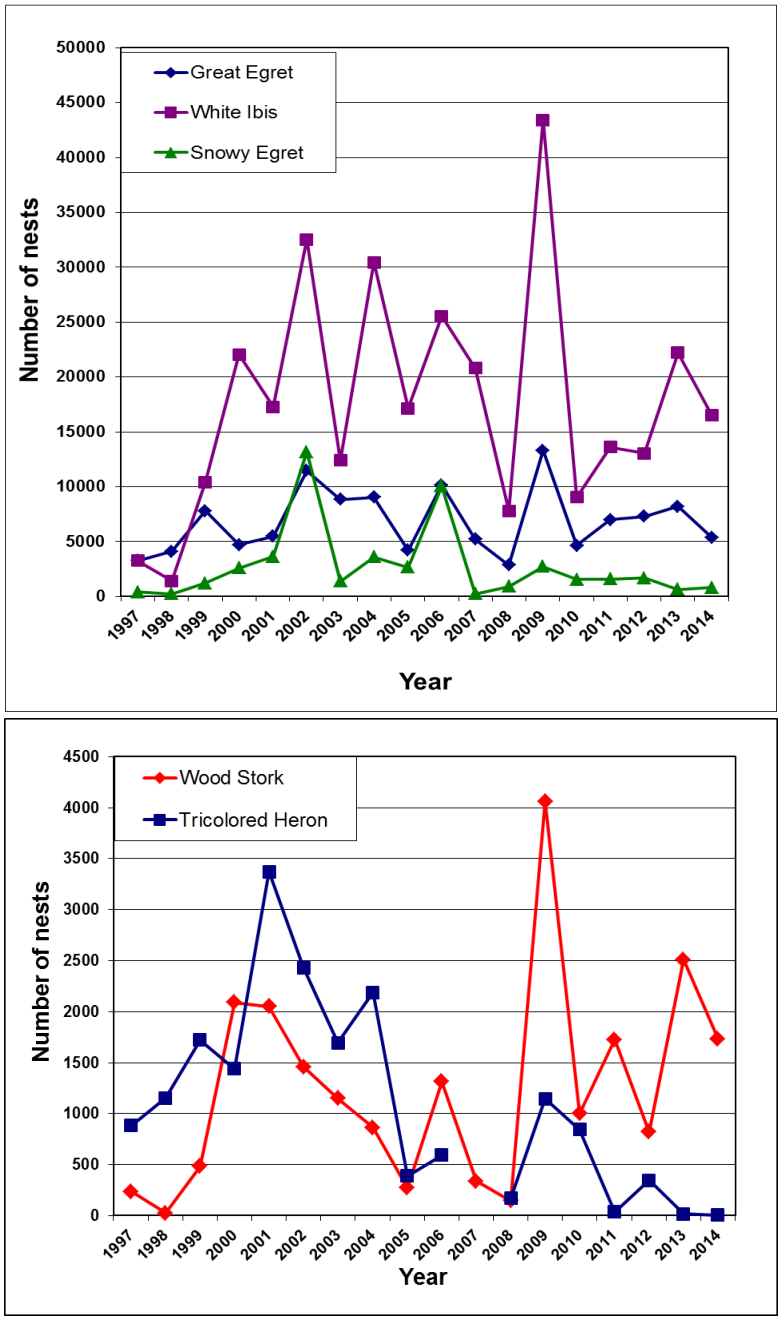

Figure 6-11. Historical wading bird nesting numbers in the Everglades for individual species since 1997.

Spatial Distribution and Timing of Nesting

ENP historically supported the majority of nests in the Greater Everglades, but in recent decades there has been a shift towards nesting at inland colonies in the WCAs. An important goal of restoration is to restore the hydrologic conditions that will reestablish prey availability across the southern Everglades landscape that, in turn, will support the return of large successful wading bird colonies to the traditional estuarine rookeries downstream of Shark Slough. In 2014, ENP supported 25 percent of nests, while WCA-3A and WCA-1 supported 40 and 34 percent, respectively. Although this represents a slight improvement in the proportion of birds nesting in

ENP relative to the decadal average (19 percent) it falls far short of the 50 percent restoration target.

Nesting Success

The University of Florida measured nest success (P; the probability of fledging at least one young, the Mayfield method) at five colonies in the WCAs and ENP. Nest success varied among species with white ibis (P = 0.48, SD = 0.05, n = 187) and *Egretta* herons (P = 0.75, SD = 0.04, n = 86) being the most successful, while great egrets generally fared less well (P = 0.23, SD = 0.04, n = 115). Wood Stork nesting was also unsuccessful according to this criterion (P = 0.18, SD = 0.07, n = 23), but this primarily reflects nesting failure after the early season reversal events and does not include nesting from much later in the season, which was largely successful.

Role of Hydrology on Nesting Patterns

Wading bird reproductive patterns in south Florida are driven principally by hydrology through its influence on aquatic prey production and vulnerability to predation (Frederick et al., 2009). The 2014 breeding season was preceded by wetter than average conditions during the WY2013 dry season and WY2014 wet season, which kept water levels above ground for extended periods across large areas of the Everglades. Such conditions generally promote the production of small fish (Trexler et al., 2005), and increased fish biomass might account for the observed early nesting and increased nesting effort by the piscivorous wood stork in 2014. However, this does not explain why other sympatrically nesting piscivorous species, such as the great egret, fared relatively poorly in 2014. In contrast to fish, production of the slough crayfish *Procambarus fallax* typically increases after pulsed dry conditions via predator release or nutrient pulse mechanisms (Frederick and Ogden, 2001; Dorn et al., 2011; Dorn and Cook, in Review). The wet conditions during 2013 were not conducive for crayfish production and this might explain the reduced nesting by the invertivorous white ibis in 2014, which relies heavily on crayfish during reproduction (Boyle et al., 2014). With regard to prey vulnerability, recession rates and water depths were generally ideal for wading bird foraging from October 2013 through January 2014 but several rain events from early February to early April promoted large-scale water level reversals that caused the dispersal of concentrated prey. This probably accounts for the large proportion of nest abandonments by wood storks and great egrets that started shortly after the reversal events in February and April. With regard to the roseate spoonbill, consistently high water levels in the coastal marshes, possibly as a result of sea-level rise (see Lorenz and Chasey, 2014), are likely responsible for the poor nesting effort and success during 2014.

Restoration Targets

Wood storks, white ibises and great egrets met the numeric CERP targets (three-year running averages) but snowy egrets/tricolored herons did not (**Table 6-3**). The two other CERP targets (an increase in the proportion of nesting wading birds in the coastal Everglades and a shift in the timing of wood stork nesting to earlier in the breeding season) are discussed above and did not meet the necessary requirements. With respect to the annual stoplight targets, the 2014 white ibis nesting effort did attain the number of nests (> 16,977 nests) required for an exceptional nesting event, but the interval between such events averaged over the past five years is only 2.0 years, which is only slightly greater than the restoration target of 1.6 years recorded from the 1930s. The ratio of tactile (storks, ibises and spoonbills) to visual foragers (herons and egrets) was only 3.4, an order of magnitude lower than the restoration target of 32.

Table 6-3. Wading bird nests in the WCAs and the ENP compared to Comprehensive Everglades Restoration Plan (CERP) targets. Target numbers are based on known numbers of nests for each species during the pre-drainage period (1930–1940), and which were summarized by Ogden (1994).

Species	2003-2005	2004-2006	2005-2007	2006-2008	2007-2009	2008-2010	2009-2011	2010-2012	2011-2013	2012-2014	Target
Great egret	7,829	8,296	6,600	5,869	6,956	6,774	8,303	6,296	7,490	6,961	4,000
Snowy egret/ Tricolored heron	4,085	6,410	4,400*	3,778	1,723	2,442	2,622	1,004	716	583	10,000-20,000
White ibis	20,993	24,926	21,133	17,541	23,953	20,081	22,020	11,889	16,282	17,261	10,000-25,000
Wood stork	742	800	633	552	1,468	1,736	2,263	1,182	1,686	1,689	1,500-2,500

INTER-HABITAT MOVEMENTS OF FISH IN RESPONSE TO WATER LEVEL CHANGES AT LILA

Jennifer Rehage[1], Greg Hill[1], Mark Cook and Eric Cline

In the ridge and slough landscape of the Everglades, the seasonal pattern of recurrent drying dictates the amount, extent and quality of wetland habitats and therefore plays a major role in structuring aquatic communities (Trexler et al., 2005; Parkos et al., 2011; Rehage et al., 2014a). Yet, our understanding of how Everglades organisms respond to changing water levels and inundation patterns at the local scale, and how these, in turn, relate to larger-scale distributional patterns remains limited**.**

Everglades aquatic fauna are known to seek deeper refugia as waters recede and large swaths of the landscape go dry, including moving into canals (Rehage and Trexler, 2006), mangrove creeks (Boucek and Rehage, 2013), alligator holes (Parkos et al., 2011), and solution holes (Kobza et al., 2004; Rehage et al., 2014a; Cook et al., 2014). Fish also move to and/or remain in shallower and perhaps suboptimal dry-down habitats (e.g., local depth maxima), which often dry as the dry season progresses, creating high concentrations of prey on which wading birds depend on for nesting success (Ogden, 1994; Gawlik, 2002; Frederick et al., 2009). However, little is known about the habitat and movement decisions fishes make in response to varying water levels, and which ultimately determine these important predator-prey dynamics.

In this study, the objective was to understand the fine-scale movements and habitat selection of Everglades fishes in response to varying hydrology. In particular, three key questions were addressed: (1) What are the general patterns of fish movement and habitat use across multiple Everglades ridge and slough habitats? (2) How are these patterns influenced by the seasonal decline in water level and hence how do fish become available to foraging birds? and (3) How are these patterns also affected by unseasonal variation in hydrology such as water-level reversals, which are known to disrupt wading bird nesting? Fish distribution and habitat selection are expected to be strongly affected by habitat-specific water levels and the degree of habitat inundation. Habitat profitability is expected to vary as a function of water depth, and to strongly drive habitat selection. A threshold response, where use of the shallower habitats (ridge and slough) will increase and decrease as certain critical water levels are reached, was hypothesized.

[1] Florida International University, Miami, FL

Therefore, habitat use by fishes is expected to vary seasonally, and to also be very responsive to unseasonal fluctuations such as reversals.

Methods

In large, replicate enclosures constructed at the Loxahatchee Impoundment Landscape Assessment (LILA), the fine-scale movement and habitat use of passive integrated transponder (PIT)-tagged warmouth (*Lepomis gulosus*) was tracked (**Figure 6-12**; Rehage et al., 2014b). Each enclosure contains three characteristic marsh habitats along a depth gradient: (1) 25 percent shallow ridge [0–30 centimeter (cm) depth], (2) 50 percent mid-water slough (0–70 cm depth), and (3) 25 percent deep alligator-hole (70–120 cm depth). Three flat-bed passive antennas placed at the edges and center of each habitat allow for continuous tracking of fish movement in and out of each habitat (Rehage et al., 2014b). When PIT-tagged fish cross the electromagnetic field of an antenna at any depth, the unique code of the tag is read and stored in the data logger along with a time stamp, such that antennas detections accurately reflect use of the three habitats (Rehage et al., 2014b). Six fish were stocked per enclosure and their movements and habitat use were tracked across an entire hydrological cycle (**Figure 6-13**). Data collection was conducted between March and July covering the transition from high to low and back to high water in 2013 (**Figure 6-14**), and an experimental reversal in 2014. For the reversal, water levels were raised in the midst of the dry season for a short period (13 days in early May 2014; **Figure 6-15**).

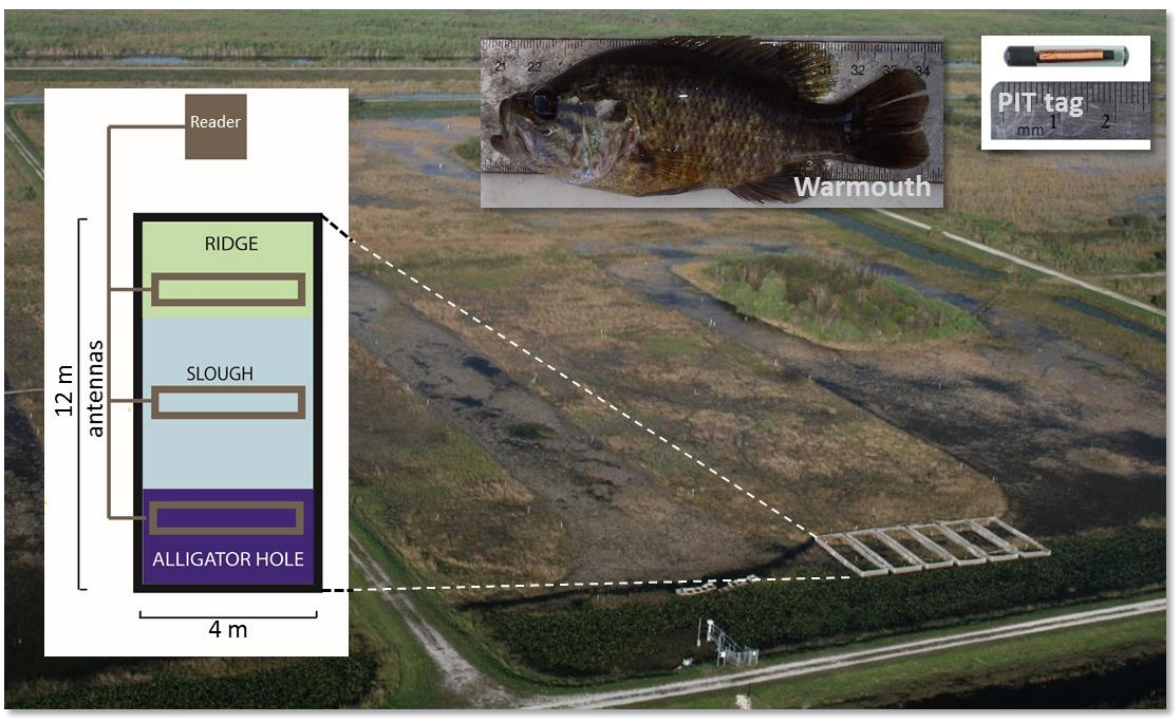

Figure 6-12. Aerial of macrocosm 1 at the Loxahatchee Impoundment Landscape Assessment (LILA) showing location of the six study enclosures. Schematic shows enclosure dimensions and setup of three antennas used for fish detection across habitats. Images show focal fish, native warmouth (*Lepomis gulosus*), and a passive integrated transponder (PIT) tag used to uniquely tag warmouth and that are detected by antennas.

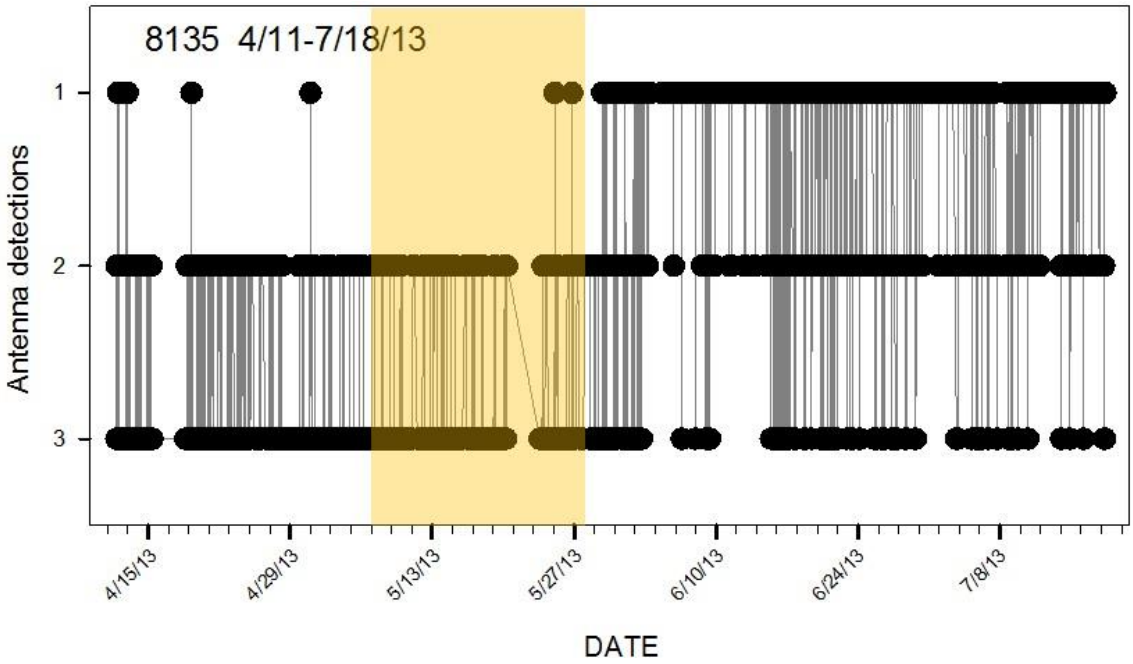

Figure 6-13. Example of continuous, individual detections for one of the study warmouth (Tag # 8135) in enclosures recorded across the 3 habitats (1=ridge, 2=slough, 3=alligator hole) over the period April 11, 2013 to August 18, 2013. Yellow shading shows minimal water conditions over the period of data collection (see **Figure 6-14**). Detections show a change in habitat use after reflooding, Fish # 8135 increases use of the ridge and lowers use of the deeper habitat as water levels increase.

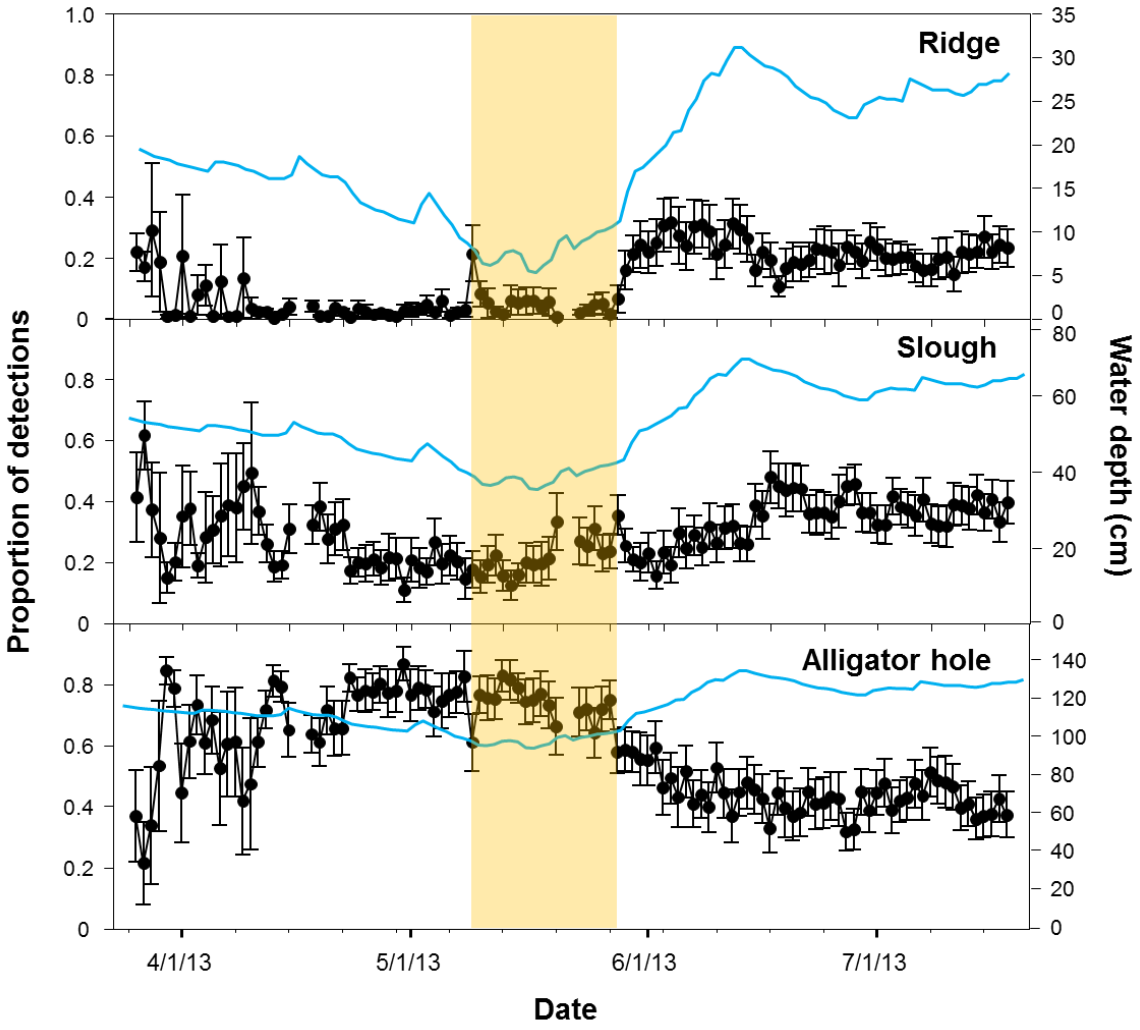

Figure 6-14. Proportion of antenna detections across enclosure habitats for all study warmouth (n=23 fish) shown daily for March to July 2013. Blue lines show water level in each habitat, while yellow shading highlight minimal water conditions over the period of data collection**.**

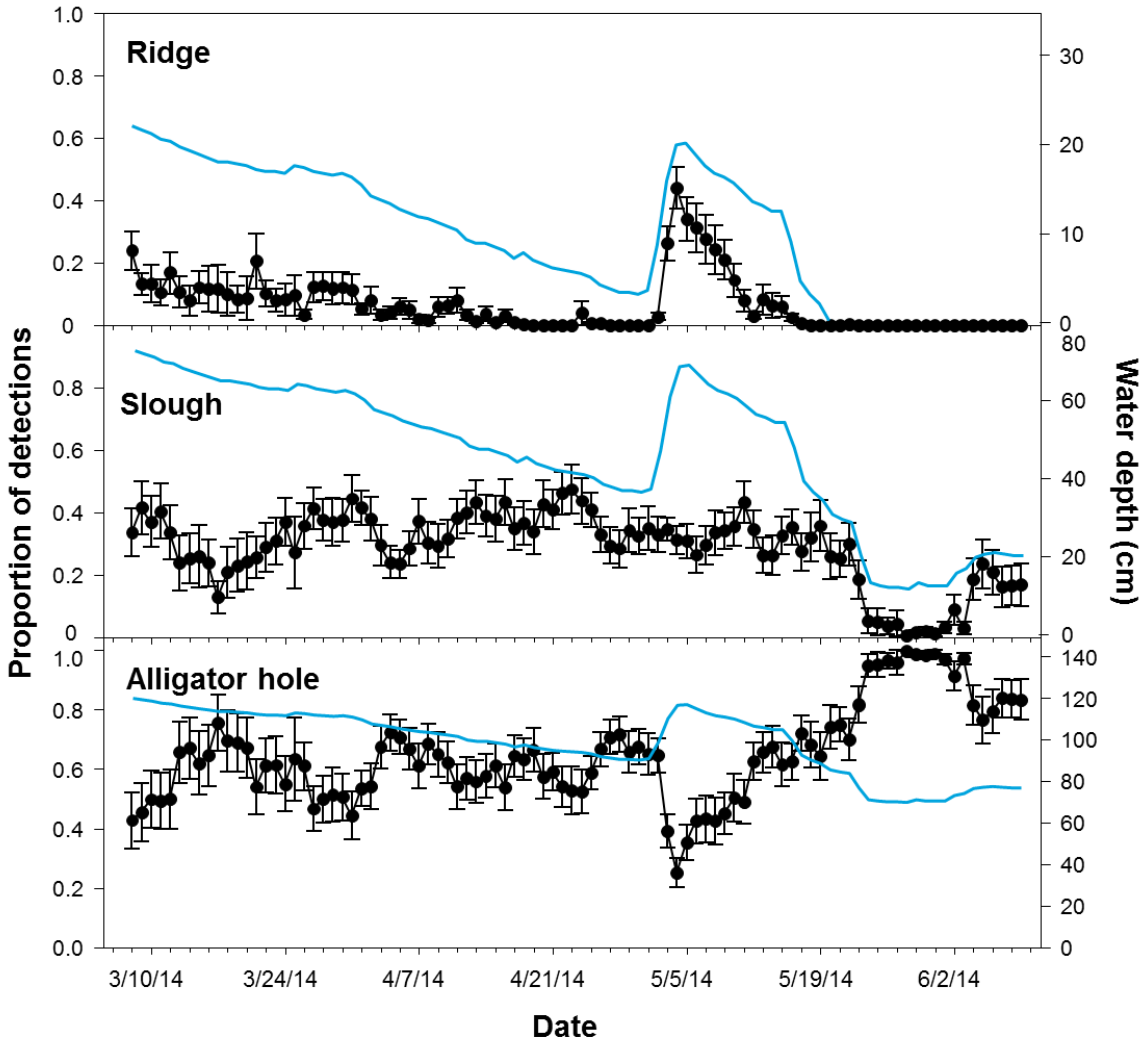

Figure 6-15. Proportion of antenna detections across enclosure habitats for all study warmouth (n=27 fish) in March to June 2014 through the experimental reversal. Blue lines show water level in each habitat.

The focal species of this research was native warmouth, a widespread and common centrarchid in the Everglades (Rehage and Trexler, 2006; Rehage et al., 2014a; **Figure 6-12**). Centrarchids (sunfishes) are the dominant mesoconsumers in the freshwater Everglades (Rehage and Trexler, 2006; Parkos et al., 2011; Boucek and Rehage, 2013), and preferred prey for wading birds (Ogden et al., 1976). Centrarchids are also known to move and alter habitat use in response to seasonal hydrology (Parkos et al., 2011; Rehage and Boucek, 2013). Warmouth were collected via boat electrofishing from the L-40 canal, weighed, measured, PIT tagged, and stocked in enclosures at the beginning of data collection in March of each year.

From continous detection data (> 100 days each year and up to 50,000 detections per fish), daily measures of habitat use were obtained by calculating the proportion of detections in each

habitat for each study fish. These daily proportions of antenna detections were compared across the three habitats, and across hydrological periods of interest using two-way analysis of variances (ANOVAs). For the 2013 data run, antenna detections across four hydrological periods were compared: (1) decreasing, (2) minimal, (3) increasing, and (4) high water conditions (**Figure 6-14**). In 2014, detections were compared across habitats and three hydrological periods: (1) decreasing pre-reversal, (2) reversal, and (3) decreasing post-reversal (**Figure 6-15**). Statistical analyses were conducted in SYSTAT® 13.

Results

2013

Across all study fish, warmouth used the deepest habitat most extensively, with 61 percent of antenna detections in the alligator hole, 27 percent in the slough and 12 percent in the ridge (habitat effect, $F_{2, 321} = 724.5$, $p = 0.0001$; **Figure 6-14**). As expected, fish behavior was strongly influenced by changing water levels (hydrological period x habitat interaction, $F_{6, 321} = 78.9$, $p = 0.0001$). During the drydown period (mid-March to mid-May), warmouth were detected in all three habitats when water levels were relatively deep but were not detected on the ridge once ridge depths fell below ~18 cm (early April; **Figure 6-14**). From this point until reflooding, more detections (~80 percent) occurred in the alligator hole (95–115-cm depth) than in the slough (~20 percent; 40–60-cm depth). On reflooding at the start of the wet season, warmouth detections initially increased on the ridge after water levels reached ~ 10 cm in this habitat (early June 2013). At this point, over 30 percent of tag detections were recorded in the ridge, reflecting high use of this habitat upon first reflooding ($p < 0.031$). Slough habitat use was unaffected by this reversal, but use of the alligator hole markedly decreased (**Figure 6-14**). Subsequent wet season maximum depths occurred in mid-June (depths ~ 70 cm in sloughs), when detections in the ridge declined while those in the slough increased until they were comparable with those in the alligator hole.

2014

Very similar patterns of habitat use for warmouth to that of 2013 were documented, with higher overall detections in the deepest habitat (habitat effect, $F_{2, 273} = 759.6$, $p = 0.0001$; **Figure 6-15**). Approximately 65 percent of detections were in the alligator hole, 29 percent in the slough and 7 percent in the ridge. During the 2014 mid-dry season reversal, warmouth habitat use shifted rapidly to use of the ridge upon first flooding of this habitat after depths reached ~ 10 cm (hydrological period x habitat interaction, $F_{4, 273} = 85.5$, $p = 0.0001$). Again, slough habitat use was unaffected by this reversal, but detections in the alligator hole markedly decreased (from ~70 to 20 percent), suggesting a shift from the deepest to the shallowest habitat as a function of the reversal. Minimum water levels were lower in 2014 than in 2013, and when depths reached 18 cm in the slough all warmouth moved from the slough to the alligator hole (i.e., promoting a concentration event). The concentrated fishes in the alligator hole began re-dispersing back into the slough shortly after the onset of the rainy season (early June) once water levels started to increase in the slough.

Discussion and Relevance to Water Management

Linkages among hydrological variation, prey dynamics and wading bird foraging and nesting success remain poorly understood, yet are critical to Everglades restoration and water management. A key unknown is how does hydrological variation affect fish distribution and habitat selection across the landscape and therefore influence their concentration and availability to wading birds as prey.

Study findings show that native warmouth are primarily a deep-habitat user, but they use shallow habitats at particular times of the year and at particular hydrological conditions. At low water, most warmouth showed extensive use of the deepest alligator hole habitat, where they are unavailable to wading birds. However, about 20 percent of detections were in the ridge at decreasing and minimal water levels. And throughout the hydrological cycle, a third of detections are in the slough, where conditions are optimal for foraging.

At the onset of the wet season, most fish quickly and surprisingly shifted habitats to use the newly-reflooded ridge, suggesting that this habitat may be particularly profitable when first rewetted. The use of the ridge decreases after this first reflooding peaks. These rapid shifts in behavior indicate that reflooding events such as reversals can cause important distributional changes in prey fishes, promoting use of newly available habitats and thereby reducing densities in alligator holes, as well as in sloughs where wading birds typically forage. Reflooding events may then lower slough prey densities as prey move to ridges, and where due to the high sawgrass density, wading birds foraging may be less likely and less successful.

Seasonal hydrology is a key driver of patterns of fish abundance and distribution across the Everglades landscape, and our study is the first one to document its effects on fine-scale fish behavior. Our experimental approach allows us to provide the fine-grained behavioral resolution of aquaria studies, with the unmatched benefits of a large spatial scale, replication, natural field conditions, and the ability to manipulate hydrology uniquely provided by LILA. Fine-scale behavioral studies can improve the understanding of landscape patterns of fish distribution, and particularly inform how fish behave as prey for wading birds.

CAPTURING DIGITAL AERIAL IMAGERY FOR VEGETATION AND WILDLIFE MONITORING DATA

Christa Zweig

Unmanned aerial systems (UAS) are desirable for their high-resolution aerial imagery that can be used to assess many features important to District operational, land management, and restoration decisions. Far beyond taking pictures, since images from low-altitude flights are geo-referenced data, they can be analyzed to evaluate the effects of management decisions on vegetation health, vegetation cover, wildlife populations, and wildlife use. These data provide spatial coverage that bridges the gap between field data and high-altitude or satellite imagery for ecological and operational targets (levee inspections, exotic vegetation assessment, Stormwater Treatment Area (STA) vegetation health, etc.). Imagery also provides a permanent, unbiased record of inspections and assessments. However, a primary barrier for UAS operations in South Florida is the Federal Aviation Administration (FAA) restriction on UAS in Class B airspace—within a 30 mile radius of Miami International Airport (**Figure 6-16**). UAS currently cannot fly within Class B airspace unless special permission is granted by the Federal Aviation Administration (FAA).

To address this issue, the feasibility of affixing a UAS payload (camera, GPS, inertial navigation system, etc.) to a SFWMD Bell 407 helicopter was evaluated. The helicopter would have flexible altitude requirements, the ability to change targets with short notice, and would be able to enter the Class B airspace without special permission. The payload was from the University of Florida's Unmanned Aerial Systems Research Team, a team that develops UAS for ecological research. The payload had been previously tested on a Cessna 172, but the Cessna also lacked the flexibility (airspeed, altitude, etc.) desired in an aircraft.

Figure 6-16. Approximate location of Class B restricted airspace around Miami International Airport. Unmanned aerial systems (UAS) cannot be flown in this airspace without special permission from the Federal Aviation Administration.

Methods and Materials

The payload was contained in a 49.5 x 17.7 x 17.7-cm aluminum box that was screwed to the step of the Bell 407. The step was a spare and only used on payload flights. The attachment was inspected by an FAA-approved mechanic and the empty box was affixed and tested at different airspeeds for stability. The first box-on-a-helicopter (BOH) test occurred in September 2013. This test was to provide information on the quality of imagery from the BOH and answer preliminary questions:

1. Was there too much vibration for the camera to take sharp images?

2. What is the best airspeed for sharp images and to account for overlap of adjacent images for mosaicking?

3. What is the resolution of images at different altitudes and what kind of observations could be made at different altitudes (vegetation species, wildlife, etc.)?

Results and Discussion

The vibration from the helicopter was negligible and did not affect image quality. Airspeeds of 40–50 knots were sufficient for image overlap and image resolution at heights of 91.4 meters (m), 152.1 m, and 213.4 m was 1.7 cm, 2.5 cm, and 3.7 cm, respectively. Birds and turtles were

easily counted from the photographs and alligators were readily apparent, even under water (**Figure 6-17**). These wildlife data can be used to estimate wildlife populations using a double-observer method. Resolution is very good, even compared to high-altitude aerial imagery, and particularly to medium-resolution satellites, like Landsat (**Figure 6-17**). Vegetation coverage could also be estimated from a sample of photographs. The high-resolution imagery has very large storage needs (each photo is approximately 5 megabytes and there are thousands of photos per trip), so the use of photos as samples will be investigated.

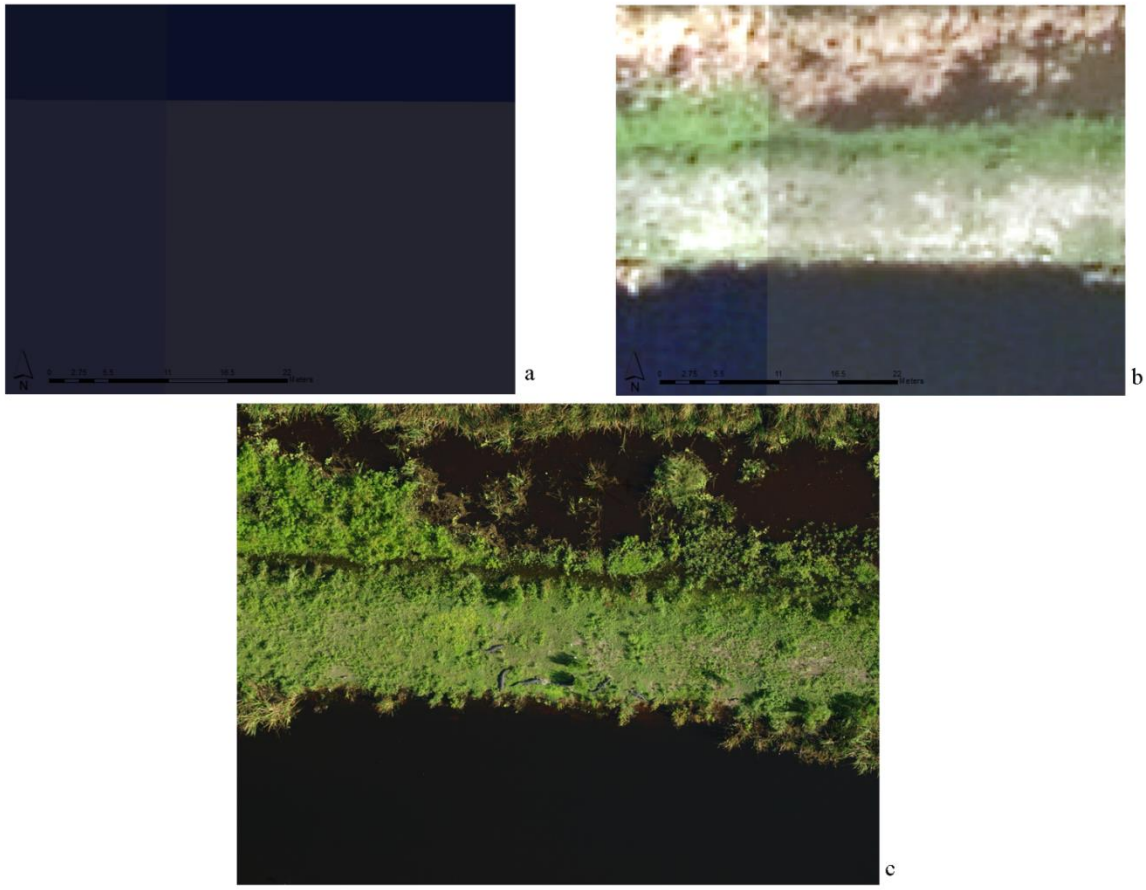

Figure 6-17. Imagery comparison between (a) Landsat (obtained from the U.S. Geological Survey: http://glovis.usgs.gov), (b) high-altitude aerial imagery (from the SFWMD), and (c) UAS payload on helicopter. Five alligators are present in the middle of the UAS payload imagery.

Relevance to Water Management

Based on results of this test, the BOH would be useful for gathering quick-response, multiple-use data for monitoring SFWMD assets, structures, effectiveness of the STAs, and effects of water management decisions on restoration. These data are appropriate for monitoring ecological and operational targets (levee inspections, exotic vegetation assessment, STA vegetation health, etc.), and can be considered a valuable source of data.

PLANT ECOLOGY

Plant studies form an important basis for evaluating restoration success. This section evaluates a potential tree island restoration technique being tested in LILA and a study of the effects of hydrology and soils on tree survival, growth and litterfall production on a conserved and a degraded tree island in Water Conservation Area (WCA)-3A.

DEPLOYING TREE SAPLINGS IN PEAT BAGS AS A POTENTIAL RESTORATION TECHNIQUE: A PILOT STUDY

Thomas Dreschel and Eric Cline

Tree islands are a unique feature and although they may only represent up to 14 percent of the landscape (Willard et al., 2006), they support all the amphibious and terrestrial fauna found there. Everglades tree island heads are also the site of phosphorus enrichment and are thought to be a controlling factor in the oligotrophy of the Everglades. Therefore, they are both biodiversity and biogeochemistry "hot spots" (Sklar and van der Valk, 2002). Tree islands have been heavily impacted by man and nature through construction, drainage, flooding, fire and extreme climactic events. The following is a quote from a review report on Everglades restoration titled "Progress Toward Restoring the Everglades: The Fourth Biennial Review, 2012" (emphasis added): "*With hydrologic restoration, many tree islands that are currently on a trajectory of drowning can recover, particularly if their elevation differences remain, although active restoration in the form of tree planting may be needed in some cases (Sklar and van der Valk, 2002)"*.

Natural recolonization of degraded islands can occur through seed dispersal if there are nearby islands with sufficient diversity and abundance of species (Sklar and van der Valk, 2002; Wetzel et al., 2005; Wu et al., 2002). Nevertheless, with long-term flooding and associated declines in plant diversity, opportunities for natural recovery through natural seed dispersal and recolonization will be lost over time. A quote from Sklar and van der Valk (2002) sums up the possible difficulties in restoring tree island habitats: "It may be possible to restore severely subsided tree islands by raising the elevation of their heads, although such efforts would be expensive and labor intensive."

Measurements at a Ghost Tree Island

Everglades ghost tree islands are ones that have lost a significant amount of elevation and forest structure due to soil oxidation (Aich et al., 2014). Measurements were needed to determine the amount of elevation required to allow the reestablishment of woody species on these islands. The typical ghost tree island maintains a small head (the highest region, typically located within the upstream third of the island) but the bulk of the island has lost elevation and now resembles a large sawgrass (*Cladium jamaicense*, Crantz) ridge. The tree islands of WCA-2A are now almost exclusively considered ghost tree islands and Dineen Island is one of the prominent ghost tree islands located there (Dineen, 1974).

The increased stages produced by Tropical Storm Issac in 2012 provided an opportunity to visit and evaluate the hydrology on Dineen Island. In October 2012, Dineen Island stage (SFWMD, 2012) was at about 0.7 feet (0.2 m) above flood regulation. The water depth measured at the island was 2.5 feet (0.8 m) at the head; therefore, the head was at about 1.8 feet (0.6 m) below peak flood regulation and about a foot above the slough. The small head of the island (a circular area about 230 feet or 70 m in diameter) contained willow (*Salix* spp.), buttonbush (*Cephalanthus occidentalis*), Brazilian Pepper (*Schinus terebinthifolius*) and a variety of

herbaceous plants (Ewe et al., 2009). Downstream of the remaining head, most of the tree island was at "ridge" level (Ewe et al., 2009; Aich et al., 2014).

Tree Island Elevation

Historically, tree islands were typically 2–4 feet (0.6–1.2 m) above slough bottom (McVoy et al., 2011). Ridges were typically 1–2 feet (0.3–0.6 m) above slough bottom (McVoy et al., 2011). Consequently, tree islands should be about 1–2 feet (0.3–0.6 m) above the ridge. Dineen Island is about 1.8 feet (0.55 m) below peak flood elevation and a foot above the slough. As such, an additional 1–3 feet (0.6–0.9 m) would be required to raise the island to an elevation to support woody vegetation establishment.

One type of tree island is formed from peat that has broken away from the bedrock and floats to the surface, whereupon upland plants can establish to form a "pop-up" or floating tree island. Floating islands can move and establish on a nearby peat surface, thereby forming "battery" islands. These floating islands and battery islands are common in WCA-1, due to the thick peat underlying the region. The concept described here is designed to simulate this process to provide a means to establish woody vegetation on the ghost tree islands.

A conceptual approach for creating artificial floating islands or pop-ups that eventually establish on ghost tree islands is being tested. The approach taken was to meet the requirements of being deployable by airboat under wet conditions and must provide sufficient height above the current substrate. Using the measurements from Dineen Island, it was determined that about 1.5 feet (0.45 m) of elevation are needed. In addition, the trees must be able to survive and become established through flood and drying cycles and the approach must be low cost and simple.

Methods and Materials

LILA (Aich et al., 2011) was used to conduct tree island restoration studies. LILA consists of four macrocosms (designated M1 through M4) which contain tree islands, ridges and sloughs. Water flow and stage are carefully controlled within LILA (Schilling et al., 2013), which is designed to be a hydraulically closed-loop ecosystem supplied entirely from direct rainfall. The studies of the groundwater and surface water hydrology of LILA tree islands have provided unique insight into the impacts of hydrology on tree growth and survival (Stoffella et al., 2010) and also into the effect that the trees have on the hydrology (Sullivan et al., 2010, 2012). The large ridge along the southern edge of each macrocosm has a boardwalk near the western corner. These ridges provide an analogue of a ghost tree island with ready access for study deployment and monitoring.

Commercially available peat bags [0.08 cubic meters (m^3) or 3 cubic feet (ft^3)] were used to support one or two tree saplings until they can become established near the ghost tree island head and provide a seed source for further recruitment. To do this, the saplings were planted into the bags, which were then floated onto the site, punctured and tethered in place using PVC poles. If the water levels became too high during the first year of establishment, the bags would float up, protecting the sapling from complete inundation. During the dry season, when water levels drop below ground at the site, the roots will penetrate the substrate beneath the peat bag and allow the permanent establishment of the tree at the site, at about 0.45 m (1.5 feet) above the current substrate.

During October–November 2012, the potential of restoring a ghost tree island such as Dineen Island by planting saplings into commercially available bags (0.08 m^3 or 3 ft^3) of dry Canadian sphagnum peat measuring 0.61 m x 0.46 m x 0.30 m (2 feet x 1.5 feet x 1 feet) was investigated.

One bag was punctured and deployed onto a LILA ridge (Macrocosm 1) to monitor flotation and durability in a natural setting.

One-gallon strangler fig (*Ficus aurea*) and pond apple (*Annona glabra*) saplings were placed into the peat bags after the pot bottoms were removed with a knife (**Figure 6-18**, left). Hereafter, the species will be designated by genus. The saplings were left within the pots for additional support and height. The bag upper surface was cut to produce one or two openings about 20 cm (0.66 feet) across. About 1,000 cubic centimeters (cm^3) (0.035 ft^3) of peat was removed from the opening to allow the bottomless pot to be placed inside the bag (**Figure 6-18**, center). The pots were then secured in place with several windings of duct tape, which affixed the bag triangles to the pot (**Figure 6-18**, right). Upon deployment, monitoring was initiated that includes bag conditions, flotation and tree appearance and growth.

Figure 6-18. Tree sapling with cut pot bottom (left), mounting of the pots (center), and pots taped to the peat bag and deployed (right) (photos by the SFWMD).

The study trees were deployed on October 31, 2012, and experienced the hydrograph shown in **Figure 6-19**. The study was deployed during a period of extremely high water in LILA due to Tropical Storm Isaac, with water levels dropping during the following six months to achieve the target hydrograph. Trees were deployed when the water levels were at about 0.9 m (3 feet) above the surface of the ridge. The following year experienced high water levels and, although the water levels came down during the dry season, they remained about 0.23 m (0.75 feet) above the ridge at the lowest point in 2013. Not until May 2014 was a stage below the ridge achieved. It was anticipated that the sapling roots would follow the water level; therefore, until the water level dropped below the surface of the ridge, the roots likely remained confined to the pot and bag.

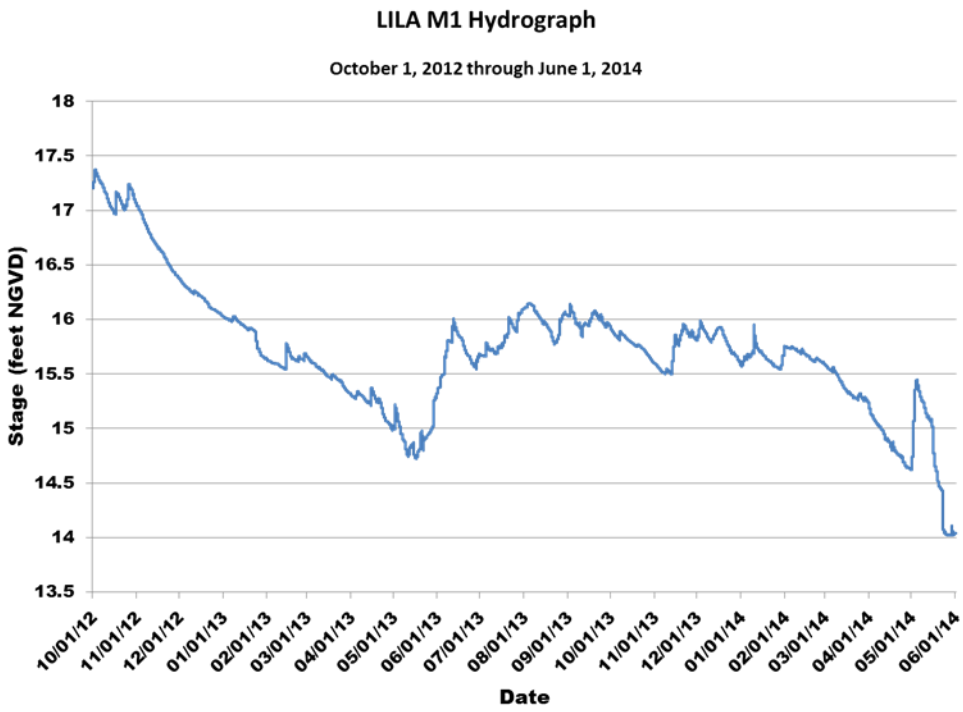

Figure 6-19. Hydrograph of LILA M1 during the pilot study (SFWMD, 2014a).

For the pilot study, twelve bags were planted and monitored beginning in October 2012. The pop-ups consisted of one or two trees per bag (*Annona* and *Ficus*) and two bag orientations in the following: three bags oriented horizontally with both species; six bags each with a single *Annona* and three bags each with a single *Ficus*, with a mixture of horizontal and vertical orientations. **Figure 6-20** presents examples of each at planting.

Figure 6-20. Examples of the treatments established for the pilot study: *Annona* and *Ficus* together (left), *Annona* with horizontal bag orientation (center), and *Ficus* with vertical bag orientation (right) (photos by the SFWMD).

Saplings were harvested after approximately 18 months. An *Annona*/*Ficus* combination (shown in **Figure 6-20**, left) and a single *Ficus* (shown in **Figure 6-20**, right) were examined. The peat bag was cut to expose the root system of each and the peat removed. Observations included the fact that the pond apple roots had filled the bag and had begun to grow out of the bottom of the bag (**Figure 6-21**). The *Ficus* that was in the same bag did not exhibit much root growth although the roots had grown from the pot into the bag (**Figure 6-22**, left). It appears that the rapid growth of the *Annona* inhibited root expansion by the *Ficus* sharing the bag. The larger, individually grown *Ficus* roots had grown into the bag but not outside the bag (**Figure 6-22**, center and right).

Figure 6-21. Harvest of *Annona* and *Ficus* combined treatment showing expansion of Annona root throughout the peat bag with a small amount of roots emerging into the substrate below (photos by the SFWMD).

Figure 6-22. *Ficus* root growth in the peat bags. *Ficus* that shared a peat bag with *Annona* (left), and *Ficus* grown individually showing greater root growth (center and right) (photos by the SFWMD).

More recent plantings (8 months) of red maple (*Acer rubrum)* and *Annona* were examined and both demonstrated root growth out of the pot into the peat bag (**Figure 6-23**). Much of the larger *Annona* root material was contained within the remaining bottom edge of the pot, indicating that the entire base of the pot should be removed to allow unrestricted root growth.

Figure 6-23. *Acer rubrum* (left) and *Annona glabra* (center and right) saplings eight months after planting in peat bags deployed in a LILA slough (photos by the SFWMD).

Next Steps

Two field studies are currently being conducted at LILA. The effects of added nutrients, the necessity of providing floats and the further effect of crowding on tree establishment and growth are being tested. The three species of tree: *Annona*, *Ficus* and *Acer*, as well as the treatments/controls, were randomly assigned to one of the 45 sites adjacent to the boardwalk. These three species of trees, native to South Florida and found on Everglades tree islands were chosen because *Annona* is known to be very tolerant of flooding whereas *Ficus* and *Acer* are not (Stoffella et al., 2010). Also, these trees were readily available from seed stock taken locally and germinated and grown initially at a local native plant nursery.

The two current studies are being conducted at two locations and consist of a control and two treatments. These studies involve 105 trees, 35 each of *Annona*, *Ficus*, and *Acer* in the following:

- Forty-five pop-ups were placed with their 0.46 m (1.5 feet) edge in the vertical position (vertical); two sections of PVC pipe were driven through the peat bags into the ridge, holding them in place with one pot per bag. The treatments are one set of five of each tree for control; one set of five of each tree treated with one fertilizer spike; and one set each tree with two fertilizer spikes (Vigoro Tree and Shrub Fertilizer Spikes). Therefore, this study required 45 bags, with fifteen of each tree species.
- Forty-five pop-ups were placed with their 0.30 m (1.0 foot) edge in the vertical position (horizontal); two sections of PVC pipe were driven through the peat bags into the ridge, holding them in place. The treatments are one set of five of each tree for control (one tree per bag); one set of five planted with two trees each of the same species (thirty of each species); and one set of five planted with one tree each with flotation. This required forty-five bags, twenty of each tree species.

Digital photos of each tree are taken at regular intervals (approximately monthly). Measurements of total height (cm), canopy width (cm) and basal diameter [millimeter (mm)] are taken at least annually. Harvesting for measurements of above and below ground biomass will be conducted at the completion of the studies.

Discussion

Observations of condition and digital photos are taken on a monthly basis. Initial observations from monitoring the pilot study trees and the initial harvest:

- It was determined that when deployed dry, the bags float for about six months before becoming saturated and sink to the sediment surface.
- Although the saplings experienced a great deal of herbivory, particularly by eastern lubber grasshoppers (*Romalea microptera*), the trees were able to continue to bud and produce new leaves.
- *Annona* gallon saplings can fruit within a year of planting.
- *Annona* saplings can produce a root system that fills much of the bag and emerges out of the bag within 18 months (essentially growing from **Figure 6-23**, right, to **Figure 6-21**, right, in about a year).
- *Ficus* saplings can survive and grow in our system but do not thrive as with *Annona* saplings.
- *Ficus* saplings should not be grown in the same peat bag as *Annona*.
- When removing the bottom of the pot, the entire bottom should be removed and not just a hole cut into the bottom.
- All three species tested will produce roots that penetrate the peat.
- A greater number of bag penetrations would be of an advantage but a balance between penetrations and maintaining bag integrity must be achieved.

Several concerns arose for this approach, particularly when it is taken into the field for the restoration of Dineen Island. The first issue is putting “artificial” materials (plastic bags and plastic pots) in WCA-2A, but as the trees will be monitored frequently, a field crew can collect, remove and recycle the plastic debris, once the trees are established. Second, there is also a concern as to whether the peat bags can survive long enough for tree establishment. Our initial test of the bag indicates that it maintains integrity for at least 18 months of exposure without showing any signs of degradation. Finally, extensive restoration would require a “flotilla” of airboats and thousands of pop-ups.

Relevance to Water Management

Developing a cost-effective method for planting trees on degraded tree islands is essential to the restoration of these important features of the Everglades. The planted trees can provide a seed bank for the recruitment of native species. Restored tree islands will provide habitat and contribute to Everglades oligotrophy. Our initial observations and measurements indicate that the approach described above is a viable one. The continued studies should provide insight in the value of adding nutrients in increasing the survival and growth of the species studied. Future studies and activities should include other pertinent tree island species and deployment on select ghost tree islands in WCA-2A.

LITTERFALL AND TREE GROWTH DYNAMICS IN A PRISTINE TREE ISLAND AND A DEGRADED TREE ISLAND IN WCA-3A: THE IMPORTANCE OF ECOLOGICAL FUNCTIONS ON TREE ISLANDS

Carlos Coronado-Molina, Fabiola Santamaria[2]
and Michelle Blaha[2]

In wetland forests, leaf tissue and tree biomass production are the dominant components of aboveground net primary productivity and a major source of nutrient demand (Conner and Day, 1992; Meir et al., 2006). Therefore, production of leaves in the canopy and subsequent litterfall to the soil surface, along with decomposition and export processes, describes litterfall dynamics in forest wetland ecosystems. Additionally, measurements of litterfall in forests are typically used to describe ecosystem function and test hypotheses about primary production under a variety of environmental conditions (Cormier et al., 2013; Castañeda-Moya et al., 2013). The importance of litterfall and tree growth dynamics studies lies on its contribution to understanding temporal and spatial patterns of aboveground primary production, defining the effects of hydroperiod fluctuations on primary production, contributing to peat accumulation, and determining nutrient cycling dynamics.

The study of aboveground production along with functional responses of plant community to nutrient availability and extreme hydrological conditions is a staple of wetland ecology (Grime and Mackey, 2002), and it is widely believed that extreme hydrological conditions, either too dry or too wet, can limit plant community structure and function (Givnish et al., 2008). For instance, long-term soil saturation induces soil anoxia, which limits nutrient availability and gas exchange, while short hydroperiods promotes muck fires that decrease soil elevation (Givnish et al., 2008). Even though long hydroperiods have negative effects on individual woody species, its overall effects on stand productive are not well understood because the net integrative effects of flooding are masked by plants compensatory responses across the hydrological gradient that includes woody plants shift between sexual and clonal reproduction (Tardif and Bergeron, 1999). Indeed, there is a growing understanding of the role of vegetative growth in allowing woody plants to persist in ecosystems where stressful abiotic conditions (i.e., high water depth, long hydroperiods and poor soil nutrient) limit plant function, size, lifespan, and recruitment opportunities (Klimensová and Klimeŝ, 2007).

This study examines the effects of hydrology and soil properties on tree species dominance, tree growth, and litterfall production across a hydrological gradient within WCA-3A. Specifically, this study compares forest structure, growth rate, species contribution to leaf fall, and litterfall between a pristine and a degraded tree island. It is hypothesized that soil saturation and poor soil nutrient conditions have a negative effect on the structure and function of tree islands.

Methods

The study was conducted in two tree islands located in WCA-3A. These tree islands are 3AS3 (25˚51’ 24” N and 80˚46’10.8” W) and 3AS17-6 (25˚54’50.10” N and 80˚39’18.10” W). Tree island 3AS3 is located within a conserved ridge-slough mosaic and is considered a relatively pristine tree island due to its forest structure attributes, wood tree diversity, and soil properties (**Table 6-4**). The head of this tree island is dry with typically no standing water throughout the year with woody vegetation dominated by *Chrysobalanus icaco* (cocoplum), *Annona glabra*

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(pond apple), and *Salix caroliniana* (willow). The wet head is also characterized by short hydroperiods with more diverse woody vegetation that includes *C. icaco*, *A. glabra*, *S. caroliniana*, *Acer. rubrum* (red maple), and *Ilex cassine* (dahoon holly). The near tail, with high woody tree diversity but with shorter and smaller trees, is characterized by high water depth and long hydroperiod (**Figure 6-24**). Tree island 3AS17-6 is located within an impounded region in southeastern WCA3-A resulting in long hydroperiods. This tree island is considered a degraded tree island due to its poor forest structure, low tree diversity, and poor soil properties (**Table 6-4**). The vegetation is typical of environments under very wet conditions with *A. glabra* and *S caroliniana* dominating the head and wet head communities with near tail comprised of dense *Cladium jamaicense* (saw grass) intermixed with some shrubs comprised by *Myrica cerifera* (wax myrtle) and *Cephalanthus occidentalis* (buttonbush) (**Table 6-4**). The three vegetation zones—head, wet head, and near tail—have similar hydropatterns with very high water depth and very long hydroperiod in which much of the islands remain flooded for more than 11 months in a typical year (**Figure 6-24**).

Litterfall plots, 5 x 5 m, were established on each tree island. Five 0.25-square meter (m^2) litter traps were randomly established with each study plot. Traps were set at a height of 1.5 m above the ground surface to avoid the inundation of the litterfall collected in the traps during high water events. Litterfall was collected at six week intervals from January 2011 through January 2014. Litter is defined as leafy materials (leaves dropped by trees), reproductive materials (fruits, seeds and flowers) and woody material (branches, twigs and bark). Samples were oven dried for seven days at 60 degrees Celsius ($^{\circ}$C). The dried contents from each litter trap were sorted to leaves, reproductive and woody components. Herbaceous and all highly decomposed, unidentifiable leafy and reproductive materials were designated as miscellaneous components.

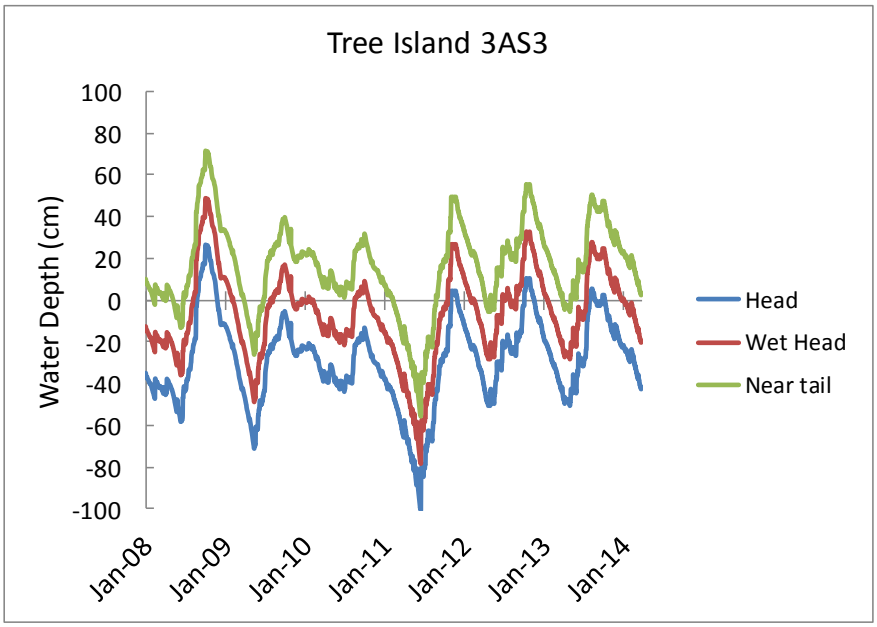
To characterize tree growth dynamics, stainless steel dendrometer bands were installed on tree individuals at each tree island. The circumference of each tree was measured to the nearest 0.25 mm with a hand-held ruler. Measurements, made approximately every 4 weeks, were used to calculate growth in diameter over time [millimeter per day (mm day^{-1})]. Two dominant tree species, *Annona glabra* (n=18), and *Salix caroliniana* (n=18), greater than 2.5 cm in diameter at breast height (dbh), were randomly chosen. *A. glabra* is a multi-stemmed and semi-deciduous tree with an average height of 10 m.; their geographical distribution is wide since it grows from South Florida to South America. *S. caroliniana* is a temperate deciduous species with a wide distribution since it occurs from southern Maryland to South Florida, Cuba and Central America (Tomlinson, 1980).

Table 6-4. Soil physico-chemical properties and forest structure attributes at the two tree islands under study (3AS3 and 3AS17-6).

	Tree island 3AS3			Tree Island 3AS17-6		
Soil Properties	Head	Wet Head	Near Tail	Head	Wet Head	Near Tail
Bulk Density (g cm^{-3})	0.46	0.20	0.09	0.11	0.10	0.11
Total C (mg cm^{-3})	75.5	60.6	61.6	51.3	50.2	49.1
Total N (mg cm^{-3})	3.39	3.27	2.83	3.32	3.42	3.08
Total P (mg cm^{-3})	24.8	0.33	0.09	0.52	0.28	0.05
Soil TC (mol/g)	1.71	3.02	3.79	3.82	3.82	3.81
Soil TN (mol/g)	0.07	0.15	0.18	0.21	0.22	0.20
Soil TP (mol/g)	0.145	0.005	0.002	0.015	0.008	0.002
C:N (mol/mol)	28.6	23.3	22.2	18.2	17.3	18.9
N:P (mol/mol)	1.35	39.1	86.7	53.1	90.9	141.4

Structure Attributes	Head	Wet Head	Near Tail	Head	Wet Head	Near Tail
Basal Area (m^2 ha^{-1})	16.2	19.4	9.6	9.5	6.5	-
Tree Height (m)	5.2	5.4	4.3	4.7	3.2	-
Density (tree ha^{-1})	3000	2900	4500	2300	3400	-
Leaf Fall (g m^{-2} yr^{-1})	438	496	444	409	301	-
Litterfall (g m^{-2} yr^{-1})	704	760	618	590	474	-
Species Composition						
Salix caroliniana	x	x	x	x	x	
Chrysobalanus icaco	x	x	x	x		
Annona glabra	x	x	x	x	x	
Myrica cerifera	x				x	x
Acer rubrum		x	x			
Ilex cassine		x	x			
Magnolia virginiana			x			
Persea palustris			x			
Cephalanthus occidentalis				x	x	
Cladium jamaicense					x	

Key to units: C – carbon; g cm^{-3} – grams per cubic centimeters; g m^{-2} yr^{-1} – grams per square meter per year; m – meters; m^2ha^{-1}square meter per hectare; mg cm^{-3} – milligrams per cubic centimeter; mol – mole; N - nitrogen; P - phosphorus; basal area m^2 ha^{-1} and density – tree per hectare.



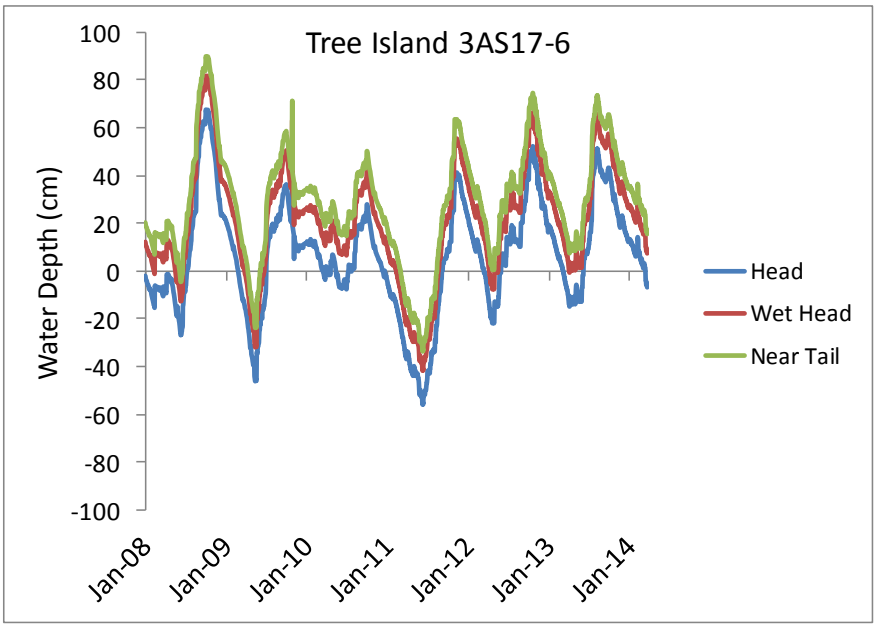


Figure 6-24. Hydrology pattern at Tree Island 3AS3 and Tree Island 3AS17-6 from 2008 to 2014, which includes the study period from 2011–2013).

Results and Discussion

Litterfall: Spatial and Temporal Patterns

At Tree Island 3AS3, average litterfall ranged from 0.5 to 5.1 grams per square meter per day (g m^{-2} day^{-1}) in which temporal pattern was strongly seasonal with the highest litterfall production occurring at the onset of the wet season (July-August) and the lowest during the onset of the dry season (December-February) (**Figure 6-25**). This temporal pattern was significantly different with wet season being higher than dry season ($p < 0.05$). Spatially, litterfall pattern was significantly lower on the near tail ($p < 0.05$) relative to the head and wet head where litterfall was significantly similar ($p > 0.05$). Species composition on this tree island was an important factor in determining litterfall patterns. Five woody species contributed with more than 70 percent of the total leaf fall production. On the head, *C. icaco*, *S. caroliniana* and vines contributed with about 70 percent of the total leaf fall. In contrast, *A. rubrum*, *S. caroliniana* and *I. cassine* contributed 65 percent of the total leaf fall recorded on the wet head. In the near tail, *A. glabra*, *S. caroliniana*, *C. icaco* and *Magnolia virginiana* (sweet bay) contributed 70 percent of the total leaf fall. When litterfall was separated into their different components (leaves, reproductive, woody, and miscellaneous), leaf fall contributed 70 percent of the total litterfall production. The reproductive component along with the woody component contributed 20 percent of the total litterfall and miscellaneous contributed the remaining 10 percent.

At Tree Island 3AS17-6, average litterfall ranged from 0.5 to 4.0 g m^{-2} day^{-1} on the head and from 0.3 to 2.8 g m^{-2} day^{-1} on the wet head. Litterfall pattern showed a strong seasonality on the head with high litterfall production occurring at the onset of the wet season (July-August) and the lowest during the onset of the dry season (December-February) (**Figure 6-26**, panel a). In contrast, on the wet head the seasonality was less clear with litterfall production decreasing over the study period (**Figure 6-26**, panel b). This temporal pattern was significantly different with wet season being higher than dry season ($p < 0.05$) only on the head with no significant seasonality on the wet head ($p > 0.05$). Spatially, litterfall pattern was significantly lower on the wet head ($p < 0.05$) relative to the head. Species composition on this tree island was an important factor in determining litterfall patterns. On the head, *A. glabra* and *S. caroliniana* contributed 90 percent of the total leaf fall on the head tree island. In contrast, *S. caroliniana*, *A. glabra* and *C. occidentalis* contributed 85 percent of the total leaf fall recorded on the wet head. Leaf fall contributed the most to the total litterfall with 70 percent of the total litterfall, the reproductive and woody component contributed 25 percent and miscellaneous contributed the remaining 5 percent.

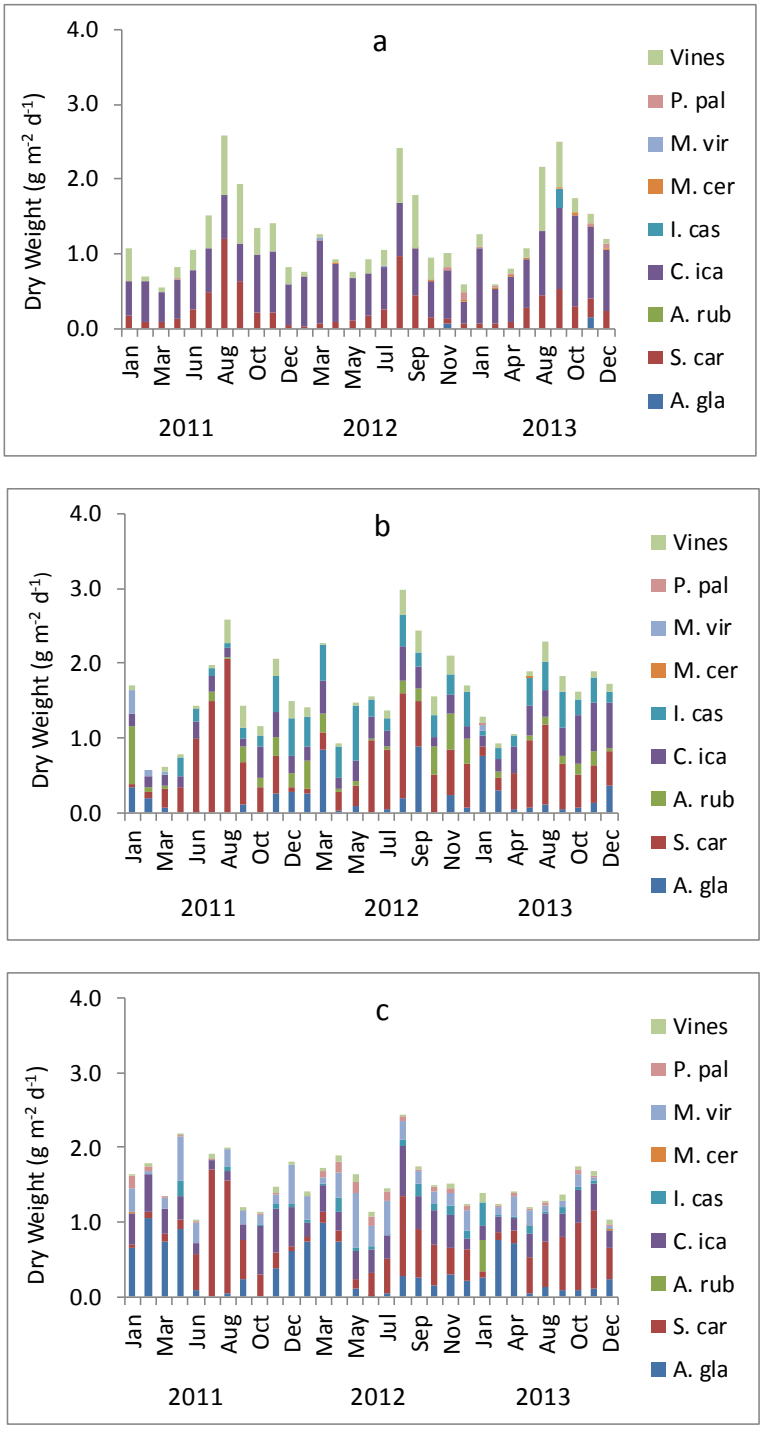
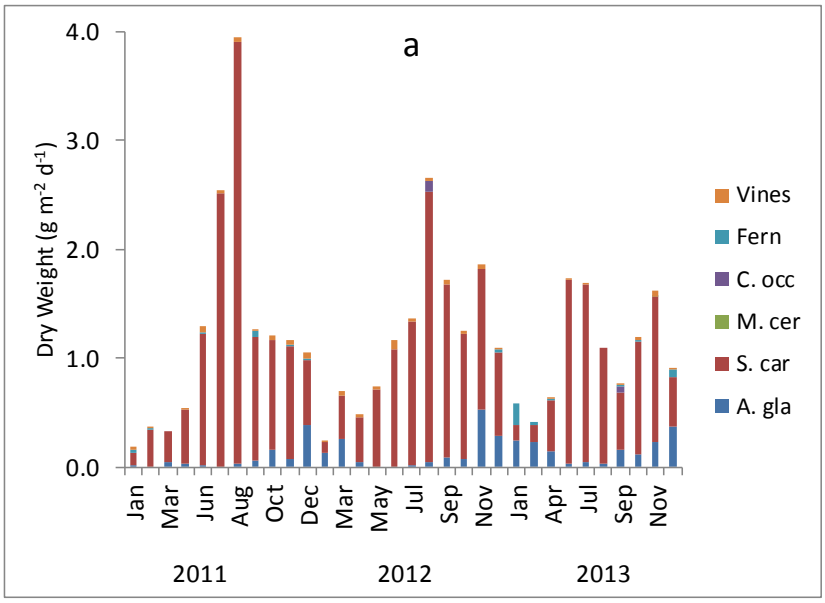


Figure 6-25. Temporal and spatial pattern of leaf fall at Tree Island 3AS3: (a) tree island head, (b) tree island wet head, and c) tree island near tail. Figure shows woody species contribution to leaf fall.



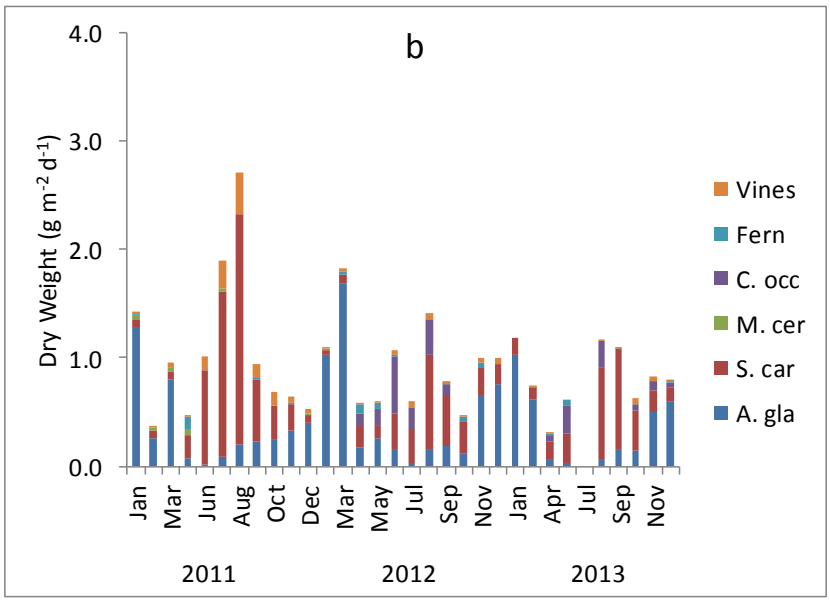


Figure 6-26. Temporal and spatial pattern of leaf fall at Tree Island 3AS17-6: (a) tree island head and (b) tree island wet head. Figure shows woody species contribution to leaf fall.

Tree Growth: Spatial and Temporal Patterns

On Tree Island 3AS3, *S. caroliniana* individuals growing on the head had higher growth rates [mean 0.014 square millimeter per day (mm^{-2} day^{-1})] than *A. glabra* tree individuals also growing on the head (mean 0.007 mm^{-2} day^{-1}). This difference in growth rates was statistically significant ($p < 0.05$). Similarly, growth rates on the head were highly seasonal in which the highest growth rates of *S. caroliniana* occurred during the dry months (March–May) of each year while the highest growth rates of *A. glabra* occurred at the beginning of the rainy season (June–July) (**Figure 6-27**, panel a). On the wet head, *S. caroliniana* had higher average growth rates (mean 0.007 mm^{-2} day^{-1}) than *A. glabra* (mean 0.004 mm^{-2} day^{-1}; however these growth rates were not significantly different ($p > 0.05$). The seasonal growth pattern of *S. caroliniana* was similar to those individuals distributed on the head with higher growth rates during the spring months (March–May) (**Figure 6-27**, panel b). Growth seasonality of *A. glabra* on the wet head was less clear as growth rates steadily decreased over the study period (**Figure 6-27**, panel b).

On Tree Island 3AS17-6, *S. caroliniana* individuals growing on the head had higher growth rates (mean 0.025 mm^{-2} day^{-1}) than *A. glabra* tree individuals growing on the head (mean 0.006 mm^{-2} day^{-1}) and this difference was statistically significant ($p < 0.05$). Similarly, growth rates on this degraded tree island were highly seasonal, particularly for *S. caroliniana* with highest growth rates occurring during the dry months (March–May) (**Figure 6-28**, panel a). In contrast, highest growth rates of *A. glabra* occurred during early summer time in 2012 and during the fall in 2013 (**Figure 6-28**, panel a). On the wet head, *S. caroliniana* had higher average growth rates (mean 0.01 mm^{-2} day^{-1}) than *A. glabra* (mean 0.003 mm^{-2} day^{-1}; however these growth rates were not significantly different ($p > 0.05$). The seasonal growth pattern of *S. caroliniana* was similar to those individuals distributed on the head with higher growth rates during the spring months (March–May) and lower during the onset of the summer time (July–September) (**Figure 6-28**, panel b). Growth seasonality of *A. glabra* was less apparent as growth rates steadily decreased over the study period (**Figure 6-28**, panel b).

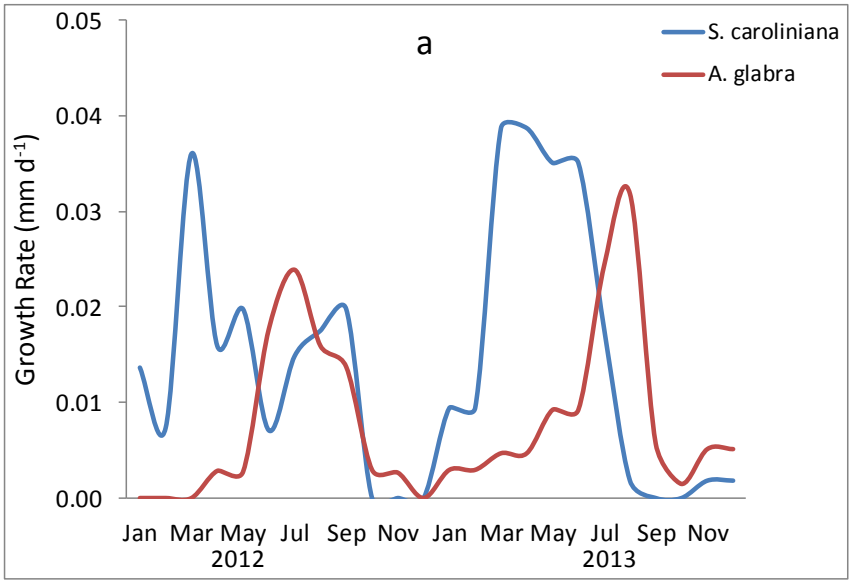
These results suggest that hydropatterns and soil properties played a role in determining forest structure and species composition, which in turn may be driving both tree growth and litterfall spatial patterns observed on those tree islands. Poor nutrients conditions associated with low soil TP, high water depth and long periods of inundation can led to low litterfall values and low growth rates on the degraded tree island (**Table 6-4**). In contrast, rich nutrient conditions and short period of inundation may play an important role in determining the high litterfall values and relatively high tree growth rates on pristine tree islands (**Table 6-4**). Comparing environmental conditions on pristine and degraded tree islands underlines the importance soil fertility and hydrology, with more natural wet and dry cycles, observed in pristine tree islands. It makes it clear that these environmental conditions should be achieved on degraded tree islands to improve and restore the structure and function of these tree islands.

Significance to Water Management

These results indicate that litterfall production is an ecological process that is strongly influenced by several environmental parameters, such as hydrology, air temperature, rainfall, and wind, operating over large spatial and temporal scales (Cormier et al., 2013) with soil fertility operating at a small spatial scale. Consequently, assessing the effect of hydrology and soil nutrient conditions on tree islands function requires long-term monitoring programs. Results from this study suggest that current hydrological conditions of high water level, low water flow, and impounded conditions are to be restored to better succeed in restoring the structure and function of degraded tree islands.

The preservation of the plant community dynamics on tree islands, including the natural shifts in species composition, forest structure and function (i.e., litterfall production, tree growth,

nutrient cycling) is directly dependent on the existence of a mosaic of hydrological conditions, which requires water management policies that promote natural wet and dry cycles through the Everglades ecosystem.



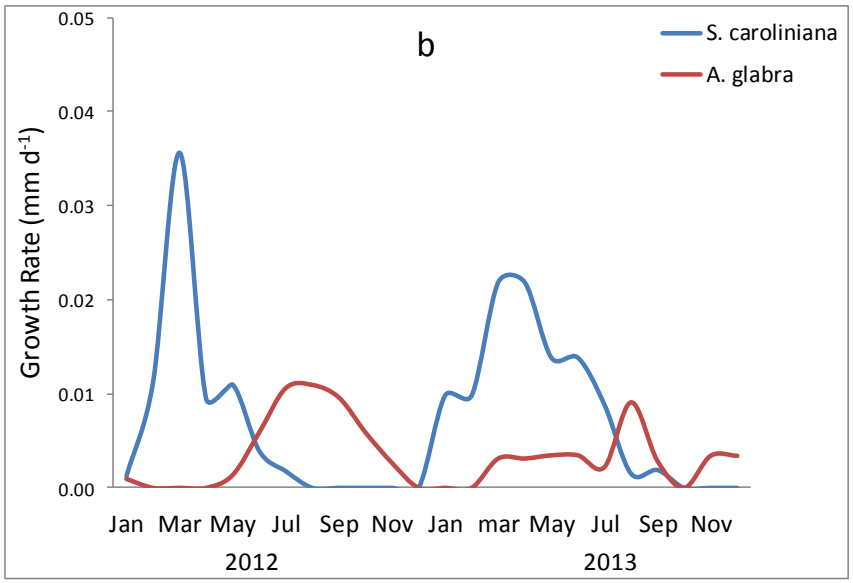


Figure 6-27. Spatial and temporal pattern of tree growth [millimeter per day (mm day^{-1})] for *Salix caroliniana* and *Annona glabra* at the (a) head and (b) near tail of Tree Island 3AS3.

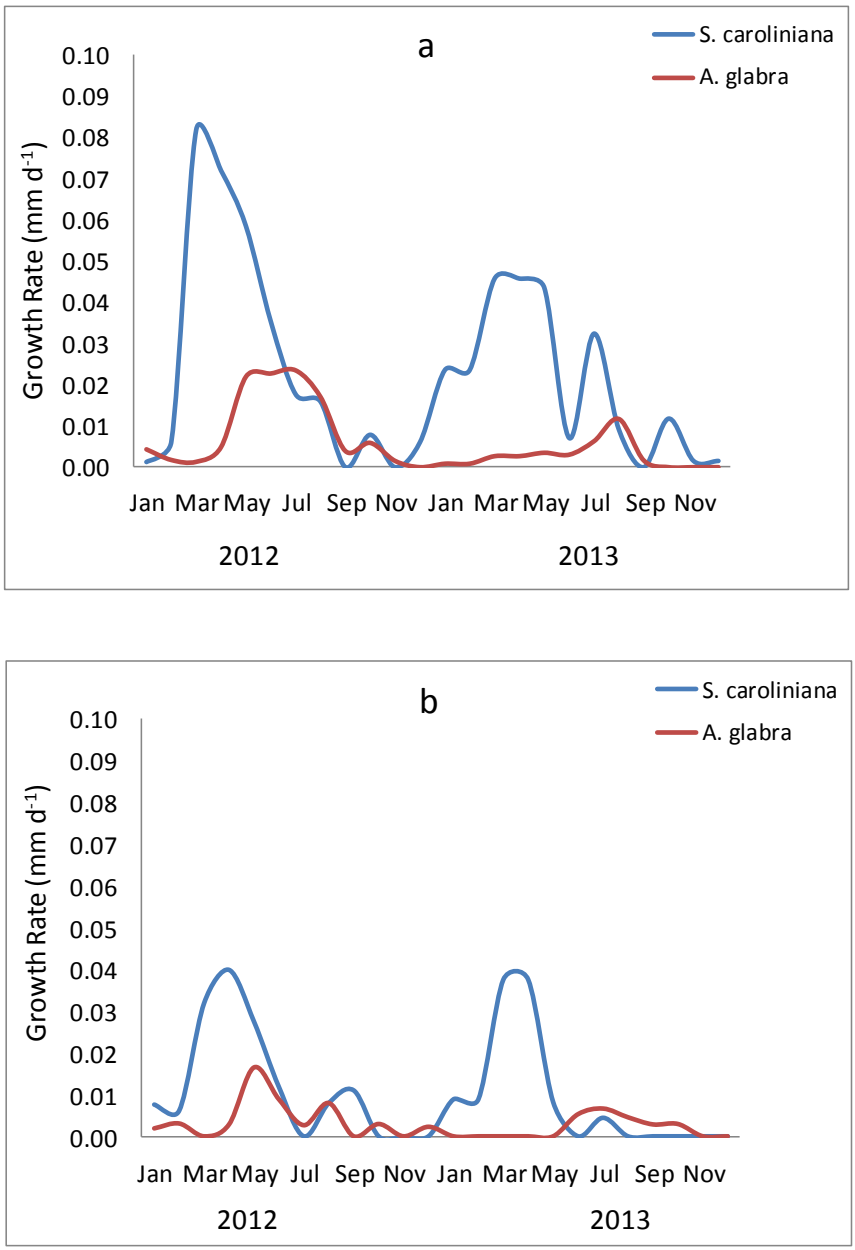


Figure 6-28. Spatial and temporal pattern of tree growth (mm day^{-1}) for *Salix caroliniana* and *Annona glabra* at the (a) head and (b) near tail of Tree Island 3AS17-6.

ECOSYSTEM ECOLOGY

This section focuses on both the fresh water and coastal areas of the Everglades. The first project presents the results of the active marsh improvement project slough study, examining the efficacy of various dosages of herbicide to maintain open areas formerly extensively invaded by cattail (*Typha domingensis*). The second ecosystem project is a detailed description of ecological monitoring and research conducted in Florida Bay including water quality (temporal and spatial analyses) and benthic vegetation (monitoring and modeling relative to restoration projects).

ACTIVE MARSH IMPROVEMENT PROJECT – SLOUGH STUDY

Susan Newman, LeRoy Rodgers, Michael Manna,
David Black and Kristin Seitz

The objective of the Active Marsh Improvement – Slough Study was to reduce the extent of the cattail expanse at the leading edge of the nutrient front in WCA-2A, thereby reestablishing open water sloughs free of dense cattail stands, and determine what species will immigrate to these areas with the removal of cattail competition. In order to minimize the application of herbicides in the Everglades, this study was also designed to determine the minimum effective dosage rate of Clearcast™ (imazamox) to manage cattail while limiting the detrimental effects to desirable emergent, floating, and submerged plant species. Because the emphasis of this study was on herbicide effects, plus the presence of open water areas within the plots, fire was not used to clear standing dead.

Methods

Nine 100 x 100 m plots, two herbicide treatments of 0.21 or 0.28 kilograms acid equivalent per hectare (kg ae ha^{-1}); 24 and 32 ounce per acre, respectively) and one control, were established in a randomized block design at three locations along the southernmost extent of the nutrient enrichment gradient, i.e., cattail front, in WCA-2A. Percent cover and species composition were assessed within 0.5 x 2 m quadrats in six ridge and six slough sampling sites in each plot. Because of the interest in the relative effectiveness of the herbicide treatments, data were analyzed as proportional change relative to initial condition. Treatment comparisons were conducted using mixed model analysis, with block, i.e., the east-west location of the plots, was set as random, and with differences assessed using least squares means (SAS version 9.3, 2011).

Results and Discussion

Herbicide damage to more desirable ridge and slough species was minimal, short-lived and previously reported in the 2014 SFER – Volume I, Chapter 6 (Sklar and Dreschel, 2014). Here the focus is on the effectiveness of the herbicide rates in managing cattail throughout the two-year study. There was an initial decline in cattail percent cover 12 months after treatment (MAT), with proportional declines averaging 36 and 88 percent, for 0.21 and 0.28 kg ae ha^{-1}, respectively (**Figure 6-29**). By 21 MAT, the 0.28 kg ae ha^{-1} rate was still effective, as shown by the maintenance of an 84 percent loss relative to initial, while cattail cover in the lower herbicide rate was similar to untreated controls. At 24 MAT the effectiveness of the higher rate was reduced to a 39 percent decrease, suggesting recovery of the cattail community. These preliminary analyses indicate the 0.21 kg ae ha^{-1} rate would not be ecologically beneficial or cost effective in the long-term. However, the 0.28 kg ae ha^{-1} rate maintained greater efficacy, and while there was earlier evidence of stunted growth of more desirable species, e.g., sawgrass (Sklar and Dreschel 2014)

these species recovered and therefore were not adversely affected by the single herbicide application. In invasive plant management, multiple herbicide applications are typically required before the target weed is fully controlled (Monaco et al., 2002). As such, additional application of imazamox at 0.28 kg ae ha^{-1} may be necessary to maintain a more restored state. However, timing and application frequency requires further study because a recent observation suggested that a second application of imazamox within 24 MAT caused a decline in sawgrass cover (Manna pers. obs.). Spot treatments of recovering cattail using ground-based applicators would likely reduce frequency of any large-scale reapplication.

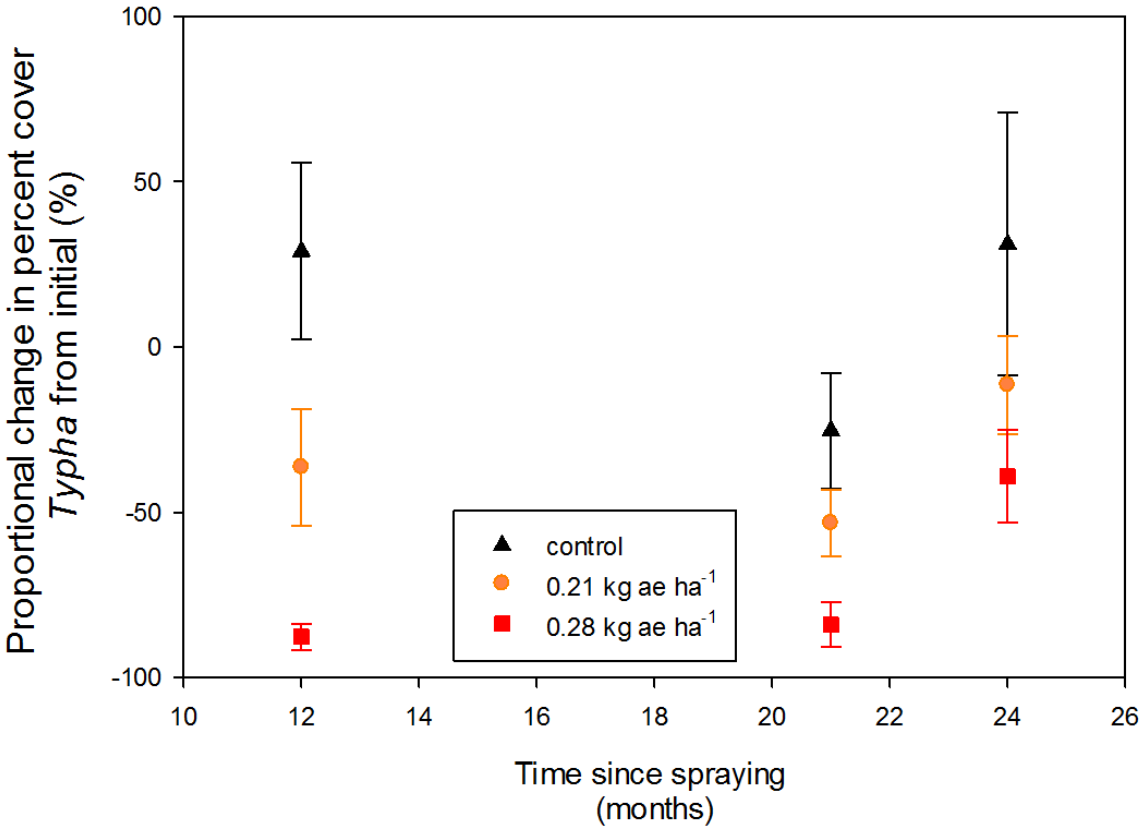


Figure 6-29. Changes in proportional cattail cover, relative to initial conditions, in response to the application of two rates of imazamox (mean ± 1.0 standard error; significant differences based on least squares-means treatment comparisons for each time period).[Note: kg ae ha^{-1} – kilogram acid equivalent per hectare.]

Relevance to Water Management

Nutrient loads to the Everglades have been significantly reduced however the eutrophied downstream ecosystem is resilient and resists change. Active marsh improvement projects show these areas can be rehabilitated such that they provide habitat for high quality prey production and wading bird foraging (Hagerthey et al., 2014). Based on the promising results of Rodgers and Black (2013), in 2011 this study was initiated to assess whether a lower, but equally effective, imazamox application rate could manage cattail, as part of the Active Marsh Improvement Strategy. This study demonstrated that the lower rate, 0.21 kg ae ha^{-1}, would not be recommended to manage cattail in similar nutrient enriched conditions. In contrast, the higher rate, 0.28 kg ae ha^{-1}, was effective and maintained its maximum effectiveness for 21 MAT, but showed signs of declining efficacy at 24 MAT. Overall these results confirm imazamox to be a viable tool to manage ridge and slough habitat patterning within the Everglades. The reapplication of imazamox is a realistic approach, but our limited knowledge of the effects of reapplication on non-target species suggests an assessment of timing and frequency of reapplication is essential before broad-scale implementation.

FLORIDA BAY WATER QUALITY CONDITIONS AND STATUS

Steve Kelly, Fabiola Santamaria[2] and Michelle Blaha[2]

Water quality in Florida Bay (eastern, central and western regions), Whitewater Bay to the west, and Barnes Sound in Biscayne Bay to the east and other southern coastal systems has been monitored since 1991 (WY1992) to ensure that District operations and projects protect and restore the ecosystem to the extent possible. CERP performance measures focus on chlorophyll *a* (Chl*a*) concentration, an indicator of algal blooms, as well as the nutrient inputs that initiate and sustain blooms. Operational changes to the south Dade conveyance system including the C-111 Spreader Canal Western Project which became operational during WY2013 are not expected to alter downstream water quality, or to increase the magnitude, duration, or spatial extent of algal blooms downstream. As conditions have not changed significantly during WY2014, here we present a brief update of ecologically important parameters and how they differ from WY2013. For a complete description of water quality assessments in Florida Bay, refer to Chapter 6 of the 2014 SFER – Volume I (Sklar and Dreschel, 2014).

As reported in the 2014 SFER, annual averages of all parameters analyzed (Chl*a*, total dissolved phosphorus, total dissolved nitrogen, total organic carbon, dissolved inorganic nitrogen and turbidity), were similar between WY2012 and WY2013 and continue to be similar during WY2014 with the following updates (**Table 6-5**): Chl*a* in the eastern and central bay, elevated during WY2013, has returned to or is now below the period of record (WY1992–WY2011) levels, while Whitewater Bay concentrations remain elevated and Barnes Sound concentrations became elevated during WY2014 (**Figures 6-30** and **6-31**); total dissolved nitrogen remains elevated in the central bay and Whitewater Bay; dissolved inorganic nitrogen in the eastern bay, reported as much lower in WY2013, remains so, while dissolved inorganic nitrogen in Whitewater Bay, reported as much higher in WY2013, is now below period of record levels and dissolved inorganic nitrogen in Barnes Sound remains elevated. These annual averages continue to be stable during the last five water years, indicated by little to no inter-annual concentration changes, except for an increase of Chl*a* in Whitewater Bay. Total dissolved phosphorus, total dissolved nitrogen, total organic carbon and turbidity continue to be similar in WY2014 to WY2012 and WY2013.

Table 6-5. Chl*a*, total dissolved nitrogen, and dissolved inorganic nitrogen differences in WY2013 and WY2014 from period of record (WY1992–WY2011) averages.

Parameter	Region	WY2013 versus Period of Record	WY2014 versus Period of Record
Chl*a*	East	200%	99%
	Central	142%	42%
	Whitewater Bay	113%	156%
	Barnes	86%	122%
Total dissolved nitrogen	Central	121%	113%
	Whitewater Bay	12%	128%
Dissolved inorganic nitrogen	East	55%	68%
	Whitewater Bay	276%	48%
	Barnes	171%	200%

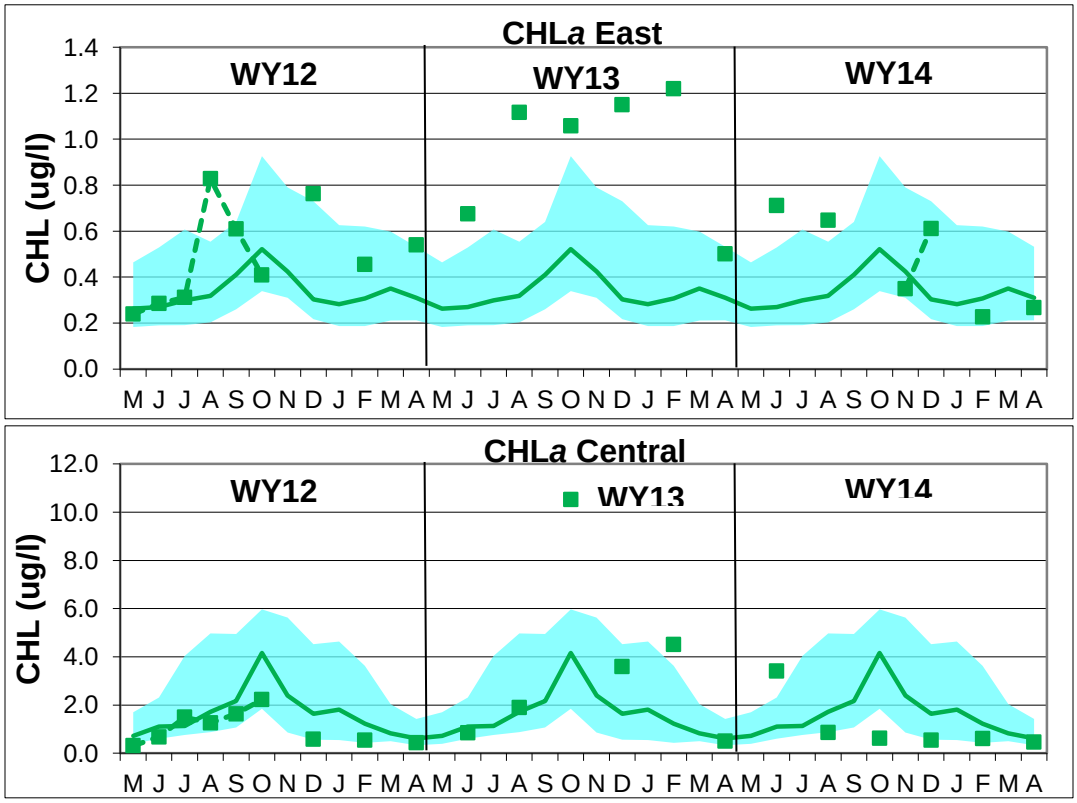


Figure 6-30. Chlorophyll *a* (Chl*a*) concentrations in micrograms per liter (µg/L) in the two of the regions studied during WY2012 through WY2014 (solid symbols) compared to the temporal median of the monthly spatial medians and the interquartile range for the entire period of record, WY1992–WY2011 (solid line and blue shading). Dashed line becomes points after October 2011 because sampling was then conducted every other month.

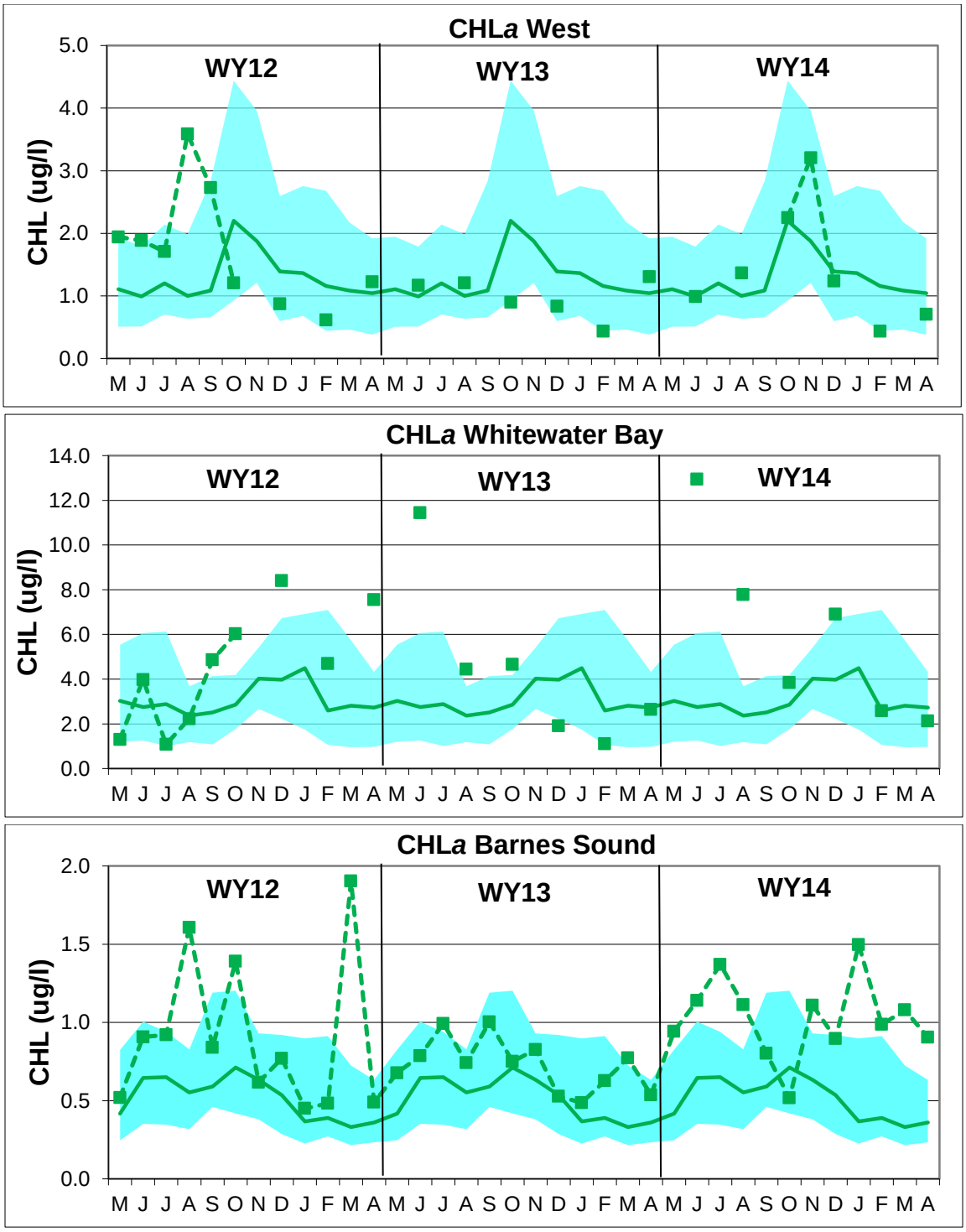


Figure 6-31. Chl*a* concentrations in µg/L in three of the regions studied during WY2012 through WY2014 (solid symbols) compared to the temporal median of the monthly spatial medians and the interquartile range for the entire period of record, WY1992–WY2011 (solid line and blue shading). Dashed line becomes points after October 2011 because sampling was then conducted every other month in all areas except Barnes Sound.

C-111/TAYLOR SLOUGH ECOSYSTEM TRENDS

Christopher Madden

The Taylor Slough and the C-111 Basin watersheds can deliver significant contributions of fresh water to the estuarine portions of Florida Bay (Hunt and Nuttle, 2007). These watersheds and the mangrove transition zone that forms the northern shore of Florida Bay may undergo hydrological and ecological change as a result of restoration activities that increase freshwater flow to the area, particularly the C-111 Spreader Canal Western Project, which came online in July 2012. The District is monitoring how changes in the quantity, timing, distribution and quality of water delivery affect the ecology of the southern Everglades wetlands and the Florida Bay estuary. This integrated monitoring/science project addresses questions relating to ecosystem dynamics at estuarine sites extending from Highway Creek and the Triangle Basin in the east to Alligator Creek in the west, encompassing creek sites in Trout Creek, Joe Bay, Argyle Henry, Taylor River Mouth and McCormick Creek. Nutrients, salinity and water flow are monitored at these major discharge points. Soil salinity, water depth, marsh vegetation, periphyton and surface and porewater nutrients are measured at interior marsh sites in northern and southern C-111 Basin, the Triangle Basin east of US Highway 1, and an array of salinity transects through the mangrove ecotone.

Water level recorders in the C-111 Basin show that the annual hydropattern in WY2013 and through January WY2014 remains temporally consistent with previous years (beginning March 2006) with the exception that levels at W3 in the southern C-111 Basin (green line, **Figure 6-32**), for the first time exceeded levels at all other sites and at any time previously at W3. All sites dried down in early WY2014 except W3; sites at W1 and USC were overall lower in WY2014 than in previous water years. It is important to monitor water levels in these eastern sites because the C-111 Spreader Canal Western Project features and operations are designed to retain more water in Taylor Slough to the west and may result in drier conditions at these eastern sites.

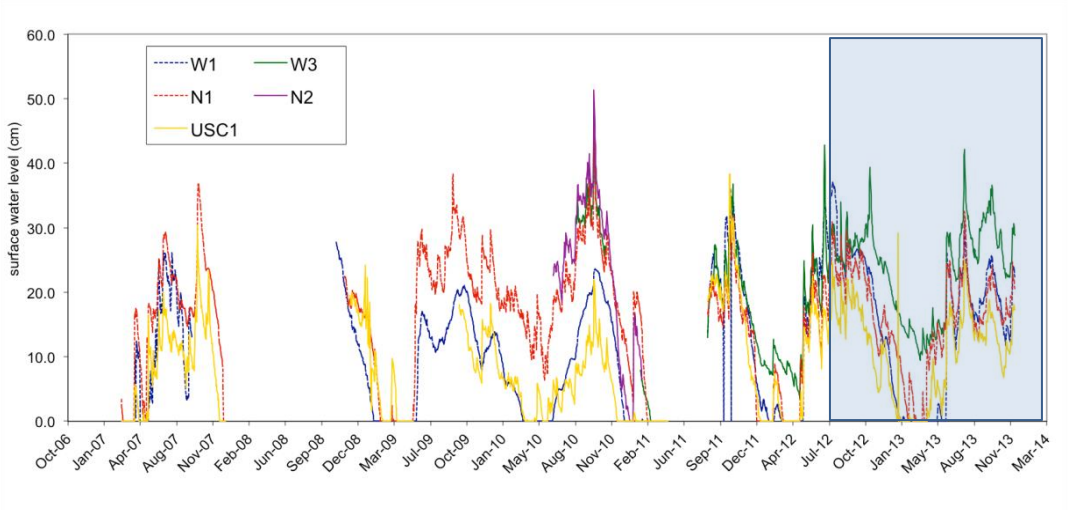


Figure 6-32. Surface water level in centimeters (cm) at C-111 Basin freshwater marsh monitoring sites. W stations are in the southern basin, N stations are in the northern basin and USC is in the Triangle east of US Highway 1. The blue region of the graphic shows the period since initiation of the C-111 Spreader Canal Western Features Project in July 2012.

Macrophyte species composition and aboveground *Cladium* biomass are measured bimonthly in the C-111 Basin (stations W1 & W3), in the northern C-111 Basin (N1 and N2), and in the Triangle Basin at site USC1. *Cladium* biomass at N1 and W1 (**Figure 6-33**) increased in WY2013 and WY2014 relative to the mean during the period of record (2006–present), while standing biomass at W3 (not shown) was relatively constant and biomass at the Triangle Basin site USC1 was at or below its long-term average in both WY2013 and 2014. Greatest standing biomass was measured at the northern C-111 Basin sites, followed by the southern C-111 and Triangle basins sites. A notable feature is a near-doubling of biomass at the W1 site during WY2014 to attain the highest sustained biomass level of any site.

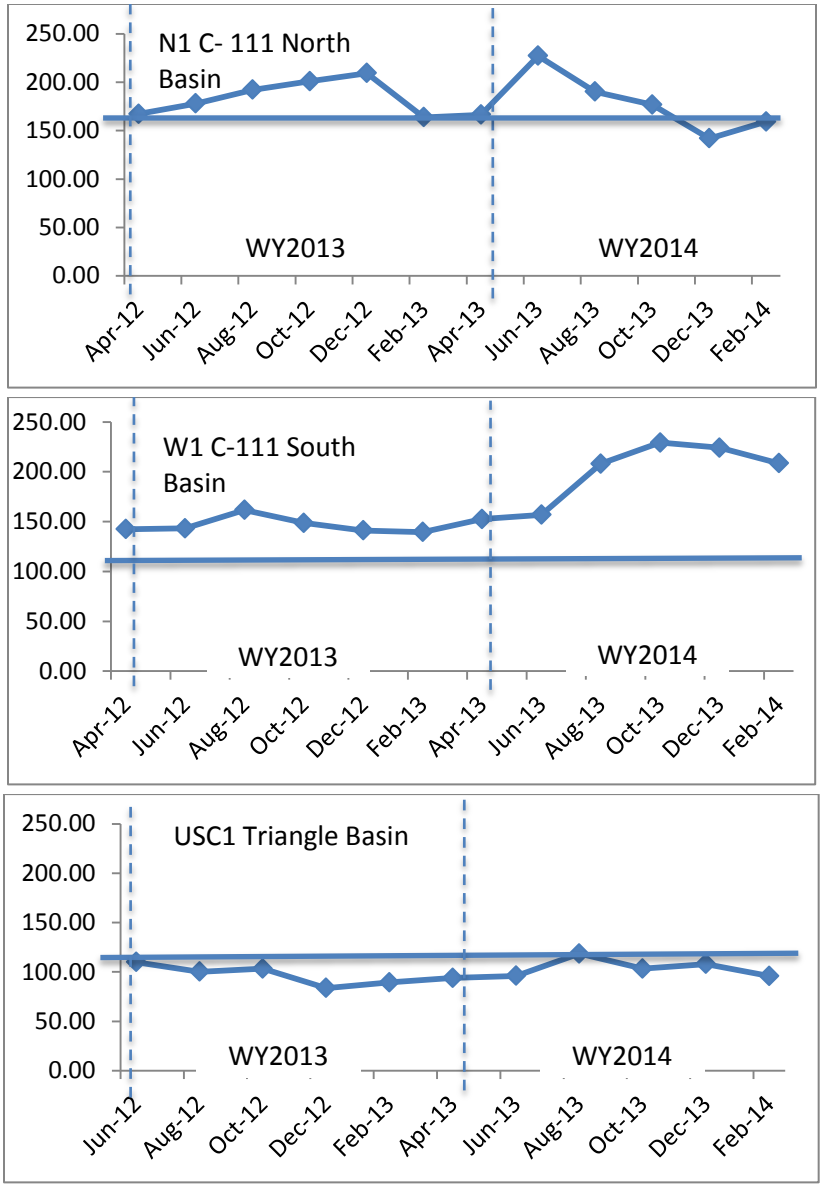


Figure 6-33. *Cladium* biomass in grams per square meter (g m^{-2}) at C-111 and Model lands freshwater marsh sites compared to the long-term (2006–present) mean biomass (horizontal blue line) at sites in the (A) northern C-111 basin, (B) southern basin and (C) Triangle Basin east of US Highway 1. Dashed line indicates the separation of water years.

Nutrients are measured at principle discharge points to Florida Bay to ensure that upstream management is not degrading water quality in the estuary. Nutrients in water discharging during WY2014 from Taylor River to Florida Bay decreased in concentration of both total nitrogen (TN) and total phosphorus (TP) from levels in early WY2013 (**Figure 6-34**). TN concentrations were above the long-term mean (1996–present) of 55 micromole (µM) for several weeks in early WY2013 with a 30-day running average almost 20 percent greater than the mean, then declined to approximately the mean through the remainder of WY2013 and WY2014. Daily TP concentration was also elevated in early WY2013 to several times the long-term mean of 0.32 µM and the 30-day mean nearly doubled the long term mean. Concentrations of TP then declined to the mean for the remainder of WY2013 and at or below the mean for the majority of WY2014, declining to half the mean during the dry season. These elevated TN and TP concentrations coincided with the initiation of the WY2013 wet season and are likely partially related to mobilization of nutrients from the soil and vegetation substrates. A similar but muted elevation was observed in WY2014 for TN as well when signification precipitation events began several weeks later than in WY2013. Transient spikes in both TN and TP occur throughout the year, possibly related to local biological and hydrologic events.

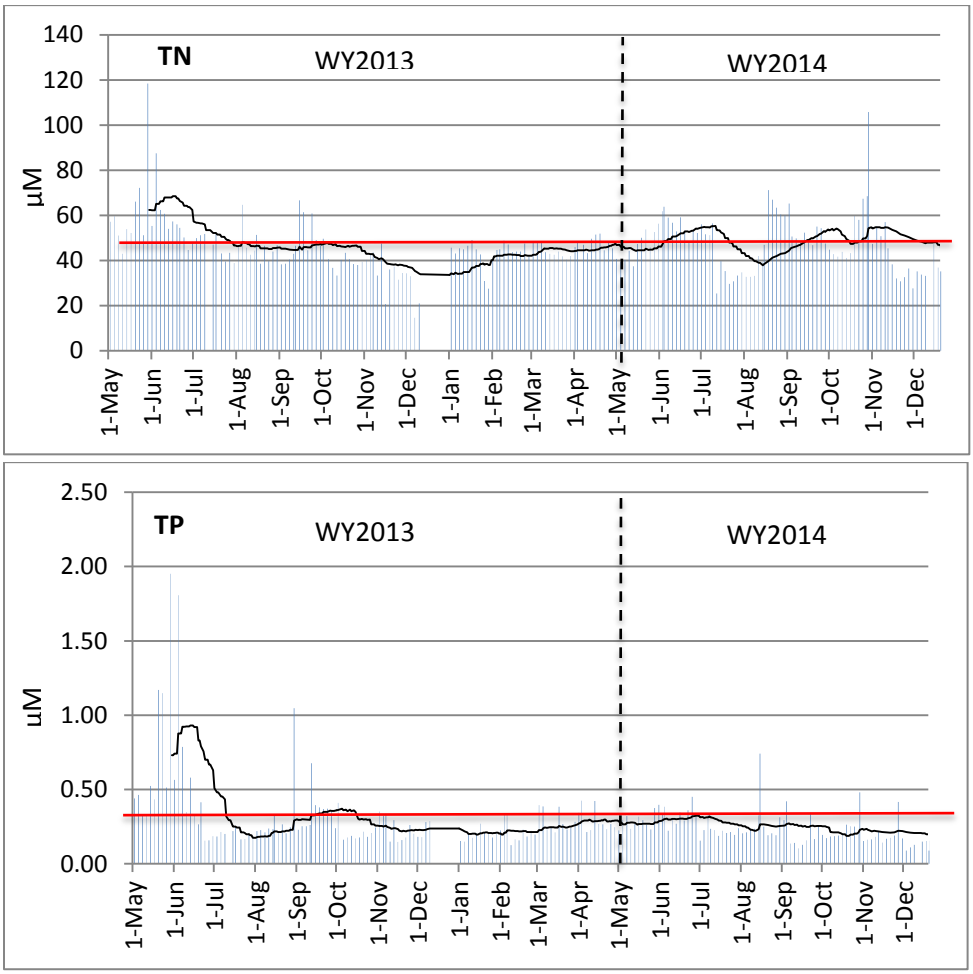


Figure 6-34. Nutrients in Taylor River discharges to Florida Bay in WY2013 and WY2014. total nitrogen (TN) (top) and total phosphorus (TP) (bottom) concentrations are compared to the long-term mean (1996–present) denoted by the red line. The black line represents the 30-day running average.

Relevance to Water Management

It is important to monitor and document ecosystem changes relative to changing water flow patterns resulting from restoration. A thriving fresh marsh (*Cladium*) community is important as habitat and for nutrient processing; alterations in hydrology must be monitored for negative impacts on the vegetation community, either by reductions in water or increases in salinity. Similarly, as freshwater discharge is increased, it is critical to avoid introduction of enriched levels of nutrients to Florida Bay. Long-term monitoring of major discharge points allows managers to discriminate between natural variability and trends that might negatively impact the estuary.

FLORIDA BAY BENTHIC VEGETATION

Amanda McDonald and Joseph Stachelek

Benthic vegetation, composed of seagrass and benthic macroalgae, provides habitat structure in Florida Bay and its associated creeks, ponds, swamp forests, and marshes of the mangrove transition zone. Monitoring and research of benthic vegetation is critical to understanding the effects of water management and restoration on wetland and estuarine ecosystems. Results from these efforts are used in assessing the effectiveness of the current Florida Bay MFL rule, which is based on the salinity tolerance of widgeon grass (*Ruppia maritima*). These surveys are used to provide ecosystem status updates for RECOVER, assessments of District operations, and calibrate and verify the Florida Bay Seagrass Community Model (SEACOM).

Methods

Benthic vegetation is monitored regionally in select locations using a randomized design where several 0.25-m^2 quadrats are assessed for benthic vegetation using indices of percent cover. Three separate monitoring programs cover different areas in Florida Bay. The South Florida Fish Habitat Assessment Program (FHAP) and the Miami-Dade County Department of Environment Resource Management (DERM) provide estimates of benthic vegetation cover using a visual index of bottom occlusion. FHAP monitors 17 basins throughout Florida Bay and along the southwestern coast every May while DERM monitors the nearshore embayments of northeastern Florida Bay quarterly. Audubon of Florida monitors SAV using a point-intercept method every other month at sites along nine transects extending from the freshwater marshes of the southern Everglades to Florida Bay. A more complete description of the monitoring programs and the methodologies are presented in 2011 SFER – Volume I, Chapter 12 (Alleman, 2011).

Results

Despite sustained high water levels and exceptionally low salinities in WY2014, there was little overall change in SAV cover in the mangrove creeks upstream of Florida Bay relative to WY2013. Exceptions included increased *Halodule wrightii* cover along the Joe Bay and Taylor River transects. These increases were preceded by record low cover in the previous water year (WY2013). Conversely, *H. wrightii* cover decreased in Highway Creek during high water levels and low salinity conditions. This continues a trend of steady decline there that began in WY2012 a year after surveys found unusually high cover nearing 100 percent. Surprisingly, the decline in *R. maritima* in Highway Creek (14 percent in WY2013 to 2 percent in WY2014) was accompanied by an increase in *Chara hornemanni* to record high abundance (30 percent in WY2013 to 67 percent in WY2014). The reason for this trend is unknown but it is possible that

dry season flow reversals differentially affected the two species (see the *Florida Bay Hydrology* subsection in the *Hydrologic Patterns for Water Year 2014* section).

Throughout Florida Bay in WY2014, total seagrass cover increased slightly at all basins except Johnson Key Basin in western Florida Bay, but was not significantly different from WY2013. In Rankin Lake and Whipray Basin, where *H. wrightii* had decreased from WY2012 to WY2013, results were mixed. In both cases, total seagrass cover increased because *Thalassia testudinum* increased slightly. However, while the frequency of sampled quadrats that contained *H. wrightii* with at least 5 percent bottom occlusion increased in Rankin Lake (17 percent in WY2013 to 25 percent in WY2014), Whipray Basin showed a continued decrease (14 percent in WY2013 to 9 percent in WY2014). It was interesting to note that the number of quadrats where *H. wrightii* was present regardless of percent cover increased slightly and insignificantly from 44 percent in WY2013 to 48 percent in WY2014.

Relevance to Water Management

Prior to the dry season of WY2014, relatively wet conditions had persisted for about two years throughout the mangrove transition zone and Florida Bay proper. This may explain the apparent system-wide stability of the benthic vegetation community. The unexpected drop in *R. maritima* cover in Highway Creek will be closely monitored because it is an area that may receive decreased surface water inputs due to C-111 Spreader Canal Western Project operations shifting water toward the west.

SYNOPTIC FLORIDA BAY ECOLOGICAL SURVEYS

Joseph Stachelek, Christopher Madden,
Fabiola Santamaria[2] and Michelle Blaha[2]

The District monitors conditions in Florida Bay in order to understand effects of water management and restoration projects such as the C-111 Spreader Canal Western Project. One unique aspect of Florida Bay is that it is a complex arrangement of distinct basins with limited circulation. This creates a challenge for tracking system-wide conditions because each basin operates somewhat independently from one another.

Methods

In order to resolve spatial patterning within the complex arrangement of the basins making up Florida Bay, high resolution surveys have been conducted since 1994. These surveys involve tracking water quality using a boat mounted flow-through collection system (Madden and Day, 1992; **Figure 6-35**). Despite the high resolution of the data, standard interpolations tended to "bleed through" barriers in the landscape. This obscures conditions where different water masses are located in close proximity but are narrowly separated by islands, peninsulas, or exposed mud banks. A software tool was developed by Everglades Systems Assessment Section staff to improve mapping accuracy by preventing interpolation through these barriers (Stachelek, 2014). The tool produces more accurate interpolations in the nearshore embayments of Florida Bay where effects of hydrologic restoration will be strongest.

Interpolated maps were assembled in a stacked series (1998–2003, n = 41) to evaluate the effects of recent restoration efforts. Each pixel in the stack was extracted as a time series and statistically compared to surface water deliveries through the major creeks feeding Florida Bay (**Figure 6-36**, panel a). The output of this process is a series of maps corresponding to each major creek showing regression diagnostics such as goodness-of-fit (**Figure 6-36**, panel b).

Results

The results show the extent of the bay (area enclosed by each contour) that fluctuates in accordance with each surface water input (**Figure 6-36**, panel b). Discharge through the western creeks (Taylor River and Mud Creek) appears to be correlated with a larger area of the bay than the eastern creeks (Trout and West Highway Creek). This is surprising given that discharge through Trout Creek is so much larger than the other surface water inputs (**Figure 6-36**, panel a). One reason for the disparity between discharge magnitude and correlation area may be the extent to which topography restricts flow. Trout Creek discharge may have a larger wind-driven component than Taylor River because of its more open topography.

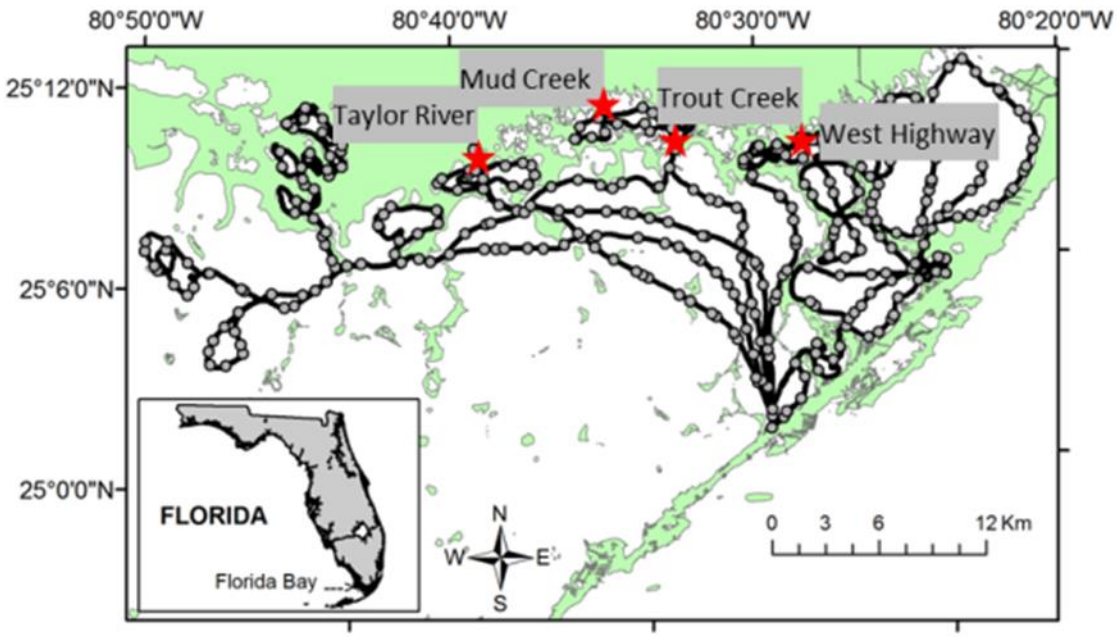


Figure 6-35. Florida Bay showing a Dataflow survey track (black line), subset of data points used for interpolation (filled circles), and locations of major discharge creeks (red stars).

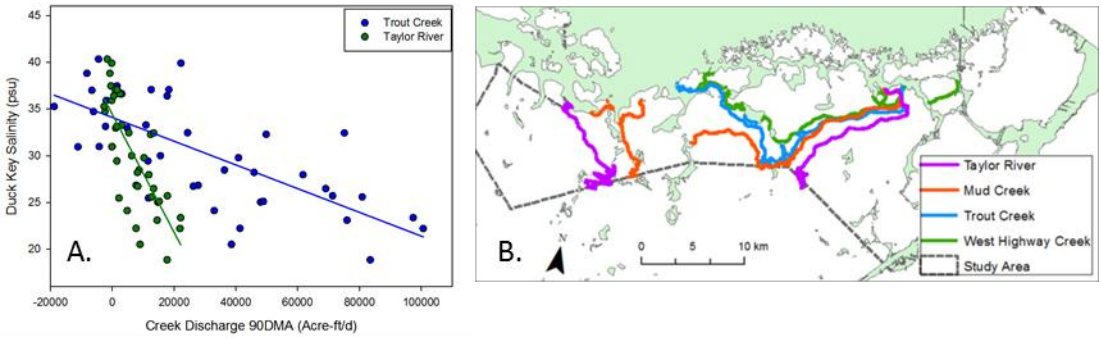


Figure 6-36. (a) Example regression for a single pixel-stack, and (b) pixel-level raster regressions corresponding to the 4 major gauged creeks. Each contour was drawn where the coefficient of determination (r^2) for the regressions exceeds 0.6. Areas north of the identified contours exceed this cutoff.

Relevance to Water Management

The western creeks have particular importance because ongoing restoration efforts are expected to increase their water deliveries. In addition, Taylor River is used as the sentinel monitoring site in the Florida Bay Minimum Flow and Levels (MFL) rule. The robust relationship between Taylor River discharge and near-shore salinity suggests that it is an appropriate sentinel monitoring site for tracking trends and conditions of Northeastern Florida Bay.

RUPPIA SURVIVAL AND LIFE HISTORY: CONDITIONS FOR EXPANSION

Christopher Madden

Studies are being conducted to determine the factors influencing *R. maritima* presence and abundance throughout the mangrove ecotone in Florida Bay. *R. maritima* is a desired benthic vascular plant that provides shelter and food for numerous birds, invertebrates and fish, creates quality habitat and increases higher trophic level productivity in Florida Bay. *R. maritima* is an explicit restoration target for expansion in CERP performance measures and is the valued ecosystem component by which the effectiveness of the Florida Bay MFL rule is assessed.

Methods

R. maritima life history is being monitored in plots along two transects in Taylor Slough to determine growth and survival along a salinity gradient. Experiments to determine factors affecting growth and recruitment were done by manipulating competitor species and nutrient levels *in situ*. Healthy *R. maritima* shoots were transplanted to three sites along the estuarine gradient transect in eastern Taylor Slough and at two sites in western Taylor Slough with and without the presence of competitor species, and with and without phosphorus fertilizer added to the sediments. Growth and survival were evaluated after four weeks.

Results

R. maritima can be seasonally light-limited in the western lakes area where high concentrations of phytoplankton (chl as high as 100 µg L^{-1}) cause a shading effect compared to clearer areas in central and eastern bay. Survival was markedly low in the western transect, with no shoots surviving in Garfield Bight and < 1 per replicate in West Lake (**Figure 6-37**). Light levels at the *R. maritima* canopy differed across sites depending on competitor species and the presence of competitors. *C. hornemannii* and *H. wrightii* significantly decreased light intensity compared to controls containing *R. maritima* only. Light levels at the western ecotone sites were only < 25–50 percent those at sites in the eastern ecotone along Joe Bay ($p < 0.05$) indicating light to be a controlling factor of *R. maritima* distribution when other benthic vegetation is present.

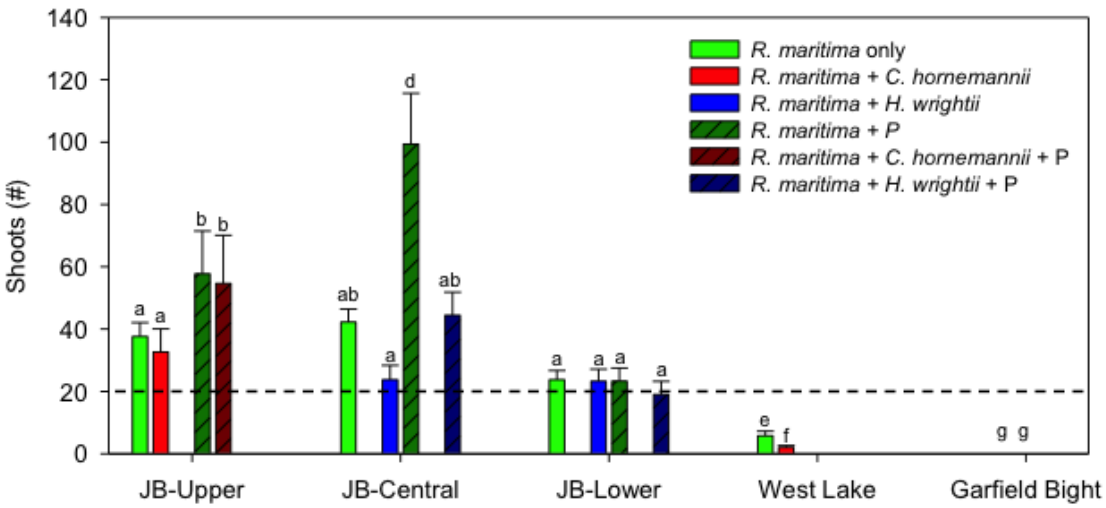


Figure 6-37. *R. maritima* experimental transplants into three eastern (JB) and two western transect sites with and without phosphorus addition and competitors. Results after 4 weeks show the number of shoots compared to the initial planting (black dashed line).

Nutrients were also found to play a role in determining the success of *R. maritima*. Koch and Strazisar (2014) found that the presence of competitor macrophyte species affected adult survival of transplanted *R. maritima* short shoots differentially in Taylor Slough depending on whether they were in a nutrient poor (east) or nutrient rich (west) part of the system. The addition of phosphorus fertilizer to sediments resulted in significantly higher survival and clonal reproduction whether *R. maritima* was grown alone at the central site or in the presence of *H. wrightii*. This suggests that the higher availability of sediment phosphorus may ameliorate effects of light competition between *R. maritima* and competitors. At the lower end of the eastern transect, there were no differences in shoot production whether in the presence of elevated phosphorus or competitors, and the population did not increase above the initial planting. This suggests a third controlling factor at the seaward end of the distribution, where highly variable salinity renders the bioenergetics unfavorable for survival of *R. maritima*.

Relevance to Water Management

The presence of and survival of *R. maritima* is critical to habitat quality in the estuary-ecotone and to the survival of many key species. Restoration actions are designed to maintain *R. maritima* by averting episodes of hypersalinity and preserving a natural estuarine hydrologic cycle. Knowledge of the interaction of *R. maritima* with competitors, nutrients and abiotic factors allows us to predict the boundaries of where restoration of this habitat will be effective. Results indicate that *R. maritima* is controlled by light in the western lakes, by phosphorus availability in the fresher waters of the upper eastern transect and by salinity in the lower eastern transect.

SUBMERGED AQUATIC VEGETATION MODEL ANALYSIS OF RESTORATION EFFECTS

Christopher Madden and Amanda McDonald

The SEACOM model (Madden and McDonald, 2010) is a seagrass community ecological simulation model of Florida Bay. The model was used over the past 18 months in support of RECOVER to predict potential trajectories of seagrass [submerged aquatic vegetation (SAV)] biomass and species composition under historical salinity conditions simulated by the Natural Systems Model (NSM), the existing condition baseline (ECB), the future without project model (FWO) and Central Everglades Planning Project (CEPP) implementation of restoration flows to Florida Bay (Alt 4R2). Hydrologic output for each model run was generated by the Regional Simulation Model (RSM) and a multiple linear regression (MLR) algorithm was used to generate salinities for downstream locations at critical points in Florida Bay. The desired outcome of restoration is a more diverse, mixed SAV community, characterized by enhanced *R. maritima* habitat in the northern sites and mixed *T. testudinum-H. wrightii* in more saline sites. The model demonstrated that this outcome can be expected in some areas as a result of CEPP implementation. Downstream sites modeled included TR (Taylor River mouth and downstream Little Madeira Bay) and WB (Whipray Basin in central Florida Bay).

The SEACOM model was initialized for average year conditions (the standard model) for each Florida Bay location based on 1996–2005 averages for salinity and temperature (daily values from ENP continuous monitoring platforms), and water column nitrogen and phosphorus data (monthly values from the District's Marine Monitoring Network). SEACOM was run with a time step (dt) of 0.1 day for a 50-year simulation period to fully stabilize SAV values. The final seagrass values provided by the equilibration run were applied as initial conditions for each of the 40-year scenario runs.

SEACOM output for the TR site under pre-drainage hydrology modeled by NSM showed a fully diverse mix of SAV species under the wetter conditions during historical high freshwater flow conditions (**Figure 6-38**, panel a). *T. testudinum* was more constrained by lower salinities under NSM, while *H. wrightii* and *R. maritima* thrived. The FWO scenario (not shown) and the ECB scenario (**Figure 6-38**, panel b) under reduced freshwater input were similar for TR and showed no presence of *R. maritima* and a stable mixed *T. testudinum-H. wrightii* community dominated by *T. testudinum*, as currently observed. Alt 4R2 projects a favorable outcome for restoring Florida Bay SAV at Taylor River (**Figure 6-36**, panel c), resulting in a mixed stable community of three SAV species in Little Madeira Bay with a significant presence of *R. maritima*. NSM conditions for Whipray (not shown) reflect a stable *T. testudinum*-dominated mix of *T. testudinum* and *H. wrightii*, and no presence of *R. maritima.* This is similar to current conditions and the FWO scenario for Whipray Basin, indicating little difference between historical pre-drainage and current salinity conditions at that site, which is distal from freshwater sources in the central bay.

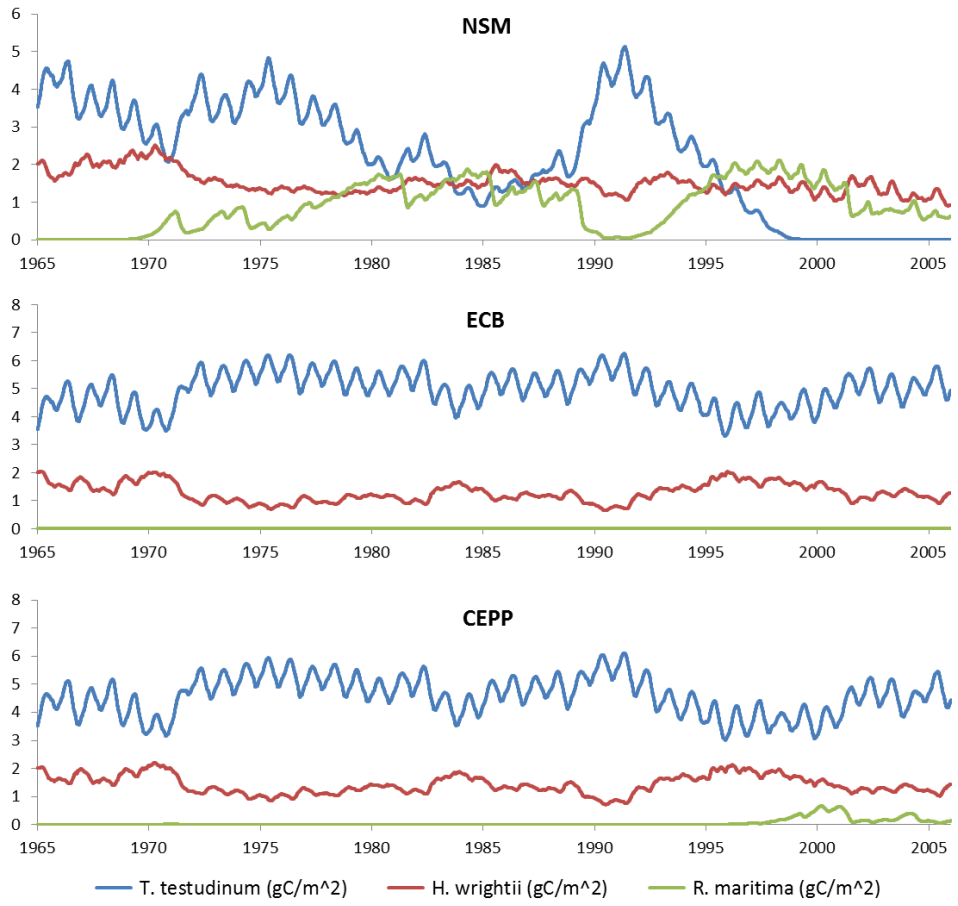


Figure 6-38. The predicted Florida Bay seagrass community over 40 years at Little Madeira Bay/Taylor River (TR) under (a) historical NSM hydrology and salinity conditions, (b) existing (ECB) and future conditions without restoration (FWO), and (c) under CEPP restoration conditions (Alt4R2).

Relevance to Water Management

Under hydrologic conditions projected by the RSM, if CEPP is implemented, it can be expected that habitats in nearshore areas of Florida Bay SAV communities will improve, moving toward the SAV performance measure targets developed for RECOVER. Continued calibration and application of the SEACOM model will enable the District to better project SAV outcomes related to restoration management for increasing areas of Florida Bay.

LANDSCAPE PATTERNS AND ECOLOGY

The first part of this section examines an imagery-analysis technique to track cattail expansion in the Everglades. The second subsection documents the findings from the first experimental high-flow event of the Decomp Physical Model (DPM), which occurred from November to December 2013. Findings of hydrologic, biogeochemical and fish monitoring are compared with findings from the three "before" sampling years (fall 2010, 2011, and 2012) when flow velocities were minimal. The third subsection examines the results of climate change workshops conducted in South Florida. Climate change has become a focus of water management in South Florida because it has the potential to either facilitate or greatly harm Everglades restoration and water supply for the natural and built environment.

TRACKING TRANSITIONS FROM SAWGRASS-DOMINATED TO CATTAIL-DOMINATED LANDSCAPE IN WCA-2A USING MEDIUM-RESOLUTION IMAGERY

Christa Zweig

In the past, classifying cattail versus sawgrass in WCA-2A was difficult using automated, pixel-based remote sensing techniques on medium-resolution imagery (such as Landsat) due to the similar appearance and spectral characteristics of cattail and sawgrass. The preferred method was hand-delineating cattail patches from aerial photography, but while effective, this method requires a considerable amount of time and effort and costly imagery. Automated classification would greatly reduce the time and effort spent, enabling District scientists to provide current data and analyses on the effects of water management policies using free data. The ability to classify cattail patches using advanced remote sensing techniques and landscape pattern ecology was tested.

The ecological concept that is important to facilitating cattail and sawgrass community classification with medium-resolution imagery is that cattail invades the sloughs of enriched areas first before taking over the sawgrass ridge, filling in the characteristic ridge and slough pattern. In theory, areas that have lost this pattern in the imagery should be part of the cattail plume. This knowledge of cattail's invasion ecology and a combination of remote sensing techniques should enable us to make creative use of remote sensing technologies and resolve previous complications in separating the two similar communities with automated classification. We tested our ability to automatically classify two similar vegetative communities using ecological theory and remote sensing techniques by classifying three years of Landsat imagery by texture and spectral characteristics, assessing their accuracy, and comparing the results to previous high-resolution, hand-delineated maps.

Methods

Landsat Thematic Mapper imagery from February 18, 1996 and November 11, 2011 and Landsat Enhanced Thematic Mapper data from January 12, 2003 was obtained. These images best represented previous analyses, both chronologically and seasonally, using the best data available. Images chosen include those from 1996 and 2003, which were acquired in approximately the same season (dry season). The 2011 image was from the wet season, due to lack of cloud-free images in the spring. Feature Analyst (Overwatch Systems, Austin, Texas, USA) extension for ArcGIS 10.1 (ESRI, Redlands, California, USA) was used to classify each image independently from each other into cattail, enriched ridge and slough, and ridge and slough

(sawgrass ridges and open water habitats). Feature Analyst uses machine learning algorithms that combine spectral and texture (object recognition) characteristics to classify remote sensing data (Blundell and Opitz, 2006; Opitz and Blundell, 2008) in an iterative process. Accuracy was assessed from past vegetation data obtained by other studies.

Results

Overall accuracy for the classifications were 89.3 percent for 1996, 75.7 percent for 2003, and 85.2 percent for 2011. Producer and users accuracy were also higher for 1996 and 2011 (**Table 6-6**) than 2003.

Table 6-6. Classification accuracies (%) for WCA-2A. Classes are cattail and ridge and slough. Producer's accuracy represents the probability of a reference pixel being classified correctly, and user's accuracy is the probability that a pixel classified on the map accurately represents the current vegetation configuration.

	1996		2003		2011	
	Cattail	Ridge and Slough	Cattail	Ridge and Slough	Cattail	Ridge and Slough
Producers	86.7	90.2	87.5	65.5	73.3	92.2
Users	76.5	94.9	68.9	85.7	84.6	85.4
Overall	89.3		75.7		85.2	

The 1996 and 2003 classifications were compared to hand-delineated classifications from aerial photography in 1995 and 2003 (**Table 6-7**). The automated method was within 1 to 5 percent of the original totals in 1996 and 2003, respectively (**Figure 6-39**). Cattail coverage has increased by approximately 500 acres in the last 8 years along the leading edge of the plume and the northern border of WCA-2A.

Table 6-7. Area (hectares) of cattail coverage in WCA-2A derived from automated classification compared to previous photogrammetric classification.

Image Captured	Automated	Photogrammetric	Image Captured
February 1996	9,768	9,312	June/November 1995
January 2003	11,683	11,808	January/February 2003
November 2011	12,145		

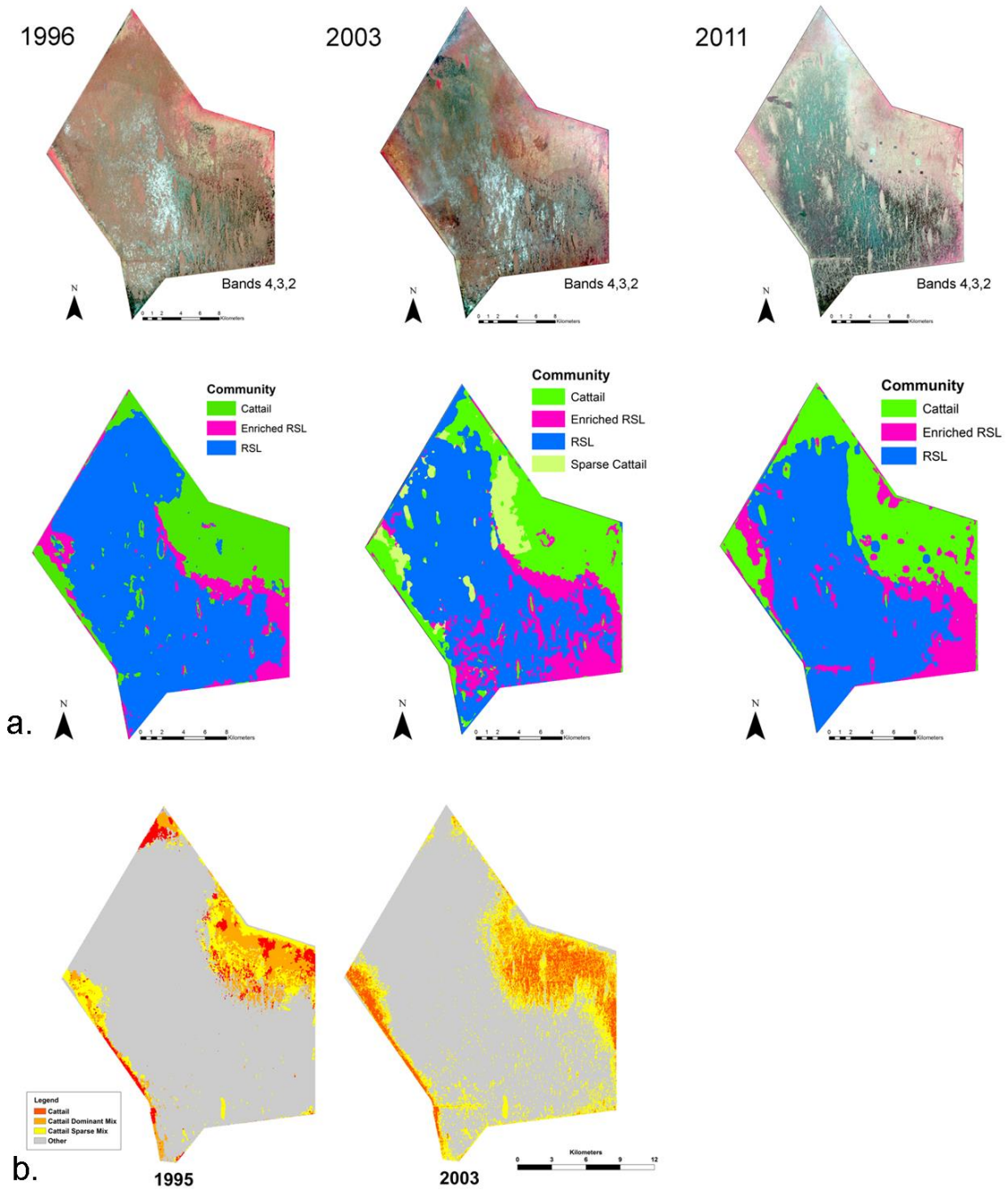


Figure 6-39. (a) Automatic cattail classifications in WCA-2A from Landsat and (b) hand-delineated maps from Rutchey et al., 2008.

Discussion

Mapping the extent and spread of cattail invasion and loss of sawgrass in a timely manner is important for restoration and water management decisions, but has been difficult due to the spectral similarity and similar growth forms of the species. In this study, combining ecological theory—the invasion ecology of a species—together with a combination of advanced remote

sensing techniques permitted the automatic classification of two similar communities to acceptable (75–89 percent) accuracy that could not be differentiated by pixel-based techniques in the past. Changes in cattail coverage can also be mapped rapidly—completing a classification within one day—as opposed to previous manual classifications that can take months to years to complete (Rutchey and Vilchek, 1999; Rutchey et al., 2008).

It is important to note that this classification method is best for finding coarse changes in cattail coverage along the plume front. It will not correctly classify newly invaded areas where sloughs have not been obscured. However, the rapidity at which data can be interpreted from medium-resolution satellites with a long period of record, like Landsat, creates an opportunity to take advantage of the program's longevity and classify more historical images.

Relevance to Water Management

These data, along with hydrology and soils data, would be valuable for developing models of the ecological processes behind the cattail invasion and being able to predict future cattail spread with different water management scenarios. It also provides a general map of cattail communities within WCA-2A.

REINTRODUCING SHEETFLOW TO THE RIDGE AND SLOUGH LANDSCAPE – FINDINGS FROM THE FIRST HIGH FLOW EVENT IN THE DECOMP PHYSICAL MODEL

Carlos Coronado-Molina, Judson Harvey[3], Jay Choi[3], Brendan Buskirk[3], Jesus Gomez-Velez[3], Allison Schwartz[3], David Ho[4], Ben Hickman[4], Laurel Larsen[5], Joel Trexler[1], Mike Bush[1], Michael Manna, Susan Newman, Colin Saunders, Fred Sklar, Christopher Madden, Fabiola Santamaria[2] and Michelle Blaha[2]

The DPM is a landscape-level field test to reduce uncertainties about two fundamental aspects of Everglades restoration: (1) how much sheetflow is needed to restore patterning and microtopography and (2) what are the optimal canal backfilling options? Empirical and modeling studies indicate that in the predrainage Everglades, unimpeded sheetflow generated velocities high enough [> 2–3 centimeters per second (cm s^{-1})] to entrain and effectively move sediment from sloughs to ridges. This process built and maintained the characteristic ridge and slough topography and patterning (Larsen et al., 2011). Since canals can effectively trap sediments (Merckel and Vargas, 2000), some level of backfilling may be needed to both maintain the redistribution of sediments and also to reduce nutrient-rich canal sediments from impacting water quality in the marshes downstream. In addition, it is unknown how partially or completely backfilled canals may affect fish assemblages in canals, including native and invasive species and sport fishery, chiefly bass (*Micropterus* spp.).

This report documents the preliminary findings from the first experimental high-flow event, which occurred from November to December 2013. Findings of hydrologic, biogeochemical, and fish monitoring are compared with findings from the three before sampling years (fall 2010, 2011, and 2012) when flow was minimal. These findings are preliminary, as two additional high-flow treatments will be conducted in 2014 and 2015. The flow event itself is an important

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achievement, generating sustained, high water velocities largely absent from the system since the early twentieth century. As such, this portion of the SFER has slightly enhanced methods and results sections. The reporting objectives are three-fold. First, hydrology at landscape (0.1-1 kilometers) and habitat (10-100 m) scales are summarized before and during the flow event. Second, water quality and sediment dynamics are assessed under pre- and high flow conditions. While previous SFER reporting has included mainly these physical and water quality response variables, here for the first time, fish population dynamics are characterized in the study, comparing their presence among canal backfilling treatments and interior marshes.

Methods

The DPM utilizes a before-after-control-impact experimental design, consisting of field monitoring of hydrologic and biological parameters under no flow (baseline) and high flow (impact) conditions in impacted and non-impacted marsh and canal control sites (**Figure 6-40**).

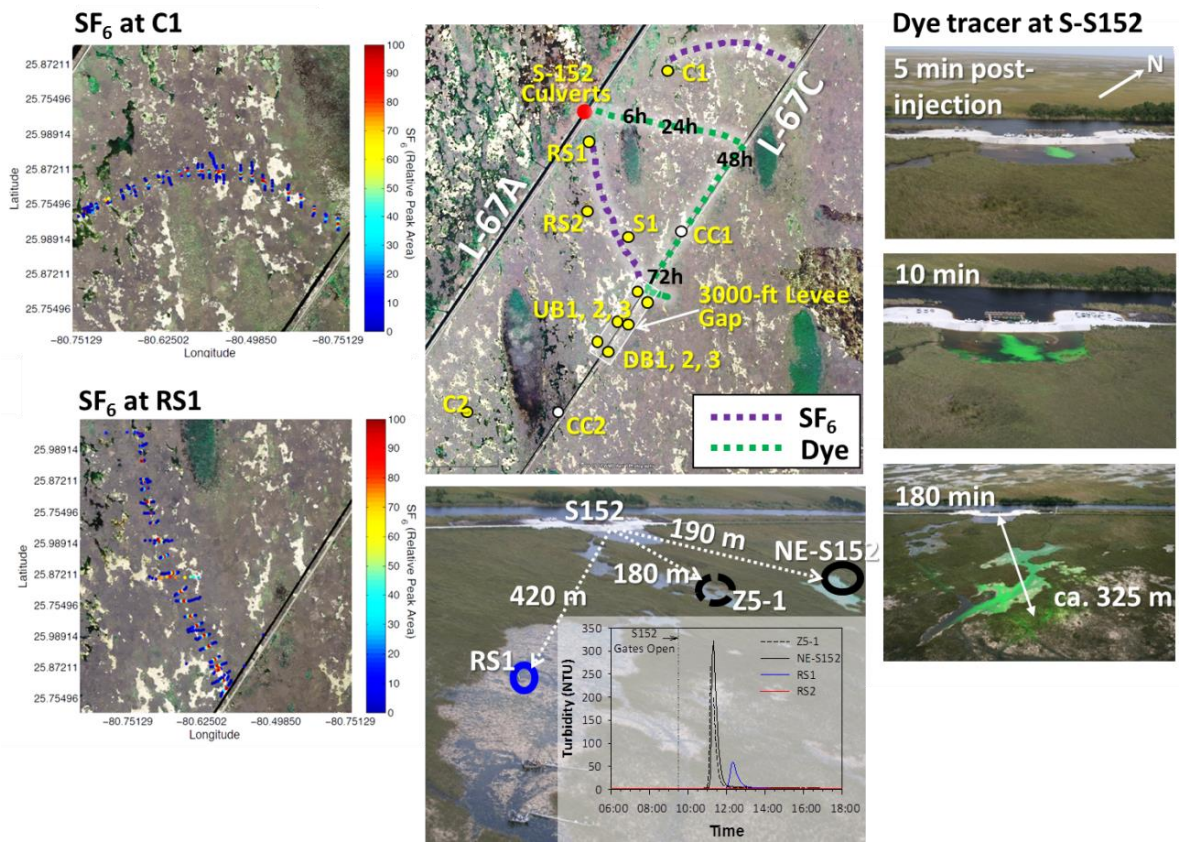

Figure 6-40. Left column: Flow paths of SF_6 at C1 and RS1. Right column: Photographs of dye movement shortly after the opening of the S-152 culverts on November 5, 2013. Center top: DPM study area showing sentinel sites (circled) and flow paths of SF_6 and dye from November 5–15, 2013. Approximate locations of dye front after 6, 24, 48, and 72 hours post-injection are superimposed on the flow path. Center bottom: Turbidity peaks measured at select sites on November 5, 2013.

To evaluate scientific hypotheses associated with the sheetflow and canal backfilling uncertainties, the DPM uses an inflow structure (S-152) consisting of 10 gated culverts on the L-67A levee to provide high sheetflow into an area between the L-67A and L-67C levees known as the pocket (**Figure 6-40**, top center). To evaluate the effects of canal backfilling and levee removal, additional constructed features on the L67C canal/levee include three 1,000-foot long canal backfill treatments (i.e., partial, complete and no-backfill treatments) and 3,000-feet of removal of the L-67C levee **(Figure 6-40**, top center; see also **Figure 6-46)**. Construction of DPM structures and features were initiated in June 2012 and completed in October 2013, in time to allow the first of three planned high flow events. With the exception of those field methods added specifically for the high flow event, only abbreviated descriptions of methods are presented. Additional methodological details are provided in the 2013 and 2014 SFERs (Sklar et al., 2013; Coronado-Molina et al., 2014).

Hydrologic Monitoring

To characterize initial flow conditions downstream of the S-152 structure, a water tracing experiment was conducted using a visible dye tracer, Sodium Fluorescein. Widely used in hydrologic monitoring (Hubbard, 1982), the dye has a shorter half-life relative to the commonly used Rhodamine (Hubbard, 1982) and low eco-toxicity (Field, Wilhelm et al., 1995). After S-152 discharges stabilized, 100 liters (L) of dye was mixed with site water (1:4 ratio) and injected upstream of S-152 at 10:15 am. The plume of dye was photographed from a helicopter over the course of the next four hours, and later in the week, field personnel noted dye locations by airboat and helicopter whenever possible.

Sulfur hexafluoride (SF_6) tracer release experiments, used to quantify flow and dispersion in pre-flow years, were conducted during the high flow event at C1 and RS1. For each experiment, 5 L of water saturated with SF_6 was injected as a point source. Post-injection, the tracer was sampled each day using a high-resolution SF_6 analysis system mounted on an airboat (Ho et al., 2009). Analysis of the spatially explicit data provided estimates of tracer heading (flow direction), advection rate (cm s^{-1}) and dispersion coefficients [square centimeters per second (cm^2) s^{-1}] for each site (Ho et al., 2009; Variano et al., 2009).

To quantify small-scale water flow, water velocity was measured continuously using acoustic Doppler velocimeters (ADV) at six “sentinel” sites during the wet season and for shorter periods at an additional nine “discrete” measurement sites. At continuously measured sites the flow speed and direction were measured at mid-water column to a resolution of 0.01 cm s^{-1} (SonTek, 2001). Vertical profiles of flow speed and direction also were measured on select site visits by adjusting ADV positions vertically in the water column. Additional measurements were made using a SonTek Handheld FlowTracker-ADV® co-located with sediment trap and fauna sampling. On November 5, a spatial survey of flow was conducted at select sites near (< 500 m) and far (> 1,000-m) from the S-152 structure.

Water Quality and Sediment Dynamics

Monthly mid-water column samples were collected July 2013–March 2014, using a peristaltic pump and following standard District protocols. To obtain more detailed information on flow effects on particle chemistry, total particulate phosphorus (TPP) was obtained from samples collected October 28 and during flow in November. Samples were collected via a peristaltic pump, passed through 500 µm Nitex mesh prior to being stored on ice and processed in the laboratory. Samples were then filtered through a 0.2 µm Pall™ membrane filter, the filters were digested and analyzed for total particulate phosphorus.

To provide more information on suspended sediments, four Campbell Scientific turbidity sensors were deployed at sites varying in location relative to the S-152 structure. Turbidity was

measured at 30 second (s) intervals. In addition to providing long-term data, it was expected these sites would capture sediment pulses associated with the initial flow release. The timing of observed peaks was used to quantify velocities of sediments transported from the S-152 to each monitoring site.

Critical entrainment threshold velocities (CET; minimum velocity required to entrain sediments) were determined using an annular benthic flume constructed of two cylinders forming a 0.1-m annular channel (Partrac 2005, 2006, 2008). The flume creates bed shear stress via a rotating lid and is calibrated to derive the relationship between rotation and velocity 5 cm above the sediment. CET is obtained by the relationship between flow velocity and turbidity (from an optical backscatter sensor). CET velocities were measured in sloughs at select sites before and after the 2012 and 2013 operational windows.

Particle transport was quantified using a dual signature tracer (DST) composed of fluorescent, paramagnetic material hydraulically matched to the size and settling velocity of Everglades floc (PARTRAC 2005, 2006, 2008). At RS1 and C1, 25 kilograms (kg) of frozen DST was deployed 5 days prior to the S-152 structure opening. A special sampling design was performed at RS1 to determine sediment transport velocities. Magnets were deployed at two boardwalks 25-m and 55-m downstream of the drop site. The boardwalks, oriented normal to flow, span slough-to-ridge transects, and magnets were deployed at 4 locations per boardwalk. On November 5, magnets were deployed at mid-water column and collected and rinsed every 15 minutes from 9:00 am until 12:00 pm and every 60 minutes after that. Capture rates (particles per second) were calculated per sample, and velocities calculated based on location and timing of peak capture rates.

Sediment transport and accumulation were also measured using horizontal traps in marsh sites (Phillips et al., 2000) and vertical sediment traps in canal sites (Kerfoot et al., 2004). Traps were deployed in ridges and sloughs at RS1, RS2 and C1 and sloughs at DB1, DB2 and DB3. Vertical traps were deployed in canal control and backfill sites. Traps were deployed at three-week intervals from November to December and six weeks after that. As median sediment particle size in Everglades wetlands is less than 100 µm (Noe et al., 2007) only the fluxes of small particles (< 1 mm) are reported here. Trap samples were collected in settling funnels and dried at 80º C for weight determination. Marsh loading and canal accumulation rates were estimated based on weight, inlet tube area, and deployment time.

Fauna Assemblages

A boat-mounted electrofisher was used to document the community of large fishes over 8 cm in length (Chick et al., 1999). In the no-fill canal treatment, electrofishing was conducted along the canal edge and littoral zone where SAV is abundant. Both by electrofishing and use of a sonar device, it was determined that fish density was consistently low in open water sections of the canal, so all data comparisons between canals and marsh areas or among canal treatments are based on canal edge populations.

Results and Discussion

Hydrologic Responses to Increased Flow

Fluorescein dye was visible downstream of the S-152 within minutes after injection, and quickly demonstrated preferential flow paths, moving in an east- southeasterly direction (**Figure 6-40**). Using aerial monitoring, travel velocity for the leading edge of the dye in the first 95 minutes of flow was 5.4 cm s^{-1}. The dye front then moved into a tree island approximately 500 m from S-152. By the second day the plume had become more diffuse (600 m wide) but was

clearly visible in the water. The dye front was easily identified, 800 m east of the tree island, providing a travel velocity from minute 95 to 1,450 post-injection of 1 cm s^{-1}.

Movement of SF_6 tagged water was mapped for 4 days each at C1 and RS1 (**Figure 6-40**). Net advection at C1 and RS1 over 4 days was 0.29 ± 0.02 cm s^{-1} and 0.42 ± 0.02 cm s^{-1}, respectively, which was double and quadruple the rates measured during the pre-flow year of 2011 (0.15 ± 0.08 and 0.11 ± 0.01, respectively). At C1, the initial water flow direction was 70 degrees for 600 m and changed to 100 degrees for 370 m. Finally, the water flowed at 120 degrees for 645 m into the canal. At RS1, flow direction was 170 degrees for 800 m, and changed to 155 degrees for the final 1,060 m before entering the canal. In contrast, flow directions measured at C1 and RS1 in 2011 during pre-flow conditions were 109 degrees ± 3.1 degrees and 148 degrees ± 2.5 degrees, respectively.

During the S-152 flow release, speeds at control sites (C1 and C2) generally remained below 1 cm s^{-1}. Flow speeds increased above background values (which were < 1 cm s^{-1}) along the experimental flow path from RS1 (reaching speeds up to 4.5 cm s^{-1}), RS2 (2 cm s^{-1}), S1 (1 cm s^{-1}), UB1-3 (1 cm s^{-1}), and DB1-3 (3 cm s^{-1}) (**Figure 6-41**). Flow speeds in sloughs were generally 25–40 percent faster than in ridges as a result of lesser vegetation biomass that decreases flow resistance in sloughs. Also, the flow directions in sloughs tended to align with slough direction and while flow on ridges was somewhat misaligned with sloughs (with direction indicating that flow jumps across ridges between sloughs), these patterns in flow speed and direction through sloughs and ridges corroborate previous observations in the Everglades ridge and slough landscape (Harvey et al., 2009).

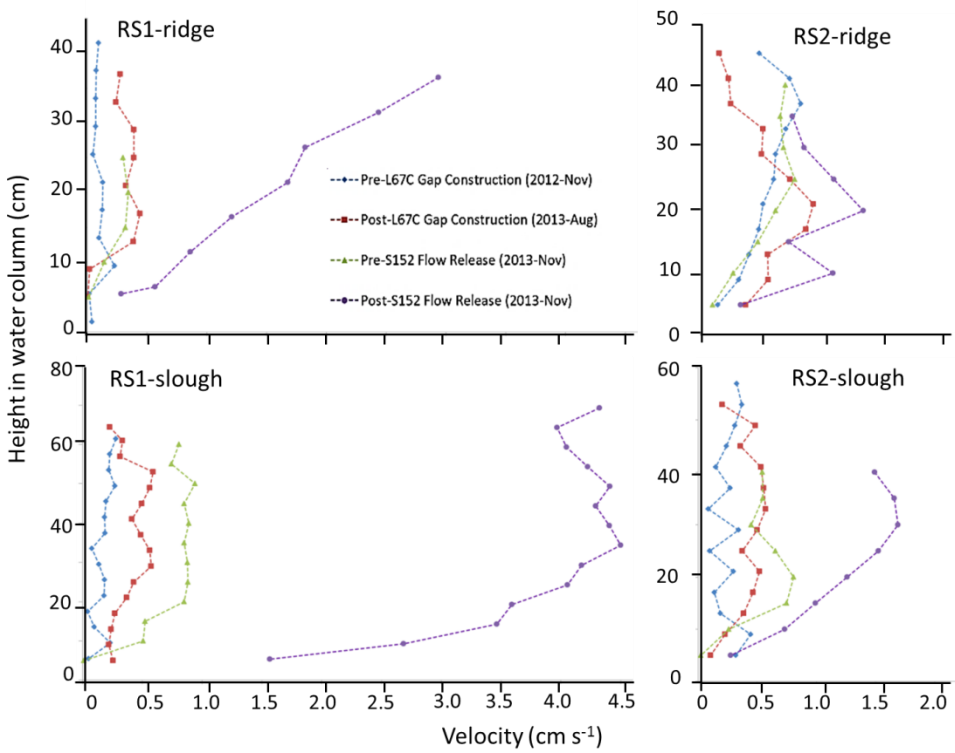

Figure 6-41. Acoustic Doppler velocimeters (ADV)-based velocities at RS1 (left) and RS2 (right) before and after flow was initiated through the S-152 structure in November 2013. Values, averaged per depth interval, are from sampling performed on one day in each of the periods indicated.

Flow speeds described by various methods indicate substantial temporal and spatial variation during the flow event (**Table 6-8**). ADV-based flow speeds tended to be faster than those measured with the SF_6 tracer due to sensitivity of SF_6 to all processes affecting bulk transport of water, including movement into and out of slowing flowing waters in thick periphyton mats and vegetation. It is likely that the higher velocities of the dye, relative to SF_6, reflects that the dye delineated the preferential flow path of water, initially captured flows closer to the S-152, and incorporated some uncertainty given the qualitative approach taken. The dye did however demonstrate slower speeds on days 2 and 3 (**Figure 6-40**; **Table 6-8**). When judged at a larger scale, the ADV-based flow directions agreed with measurements made based on movement of the SF_6 tracer from its point of release at RS1. ADV data indicated that although the transport of released water was very strongly detected at RS1, it was more weakly detected at RS2, S1, and the UB sites. One reason is that the released water, after first being transported in a south-southeastern direction toward those sites, then veered off in an easterly direction to eventually be intercepted by the L-67C canal.

Effects on Water Quality, Particulate Entrainment and Transport

During the entire sampling year, all DPM samples in the pocket had TP concentrations considerably < 0.01 milligram per liter (mg L^{-1}) (**Figure 6-42**). S-152 concentrations remained below 0.01 mg L^{-1}, when flowing and when closed. Therefore, the flow event did not provide increased water column TP to the system and also did not increase TP concentrations in surface waters within the flow. Prior to the flow release, the suspended sediment concentration was generally low (0.6 to 1 mg L^{-1}). In the first few hours following the flow release, the measured suspended sediment concentration increased up to 10 mg L^{-1} (Harvey, pers. comm.) but quickly declined to levels slightly above background. Comparing representative samples of the full pre-flow and flow periods, TPP concentrations were the identical, with a few exceptions (**Figure 6-42**). Both ridge and slough sites at RS1 and the ridge at C1 were slightly higher during the flow, while southern sites (S1, UB) and a canal site (CB3) were slightly lower. Given such small changes, it is unlikely these differences are significant. In contrast to TPP, both RS2 sites, S1 and UB1 had decreased mass during the flow event, with little to no difference observed due to flow.

In general, under no or low flow conditions, the TPP content of the water column was not influenced by habitat and likely did not change in response to flow. However, the lack of apparent correlation between mass and TP indicate that the sources of phosphorus to the particulate pool varied during pre-flow and flow conditions. Suspended particle sizes were quantified using a laser diffraction particle size analyzer (LISST-FLOC, Sequoia Scientific). Prior to the flow release, the median volume weighted size of suspended particulates (D50) was initially larger (330 µm) with a high degree of uniformity. During the flow release many finer particles also entered suspensions as reflected in values of D50 as low as 50 µm (Harvey, pers. comm.).

Despite a lack of dramatic changes in the water column, the flow event did have some effect on the sediments. Critical entrainment threshold (CET) velocities were generally lower in the post-flow sampling events, most noticeable at sites closest to the S-152 (**Figure 6-43**). While this reflects the changes in sediment properties following flow, increases in nephelometric turbidity units (NTUs) at sites in close proximity to the S-152 may also reflect movement of unsettled construction material (mainly limestone bedding) around the S-152. Detailed analyses of these data in concert with other sediment characteristics (e.g., floc mass, chemistry and biomarkers) that identify floc sources will help in understanding the relative contribution of construction debris to floc transport during flow.

Table 6-8. Summary of water and sediment velocity measurements during the high flow event. [Note: ADV = handheld acoustic Doppler velocimeter; cm s^{-1} = centimeters per second; DST = dual synthetic (floc) tracer; m – meters; RS1u = upstream boardwalk at RS1; RS1d = downstream boardwalk at RS1; SF_6 = Sulfur Hexafluoride.]

Methodology	Date(s) sampled	Distance of sampling area from S152 (m)	Velocity (cm s^{-1})
Water velocity			
dye front (Day 1)	11/5/13	300	5.4
dye front (Day 2)	11/6/13	300-1200	1.0
SF_6 at RS1	11/12/13 - 11/15/13	500-2000	0.42 ±0.02
SF_6 at C1	11/7/13 - 11/10/13	1200-2500	0.29 ±0.02
ADV at Z5-1	11/5/13	180	3.7
ADV at NE-S152	11/5/13	189	6.6
ADV at RS1	11/5/13	421	8.3
Sediment velocity			
turbidity peak at Z5-1	11/5/13	180	2.9
turbidity peak at NE-S152	11/5/13	189	3.0
turbidity peak at RS1	11/5/13	421	4.3
DST peak #1 - Drop site to RS1u	11/5/13	400	2.4
DST peak #1 - RS1u to RS1d	11/5/13	400	0.6
DST peak #2 - RS1u to RS1d	11/5/13	400	0.4

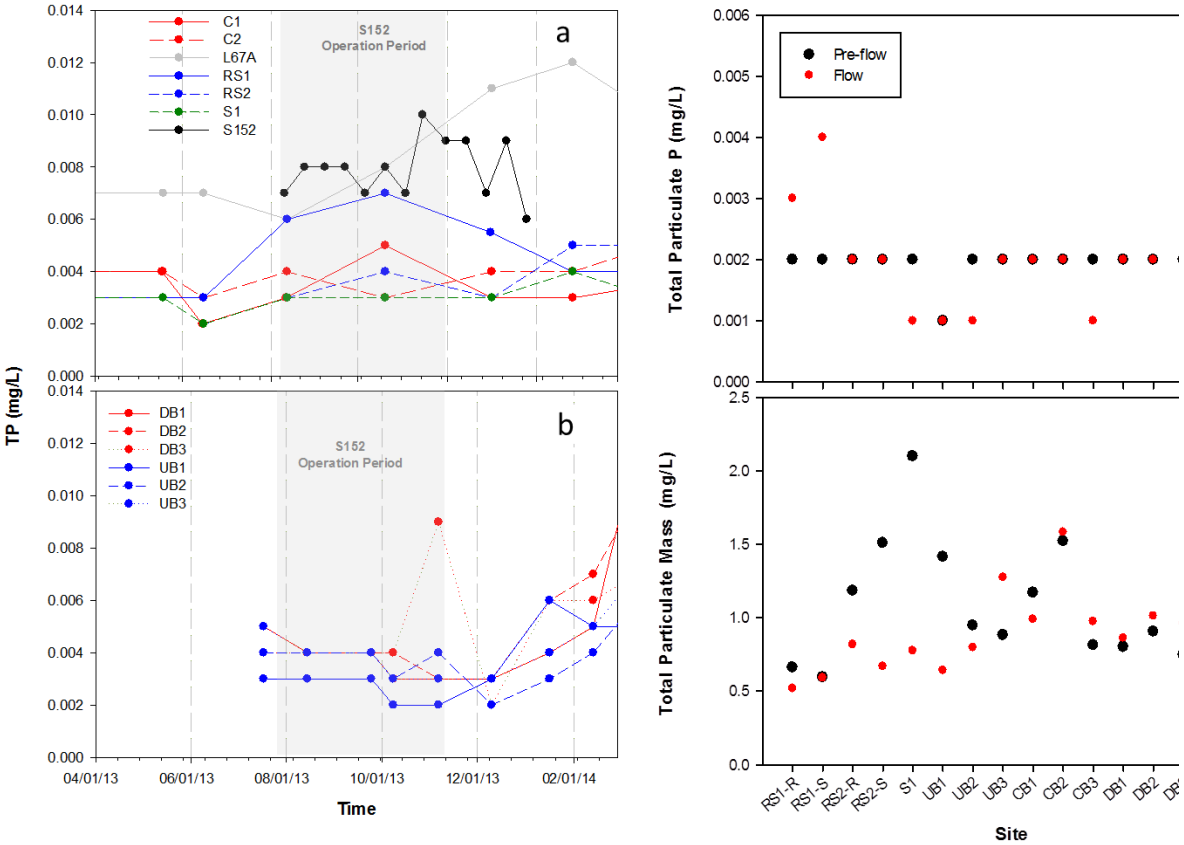

Figure 6-42. (a and b) Temporal TP concentrations in surface waters pre-operation, during and post-operation of the S-152. (c) Total particulate phosphorus (P) concentrations and (d) total mass measured mid-water column depth at sites throughout the Decomp Physical Model (DPM) project, pre-flow and during flow. [Note: -R indicates ridge, -S slough, and CB sites are canal backfill sites.]

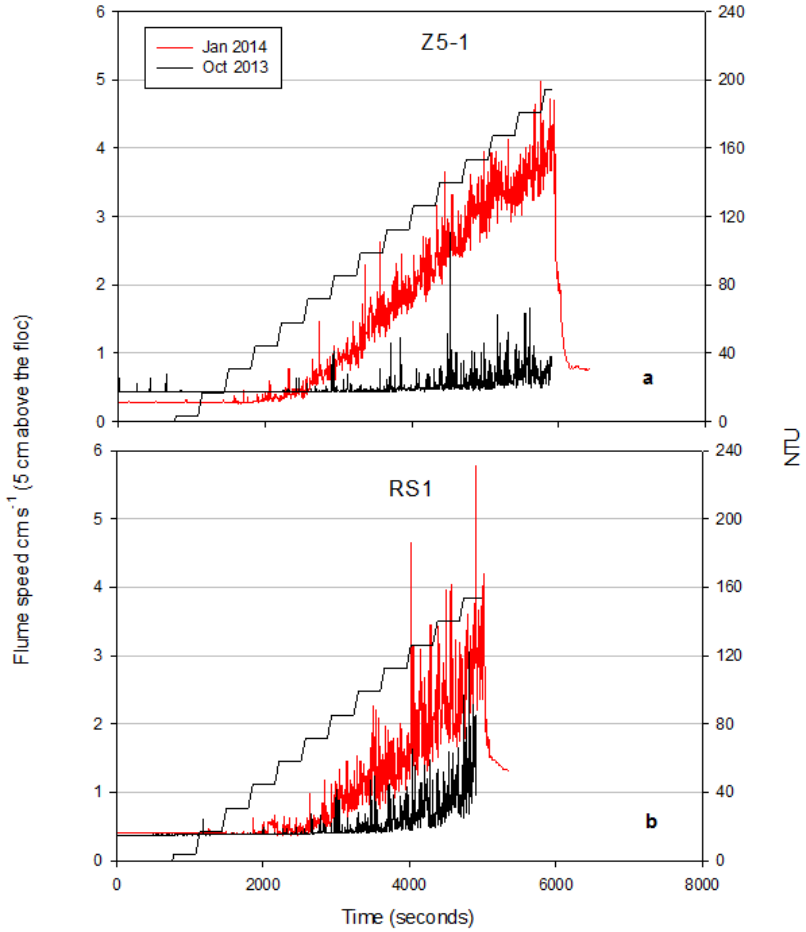

Figure 6-43. Examples of pre- and post-flow critical entrainment velocities (CET) and nephelometric turbidity units (NTU; an indication of sediment entrainment) at Z5-1 and RS1.

Sediment velocities were estimated using turbidity sensors and DST capture. Sites nearest the S-152 demonstrated turbidity peaks followed by rapid declines to baseline values (**Figure 6-40**). At Z5-1 and NE-S152, turbidity peaked at 11:15 am and 11:20 am, respectively, while turbidity peaked at RS1 at 12:20 pm. Based on the timing of the turbidity peaks, water velocities at Z5-1, NE-S152, and RS1 were 2.9, 3.0, and 4.2 cm s^{-1}, respectively. At the RS1 boardwalks, the highest DST capture rates occurred in slough portions of both upstream and downstream boardwalks (**Figure 6-44**). Peak DST capture occurred at 9:50 am at RS1u and 10:50 am at RS1d, and a second, smaller peak was observed at 10:50 am and 12:30 pm, respectively. Based on time intervals between peaks, DST velocities ranged from 0.40 to 0.64 cm s^{-1} (**Table 6-8**). Using the distance from RS1u to the drop site, an initial transport velocity was estimated at 2.39 cm s^{-1}. The latter velocity suggests that particles slowed over the course of the day. This finding was consistent with temporal variation in ADV-based velocities at RS1, reaching 10.9 ± 2.0 cm s^{-1} by 11:00 am and declining to 6.7 ± 2.1 by 3:00 pm. Similar temporal variation was observed at Z5-1 and NE-S152.

During the November–December flow event, sediment transport estimated from traps ranged from 1.1 to 11.2 milligram per square centimeter per day (mg cm^{-2} d^{-1}) (**Figure 6-45**). Transport was highest in the RS1 slough (6.8 ± 2.3, n = 3) and lowest in the RS2 slough (1.2 ± 0.1). Transport at the RS1 slough site increased from 3.3 mg cm^{-2} d^{-1} in early November to 11.2 g cm^{-2} d^{-1} by December, a 20-fold increase from the pre- flow value (0.5 g cm^{-2} d^{-1}) in October. In contrast, in pre-flow years, transport tended to be highest in November and decrease as water depths decreased. Higher transport rates in RS1 slough (compared with C1 and RS2) were consistent with velocities above the CET, suggesting entrainment likely contributed to greater transport. High velocities in the RS1 ridge in December also corresponded with relatively high transport rates in the RS1 ridge, increasing 50-fold compared to October values.

In general, sediment transport velocities were lower than bulk water transport from ADVs and dye estimates (**Table 6-8**). At sites within 400 m of S-152 (Z5-1, NE-S152, and RS-1), ADV-based velocities were about 2-fold higher than velocities of the initial sediment plume at the same sites. At RS1, DST velocities were 4- to 50-fold lower than ADV-based velocities, and roughly 2- to 10-fold slower than the initial sediment plume. To some degree, these differences among water and sediment velocities may reflect the uncertainties associated with each method. However, given the noted difference in particle sizes between the initial sediment plume and DST floc (matched to the larger, pre-flow sizes), these findings not only quantify relationships between sediment- and water-velocity under high flow, but also may indicate different velocities among sediment types (e.g., size and chemistry).

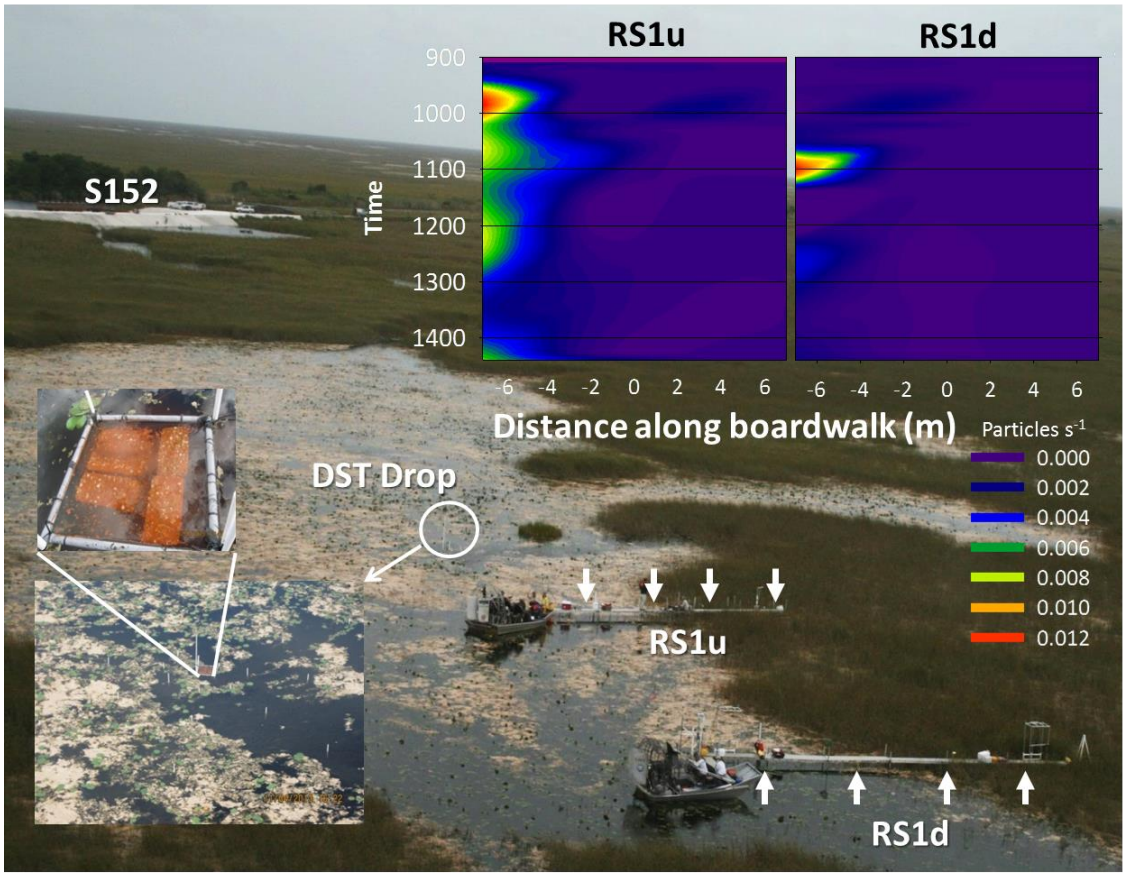

Figure 6-44. Dual synthetic tracer (DST) movement at RS1 on November 5, 2013. Drop site indicates where floc tracer was deployed prior to flow. Contours are particle capture rates (particles per second). Arrows indicate magnet locations for capturing DST.

Canal Backfilling and Flow Effects on Sediment and Food Web Dynamics

To evaluate movement of water across the different canal backfill treatments, flow velocities were monitored at a number of sites around the L67C (**Figures 6-40** and **6-46**), including sentinel sites in the marshes upstream (sites UB1, 2 and 3) and downstream (DB1, 2, 3) of the L67C canal backfill treatments as well as spot measurements associated with fauna and sediment sampling (**Figure 6-46**). Based on the trajectories of the Fluorescein dye, water moved east-southeast from the pocket into the L67C canal and was then shunted in a southwesterly direction in the canal until the L-67C levee gap was reached. Water then moved southeast into WCA-3B (**Figure 6-40**). Whereas water levels, flow speeds and flow directions reached fairly steady conditions within hours at stations within a few hundred meters from the S-152, it took three days for steady conditions to be reached 3 kilometers away. Flow speeds at DB sites were higher than at UB sites (**Figure 6-46**), most likely because a greater proportion of the released water actually reached the DB sites compared with partly bypassing the RS2, S1 and UB sites. ADV measurements at sentinel sites, made sporadically at DB sites, indicated no particular preference for flow at DB1, DB2, or DB3. However, ADV measurements associated with sediment trap and fauna sampling at several points around the L-67C indicated preferential flow path may have occurred in the northernmost section of DB1 (**Figure 6-46**).

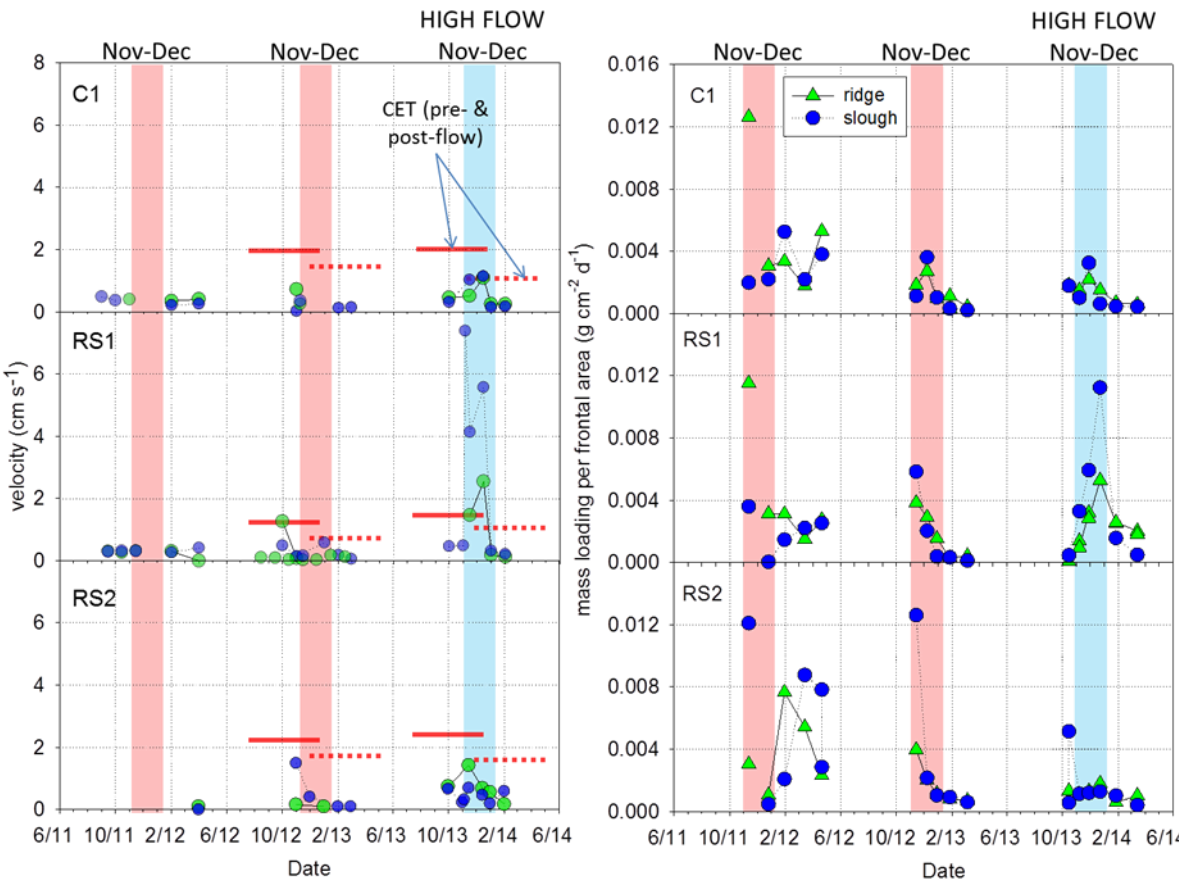

Figure 6-45. Water velocities (left) and trap-based sediment transport (right) in ridge and slough habitats at C1, RS1, and RS2. Red bars indicate CET estimates from pre- and post-operational windows in 2012 and 2013. Note that the study area burned in June 2011.

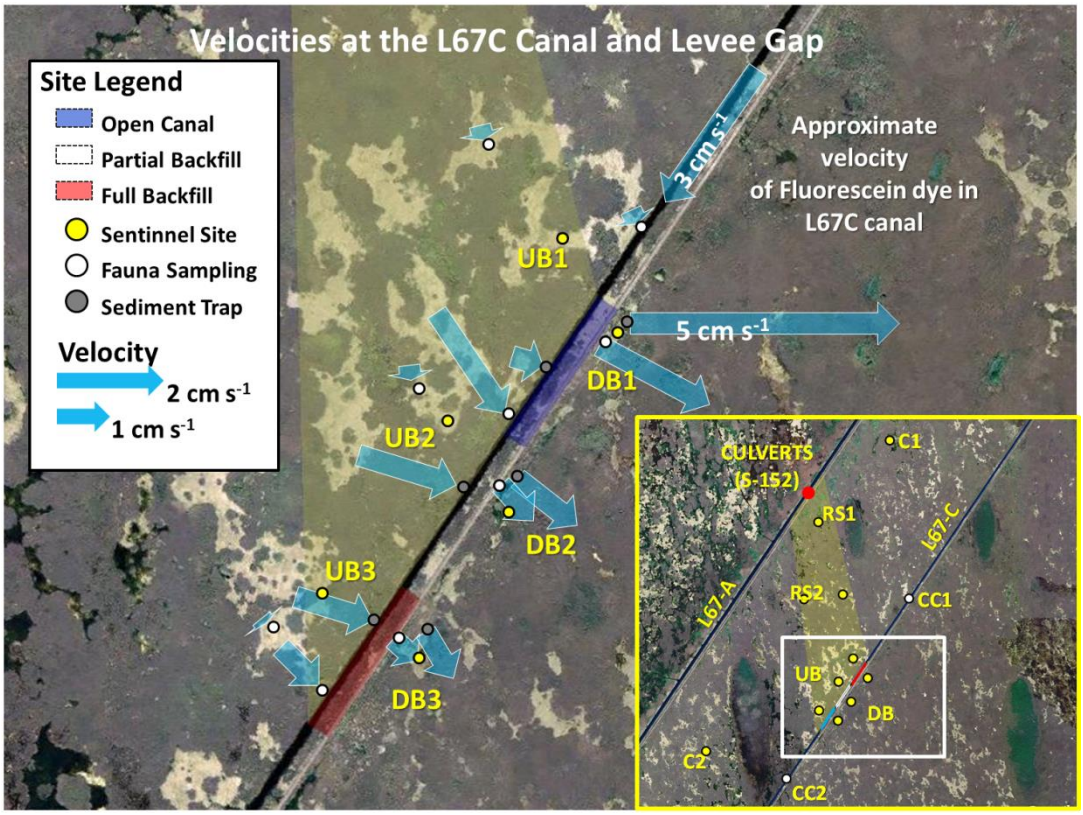

Figure 6-46. Flow vectors around the L-67C canal and levee. Sampling points upstream of the canal are represented by arrow heads. Sampling points downstream of the canal are indicated by arrow tails. Inset map shows study area in relation to the entire DPM study. Flow vectors are ADV-based, with the exception of canal flow (based on dye movement, **Figure 6-40**).

To address canal backfill questions, our main objective is to determine the extent to which sediment transport from the marsh interior contributes to sediment accumulation in the canal during both the baseline period and during the operational window period (November–December). During the baseline period in 2011 and 2012, canal accumulation averaged 3.7, 4.2, 2.7, 2.6, and 4.7 grams per meter per day (g m^{-2} d^{-1}) at the CC1, CB1, CB2, CB3, and CC2 sites, respectively (**Figure 6-47**). In contrast, during the operational window (November–December 2013) canal sediment accumulation increased in all but the CC1 site (2.5, 9.7, 7.3, 7.7, and 11.6 g m^{-2} d^{-1}, respectively). During and after the operational window (November 2013–March 2014), accumulation rate values were very variable but significantly different a most sites, except at the CC1 site where accumulation rate was significantly similar ($p > 0.05$). Another important goal was to determine the source of the particulate sediment collected in the canal traps. In this sense, particulate density was a good indicator to determine whether the material contain more organic (low density) or inorganic (high density) material.

During the baseline period (April 2011–November 2012), density values were relatively similar and averaged 0.038, 0.036, 0.033, 0.038, and 0.039 grams per cubic centimeter (g cm^{-3}) at the CC1, CB1, CB2, CB3, and CC2 sites, respectively. Similarly, during and after the operational

window, density values were significantly ($p < 0.05$) higher at the CB2 and CB3 sites ($p < 0.05$) (**Figure 6-47**). This temporal pattern observed at CB2 and CB3 can be mostly attributed to the work associated with filling of the canal and to some extent the degradation of the levee during the previous months. As such, to better answer the canal backfill questions, it is necessary to include more years of data to discern the effect of flowing water (rather than construction effects) on canal sediment dynamics during the operational window.

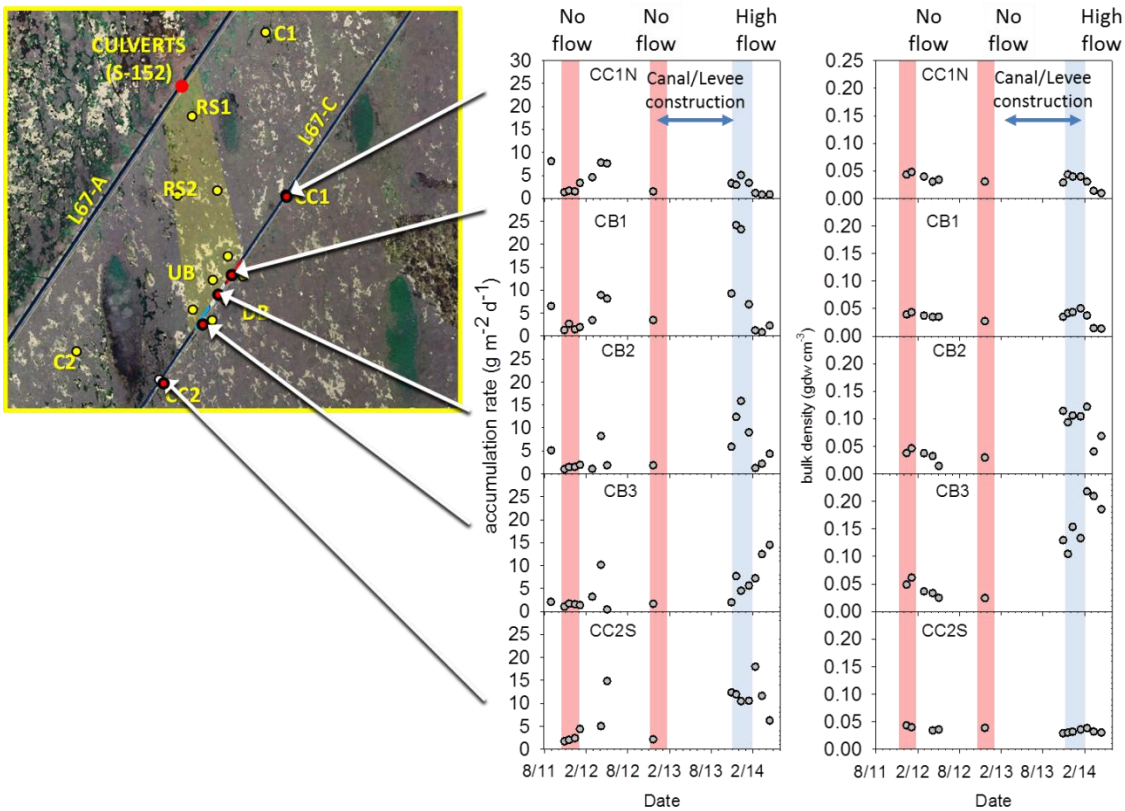

Figure 6-47. Sediment accumulation (left) and sediment bulk density (right) in L-67C canal backfill treatments. Sampling in fall 2012 was limited due to ongoing construction in the area.

Consumer Responses to Canal Backfill and Levee Removal

Beginning in March 2013, no difference was found in the catch-per-unit-effort (CPUE; an index of abundance) or species composition of large fish in the different canal treatment areas (No-Fill, Partial-Fill, Complete-Fill) at any of the sampling periods (**Figure 6-48**). However, major differences were observed among canal and marsh habitats. The canal-edge habitat was home to over four times more fish than the marsh habitat, including marsh within 50 m of the canal edge (**Figure 6-48**). Community composition was also different between canal edge, marsh edge and marsh sites, with largemouth bass (*Micropterus salmoides*) and bluegill sunfish (*Lepomis macrochirus*) the most commonly collected species in the canal, while warmouth (*Lepomis gulosus*) and bowfin (*Amia calva*) were the most abundant in the marsh. Largemouth bass were much more common in the canal habitats than in the marsh.

These results suggest that the fill treatments had no negative impact on the canal fish community. These fish appeared to treat them similarly to habitats along the edge of the L-67C canal, though some anecdotal observations suggest that they have actually aggregated in even higher density than along the canal margin on the newly created habitat at the edge of the fill area. Many sunfish nests were noted in this area, for example, and fisherman were observed focusing on these edges soon after construction. Continued observation is needed to determine if these areas will remain fishable or fill in with SAV. However, the present condition represents an increase in quality habitat for fish over 8 cm in length.

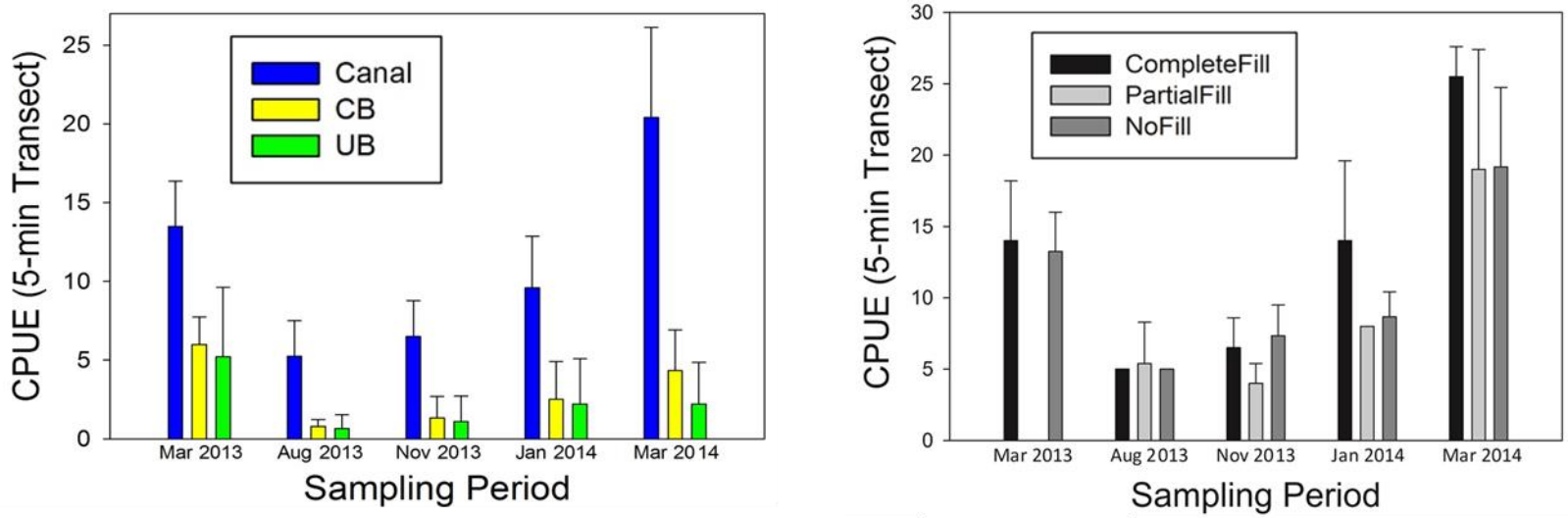

Figure 6-48. Catch-per-unit-effort (CPUE) of large fish community within the DPM study area, between March 2013 to March 2014 (left), and CPUE of large fish among the complete backfill, partial backfill and no-fill treatments from March 2013 to March 2014 (right). [Note: "Canal" refers to the vegetated edge of the canal and partial and complete fish treatment areas; "CB" refers to the canal bank habitat (marsh within 10m of the canal edge), and "UB" is marsh habitat greater than 10 m from the canal edge.

Relevance to Water Management

Sheetflow in the Ridge and Slough

During the first flow event, water velocities high enough to erode sediments and increased sediment transport up to 20-fold higher than baseline, pre-flow estimates were successfully achieved. Greater transport in sloughs than ridges does indicate the greater erosion of slough sediments, an important first step in restoring microtopography. Importantly, particulates and water TP did not increase, suggesting particle recapture is sufficient to maintain low TP conditions even while flowing. These results are preliminary, as additional years are needed to provide statistical power to test flow effects, particularly given high variability in some response variables in the baseline years, for example, after the 2011 fire. Given the limited spatial extent (500 m) of these high flows, it is likely restoring sheetflow will require much larger structures and gap features.

Several response variables demonstrated non-steady state behavior as indicated by increasing sediment transport over the duration of the event, even though S-152 discharges remained constant or decrease slightly. These results suggest additional weeks or months are needed to achieve maximum effects of sheetflow. Efforts are underway to modify the S-152 permit to extend the operational window into January. The challenge in maximizing the ecosystem responses by maintaining higher flows for longer duration, while maintaining protective water quality conditions, has important implications for operating water control structures anticipated with CEPP as well as ongoing restoration projects such as the C-111 Spreader Canal.

Ecological Responses in the Canal Backfill Treatments and Levee Gap

Additional years will be required to evaluate how backfill treatment and construction impact sediments dynamics and sediment chemistry in and downstream of the canal treatments. While flows around the L-67C gap are quite variable spatially, there is evidence of greater flows on the north end of the L-67C canal area, which disproportionately receives higher flows from the S-152. These increased flows correspond to greater accumulation in the northernmost (open) canal treatment, suggesting its role as a sediment sink. However, greater sediment transport downstream of this treatment was also observed.

Results from fish sampling suggest there has been no loss of fishing habitat with the partial or complete fills. The partial fill and complete fill areas have created a new habitat that supports a similar community to the one currently only found on the canal edge. This finding may be important as canal-edge habitats support much higher fish densities than marsh habitats.

POTENTIAL FUTURE CLIMATE SIMULATION WORKSHOPS: 2013 AND 2014

Martha Nungesser and Jayantha Obeysekera

Future climate patterns and sea level rise have the potential to become major factors in planning and management of water resources in South Florida. As a way to understand the potential challenges of an uncertain climate future, in South Florida, research scientists at SFWMD were requested by an inter-agency group facilitated by Florida Atlantic University to incorporate general climatic and sea level rise scenarios into simulations of the South Florida Water Management Model (SFWMM). This scenario analysis was designed to determine the potential hydrological conditions produced by warmer temperatures, sea level rise, and increases

and decreases in annual precipitation. These types of exploratory simulations are important because Everglades ecosystems and South Florida's water supply depend upon a surplus of rainfall over losses, particularly evapotranspiration. Presently, precipitation exceeds evapotranspiration by only 8 to 20 cm per year (Fernald and Purdum, 1998). Therefore, even slight temperature increases in South Florida that increase evapotranspiration losses could reverse that relationship unless rainfall increases equivalently.

An interagency technical workshop was held in March 2013 to investigate the potential effects of six climatic patterns (**Table 6-9**) on Everglades restoration. To quantify the implications of altered climate, simulation results were distributed to Everglades research scientists to analyze these results and identify their implications to the ecosystems. In April 2014, a second interagency technical meeting was held to identify potential management options to address future climatic and sea level changes on the natural ecosystems. Results from the second workshop are expected in about five years.

Table 6-9. Scenarios used to simulate climate change for model scenarios (Obeysekera et al., 2014). [Note: ET – evapotranspiration; noC – no climate change; RF – rainfall.]

Scenario Name	Temperature Change	Precipitation Change	Sea Level Rise	Coastal Canal Levels Increased?
BASE *	No change	No change	No change	No
-RF	No change	-10%	No change	No
+RF	No change	10%	No change	No
+ET	+1.5 °C	No change	0.46 meter	Yes
-RF+ET *	+1.5 °C	-10%	0.46 meter	Yes
-RF+ETnoC	+1.5 °C	-10%	0.46 meter	No
+RF+ET *	+1.5 °C	+10%	0.46 meter	Yes

Methods

Climate change scenarios were developed previously (Obeysekera et al., 2011) from current general circulation model output and downscaled information. These climate drivers were used in the SFWMM with the current system configuration and regulation schedules. Simulations ran through 2060, approximately 50 years in the future. Climate drivers included a relatively conservative temperature increase of 1.5° C, which translates into a 7 percent increase in evapotranspiration (Obeysekera et al., 2014), sea level rise of 1.5 feet (46 cm), and rainfall of ±10 percent applied as an adjustment to the historical daily precipitation volumes (**Table 6-9**). Daily values of water stages, flows, and volumes were produced for the entire region from Lake Okeechobee southward through ENP. Relevant model output was distributed to five technical interagency teams to analyze and prepare technical presentations for the March 2013 workshop, attended by more than 80 Everglades scientists, hydrologists, managers, and decision-makers. The 2013 meeting was held as a series of presentations over two days where the model results and implications were described, analyzed, and discussed.

Results

The future climate scenarios indicate that the present surplus of rainfall to evapotranspiration may change to one dominated by evapotranspiration: temperature-induced increases of 7 percent in evapotranspiration and rainfall decreases of 10 percent would produce a net decline of rainfall to 17 percent below the increase in evapotranspiration. The best case scenario of a 10 percent increase in rainfall would increase rainfall by 3 percent relative to increased evapotranspiration. These changes would strongly affect all natural systems of South Florida (**Figure 6-49**; **Table 6-10**). The potential risk posed by reductions in rainfall throughout the South Florida natural ecosystems and their restoration and major reductions in water supply to agriculture and urban areas (Florida Atlantic University, 2013) was significant.

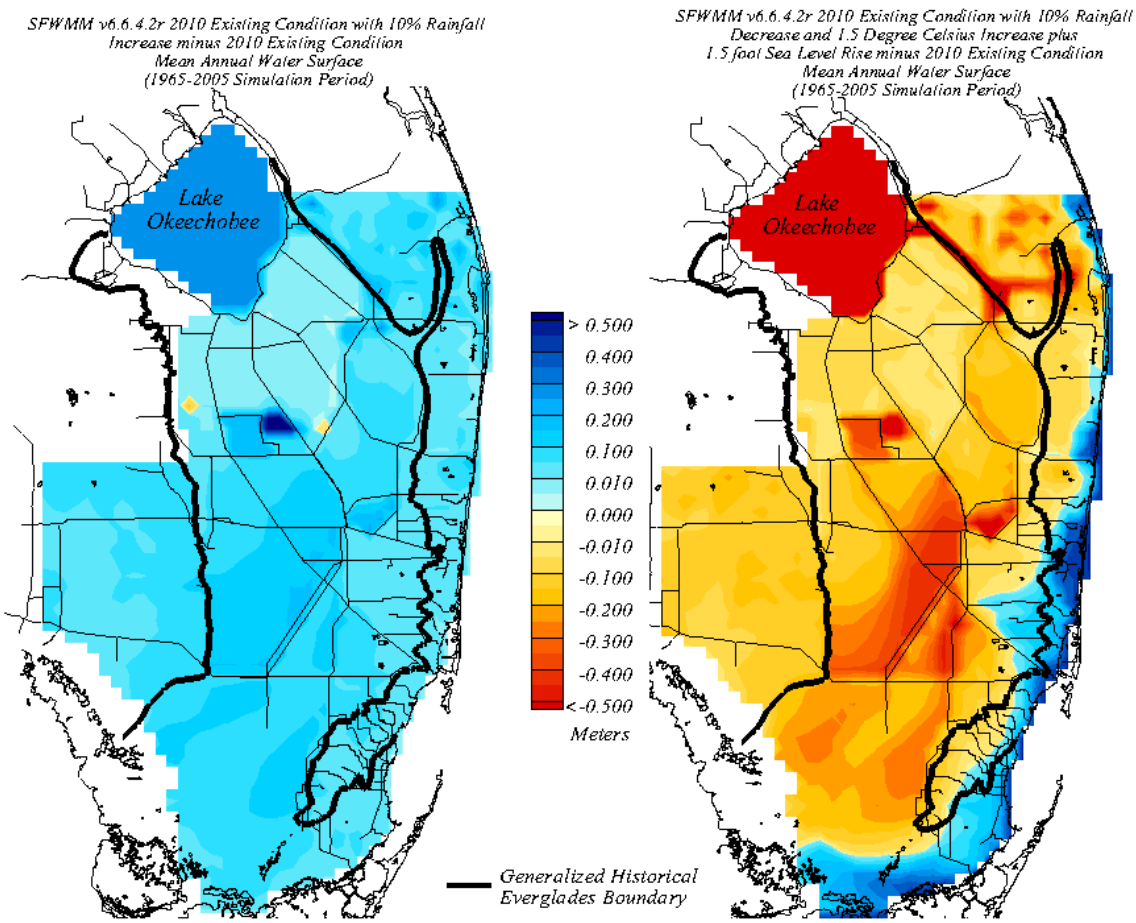

Figure 6-49. Distribution of changes in water depths under the scenarios of increased evapotranspiration, increased rainfall, and increased sea level (left), and increased evapotranspiration, decreased rainfall, and increased sea level (right). Blue colors indicate increases in stage, while yellow to brown indicate decreased stage (Obeysekera et al., 2014).

Table 6-10. Ecological implications of climate change scenarios in the Everglades. [Note: CH4 – methane; CO2 – carbon dioxide; and T – temperature.]

Ecological component-Everglades	Increased T, increased rainfall	Increased T, decreased rainfall	Ecological component-coastal	Increased T, increased rainfall, sea level rise	Increased T, decreased rainfall, sea level rise
Water depths	+	--	Seagrass communities	+	--
Surface inundation	+	--	Florida Bay salinity	-	++
Nutrient release	0	++	Coral reefs	0	-
Fire frequency	0	++	Peat accumulation	+	--
Fire intensity	0	++	Mangrove forests	-	--
CO2 emissions	-	++	Nutrient release	-	+
CH4 emissions	0	+	Saltwater intrusion	+	++
Peat accumulation	0	--	CO2 uptake	+	--
Exotic species invasion	0	--	Turbidity	0	++
Aquatic plant communities	+	--	Fisheries habitat	+	-
Aquatic wildlife communities	+	--	Ocean acidification	+	+
Hydrologic flow	+	--			
Drought frequency	-	++			
Drought intensity	-	++			
Water supply	+	--			
Water quality	0	--			

++ Major increase, + increase, 0 no net change, - decrease, -- major decrease

Under the scenario of increased temperature and decreased rainfall, simulations indicated that water levels in the Everglades would decrease by 15 cm to 1 m or more, and duration of surface water inundation would decrease by 10 to 50 percent, causing increased drought intensity and duration, loss of peat, and increased emissions of carbon dioxide and methane (Nungesser et al., in press). All of these changes would affect vegetation, wildlife, invasive species, wildfire risk, water quality, and water supply. Coastal ecosystems would be less affected, but the reduction of freshwater inflow would cause increased salinities along the coast and in Florida Bay (Florida Atlantic University, 2013). Sea level rise would inundate coastal freshwater wetlands and increase the extent of shallow marine systems, causing higher turbidity and elevated nutrients. Higher summer temperatures would harm seagrass habitat, fish, and coral reefs. Effects of rising sea levels on the Florida Bay mud banks that isolate the bay from Gulf of Mexico currents are uncertain (Koch et al., in press).

Organizers of this technical meeting arranged with the editors of the journal *Environmental Management* to produce a special issue expected to be published in 2014. The issue will be devoted to research and management issues identified for climate change in the Everglades.

Discussion

The major results of the first technical meeting in 2013 were that increased temperature and decreased rainfall could pose significant challenges to the goals of Everglades restoration and water supply, particularly in the freshwater wetlands (WCA-1, WCA-2, and WCA-3). Sea level rise would affect ENP and coastal systems through replacement of freshwater ecosystems with marine ecosystems and displace coastal mangrove forests inland.

Participants of the 2013 meeting identified the following gaps in knowledge and research needs (Florida Atlantic University, 2013):

- Need more realistic rainfall scenarios based on downscaled climate model information
- Need improved understanding of site specific relationships between climate factors
- Detailed understanding of elevation change from peat collapse and inundation by salt water
- Effects of extended drought on peat accretion, peat loss, and seed bank viability
- Need detailed hydrology-ecosystem models
- Resilience and vulnerability of populations to changes in landscape connectivity
- Understanding how to build ecosystem resilience, how management affects community and ecosystem dynamics, and how to identify critical tipping points and early-warning indicators of ecosystem stress
- The effects on ecosystems of the changes in climate-induced fire regimes, invasive species, and disease

Because these issues raised concerns whether management can mitigate some of these impacts, the steering committee organized a follow-up technical meeting for April 2014 to address management questions. Seven scientific working groups developed a series of recommendations for consideration by agency decision-makers.

Relevance to Water Management

As a framework for discussion, three types of actions were identified: (1) no-regret actions are cost-effective now and under a range of future climate scenarios and do not involve hard trade-offs with other policy objectives; (2) low-regret actions are relatively low cost and provide relatively large benefits under predicted future climates; (3) win-win actions contribute to adaptation while also having other social, economic and environmental policy benefits, including those in relation to mitigation.

The workshops produced a series of potential management actions that could be implemented as adaptation measures once future studies with more realistic scenarios are available:

- Produce baseline information by mapping vegetation, peat, and infrastructure to better assess and analyze vulnerability and detect changes over time.
- Increase water storage capabilities within the systems.
- Increase flow through the Everglades and to the coastal ecosystems.
- Improve modelling capabilities for hydrology and precipitation.
- Acquire and conserve more land and corridors.
- Increase interagency and regional coordination for climatic and sea level change.
- Critique and revise water management schedules and MFLs.
- Use existing capacity and infrastructure to increase flow and storage.
- Fully implement CEPP.
- Reduce water consumption in all sectors.

In a time of climate uncertainty, a process of adaptive restoration planning is necessary (Nungesser et al., in press). Planning for the unknown and uncertain poses particularly difficult

challenges. Over the next few decades, water management and restoration planning may wish to consider multiple climate scenarios rather than only one, and consequently, identify structures and operations that enable flexible responses rather than meet one set of expected targets. The uncertainties posed by changing climate may require a fresh view of how to manage peatlands (which lose soil when dried out), water supply for a growing human population, and saltwater intrusion into groundwater and coastal ecosystems.

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