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, 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. This chapter summarizes Water Year 2013 (WY2013) (May 1, 2012–April 30, 2013) 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

Above average rainfall translated into above average stage throughout the Greater Everglades, except in Water Conservation Area (WCA)-2A, where WY2013 was a slight 0.06 feet (ft) lower than the historical mean. Average WY2013 depth above the historical mean was 0.84 ft, 0.67 ft, and 0.53 ft, for WCA-1, WCA-3, and Everglades National Park (ENP or Park), respectively, for an average depth of 1.4 ft, 2.04 ft, and 1.42 ft, respectively. For the entire Greater Everglades, this above average stage was due to an above average minimum and not an above average maximum.

Hydrologic patterns in Florida Bay and southern ENP were similarly wet as in the upper marshes. WY2013 started out extremely wet. The high amounts of rainfall in April 2012 yielded high water levels and above average flows in the beginning of the wet season. Water levels were at or above average the entire year. Cumulative flow from the five creeks discharging to eastern and central Florida Bay for the first five months of WY2013 (May–September) was 12,232 acre-feet greater than the average annual total from WY1997-WY2011 of 255,893 acre-feet. Even though January through March was below average, total flow for WY2013 from the five creeks ended with a surplus of 102,342 acre-feet over the average total from WY1997–WY2011. The above average inflows yielded below average salinities throughout Florida Bay and its associated mangrove ecotone during the wet season. Taylor River salinity, which did not reach fresh conditions until September or October, declined to around 3 by June.

WILDLIFE ECOLOGY

The 2013 wading bird nesting season in the Everglades was characterized by an average numbers of nests for most species and a relatively high level of nest failures and abandonment. An estimated 35,879 wading bird nests were initiated in the Everglades during the 2013 nesting season. This estimate is a moderate improvement relative to 2011 (25,284 nests) and 2012 (24,191 nests), comparable to the decadal average (34,732.7 nests), and 51 percent lower than the 73,096 nests for 2009, which was the best nesting year on record in the Everglades since the

1940s. Nest failures were largely associated with high rainfall events in February and early April that promoted large-scale water-level reversals and the loss of food resources.

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 assesses the movement of crayfish across various Everglades depth features and habitats under an experimental water level recession (drought). The observed elevated abundances of the slough crayfish (*Procambarus fallax*) in relatively deep water [~ 20 centimeters (cm)] in both this study and Kushlan (1979) suggest that crayfish may be exploited by birds at greater depths than during the shallow water concentration events considered optimal for fish availability. Additionally, the prey base in the Florida Bay Transition Zone is described. It was found that above average water levels and below average salinities led to above average fish abundance in the first half of WY2013. In addition, the majority of fish collected were generally associated with oligohaline conditions (salinity < 5).

PLANT ECOLOGY

The two plant projects discussed in this chapter focus on hydrologic impacts and restoration goals. The first study examines the plant community development in the ridge and slough at LILA dependent upon hydrology. More than a decade after initial construction, the LILA marsh now consists of a patchwork of six distinct vegetation associations that are internally homogeneous, with diagnostic species occurrences. Vegetation composition in the ridge and slough phases of the landscape is primarily a manifestation of hydrologic differences; a difference of 25 cm in mean annual water depth distinguishes them. In contrast, the variation in vegetation composition within a landscape unit, particularly on the ridges, is weakly related to the hydrology, as the mean annual water depth did not differentiate between sawgrass- and maidencane-dominated associations.

In the second study, the survival and growth of trees on LILA tree islands was tracked relative to the hydrology experienced and the underlying substrate. Trees commonly found on frequently flooded sites in the Everglades were generally less sensitive to water level than upland trees. Upland species needed to be 20 to 40 cm above mean water surface to have much chance of surviving. For the majority of species, trees survived better on a limestone substrate. Growth responses were broadly opposite to survival responses. Eight of 10 species displayed significant differences in growth on limestone and peat surfaces; all eight grew more rapidly on the peat substrate.

ECOSYSTEM ECOLOGY

Two ecosystem-scale projects are reported in this chapter. First, an update on Active Marsh Improvement (AMI)—a project designed to provide a better understanding of the effect of physical removal of cattail using herbicides— is provided. AMI builds upon the results of the Cattail Habitat Improvement Project, which assessed whether creating openings in dense cattail areas sufficiently alter trophic dynamics such that wildlife diversity and abundance increased and determined to what extent these created open areas function compare to the natural Everglades. AMI projects provide managers with important information on how to optimize vegetation management and ecosystem restoration by documenting the selectively of imazamox, timing and frequency of application for large-scale management, effects of vegetation management on nutrient status and nutrient storage, and the relationship between hydrology, wildlife use, and cattail reinvasion.

The second ecosystem-scale project, a study of soil accretion and carbon budgets for LILA tree islands, found that soil development (accretion) was a relatively slow but more rapid at higher (drier) elevations where trees are maximally productive and where evapotranspiration

appears to concentrate nutrients from the groundwater. Soil decomposition was negatively correlated to water depth with the efflux of carbon dioxide greatest at the highest elevations. Regardless of soil accretion, surface elevation tables showed a net loss in elevation, which was likely due to subsidence.

LANDSCAPE

The Decomp Physical Model will examine the impacts of restoring flow between Water Conservation Areas 3A and 3B. To reproduce pre-drainage flow conditions, new structures are being built for the experiment, including 10 gated culverts on the L-67A levee, a 3,000-ft gap in the L67C levee, and three 1,000-ft canal backfill treatments in the adjacent canal. With a combined discharge capacity of 750 cubic feet per second, the culverts are expected to generate water velocities of 2 to 5 cm per second. This report describes measurements to determine the sediment dynamics, providing synthesis examples of ridge-and-slough and marsh-to-canal dynamics.

Further south, in Florida Bay, submerged aquatic vegetation (SAV) and algal communities were monitored to provide an understanding of the effects of water management on and status of vital wetland and estuarine plant communities and habitat. The low salinities through the WY2013 wet season allowed proliferation of fresh and low salinity favoring species of benthic vegetation in the mangrove creeks upstream of Florida Bay. This proliferation was similar, but not as pronounced, to the event at the end of WY2010 and beginning of WY2011. However, the mixed results downstream in Florida Bay, which was only sampled at the beginning of the water year in May 2012, are more representative of the higher than average salinity of WY2012 than the low salinity of WY2013.

Studies of Florida Bay water quality involved sampling and analysis of chlorophyll *a* (Chl*a*), total phosphorus, total nitrogen, total organic carbon, dissolved inorganic nitrogen, and turbidity. Most parameters had similar seasonal patterns and means in WY2012 and WY2013 continuing the stabilizing trends observed during the last four years. A localized Chl*a* increase occurred near the mouth of Taylor River during part of the wet season and declined rapidly to historical means with distance from the mouth of the embayment.

An evaluation of Florida Bay relative to the Minimum Flows and Levels (MFL) rule was conducted to examine the ecological conditions that the bay has experienced since implementation. Several exceedances were observed but no violations have occurred. The evaluation determined that currently the MFL rule provides appropriate guidance and serves to provide protection to the resources of Florida Bay.

The modeling evaluation of the Central Everglades Planning Project (CEPP) demonstrated that the CEPP alternatives provided benefit to the seagrass community in nearshore Florida Bay, particularly the ecotone and regions of the northern bay, decreasing the monospecific characteristics of the community and allowing expansion of widgeon grass (*Ruppia maritima*) into the bay. The overall outcome was that the preferred alternative, ALT 4R, created a more mixed SAV community, with reduced dominance by turtle grass (*Thalassia testudinum*), increased species richness and higher overall productivity for co-dominant species, trending toward historical conditions projected by the Natural System Model.

Table 6-1. Water Year 2013 (WY2013) (May 1, 2012–April 30, 2013) Everglades research findings in relation to operational mandates.[1]

Project	Findings	Mandates[1]
Hydrology		
Hydrologic Patterns for WY2013	Above average rainfall for Water Year 2012 came close to creating physiological stress for hardwoods on tree islands, especially in Water Conservation Area (WCA)-3A. Dry season recession rates were generally very good everywhere, except in WCA-1 where a hydrological reversal in March created a significant decline in wading bird foraging success. Nesting behavior was initially robust everywhere, but fledgling success was below average due to an early onset of the 2013 wet season and a possible low aquatic prey stock.	ROS MFL
Ecohydrology of LILA Tree Islands	Groundwater levels in the tree islands at the Loxahatchee Impoundment Landscape Assessment (LILA) varied seasonally with the surface water levels. In 2007-2008, one to two years following the planting of the tree islands, groundwater levels in the tree islands were higher than the surface water, and groundwater flowed from the center to the edges of the tree island. In the following year, a groundwater depression formed in the center of the tree islands coincident with an increase in tree biomass and evapotranspiration from the tree islands.	CERP EFA ROS
Wildlife Ecology		
Wading Bird Nesting Patterns	Nest initiations were above average for wood storks (*Mycteria americana*), white ibis (*Eudocimus albus*), and great egrets (*Casmerodius albus*), but below average for tricolored herons (*Egretta tricolor*) and snowy egrets (*E. thula*), continuing a long-term declining trend for these small herons. Wood storks initiated nesting in February, which was earlier than last year but short of the January CERP target. Rainfall events in February and early April prompted widespread nest desertion and failure. This effect was most acute for the white ibis, which exhibited almost comprehensive nest failure in 2013. Roseate spoonbills (*Platalea ajaja*) had a moderately successful year in terms of nest numbers and fledging success.	ROS CERP MFL FEIM
Inter-habitat Movements of Crayfish during a Water-Level Recession at LILA	This study examined the effect of a simulated water-level recession on the movement patterns of the slough crayfish (*Procambarus fallax*) in the ridge and slough habitats of LILA. The objective was to determine how crayfish become available to foraging wading birds. Changes in crayfish abundance and mark-release-recapture results indicated that the water-level recession prompted a large-scale movement of crayfish from ridges to sloughs, resulting in a considerable increase (668 percent) in their abundance at depths that are sufficiently shallow for foraging by the majority of wading bird species in the Everglades. Water level recession therefore appears to be an important mechanism for promoting the availability of this crayfish species for wading birds. The observed elevated abundances of *P. fallax* in relatively deep water [~ 20 centimeters (cm)] in both this study and Kushlan (1979) suggest that crayfish may be exploited by birds at greater depths than during the shallow water concentration events considered optimal for fish availability.	CERP MFL ROS
Prey Base in the Florida Bay Transition Zone	Water levels remained persistently high, well into the dry season. As a result, below average fish densities were observed. Also, there was a steady increase in exotic fish abundance due to a lack of cold temperatures in the transition zone over the past two water years.	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		
Ridge and Slough Vegetation Responses to Hydrology at the LILA Facility	More than a decade after initial construction, the LILA marsh now consists of a patchwork of six distinct vegetation associations that are internally homogeneous, with diagnostic species occurrences. Vegetation composition in the ridge and slough phases of the landscape is primarily a manifestation of hydrologic differences; a difference of 25 cm in mean annual water depth distinguishes them. In contrast, the variation in vegetation composition within a landscape unit, particularly on the ridges, is weakly related to the hydrology, as the mean annual water depth did not differentiate between sawgrass- and maidencane-dominated associations.	CERP EFA ROS
Effect of Hydrology and Substrate Type on Tree Survival and Growth at the LILA facility.	The survival and growth of trees on LILA tree islands was tracked relative to the hydrology experienced and the underlying substrate. Trees commonly found on frequently flooded sites in the Everglades were generally less sensitive to water level than upland trees. Upland species needed to be 20 to 40 cm above mean water surface to have much chance of surviving. For the majority of species, trees survived better on a limestone substrate. Growth responses were broadly opposite to survival responses; 8 of 10 species displayed significant differences in growth on limestone and peat surfaces and all 8 species grew more rapidly on peat substrate.	CERP EFA ROS
Ecosystem Ecology		
Active Marsh Improvement	Surficial soil and floc in the Cattail Habitat Improvement Project demonstrated decreased phosphorus (P) concentrations in open versus control plots. This suggests the altered regime is beginning to produce detritus with lower P concentrations. Treatment analysis of plant responses after 12 months in the Active Marsh Improvement – Slough Project, demonstrated that both rates of herbicide application resulted in decreased cattail percent cover compared to controls. However, proportional decrease in percent cover of live cattail tended to be greater in plots receiving the higher herbicide rate.	LTP ROS
Accretion and Carbon Budgets for LILA Tree Islands	Efforts focused on the effect of hydrology on topographic development of constructed islands of LILA with particular focus on carbon dynamics and soil building revealed that within a tree island, the higher (drier) elevations generally had higher litter production, higher rates of carbon dioxide (CO_2) efflux (i.e., soil respiration), and higher soil accretion. Peat core islands tend to subside more rapidly than limestone islands. In the peat islands and at higher elevations, trees were maximally productive. CO_2 efflux was significantly and negatively correlated to relative water depth. Production and soil accretion in nascent tree islands do not "build" topography at a rate [< 1 cm per year (y^{-1})] to compete with settling/subsidence.	CERP MFL ROS

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Table 6-1. Continued.

Projects	Findings	Mandates[1]
Landscape		
Sediment Dynamics in the Decomp Physical Model– Synthesis Examples of Ridge-and-Slough and Marsh-to-Canal Dynamics	Baseline data from the Decomp Physical Model confirm the conclusions – that in the current conditions of low water flow, restoration of the characteristic ridge and slough microtopography is unlikely. Water velocities were below critical entrainment thresholds required to resuspend and redistribute sediments.	CERP EFA ROS MFL
Benthic Vegetation in Florida Bay	The low salinities through the WY2013 wet season allowed proliferation of fresh and low salinity favoring species of benthic vegetation in the mangrove creeks upstream of Florida Bay. This proliferation was similar but not as pronounced as the event at the end of WY2010 and beginning of WY2011.	CERP MFL ROS
Florida Bay Water Quality Conditions and Status	Total phosphorus, total nitrogen, turbidity and total organic carbon were very similar and exhibited the same trends between WY2012 and WY2013 for all basins as was chlorophyll *a* and dissolved inorganic nitrogen in central and western Florida Bay and Whitewater Bay. In addition, the annual average of all these parameters for all basins were very similar between water years, continuing the stabilizing trends observed during the last four years.	CERP MFL ROS
Ecological Evaluation for the Florida Bay Minimum Flows and Levels (MFL)	The Taylor River site is the monitoring point on which the Florida Bay MFL is based. The most recent data from the site through WY2013 shows that an exceedance occurred in the extremely dry year of WY2012 and an exceedance nearly occurred in early WY2013). Through a combination of natural hydrology and South Florida Water Management District operations, no MFL violations have occurred since rule implementation.	CERP MFL ROS
Simulation Modeling to Evaluate Central Everglades Planning Project Alternatives and Effects on Florida Bay Submerged Aquatic Vegetation	The overall outcome was that the Central Everglades Planning Project alternative ALT 4R created a more mixed submerged aquatic vegetation community, with reduced dominance by *Thalassia*, increased species richness and higher overall productivity for co-dominant species, trending toward historical conditions projected by the Natural Systems Model.	CERP MFL ROS

[1]**Mandates**

CERP	Comprehensive Everglades Restoration Plan
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HYDROLOGIC PATTERNS FOR WATER YEAR 2013

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The amount of rain in the Everglades Protection Area (EPA) for Water Year 2013 (WY2013) (May 1, 2012–April 30, 2013) was 3 to 9 inches more than last year and significantly above average historical conditions (**Table 6-2**). In Everglades National Park (ENP or Park), the rainfall was 3.3 inches more (6.0 percent) than the historical average, and 4.7 inches more (8.5 percent) than last year. Water Conservation Areas 1 and 2 (WCA-1 and WCA-2) experienced the largest deviations from the historical average. Rainfall in WCA-2 and WCA-3 was 10.8 inches (20.9 percent) above the historic average and 8.9 inches (16.5 percent) more than last year. The rainfall in WCA-3 was 3.3 inches more (5.9 percent) than the historical average and was 4.7 inches more (8.7 percent) than last year.

Table 6-2 Average, minimum, and maximum stage [feet National Geodetic Vertical Datum (ft NGVD)] and total annual rainfall (inches) for Water Year 2013 (WY2013) (May 1, 2012–April 30, 2013) in comparison to historic stage and rainfall.[1] [Note: Average depths calculated by subtracting elevation from stage.]

Area	WY2013 Rainfall	Historic Rainfall	WY2013 Stage Mean (minimum; maximum)	Historic Stage Mean (minimum; maximum)	Elevation
WCA-1	62.80	51.96	16.49 (15.50; 17.35)	15.65 (10.0; 18.16)	15.1
WCA-2	62.80	51.96	12.45 (11.48; 14.43)	12.51 (9.33; 15.64)	11.2
WCA-3	56.15	51.37	10.24 (9.18; 11.64)	9.57 (4.78; 12.79)	8.2
ENP	58.49	55.22	6.52 (5.59; 7.38)	5.99 (2.01; 8.08)	5.1

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

Above average rainfall translated into above average stage throughout the Greater Everglades, except in WCA-2A (**Table 6-2**), where WY2013 was a slight 0.06 ft lower than the historic mean. Average WY2013 depth above the historic mean was 0.84 ft, 0.67 ft, and 0.53 ft, for WCA-1, WCA-3 and the ENP, respectively, for an average depth of 1.4 ft, 2.04 ft, and 1.42 ft, respectively. For the entire Greater Everglades, this above average stage was due to an above average minimum and not an above average maximum.

Last year, the analysis of the ecohydrology was based upon four water-years to highlight a unique time-series pattern of two droughts and to discuss the ecological implications of a drought-wet-drought-wet sequence on the restoration of wading birds. This year, the analysis returned to an evaluation based upon the last three years. To review: the WY09 drought supported many species of wading birds because prey density was high and no reversals were experienced during the dry season (see Beerens et al., 2011 and Herring et al., 2010a for the relationship

[1] Florida International University, Miami, FL

between foraging and recession rates), Then, it was followed in WY2010 by low wading bird population densities due to flooding, and low populations again in WY2011 because the WY2011 drought was extreme (see **Figures 6-1 to 6-7**). Water Year 2012 started out looking good for wading birds, but was another bad year because prey abundance was low and because wet season water levels rose very quickly; cutting short the fledgling period.

The following hydropattern figures highlight the average stage changes in each of the WCAs for the last three years in relation to the recent historic 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 District to facilitate weekly operational discussions and decisions. Tree island flooding tolerances are considered exceeded when depths on the islands are greater than 1 foot 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 in the Everglades (SFWMD, 2003). **Figures 6-1** through **6-7** show the ground elevations in the WCAs as being essentially the same as the threshold for peat conservation.

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 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 ft), 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 between 0.1 and 1.5 ft.

WATER CONSERVATION AREA 1

In WY2011, the dry season began at a below average stage and got significantly drier such that by July, water levels were, on average, some 1.7 ft below ground in WCA-1A (**Figure 6-1**). This created a significant deficit upon entering WY2012. Water levels in WCA-1A took 6 months to return to average conditions; not much time for small fish to rebound and disperse. Unfortunately, the dry season recession rates in WY2012 were supportive of good foraging conditions for only three months (from January 2012 to April 2012) before reversals and rising water levels brought the nesting season to an early end. However, even if the WY2012 foraging conditions did not end early, WY2012 nesting would have been poor because prey densities appeared insufficient to support a substantial fledgling rate.

The water level in WCA-1 during the WY2013 wet season rose quickly and was 1 ft above average by June, but not enough to cause harm to tree islands. After the summer drought in 2011, these high depths were needed to rejuvenation the aquatic prey. That is why high foraging rates were observed during the start of the WY2013 dry season. A high nesting rate was expected for WCA-1A in WY2013 until a major reversal occurred in March 2013. This reversal was followed by an end of good recession rates in April and water levels stayed above average for May and June. These were poor hydrologic conditions for foraging, nesting, and fledgling young. Although WY2013 was not good for wading birds, it may be another year of rebound for small fish because the hydrology protected them from avian foraging.

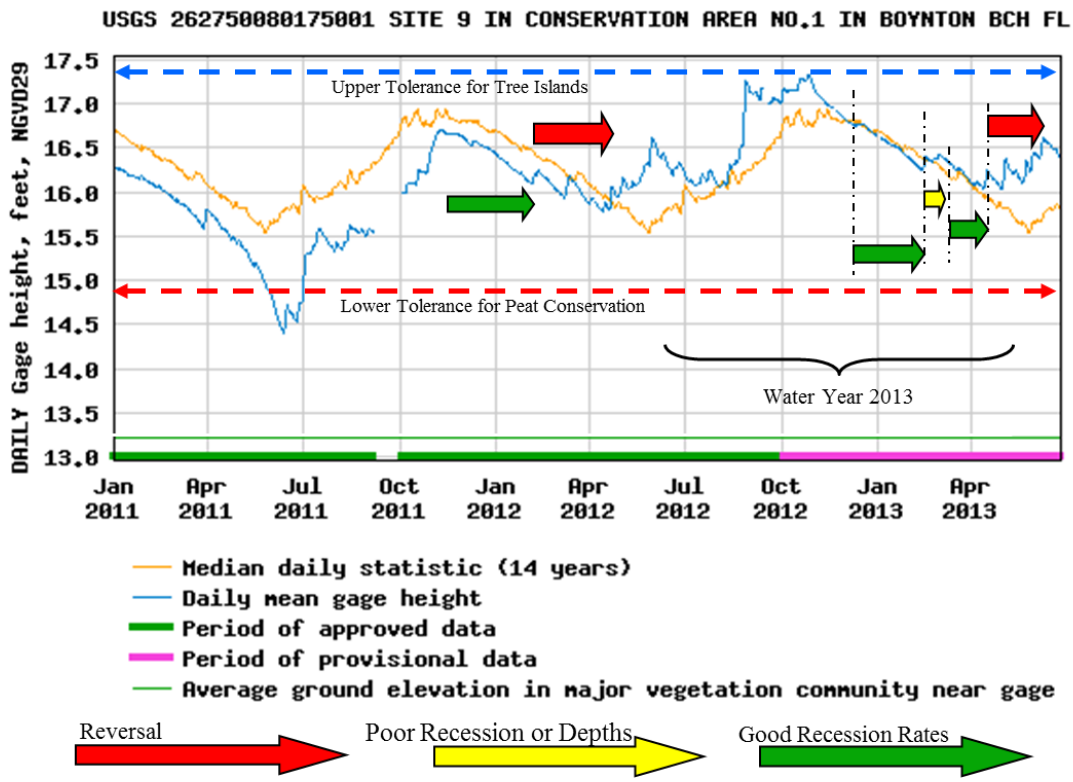

Figure 6-1. Hydrology in Water Conservation Area (WCA)-1 in relation to the 14-year median stage, as well as indices for tree island flooding, peat conservation, and wading bird foraging. [Note NGVD29 – National Geodetic Vertical Datum of 1929, USGS – United States Geological Survey.)

WATER CONSERVATION AREA 2A AND 2B

It is common for the stage levels during the wet season to exceed the upper flood tolerance for tree islands for 1–2 months in WCA-2A as it did this year (**Figure 6-2**). Although 1–2 months 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). Three 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.

Last year, WCA-2A good recession rates were long-lived, followed by a rapid and early return of the wet season (**Figure 6-2**). This WCA was also a good foraging location last year. This year, water rehydration rates during the wet season created a good environment for prey rebound, but recession rates during the dry season were only fair to good. Wading bird foraging was good, but short-lived in WCA-2A due to reversals in April and an early end to the dry season. No nesting was observed; lack of tree islands in WCA-2A and WCA-2B makes these regions unsuitable for nesting. The 2011 to 2013 hydrograph (**Figure 6-2)** for this section of the WCA continues to suggest a long-term trend of above average foraging and poor nesting. For the last two water years, the hydrograph indicated relatively equal distributions of green and red arrows.

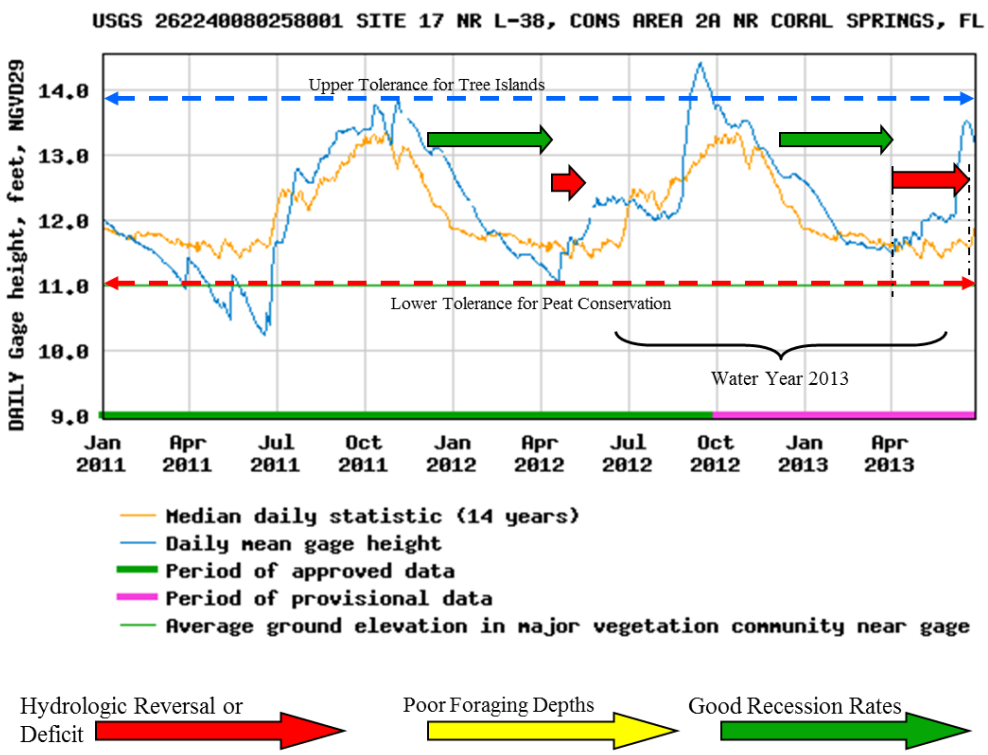

Figure 6-2. Hydrology in WCA-2A in relation to the recent 14-year average, with indices for tree islands, peat conservation, and wading bird foraging.

WCA-2B tends to be utilized by wading birds during droughts because it tends to stay deeper for longer periods than the rest of the Everglades Protection Area (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 WY2011 because dry season water levels went almost 2.5 feet below ground for an extended period of time (**Figure 6-3**). It was ecologically problematic to observe water levels increase by about four feet over a few months, as this region became rehydrated in WY2012. Young tree seedlings that happen to establish during the previous drought cannot keep their "heads" above water when it rises this quickly. Nevertheless, this region consistently gets a poor foraging depth designation (yellow arrows in **Figure 6-3**). The 2011 to 2013 hydrograph (**Figure 6-3**) for this section of the WCA suggests a long-term trend of very poor foraging and nesting. For the last two years, the hydrograph has only indicated yellow arrows.

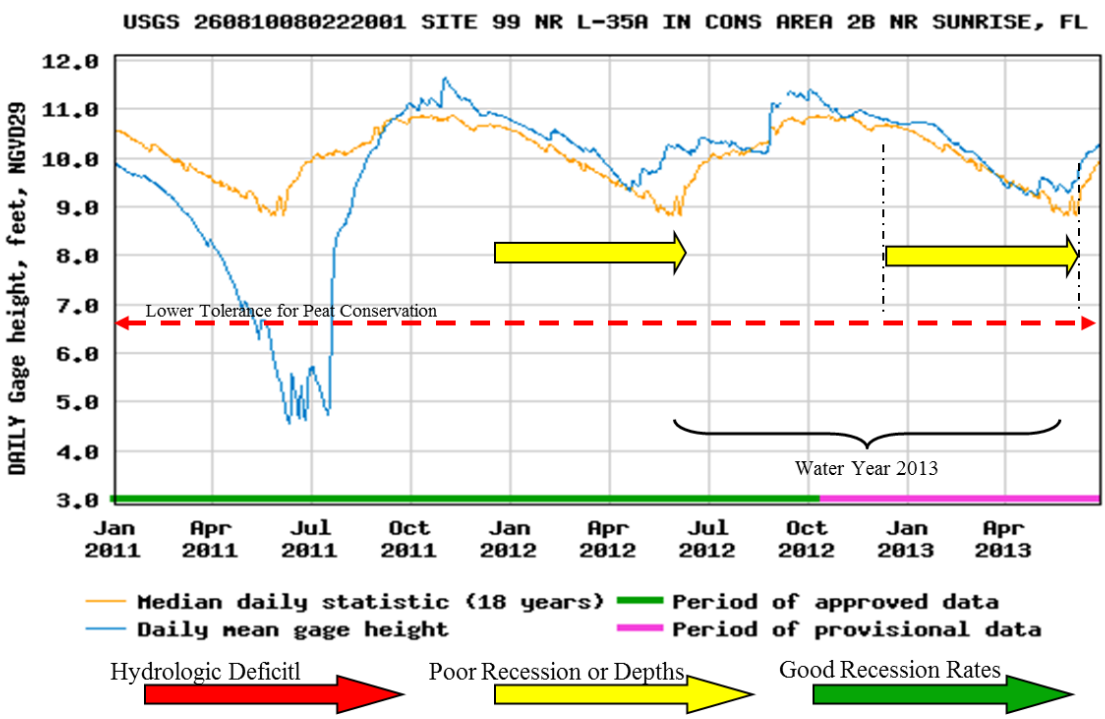

Figure 6-3. Hydrology in WCA-2B (gage 99) in relation to the recent 18-year average with indices for tree islands, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 3A

In the northeastern region of WCA-3A (gage 63), the WY2013 wet-season began early and water levels rose above the tolerance of tree islands for some 100 days (**Figure 6-4**).This is not considered enough time to cause any long lasting tree island damage (Wu et al., 2002). Instead, these high water levels helped to keep the very large Alley North Colony free from predators for the entire dry season and created the hydraulic head for excellent recession rates for an extended period of time. Despite an excellent dry season hydrology in WY2013, foraging and nesting were only average. It appears that the drought of WY2011 and the pervasive shallow conditions of WY2012 may have prevented this region from replenishing the aquatic prey stocks. Like last year, recession rates were excellent starting in December—good for wood storks (*Mycteria americana*)—and optimum depths started to appear around January. However, like last year, the water depths began to rise in April rather than June and the prey base, small that it may have been, began to disperse causing foraging to decline and nests to be abandoned (see Cook and Kobza, 2012). 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 two years.

The 2011 to 2013 hydrograph (**Figure 6-4**) for this section of the WCA suggests a long-term trend of average foraging and nesting. For the last two years, the hydrograph had large green arrows and indicated equal distributions of green and red arrows across that period.

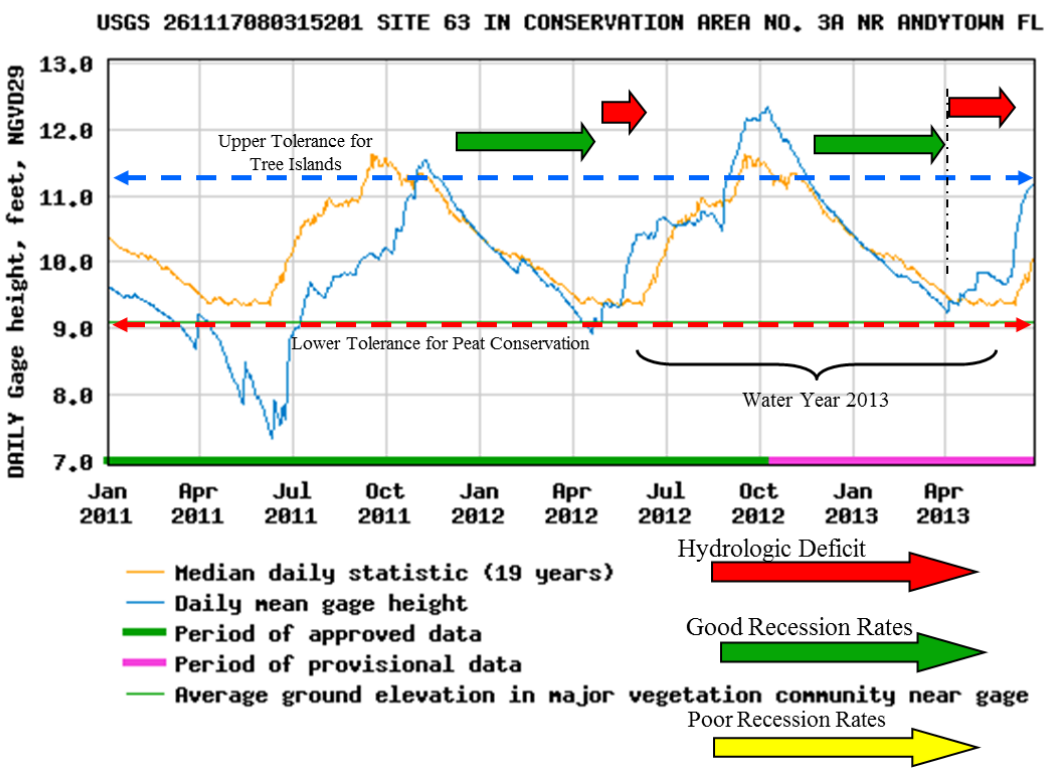

Figure 6-4. Hydrology in northeast WCA-3A (gage 63) in relation to the recent 18-year average with indices for tree islands, peat conservation, and wading bird foraging.

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. The WY2013 dry season was very conducive for wading bird foraging. However, like most regions, this did not translate into high nesting success because WY2012 in the central Everglades was poor for prey rejuvenation due to the (1) extended WY2011 drought, (2) shallowness of WY2012 wet season (i.e., not protective), and (3) good WY2012 dry season recession rates. Average-to-small flocks of wading birds were observed following the receding drydowns fronts in central WCA-3A during WY2013. Similar to observations last year, nesting birds abandoned their nest before most young birds could fledge due to an early onset of the WY2013 wet season. The 2011 to 2013 hydrograph for this section of the WCA suggests a long-term trend of above average foraging and nesting. For the last two years, the hydrograph had large green arrows and indicated equal distributions of green and red arrows across the last two years.

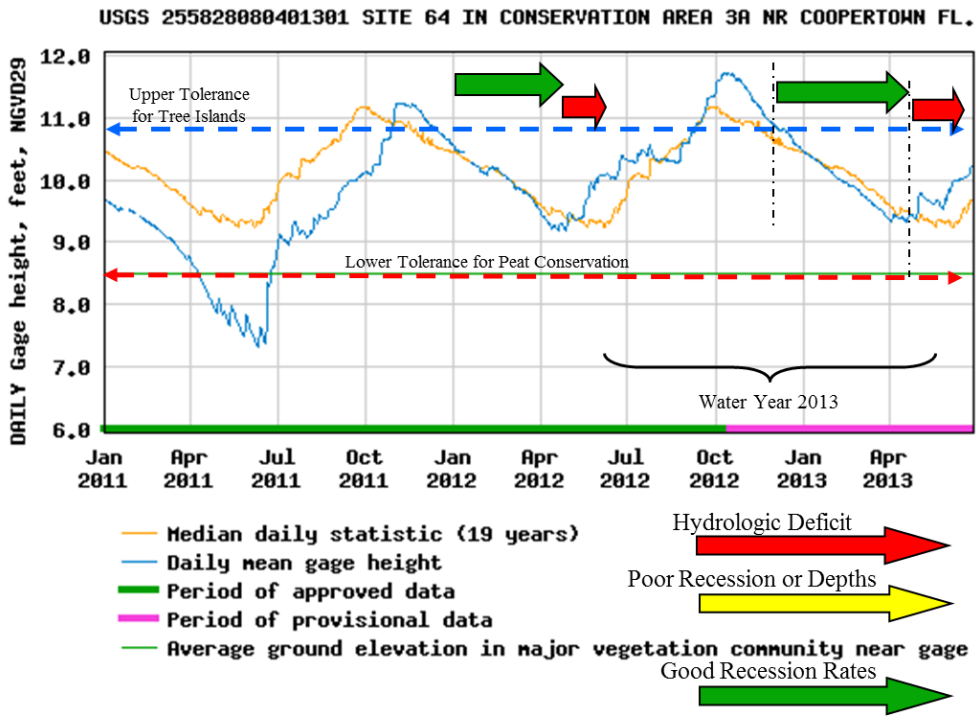

Figure 6-5. Hydrology in central WCA-3A (gage 64) in relation to the recent 19-year average with indices for tree islands, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 3B

For the last two years, in WCA-3B, water levels fell at an almost steady perfect 0.10 ft per week during the dry season (**Figure 6-6**). Last year foraging activity during the dry season was reported to be light, but this year there was a relatively large amount of foraging activity in WCA-3B. Researchers use the word "relatively" for WCA-3B because there are few sloughs in WCA-3B and, as a result, the amount of foraging habitat is very limited. Last year, water depths and recession rates were good for foraging by wading birds, but foraging was very limited due to the lack of sloughs, and the extensive WY2011 dry down and thus a lack of prey in WY2012. This year, it appears that the prey stock had time and water to become relatively rejuvenated. As the prey density data are processed over the next year or so by scientists at Florida International University and Florida Atlantic University, it will be valuable to the restoration effort to evaluate the hydrological requirements of the aquatic prey populations in relation to the amount of good foraging habitat. As with everywhere else, the dry season in WCA-3B ended in April, thus 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.

The 2011 to 2013 hydrograph for this section of the WCA indicates that the last two years were good for tree islands and excellent for wading bird foraging. WY2013 was better than WY2012 because aquatic prey densities were probably better. For the last two years, the hydrograph indicated equal distributions of green and red arrows.

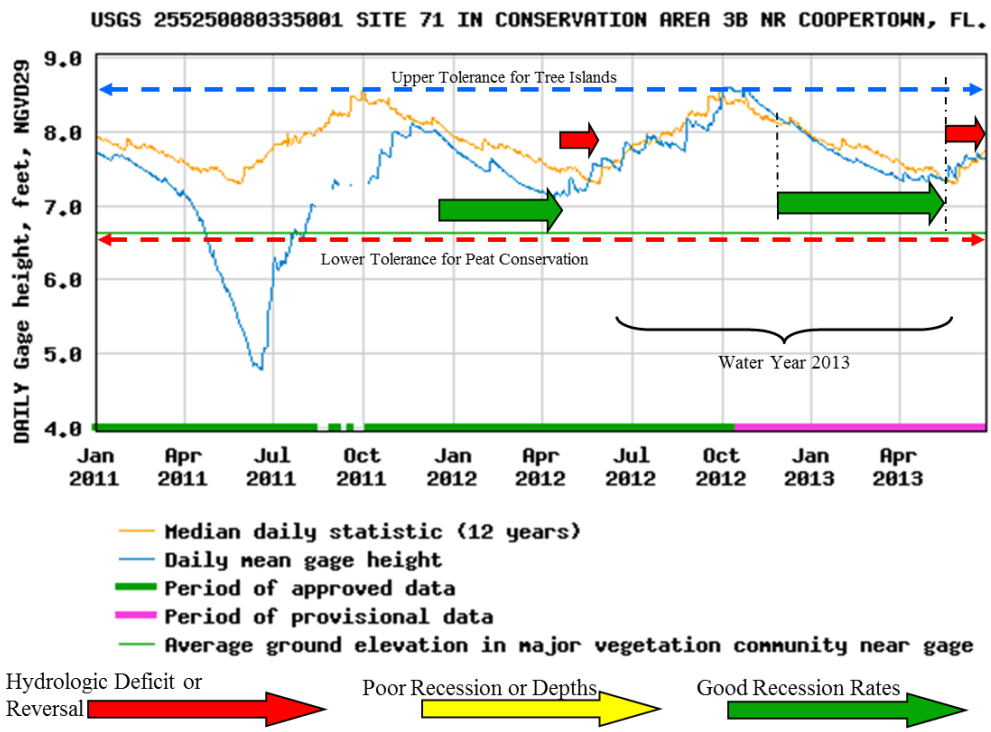

Figure 6-6. Hydrology in central WCA-3B (gage 71) in relation to the recent 12-year average and indices for tree islands, peat conservation, and wading bird foraging.

NORTHEAST SHARK RIVER SLOUGH

Last year (WY2012), the wet season was relatively dry in Northeast Shark River Slough (NE-SRS), especially June, July, August, and September, but the dry season had good recession rates from January to April (**Figure 6-7**). This year (WY2013), the wet season was relatively wet, and dry season recession rates were very good up until May. This hydrology suggests that NE-SRS was optimal in the EPA for foraging wading birds because the aquatic prey had a year to return to pre-drought condition and the nesting period was not cut short as it was in WCA-1, WCA-2 and WCA-3. The reasons why large flocks of birds are not usually found in NE-SRS are not completely clear, but this may be due the dense vegetation, the limited amount of slough, and a legacy of fires and very dry conditions. Previous *South Florida Environmental Reports* (SFERs) reporting on the hydrology of NE-SRS suggest a long-term trend of suboptimum foraging and nesting. However, the 2011 to 2013 hydrograph for this section of ENP suggests a three-year trend of greatly improved foraging and nesting hydrology (**Figure 6-7**).

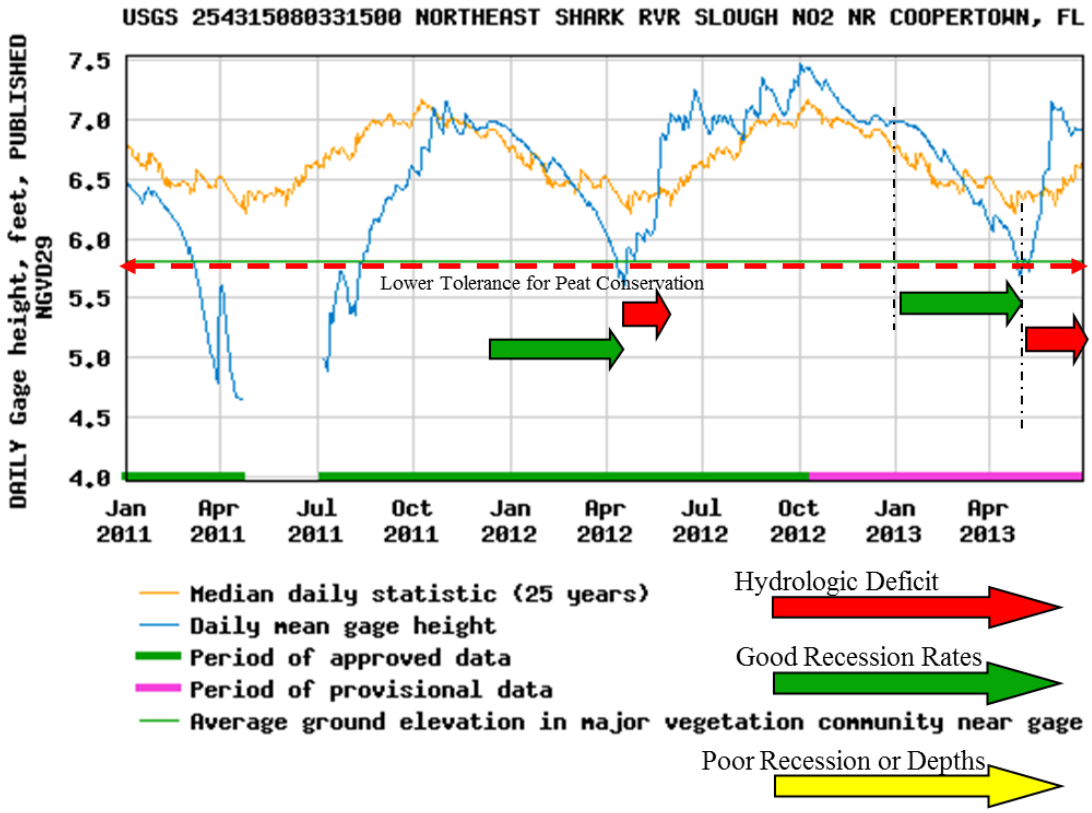

Figure 6-7. Hydrology in Northeast Shark River Slough in relation to the recent 25-year average with indices for tree islands, peat conservation, and wading bird foraging.

FLORIDA BAY

A long-term monitoring network throughout the southern Everglades and Florida Bay has been maintained by the District and other agencies to provide a continuous record of the salinity profile of the Florida Bay watershed and its associated hydrologic inputs. These data are used in support of District operations, developing and monitoring Comprehensive Everglades Restoration Plan (CERP) performance measures, assessing the effectiveness of Minimum Flows and Levels (MFLs), supporting the calibration and verification of hydrologic models, and evaluating ecological and biological trends and changes.

Methods

Salinity, rainfall, 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 using acoustic Doppler velocity meter systems by the United States Geological Survey (USGS) at five creeks discharging into Florida Bay since WY1997.

Results

WY2013 began with much higher rainfall than normal, yielding high water levels and above average flow early in the wet season. Average total rainfall measured by rain gauges in the southern part of ENP was 54.3 inches, which is higher than the WY1997–WY2011 average of 44.2 inches. The southern Everglades began the water year at between 6 and 12 inches above average level and continued at or above average throughout the year. The cumulative flow from the five creeks discharging to eastern and central Florida Bay for the first 5 months of WY2013 (May–September) was 12,232 acre-feet greater than the average total for the entire year from WY1997-WY2011 which is 255,893 acre-feet. (**Figure 6-9**). Although flow from January through March was below average, WY2013 ended with a surplus of 102,342 ac-ft above the WY1997–WY2011 average total from the 5 measured creeks. As a result of the heavy rain and high flows, salinities across the bay and the mangrove ecotone were unusually low through the summer (**Figure 6-10**). Taylor River salinity, which usually does not reach fresh conditions until September or October, declined to 3 by June. Salinities remained well below average for most of the wet season, while the dry season experienced average salinities.

Annual discharge from Taylor River was the highest in the period of record (WY1997–WY2013) during WY2013 even though the five creek total was only the second highest. WY2006 was higher by about 43,300 ac-ft. Taylor River was the only creek to have a higher annual flow in WY2013 than WY2006. In addition, Taylor River was ranked fourth in flow volume in WY2006 but was second in WY2013, behind Trout Creek which has historically been the primary outflow. McCormick Creek, to the west, recorded substantially less flow than in WY2006.

Relevance to Water Management

There were significant changes in flow patterns and increases in discharge to Florida Bay in WY2013 with respect to previous years. Increased flows and water levels in Taylor Slough is a desired goal of the C-111 Spreader Canal Western Features Project, which has been operational for only a year. Several factors likely contributed to the observed flow pattern, including high rainfall in the local sub-watershed, the installation of a hydrologic seepage barrier on the eastern border of Taylor Slough, and operational flows through the C-111 project features. Continued long-term data collection will enable determination of impacts of the C-111 project in the context of interannual variability in precipitation.

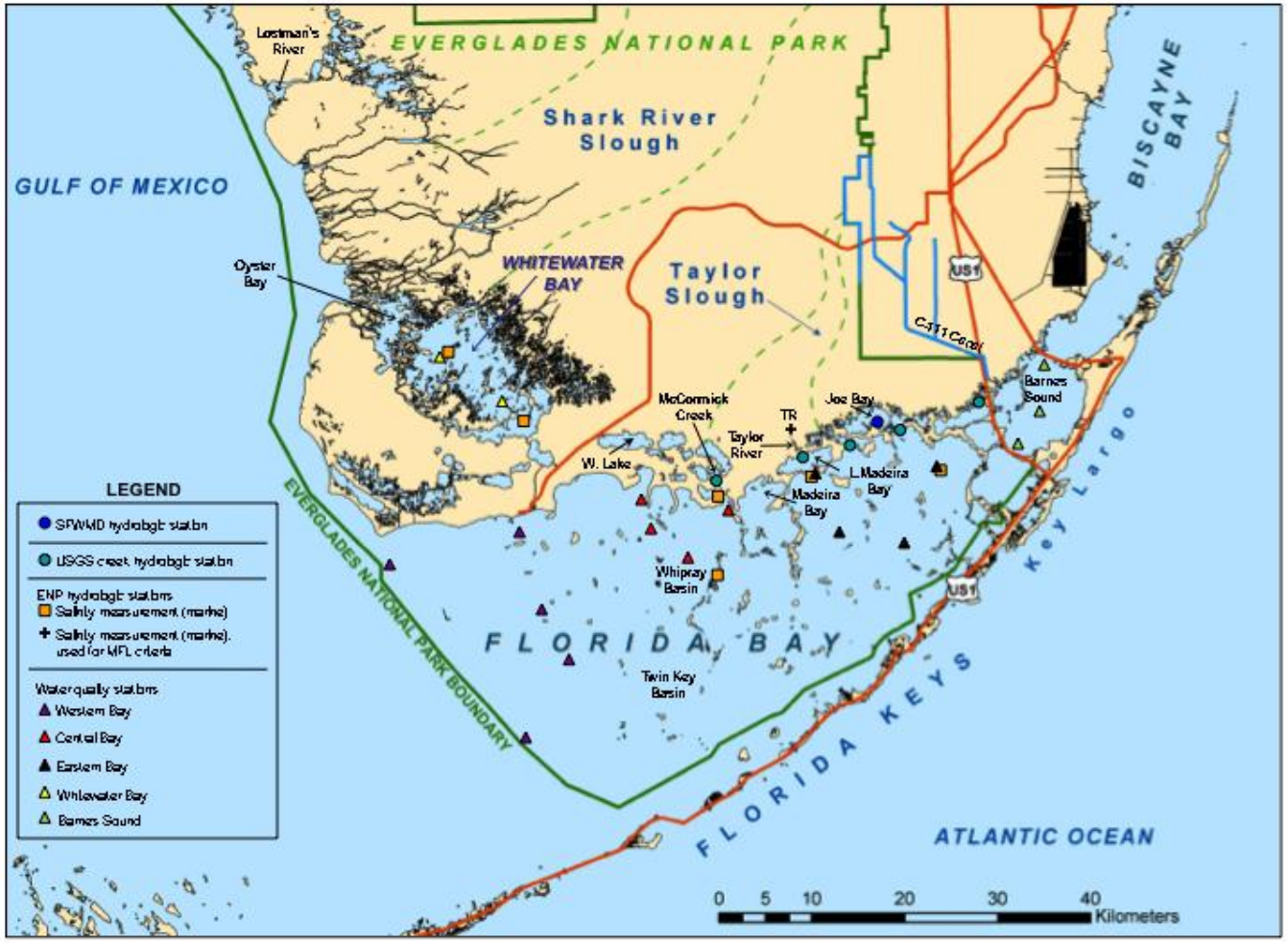

Figure 6-8. Salinity, flow, and water quality sampling points within Florida Bay and southern Everglades, showing areas influenced by water management operations from Whitewater Bay in the west to Barnes Sound in the east. Environmental parameters are monitored by the South Florida Water Management District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

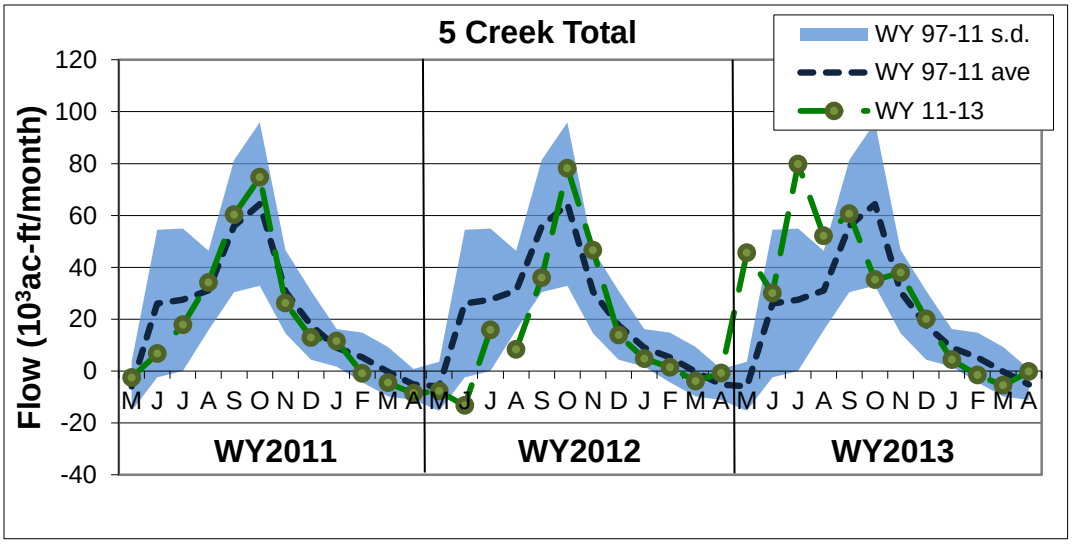

Figure 6-9. Monthly cumulative discharge in thousand acre-feet (kac-ft) per month (10^3 ac-ft/month) to Florida Bay through five creeks in WY2011 through WY2013 (WY11–13 in the legend), compared to monthly discharge mean (WY97-11 ave in the legend) and standard deviation envelope (WY97-11 s.d. in the legend) for WY1997–WY2011 (data from the USGS).

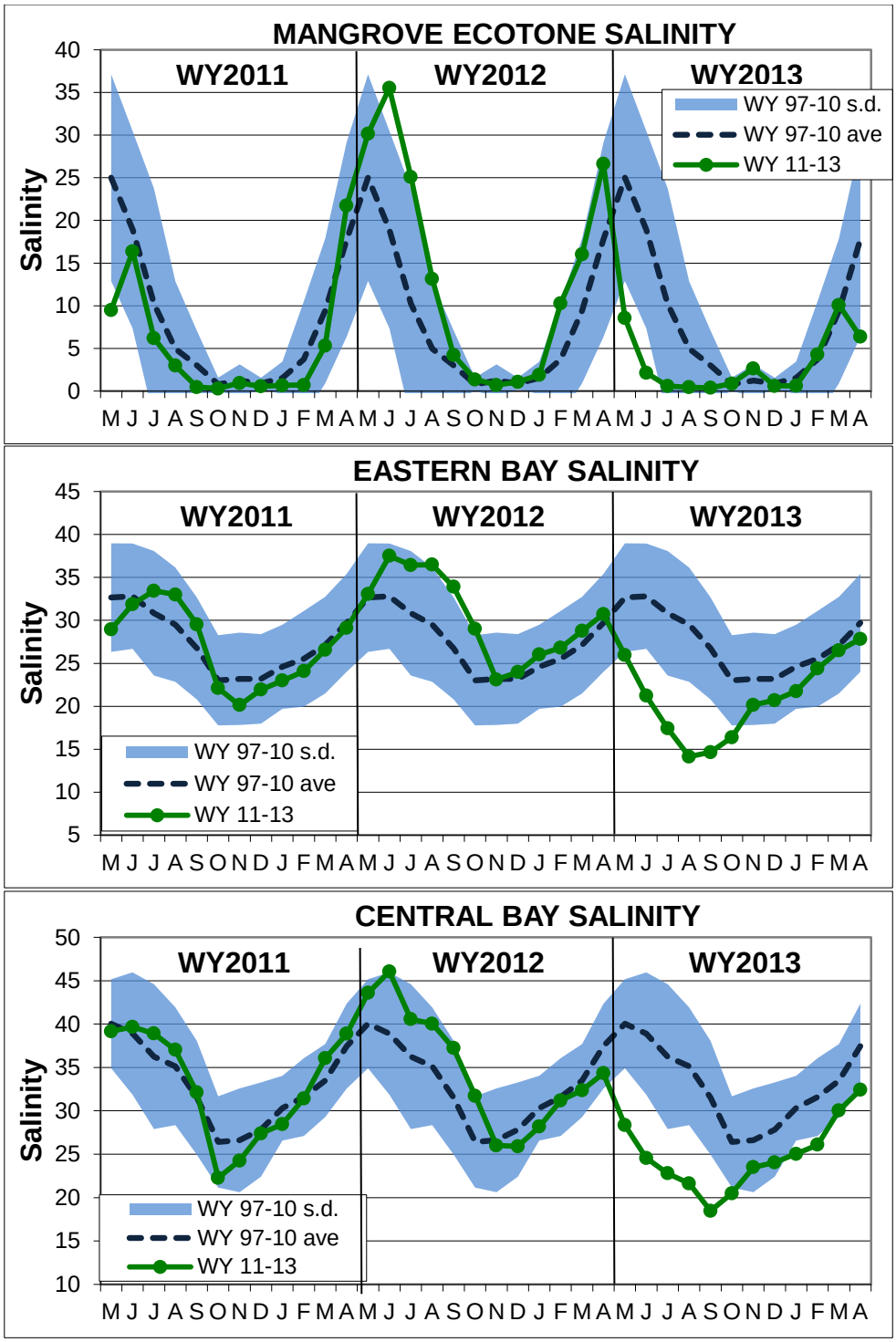

Figure 6-10. Mean monthly salinity values in the mangrove ecotone at the ENP-Taylor River platform (top), eastern Florida Bay (middle), and central Florida Bay (bottom) in WY2011-WY2013 (WY11-13 in the legend), compared to monthly means (WY97-10 ave in the legend) and standard deviation (WY 97-10 s.d. in the legend) for WY1997–WY2011. The eastern and central bay salinity values are averaged between 2 continuous monitoring platforms within each region.

ECOHYDROLOGY OF LILA TREE ISLANDS

The Loxahatchee Impoundment Landscape Assessment (LILA) was constructed in 2002–2003 as a large physical model of the Everglades where ecohydrological research and Everglades restoration efforts can be tested. Located at the Arthur R. Marshall Loxahatchee National Wildlife Refuge in Boynton Beach, Florida, LILA consists of four macrocosms, each 20 acres (8 hectares) in size, which mimic the tree island-ridge-slough landscape of the Everglades (Aich et al., 2011). Each macrocosm contains two rectangular-shaped tree islands constructed with different geologic materials: one entirely of peat; and the other with a center of limestone rubble overlain by peat (Sklar et al., 2004). Over 700 saplings of eight tree species common to Everglades tree islands were planted on each tree island in March 2006 and 2007 (Stoffella et al., 2010). Shallow groundwater wells (average depth of 1.34 meters) were located along a transect across each tree island (Sullivan et al., 2011). Groundwater levels were monitored using In-Situ Level Troll 500™ pressure transducers and then compared to surface water levels monitored via stage recorders at the eastern and western boundary of each macrocosm (Sullivan et al., 2010). Both groundwater and surface water samples were collected twice a year, in May and October, for chemical analyses (**Figure 6-11**).

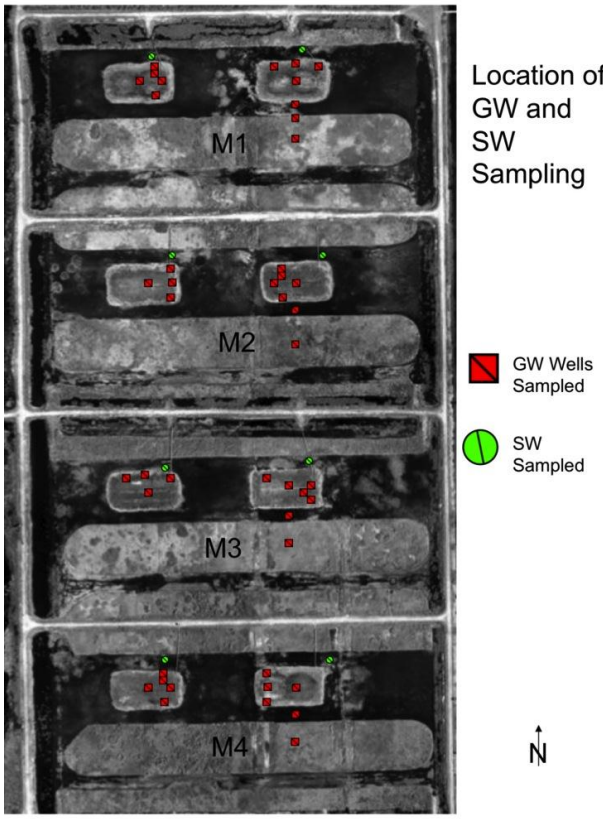

Figure 6-11. Location of groundwater (GW) wells (red) and surface water (SW) sites sampled from October 2007-April 2012 at the Loxahatchee Impoundment Landscape Assessment (LILA).

Surface water levels in all macrocosms were managed in accordance with an operational hydrograph derived to mirror seasonal water level changes in WCA-3A, with higher levels between September and November and lower levels between March and June (**Figure 6-12**). The edges of the tree islands tended to be flooded about 155 days a year. The center of the tree islands were flooded only one day per year between 2009 and 2011, but were flooded for over 35 days between June and September 2012 following the passage of Hurricane Isaac.

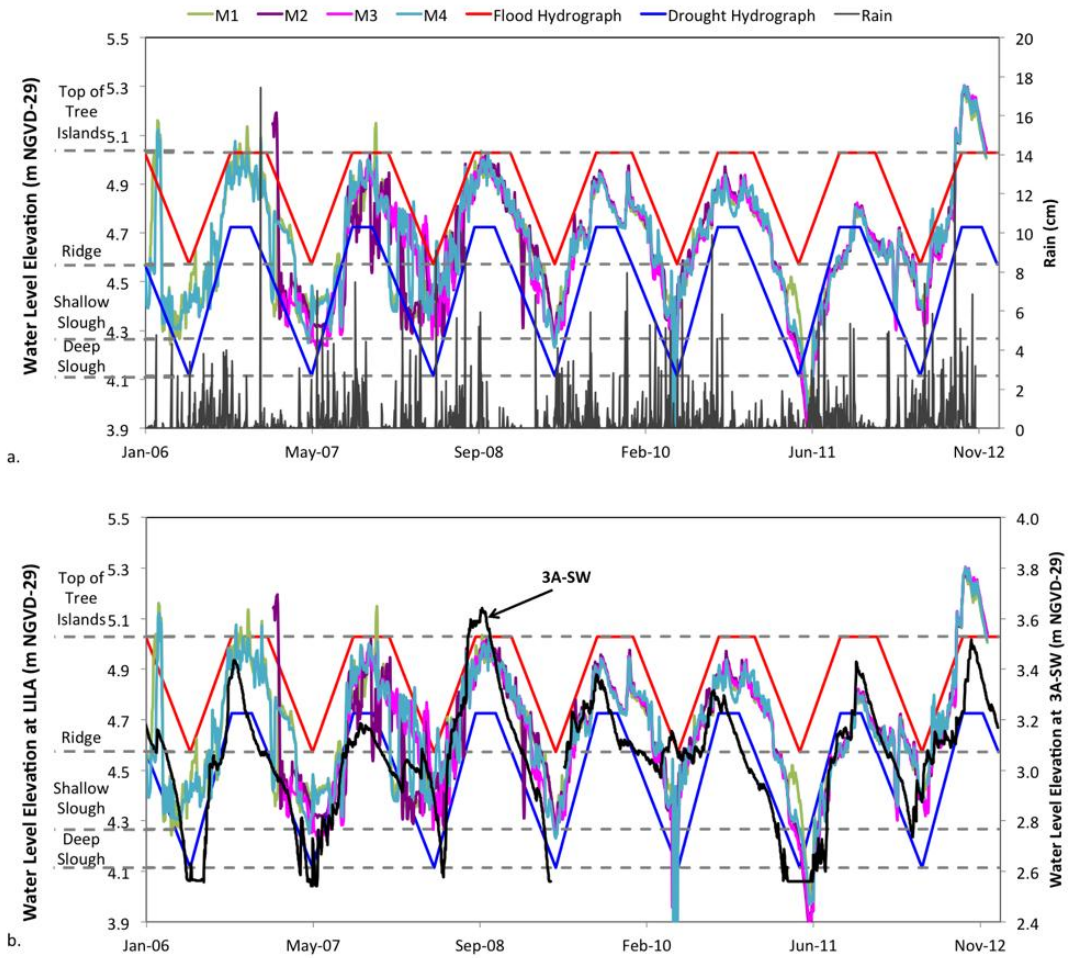

Figure 6-12. (a) LILA operational hydrograph and rainfall (right axis) as measured at the nearby LXWS station from 2006 to 2012. (b) LILA operational hydrograph compared to the surface water level at 3A-SW (black) in WCA-3A. The dotted line represents the ground elevation at LILA for the top of the tree islands, ridge, shallow slough, and deep slough.

Groundwater levels in the tree islands at LILA varied seasonally with the surface water levels (not shown). However, groundwater flow directions in the tree islands themselves became complicated as the trees grew (**Figure 6-13**). In 2007–2008, one to two years following the planting of the tree islands, groundwater levels in the tree islands were higher than the surface water and groundwater flowed from the center to the edges of the tree island (**Figure 6-13**, top). In the following year, a groundwater depression formed in the center of the tree islands (**Figure 6-13**, middle) coincident with an increase in tree biomass and evapotranspiration (ET) from the tree islands (Sullivan et al., 2011; Stoffella et al., 2010). High rainfall amounts in the spring of 2010 (**Figure 6-12**, panel a) caused higher groundwater levels in the tree islands relative to the surface water (**Figure 6-13,** bottom, April). When ET exceeded rainfall later in the year (October–January) then a groundwater depression again formed in the center of the tree island (**Figure 6-13**, bottom).

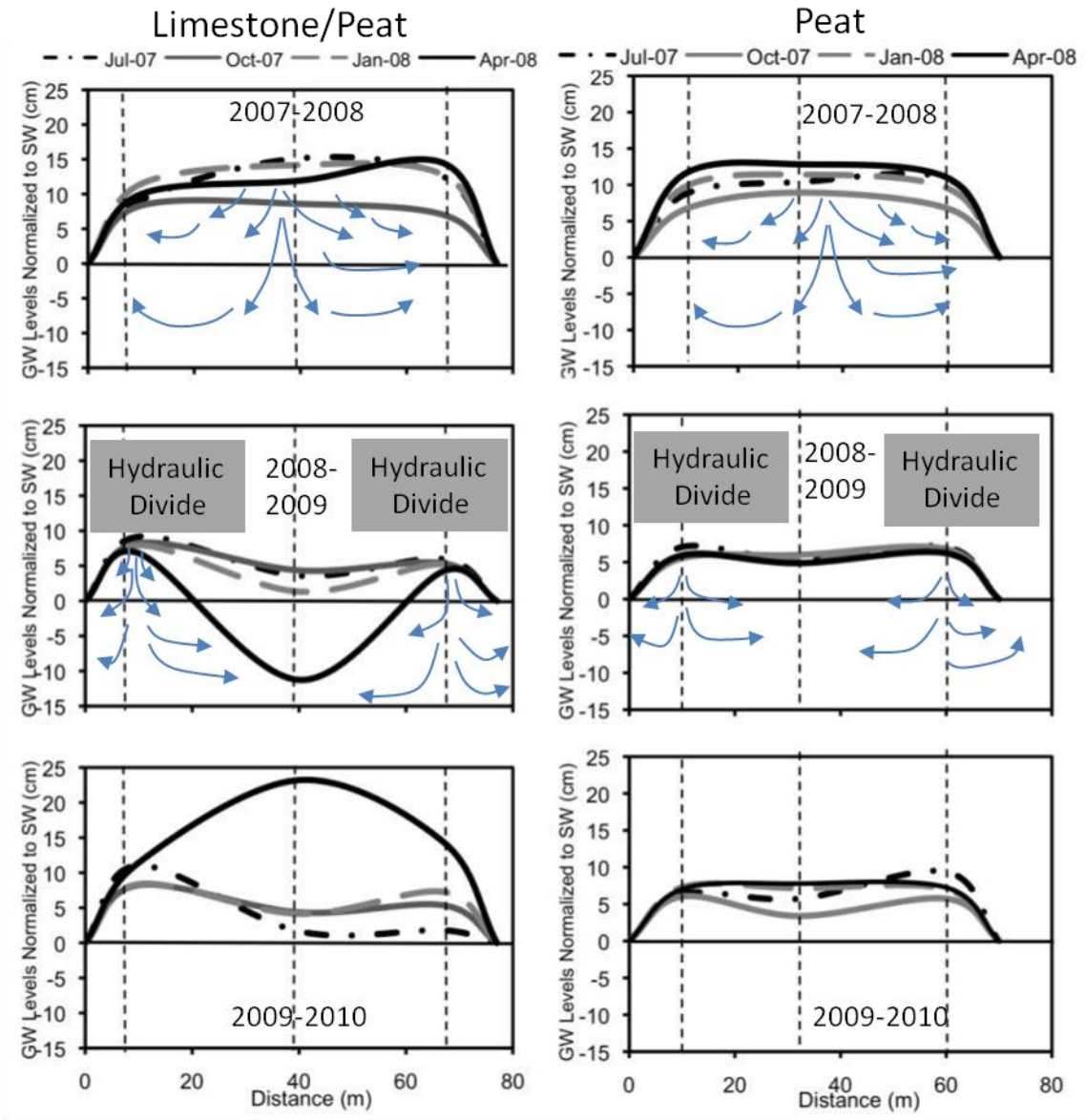

Figure 6-13. Combined mean Groundwater (GW) levels at LILA for (a) limestone and (b) peat tree islands normalized relative to surface water (SW) levels measured in the macrocosms. [Note: cm – centimeters, m – meters.]

Over time, the continued growth of the trees on the tree islands affected the underlying groundwater chemistry (Sullivan et al., 2012). Concentrations of ions not used by trees, (i.e., chloride, calcium, bicarbonate) increased in the groundwater over time, while ions used by the trees (i.e., potassium and phosphorus) decreased. The resulting increase in calcium and bicarbonate in the groundwater is predicted to result in the formation of solid calcium-carbonate minerals (e.g., calcite and aragonite) below ground, thereby increasing the soil formation and stability of the tree islands.

Relevance to Water Management

The results of this study indicate that hydrologic conditions in tree islands is a complex relationship between amounts of rain, ET, and surface water levels in the surrounding slough. During periods of low rainfall and low surface water levels, ET leads to a depression in the groundwater table and a concentration of chemical ions in the center of the tree island. The increase in ion concentrations may be important for the formation of calcium carbonate soils within the tree island, leading to their stability. In order to maintain the stability of Everglades tree islands, surface water levels need to be managed with periods of recession so that ET processes can dominate for parts of the year.

WILDLIFE ECOLOGY

Mark Cook, Eric Cline and Joseph Stachelek

Large populations of colonially nesting wading birds (order Ciconiiformes: egrets, ibises, herons, spoonbills, and storks) were a common and 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:

- A marked decline in the nesting populations of several species, particularly the tactile foraging species
- A movement of colonies from the overdrained 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.

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. 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 summarizes wading bird nesting effort and success in the Everglades and Florida Bay during the WY2013 breeding season, describes an experiment testing the hypothesis that a hydrologic concentrating mechanism is operating for the slough crayfish (*Procambarus fallax*) in the Loxahatchee Impoundment Landscape Assessment (LILA) area, and reports on Florida Bay fish production.

WADING BIRD MONITORING

Wading birds are excellent indicators of wetland ecosystem health and have a central role in 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, MFLs, and day-to-day operations of the District.

Recovery of pre-impoundment (1930–1940) wading bird nesting patterns is evaluated using the two independent sets of measures. 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 population that nests in the marsh-coastal ecotone (Ogden et al. 1997). In addition, the South Florida Ecosystem Task Force developed two additional measures for the 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 nesting in mainland colonies to more closely match pre-impoundment 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, ibis/small egrets, and heron 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. The proportion of birds that nest in the southern ridge and slough marsh-mangrove ecotone should be greater than 50 percent of the total for the entire EPA.
- Return to an interval between exceptional white ibis nesting events, defined as greater than the 70th percentile of annual nest numbers (i.e., 16,997) for the period of record. The interval between large ibis nestings in the pre-impoundment period was 1.6 years, which is the target for restoration.
- Return the ratio of nesting wading bird species breeding in the Everglades to 32 breeding tactile foragers (storks and ibises) to each breeding visual forager.

Summary of Nesting Year 2013

As discussed in previous SFERs, the majority of wading bird nesting in South Florida (typically greater than 90 percent) occurs in the Greater Everglades. The information reported in this section represents a compilation of data collected by the District, ENP, University of Florida,

and Audubon of Florida. It should be noted that the population estimates reported are simply the totals of the independent surveys and are not adjusted according to the appropriate significant figures because the precision of each independent survey estimate is unknown. The data 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 by this report is the nesting season from January–July 2013. Further details on independent sampling methods are provided in Cook and Kobza (2012).

Overall, an estimated 35,580 wading bird nests were initiated in the WCAs, ENP, and Florida Bay during the 2013 nesting season. This nesting effort was a moderate improvement on recent years (e.g., 25,284 nests in 2011; 24,191 nests in 2012), the largest total nesting effort recorded since 2009, and similar to the decadal average (34,732.6 nests) (**Figure 6-14**). However, it was 51 percent lower than in 2009, when a record high of 73,096 nests was recorded in the Everglades.

Nesting effort during 2013 varied considerably among species. Wood storks had a good year for nest initiations, with 114 and 61 percent more nests than the ten and five-year averages, respectively. Numbers of great egret and white ibis nests were moderately improved compared to recent years, up 14 and 15 percent, respectively, over the ten-year average, and 19 and 28 percent over the five-year average. By contrast, the smaller herons and egrets, which have exhibited a general decline in nest numbers in recent years, had another relatively poor nesting season. Nesting effort was reduced 76 percent for the snowy egret, 98 percent for the tricolored heron, and 96 percent for the little blue heron relative to the ten-year average. The observed decline does not appear to be due to a change in the distribution of nesting (the spatial extend of ground surveys was extended this year) and instead appears to reflect a general decline in overall nesting effort in the Everglades. Roseate spoonbills had a relatively strong year for nest initiations. For the past two years, this coastal species—which nests primarily in the keys of Florida Bay—has nested in relatively large numbers (>200 nests) at inland colonies in northern WCA-3A. This year, nest numbers were back down to normal for the WCAs (57 nests total), but they increased by about 200 nests in the ENP (360 nests total). In Florida Bay, spoonbill nesting effort (367 nests total) was similar to last year (348 nests), which continues a recent improvement in nesting effort in this region (up 140 percent over the five-year average).

Spatial Distribution and Timing of Nesting

The ENP historically supported the largest number of nests in the Greater Everglades, but in recent decades the majority of nesting has occurred inland in the WCAs. One of the CERP goals is to restore the hydrologic conditions that will reestablish prey production and availability across the landscape that, in turn, will support the return of large successful wading bird colonies to the traditional estuarine rookeries downstream of Shark River Slough. In 2012, the Park supported a relatively large proportion of nests (35 percent), while WCA-3 and WCA-1 supported 46 percent and 19 percent, respectively. This spatial distribution of nests contrasts with the general pattern over the past decade when nesting was concentrated in WCA-1 and WCA-3A, while the ENP was relatively unattractive for nesting (an average of 16 percent of nests over the past decade). Nonetheless, the ENP has become more attractive to nesting birds in recent years, with the proportion of nests increasing to 20 percent and 21 percent in 2006 and 2009, respectively, and then jumping to over 40 percent in 2010. However, the 2013 increase remains below the 50 percent CERP target and may be due to declining nesting conditions in the WCAs rather than a marked improvement in habitat conditions along the marsh-mangrove ecotone.

Wood storks initiated nesting in mid-January 2013. This is an improvement on last year when most storks delayed nesting until mid-March, but it falls short of the January CERP target. Nesting start dates for other species were consistent with recent years.

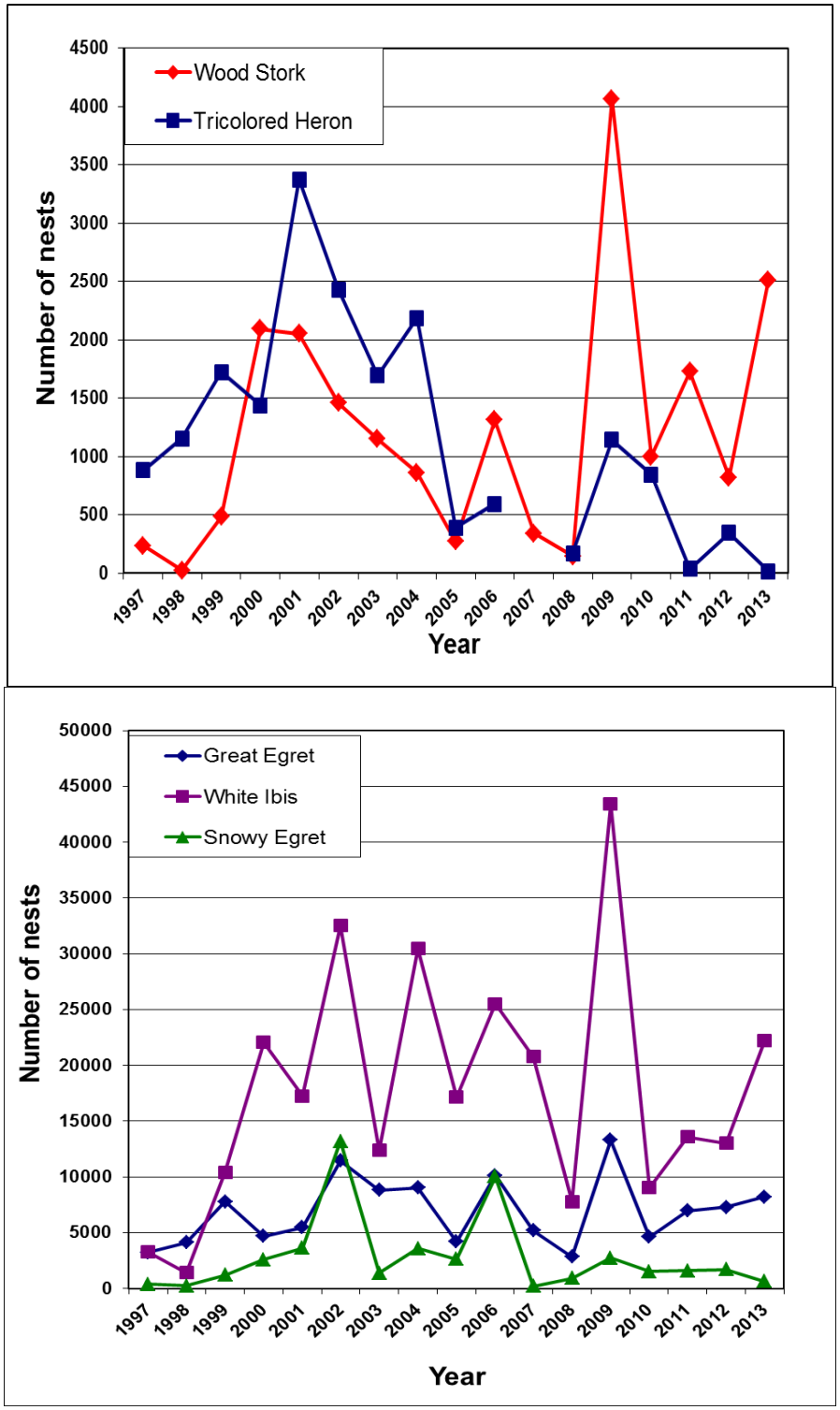

Figure 6-14. Historical wading bird nesting numbers in the Everglades for individual species since 1997.

Nesting Success

Nesting success was generally poor for most species in 2013 relative to previous years. This was certainly the case in the WCAs, where overall nest success (P; the probability of fledging at least one young, Mayfield method) was at the low end of the range for all species studied: great egrets: P=0.16, SD=0.04, n=92; white ibis: P=0.19, SD=0.04, n=72; and tricolored herons and snowy egrets combined (small herons): P=0.24, SD=0.06, n=42. Wood storks were the exception, as this species was largely successful in the WCAs and the Tamiami West colony in the northern ENP (P=0.5, SD=0.11, n=36), with most nests fledging young. However, stork nesting success was probably lower in the southern colonies of the ENP, where the presence of under-nourished, dead, or missing young suggested that the probability of fledging young was relatively depressed. In Florida Bay, roseate spoonbill nests were relatively successful, fledging on average greater than one chick per nest.

Role of Hydrology on Nesting Patterns

Wading bird reproductive patterns in South Florida are driven largely by hydrology through its influence on aquatic prey production and its vulnerability to predation (Frederick et al., 2009). The 2013 breeding season was preceded by wetter-than-average conditions during the WY2012 dry season and WY2013 wet season. This resulted in water remaining above ground for relatively extended periods of time across large areas of the Everglades, with the effect of promoting small fish production (Trexler et al., 2005). Prior to this time, the WY2011 dry season was much dryer than average such that water levels dropped below ground level across much of the Everglades. This drying is thought to promote crayfish production in subsequent years via predator release or nutrient pulse mechanisms (Frederick and Ogden, 2001; Dorn et al., 2011). These long-term hydrologic mechanisms driving prey production likely resulted in relatively large populations of prey species for wading birds during the 2013 breeding season. Increased fish and crayfish production possibly account for the observed increase in nesting effort by early nesting piscivorous species such as the wood stork and great egret and invertivorous white ibis. With regard to prey vulnerability, recession rates and water depths were generally conducive to wading bird foraging from January through mid-February in WY2013, but several heavy rainfall events in February and early April promoted large-scale, water-level reversals, dispersing concentrated prey. This probably accounts for the high level of nest failures and abandonment in many colonies in the Everglades this year. Moderate numbers of wood storks and great egrets abandoned during incubation shortly after water level reversals in February and April. White ibis, which typically start nesting in March, suffered almost complete colony abandonment at a number of colonies—of approximately 8,000 white ibis nest at Alley North colony in WCA-3A, 93 percent had failed by May 2.

Targets

Three of the four species groups met the numeric CERP nesting targets (three-year running averages) (**Table 6-3**). The two other CERP targets for the Everglades restoration (an increase in the number 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 show the requisite improvement in the timing of wood stork nesting or a sufficient shift of colony locations to the coast. Regarding the annual stoplight targets, the interval between large ibis nestings has been achieved in 9 of the last 10 years. The 2013 ibis nesting did reach the criterion (>16,977 nests), and the interval averaged over the last five years is 1.6 years, almost exactly the same as in the 1930s. However, the ratio of tactile to visual foragers was only 3.5, an order of magnitude less than the restoration target (32).

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

Species	2002-2004	2003-2005	2004-2006	2005-2007	2006-2008	2007-2009	2008-2010	2009-2011	2010-2012	2011-2013	Target
Great egret	9,656	7,829	8,296	6,600	5,869	6,956	6,774	8,303	6,296	7,490	4,000
Snowy egret/ Tricolored heron	8,079	4,085	6,410	4,400*	3,778	1,723	2,442	2,622	1,004	716	10,000-20,000
White ibis	24,947	20,993	24,926	21,133	17,541	23,953	20,081	22,020	11,889	16,282	10,000-25,000
Wood stork	1,191	742	800	633	552	1,468	1,736	2,263	1,182	1,686	1,500-2,500

INTER-HABITAT MOVEMENTS OF CRAYFISH DURING EXPERIMENTAL WATER-LEVEL RECESSION AT LILA

In the ridge and slough landscape of the Everglades, aquatic fauna respond to seasonal drying by moving from higher to lower elevation habitats where they become spatially restricted (Kushlan, 1976), often at densities (per unit surface area) orders of magnitude greater than at high water (Kahl, 1964). This concentrating effect provides the foraging conditions necessary to support large populations of predatory vertebrates (Frederick et al., 2009). Modifications to historical hydrologic conditions (Light and Dineen, 1994) have effected critical changes in these seasonal movements, which in turn are thought to have played a major role in the reduction of wading bird nesting populations (Ogden, 1994). Recent studies have advanced our understanding of the hydrologic and habitat features needed to restore the availability of aquatic fauna for wading birds (e.g., Gawlik, 2002; Lantz et al., 2010), but these did not examine faunal movements per se and they focused on species that lack physiological adaptations to loss of surface water (i.e., small-bodied fishes). Little is known about the movements of crayfish, which can physiologically tolerate periods of drying and potentially exhibit a wide range of behavioral options to drying conditions.

The slough crayfish (*P. fallax*) often represents a substantial proportion of the aquatic faunal biomass (e.g., mean±s.d. biomass ranges from 0.08±0.26 to 10.3±5.1 g wet weight m^2 in WCA-2A; Hagerthey et al., in review) and is an important dietary constituent of a variety of vertebrates (Robertson and Frederick, 1994). As it can burrow in peat substrates and survive for up to two months without surface water (Dorn and Volin 2009), it may not be constrained to move to longer hydroperiod slough habitats during the dry season, and it is unclear from available studies that it concentrates like small-bodied fishes and shrimp (Jordan et al., 2000). Nonetheless, *P. fallax* dominates the diet of the white ibis (Dorn et al., 2011), a focal wading bird species for current restoration efforts (Frederick et al., 2009) that requires relatively high densities (concentrations) of aquatic animals in shallow, open water habitat for effective foraging (Gawlik, 2002). Moreover, burrowing does appear to carry a cost for *P. fallax* in terms of weight loss and reduced growth and mortality (Dorn and Volin, 2009), suggesting that individual fitness might be improved during dry conditions by inter-habitat movements to aquatic refugia. The research team therefore designed an experiment to detect evidence of a hydrologic concentrating mechanism for *P. fallax* in the Everglades ridge and slough landscape.

The experiment was conducted in the four replicated wetlands of LILA. If a hydrologic concentrating mechanism is operating for *P. fallax*, then the predictions are that crayfish abundance would increase in sloughs relative to ridges in wetlands that underwent a simulated

water level recession, but remain unchanged in control wetlands where water levels did not decline.

Methods

The experiment was conducted from April 27 to May 18, 2005. It was centered around the relatively shallow slough of each of the four LILA wetlands, which contain two alligator holes, approximately 55 and 80 centimeters (cm) deeper than the slough, and is bordered by a wide and narrow ridge, both approximately 40 cm higher than the base of the slough (**Figure 6-15**).

Crayfish movement between habitats was quantified in terms of changes in relative abundance and by mark-release-recapture. Galvanized steel Gee minnow traps baited with fish were used to sample crayfish. Three groups of traps (hereafter trap groups) were placed linearly across the ridge and slough landscape perpendicular to the longitudinal axis of the habitats, such that a single trap group was placed in each of the wide ridge, the narrow ridge, and either the slough or alligator hole. This set-up was replicated ten times down the length of the landscape (**Figure 15a**). Each trap group was comprised of four minnow traps.

In two wetlands (hereafter recession wetlands), a constant rate, 60-cm water level decline was simulated over a 14-day period and crayfish movements were examined between ridges and sloughs at three water-level stages of the recession: (1) deep on the ridges at day 2 [4.8 meters (m) National Geodetic Vertical Datum [NGVD], hereafter the high stage), (2) shallow on the ridges at day 8 (4.5 m NGVD, hereafter the intermediate stage), and (3) dry on the ridges at day 14 (4.2 m NGVD, hereafter the low stage). In two control wetlands, crayfish movements were examined at the equivalent three junctures but here the deep stage was maintained throughout the 14-day period (day 2, 4.8 NGVD, hereafter the control–high stage; day 8, 4.8 NGVD, hereafter the control–intermediate stage; and day 14, 4.8 NGVD, hereafter the control–low stage; see **Figure 15b** for treatment stages relative to habitat elevation).

During retrieval of traps all crayfish were enumerated, identified by species and released at the site of capture. On the initial trapping day (day 2) every crayfish was marked according to the habitat where it was captured (wide ridge, narrow ridge, or slough) by clipping the telson and uropods in one of three unique patterns. During subsequent trapping days (days 8 and 14) all recaptured individuals were documented.

To determine whether crayfish abundance differed within and between habitats over time due to the depth treatments a Doubly Multivariate Repeated Measures model was employed using the Proc Mixed Procedure (SAS 9.0, SAS Institute Inc.). This multivariate approach was chosen because the movement of crayfish between ridges and sloughs is expected to be correlated over time: i.e., as crayfish leave one habitat they enter the other one. For the habitat variable, data from the two ridge habitats was combined into an overall ridge habitat level, and data from sloughs and alligator holes was combined into an overall slough habitat level. The grouping factors in the model were treatment (control and recession), habitat (ridge and slough), and wetland nested within treatment, and the repeated measures was time (sampling days 2, 8, and 14). Wetland was treated as a random factor. Mean number of crayfish caught per trap in each trap group for each habitat were the multiple response variables. Kronecker products of an unstructured covariance matrix were used to model the covariance across the multivariate observations and a first order autoregressive covariance matrix was used to model the covariance across time. The Kenward-Roger adjustment was used to calculate degrees of freedom (SAS Institute Inc., 2004). The focal interaction term in the model was the wetland(treatment)*habitat*time interaction. This tests for differences in abundances between the habitats over time as a function of the water depth treatment. If this interaction was significant ($P < 0.05$), i.e., demonstrating a significant habitat*time interaction in at least one of the treatments, univariate F-tests were employed to examine the habitat*time interaction within each treatment. CONTRAST statements

were then used to compare crayfish abundances between and within the two habitat types. The movements of marked individuals between habitats were examined with exact cumulative binomial probability.

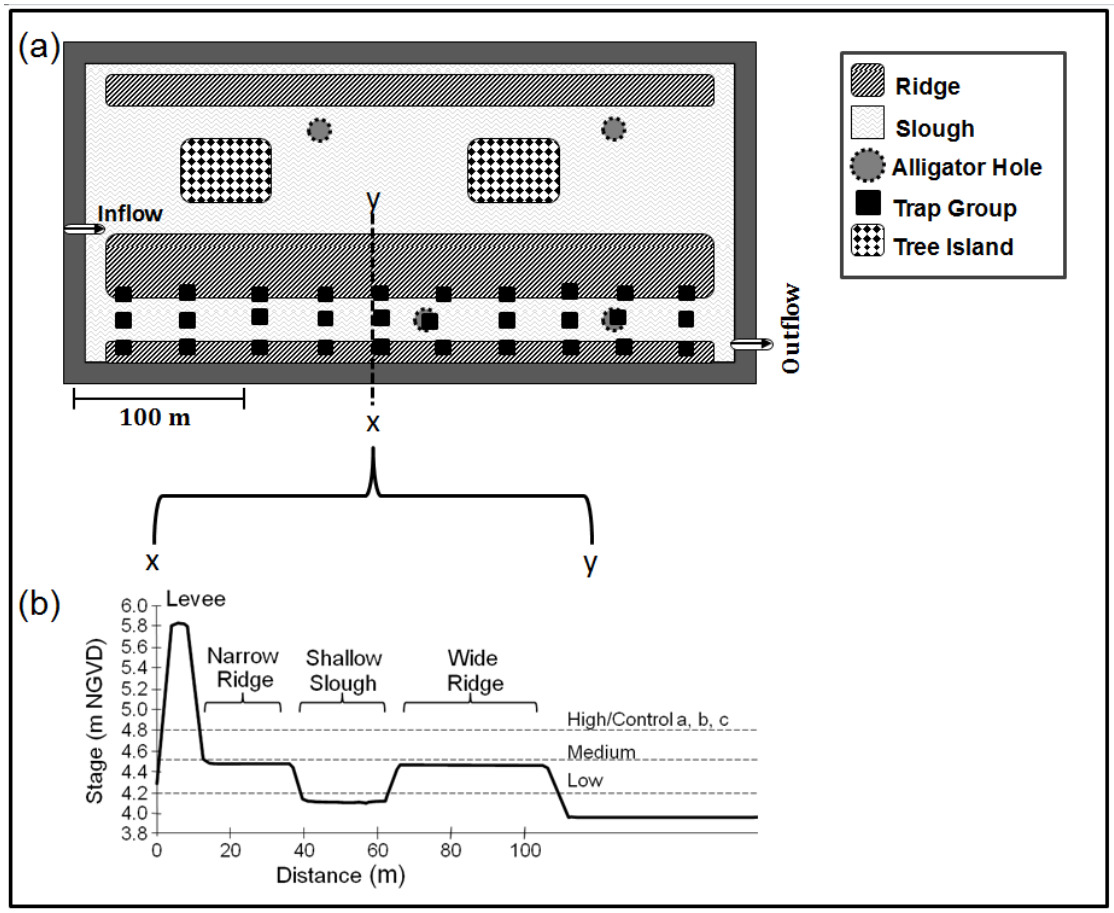

Figure 6-15. (a) Diagram of a single wetland impoundment of the LILA experimental complex showing approximate placement of ten rows of trap groups (four traps per group) within the ridge and slough landscape. (b) Cross-section of the LILA ridge and slough landscape (x to y) in relation to water level stage in meters (m) National Geodetic Vertical Datum (NGVD). Finely dashed lines refer to treatment water level stages in the recession (high stage 4.8 m NGVD, intermediate stage 4.5 m NGVD, low stage 4.2 m NGVD), and control (control high, intermediate and low, each 4.8 m NGVD) wetlands.

Results and Discussion

All model effects were significant including the focal wetland(treatment)*habitat*time interaction ($F_{4, 3.37}$ = 86.5, P = 0.001), indicating a significant habitat*time interaction in at least one of the treatments. Further analyses (F-tests) reveal that crayfish abundance significantly changed between habitats over time in the recession wetlands ($F_{5, 3.37}$ = 106.73, P = 0.0007) but not in the controls ($F_{5, 3.37}$ = 0.14, P = 0.973; **Figure 6-16**).

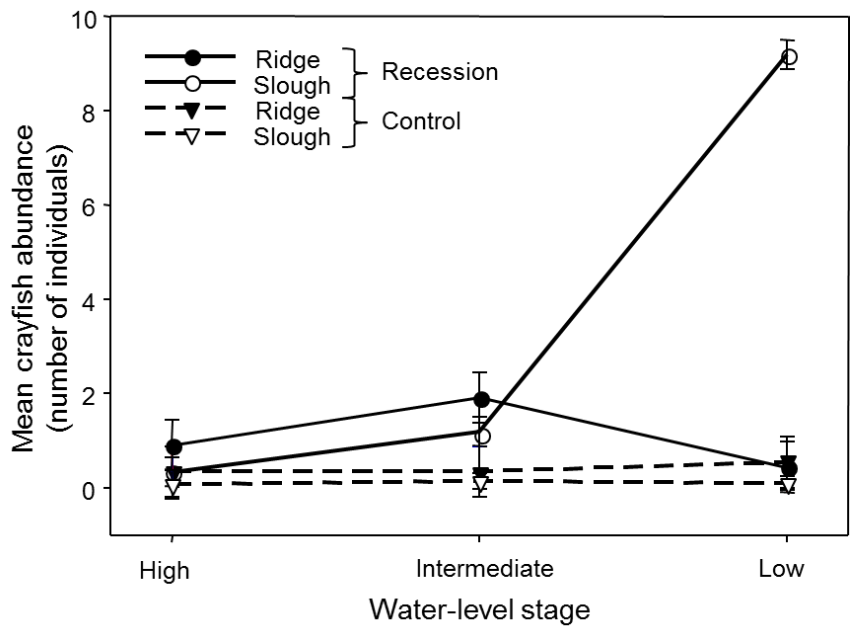

Figure 6-16. Mean number of slough crayfish (*Procambarus fallax*) per minnow trap on ridges and in sloughs for the control and recession wetlands in relation to water level stage treatment. Water level stages are high (4.8 m NGVD), intermediate (4.5 m NGVD), and low (4.2 m NGVD) for the recession treatments, and control−high, control−intermediate, and control−low (4.8 m NGVD) for the control treatments. Error bars represent ± 1 standard error.

In the recession wetlands at the high stage, crayfish abundance on the ridges was similar to that in the sloughs ($F_{1, 3.29}$ = 1.61, P = 0.287). After water levels dropped to the intermediate stage and depths became relatively shallow on the ridges, abundances in both habitats increased slightly relative to the high stage, although not significantly so (slough: $F_{1, 2.75}$ = 7.27, P = 0.08; ridge: $F_{1, 5.88}$ = 2.53, P = 0.164), and abundances remained similar between the two habitats ($F_{1, 3.29}$ = 2.58, P = 0.199). After the final decline in water level and the loss of water from the ridges at the low stage, abundances decreased on the ridges (by 77 percent from intermediate to low stage: $F_{1,5.88}$ = 5.43, P = 0.05) and considerably increased in the sloughs (by 668 percent from intermediate to low stage: $F_{1,2.75}$ = 630.25, P < 0.001). Crayfish abundance was considerably greater in the sloughs than on the ridges ($F_{1,3.29}$ = 377.49, P = 0.0002) at the low stage.

Crayfish abundance in the control wetlands was similar in ridges and sloughs during the initial sampling event (control−high stage: $F_{1, 3.29}$ = 0.37, P = 0.581; **Figure 6-16**), but unlike the recession wetlands this inter-habitat similarity was maintained during the two subsequent sampling events (control−intermediate stage: $F_{1, 3.29}$ = 0.20, P = 0.682; control−low stage: $F_{1, 3.29}$ = 0.97, P = 0.391). Moreover, there was no change in abundance within habitats among the

sampling periods, either on the ridges (control−high versus control−intermediate: $F_{1, 5.88} = 0.01$, $P = 0.99$; control−intermediate versus control−low: $F_{1, 5.88} = 0.09$, $P = 0.77$), or in the sloughs (control−high versus control−intermediate: $F_{1,2.75} = 0.06$, $P = 0.83$; control−intermediate versus control−low: $F_{1, 2.75} = 0.02$, $P = 0.89$).

In the recession wetlands at the high stage, researchers marked 145 crayfish from the ridges and 25 from the sloughs. At the intermediate stage, staff recaptured 15 of these marked individuals. Twelve of these were initially marked from the ridges and all 12 were recaptured on the ridges ($P = 1.0$), suggesting no movement from ridges to sloughs. The remaining three were initially marked from the sloughs and all three were recaptured in the sloughs ($P = 1.0$), suggesting no movement from sloughs to ridges. At the low stage, staff recaptured a further 12 individuals: ten of these were marked from the ridges and all were recaptured in the slough ($P < 0.001$), suggesting movement from ridges to sloughs; and of the two marked from the sloughs, one was recaptured in a slough and one was recaptured on a ridge (small sample size precludes analysis).

In the control wetlands during control−high stage, staff marked 56 crayfish from ridges and five from sloughs. During control−intermediate stage, six of those marked from ridges were recaptured on ridges and none were recaptured in sloughs, and of those marked from sloughs, one was recaptured in a slough and none were recaptured on ridges. During control−low stage, three crayfish marked from ridges were recaptured on ridges and none were recaptured in sloughs, while of those marked from sloughs none were recaptured in either habitat.

Both the abundance and mark-release-recapture results indicated that the simulated water level recession prompted a large-scale movement of crayfish from ridges to sloughs, resulting in a considerable increase (668 percent) in their abundance at depths that are sufficiently shallow for foraging by the majority of wading bird species in the Everglades. Water level recession therefore appears to be an important mechanism for promoting the availability of this crayfish species for wading birds. This recession-based mechanism for promoting crayfish availability appears to be similar to that for other small wetland species such as small fishes, which have been the primary focus of wading bird prey studies (e.g., Gawlik, 2002). However, the observed elevated abundances of *P. fallax* in relatively deep water (~ 20 cm) in both this study and Kushlan (1979) suggest that crayfish may be exploited by birds at greater depths than during the shallow-water concentration events considered optimal for fish availability. This idea is afforded support by a recent four-year study of the diets of nestling white ibises in the northern Everglades, which were dominated by *P. fallax* over a wide range of forging depths, while fish were consumed disproportionately only rarely during relatively very dry conditions (Dorn et al., 2011; Boyle, et al., 2012). Further, this reliance on *P. fallax* occurred during two of the most successful ibis nesting seasons (2006 and 2009) in recent decades (Herring et al., 2010b, 2011), suggesting that crayfish concentration events at the depth reported in this study can be of sufficient magnitude, both spatially and temporally, to fuel large and successful colonies of nesting wading birds.

Relevance to Water Management

Understanding the strong linkages among hydrologic patterns, aquatic prey populations, and wading bird reproductive success is a critical CERP objective and essential for operational management. Our results suggest that the interaction between topographic variation and seasonal water-level recession is the primary driver of *P. fallax* movement, and restoring this process is critical to how they become seasonally concentrated and accessible to white ibises and other wading birds in the Everglades. Promoting such movements will require restoring historical flow rates and hydroperiods over the long-term to reestablish elevational differences between ridges and sloughs (see Sklar et al., 2002), as well as managing for appropriate depths and recession rates during the nesting season.

PREY BASE OF THE FLORIDA BAY SALINITY TRANSITION ZONE

Introduction

Audubon of Florida's Tavernier Science Center maintains an extensive network of stations across the mangrove ecotone in wading bird foraging areas in southern ENP (**Figure 6-17**). At these sites, hydrologic data are collected continuously (salinity and water level), submerged aquatic vegetation (SAV) surveys are conducted every other month, and prey-base fish are sampled eight times per year. The period of record for some stations extends from WY1991 to the present, while others were initiated in the last decade. SAV and small prey-base fish are good ecological indicators because they serve as important links in the transition zone food web, reflect site specific environmental conditions, and have relatively short generation times compared to higher trophic level organisms. These qualities allow them to demonstrate a response to hydrologic and habitat conditions in a timeframe appropriate for water management.

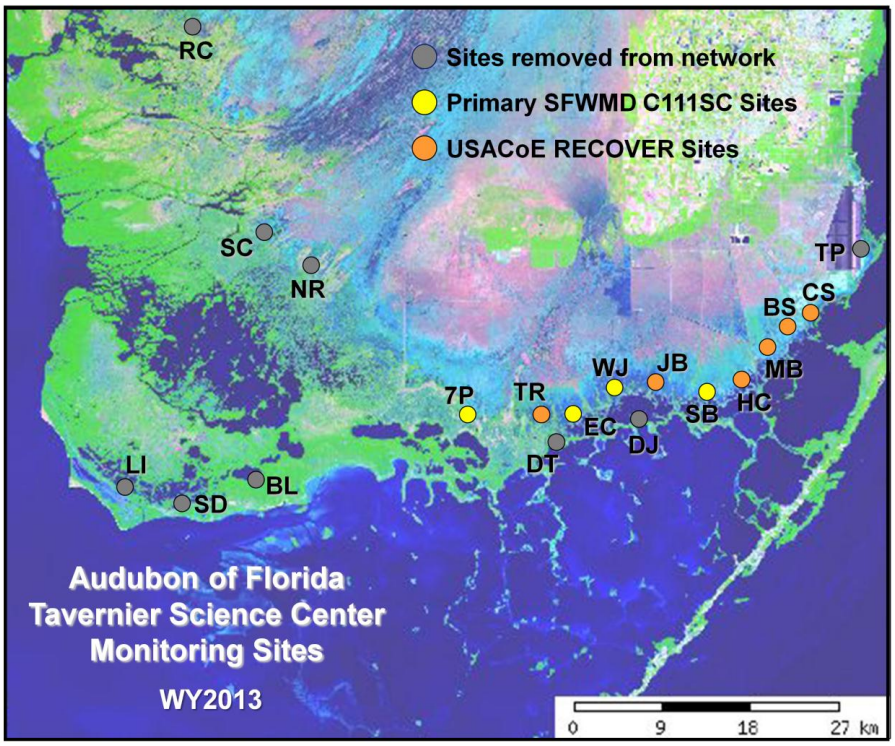

Figure 6-17. Audubon of Florida's prey base monitoring stations.
[Note: C111SC – C-111 Spreader Canal, RECOVER – Restoration Coordination and Verification, USACoE – United States Army Corps of Engineers.]

Methods

Details on the methods used to sample mangrove fish communities can be found in Lorenz et al. (1997). Audubon's sampling measures the number of fish in relation to the size of the wetland (fish abundance) and the concentration of fish as the inundated area of the wetland fluctuates due to the rising and lowering of water levels (fish availability). Fish abundance is calculated using a weighted stratified mean (Snedecor and Cochran, 1968) where each collection is weighted by the percent of potential flooded sub-habitat (creek or flats) that is actually inundated at the time of

sample collection, thus correcting for the concentration effect of fluctuating water levels. Collected fish samples are frozen while they wait to be processed. Due to the extensive time required to process samples, only provisional results from semi-annual reports provided by Audubon staff to the SFWMD are reported herein.

Results

The latest prey fish data available were from WY2012, with unvalidated results described from semi-annual reports provided to the SFWMD. Results from fish samples in WY2012 revealed an increase in the relative abundance of mesohaline fish concurrent with a decrease in the relative abundance of freshwater fish (**Figure 6-18**). This pattern was observed throughout the transition zone and included sites in the Taylor Slough and the C-111 basins. Lower representation of freshwater fish is associated with decreased biomass in the fish community as a whole (Lorenz and Serafy, 2006). Although the proportion of freshwater fish at the three sites with the longest period of record (TR, JB, HC) was approximately 15 percent in WY2011, it fell to less than 1 percent in WY2012. These values are much less than the proportions observed in the mid 1990s (~35 percent). Decreased representation of freshwater fish may be due to the lack of multi-year wet periods necessary to produce a freshwater community composition (Lorenz and Serafy, 2006).

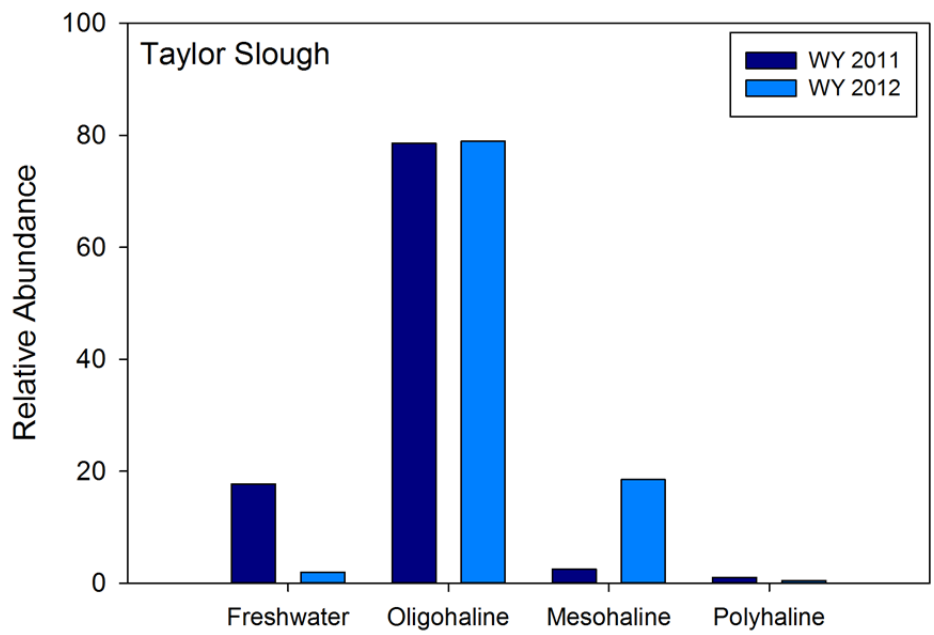

Figure 6-18. Relative fish abundance by salinity category. Fish were assigned to salinity categories based on the classification in Lorenz and Serafy (2006): freshwater (0–0.99), oligohaline (1–4.99), mesohaline (5–17.99), and polyhaline (18–30).

Semi-annual reports from Audubon indicate that above average water levels and below average salinities led to above average fish abundance in the first half of WY2013 (Audubon, 2012). In addition, the majority of fish collected were generally associated with oligohaline conditions (< 5). Water levels remained persistently high well into the dry season. As a result, below average fish densities were observed. This has negative implications for wading birds because successful foraging depends on the seasonal drying patterns to produce a water level drawdown that concentrates fish and makes them more available to birds. The reports also

describe a steady increase in the abundance of exotic fish species due to a lack of cold temperatures in the transition zone over the past two water years (Audubon, 2013). By the end of the water year, large schools of invasive cichlids were observed in the Taylor Slough and eastern C-111 watersheds.

Relevance to Water Management

Monitoring of the prey base of the Florida Bay transition zone by Audubon is supported by the District in order to assess responses to ongoing operations and the C-111 Spreader Canal Western Project. Water management in southern ENP has generally been concerned with keeping salinity low through the early dry season, facilitating a slow water level recession in the wetlands, and preventing water level reversals. However, achieving these targets is particularly challenging when the local watersheds receive much greater than normal direct rainfall (see the *Florida Bay* subsection in the *Hydrologic Patterns for Water Year 2013* section).

PLANT ECOLOGY

Mike Ross[1], J.P. Sah[1], Susana Stoffella[1],
Eric Cline and Thomas Dreschel

Plant studies form an important basis for evaluating restoration success. This section evaluates the effects of hydrology on ridge and slough vegetation community development in LILA. An evaluation of the effects of hydrology and substrate on tree survival and growth on constructed tree islands in LILA is also presented.

RIDGE AND SLOUGH VEGETATION RESPONSES TO HYDROLOGY AT LILA

Introduction

A fundamental purpose of the LILA facility is to provide a platform to gather information that can be applied to restoration of the ridge and slough landscape. This landscape is represented in much of the Everglades by slender, elongated sawgrass-dominated ridges; open sloughs featuring floating-leaved plants, arranged in a complex pattern in inter-ridge areas; and raised forest patches (tree islands) dotting the landscape, especially at the upstream ends of the largest ridges. In 2010 a program was initiated to monitor changes from the engineered landscape arranged in rectangular patches in 2003 to a landscape in which natural processes begin to impose themselves, based primarily on biotic and abiotic responses to the managed hydrologic regime. The objective of the study is to determine if changes in LILA landscape pattern will increasingly manifest as responses to water level and flow, as historical factors become less important.

Below, the changes in vegetation between the initial sampling in 2009 and the one repeated in 2012 are compared by documenting the distribution of vegetation types and species within the LILA landscape and by establishing their relationships with hydrologic conditions. This analysis will help water managers establish a link between hydrologic management and the historical trajectory of landscape patterning (i.e., loss of sloughs to expanding ridges) in the Greater Everglades. Eventually, it is hoped that ecologically based water management can restore the ridge and slough pattern that characterized the pre-drainage Everglades.

Methods

Marsh Sampling

Between December 2009 and January 2010, the ridge and slough marsh vegetation within each macrocosm was sampled using a stratified random design based on the proportional coverage of ridges and sloughs within each unit. The sampling was repeated in September 2012. Forty permanently marked sampling points were established per macrocosm using a global positioning satellite. At each point, a 1-square-meter plot was established. The vegetation contained within each plot was identified to species and cover class was estimated using a modified Braun-Blanquet scale. Water depth was measured for each plot in 2009–2010 and 2012.

Data Analysis

Ridge and slough vegetation data were analyzed using ordination, and vegetation-hydrology relationships were interpreted and compared between the initial sampling year 2009 and 2012. Species abundance was calculated as the mid-point of the cover classes, and then relativized to the maximum coverage for the species in any plot. Plots with total species cover <10 percent were not included in the analysis. Cluster analysis was therefore performed on a data matrix of 152 sites by 47 species in 2009, and 145 sites by 39 species in 2012. Bray-Curtis dissimilarity was used as the distance measure, coupled with the flexible beta (-0.25) linkage (McCune and Grace, 2002). The classification units were defined as those that emerged with 50 percent of the information accounted for and were named from one or more dominant species. Non-metric multidimensional scaling ordinations were generated separately from the 2009 and 2012 data. Analysis of similarity (ANOSIM) was used to examine the significance of differences in floristic composition between 2009 and 2012. Analysis of variance (ANOVA) was used to analyze differences among groups characterized by different water depth in both years.

Results

In the LILA ridge and slough landscape, 39 plant species, representing the gamma-diversity of the site, were recorded in 2012; this assemblage was 8 species less than observed within plots in 2009 (**Table 6-4**). Twelve species recorded in 2009 were not found in 2012 and four species were recorded for the first time in 2012, however these new species are not shown in **Table 6-4** as only plants found at more than 2 percent of cover are reported. Species richness (alpha-diversity, i.e., number of species per plot) was statistically different in the two years (4.0 ± 1.9 in 2009 and 3.1 ± 1.5 in 2012, ANOVA $F_{1,296} = 8.874$, $p < 0.01$).

Species composition in the landscape as a whole differed significantly between years (ANOSIM; 1,000 permutations, R = 0.03, p-value = 0.01). Vegetation in the LILA marsh was arranged in 6 vegetation associations: (1) sawgrass (*Cladium mariscus ssp. jamaicense*) marsh, (2) maidencane (*Panicum hemitomon*) marsh, (3) maidencane-broadleaf arrowhead (*Sagittaria lancifolia*) marsh, (4) spikerush (*E. cellulosa*) marsh, (5) spikerush (*E. elongata*) marsh, and (6) chara (*Chara* spp.)-open marsh. These groups could roughly be included in two landscape units, with Associations 1–3 representing ridge vegetation as expressed at LILA, and Associations 4–6 representing LILA sloughs. The major ridge and slough associations differed clearly in hydrology, but the two most common ridge units did not. For instance, in 2009, sawgrass marsh and maidencane marsh experienced mean water depths that were roughly the same, i.e., 31.3 cm and 27.9 cm, respectively (**Figure 6-19**). In contrast, the mean (± 1 standard deviation) annual water depth of spikerush marshes was 56.9 (±16.3) cm during the same year. The same pattern was observed in 2012 when the mean annual water depth in the sawgrass marsh and maidencane marsh were 74.6 cm and 74.7 cm, respectively, and was 98.2 (±11.5) cm in spikerush marshes in the sloughs. The difference in mean annual water depths between the two years was in part a function of high water conditions in the fall of 2012, brought about by several high rainfall events

in combination with damage to the pump that impacted the ability to manage water levels within the LILA cells.

Table 6-4. Major (>2 percent cover in at least one year) plant species in 2009 and 2012.

Species	2009 Species Frequency % N=157	2012 Species Frequency % N=150
Acrostichum danaeifolium	1.91	3.33
Boehmeria cylindrica	2.55	2.00
Cladium mariscus ssp. jamaicense	7.01	8.00
Crinum americanum	4.46	4.00
Cyperus haspan	2.55	2.67
Diodia virginiana	2.55	-
Eleocharis cellulosa	29.94	36.00
Eleocharis elongata	38.85	34.00
Eleocharis interstincta	21.02	14.00
Ipomoea sagittata	5.10	4.00
Justicia angusta	5.10	5.33
Leersia hexandra	12.10	12.00
Ludwigia repens	2.55	0.67
Nuphar advena	5.73	6.00
Nymphoides aquatica	3.82	-
Nymphaea odorata	3.18	6.67
Panicum anceps	10.19	2.00
Panicum hemitomon	50.32	52.00
Paspalidium geminatum	16.56	7.33
Peltandra virginica	4.46	1.33
Polygonum hydropiperoides	16.56	10.00
Pontederia cordata	30.57	39.33
Potamogeton illinoensis	1.91	2.67
Rhynchospora colorata	2.55	1.33
Rhynchospora microcarpa	3.82	3.33
Rhynchospora intermedia	8.28	1.33
Sacciolepis striata	5.73	-
Sagittaria lancifolia	41.40	27.33
Thelypteris interrupta	2.55	2.67
Utricularia foliosa	9.55	3.33
Utricularia gibba	2.55	-
Utricularia purpurea	24.84	11.33
Total number of species	**46**	**38**

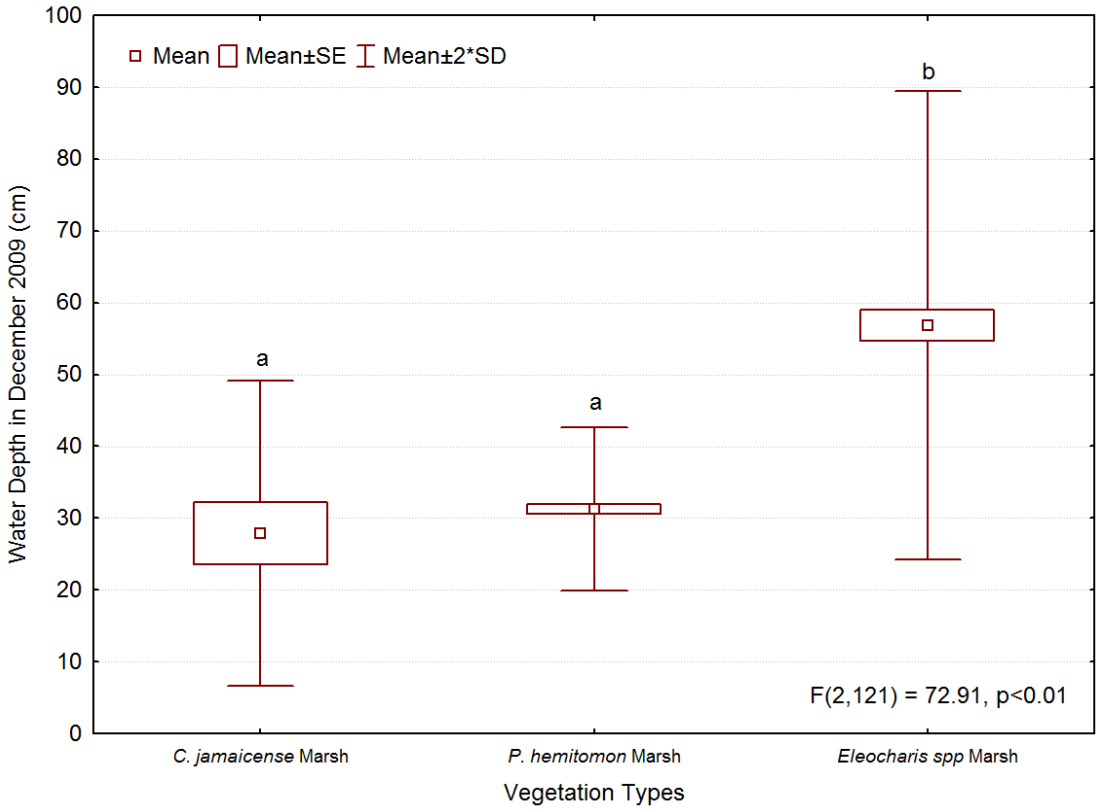

Figure 6-19. Mean water depth associated with three vegetation types present within the LILA ridge and slough landscape in 2009. F- and p-values represent the one-way analysis of variance (ANOVA) test of the effect of vegetation types on mean values of annual water depth. Vegetation types followed by the same letter did not differ at α=.05.

Discussion

The vegetation present in the LILA marsh was engineered as a bi-phasic landscape, and while it continues to maintain ridge and slough phases, intermediate communities are beginning to emerge. More than a decade after initial construction, the LILA marsh now consists of a patchwork of six distinct vegetation associations that are internally homogeneous, with diagnostic species occurrences. Vegetation composition in the ridge and slough phases of the landscape is primarily a manifestation of hydrologic differences; a difference of 25 cm in mean annual water depth distinguishes them. In contrast, the variation in vegetation composition within a landscape unit, particularly on the ridges, is weakly related to the hydrology, as the mean annual water depth did not differentiate between sawgrass- and maidencane-dominated associations. A common pattern was the shared domination of ridge edges by maidencane and narrow leaf arrowhead (*Sagittaria longifolia*), forming a community with mean annual water depth intermediate between ridge and slough, and representing a transition between the two. In the sloughs, emergent vegetation or open water conditions prevailed, with relatively little establishment of water lilies. Emergent communities were primarily dominated by two spikerush species, *E. elongata* and *E. cellulosa*. Similar to the two most common ridge communities, these communities did not differ in mean annual water depth, suggesting that other factors, e.g., site history, soil factors, etc., were determinant.

The young LILA marsh landscape is clearly in a transitional stage in which neighboring patches of distinct plant composition experience the same water regime. This is particularly

notable on the ridges, where sawgrass patches remain a minor accent in a sea of maidencane. This pattern, which has changed little in the last three years, is a legacy of the maidencane-dominated wetland that prevailed prior to the construction of LILA. This is not uncommon in Everglades marshes, where past disturbance events (e.g., fires followed by flooding, sawgrass die-off waves) leave a long-term imprint on the landscape that is not easily erased by water management.

Relevance to Water Management

Monitoring this transition in LILA provides water managers a way to predict how the ridge and slough patterning of the Everglades could respond to hydrologic management as well as other resource management techniques. A combination of prescribed fire and water control may serve as a means of driving vegetation in a desired direction, for instance, increasing the proportion of sawgrass on the LILA ridges. The experimental platform provided by LILA is well-positioned to develop such management techniques.

EFFECT OF HYDROLOGY AND SUBSTRATE TYPE ON TREE SURVIVAL AND GROWTH AT LILA

Introduction

The LILA facility is an experimental wetland constructed at the Arthur R. Marshall Loxahatchee National Wildlife Refuge in Boynton Beach, FL. LILA was created through a partnership between the South Florida Water Management District, the United States Fish and Wildlife Service, and the Army Corps of Engineers. LILA serves as a landscape-scale physical model of the Everglades and allows investigators a precise measurement of the environmental response to restoration strategies, as the hydrology is controlled and other critical processes are replicated. LILA consists of four identical 20-acre (8-hectare) "macrocosms," which were constructed in 2002–2003 from existing impoundments. Each macrocosm contains the key landscape features of the Everglades, including ridges, sloughs and two tree islands. The tree islands are constructed of either solely peat, or of peat with a limestone core.

A mixture of eight tree species was planted on each island in March 2006 and 2007. Each tree island was randomly assigned planting locations within the relatively high interior and the lower surrounding areas separately. The planting arrangement called for ~89 trees of each species per tree island for a total of 5,736.

The objective of the study is to determine how the survival and growth of seedlings of Everglades tree species planted in an experimental setting are affected by hydrology and substrate type. A fuller understanding of these relationships is a critical prerequisite for forest restoration efforts in the Greater Everglades, as well as for creation of new tree islands in areas where they have been lost.

Methods

Stoffella et al. (2010) analyzed the initial effects of hydrology and substrate type on tree growth and survival, through 2.5 years after planting. They detected several important trends in tree survival and growth in developing tree islands: species could clearly be characterized into flood-intolerant and flood-tolerant groups on the basis of early survival and growth, and survival was lower but growth faster on peat-based than limestone-based islands. As discussed below, these trends remained largely the same through five years.

All trees were monitored at two-month intervals during the first year after planting, and every six months thereafter. In the early years of the project, five structural measures were recorded on a representative subset of trees annually—basal diameter, height to crown base, total tree height,

crown length, and crown width—but only tree height was measured on all trees in all years. In order to tie together forest structure and ecosystem function, allometric relationships were developed that allowed prediction of biomass from various combinations of the five variables. The analyses reported below extend the analyses of growth and survival through censuses of all LILA trees completed in March 2011 and 2012.

Logistic and linear regressions were applied to explore the effects of hydrology on species survival and growth in aboveground biomass of planted trees. Both tree survival and growth are reported for five-year periods since planting, corresponding to 2006–2011 periods for M1 and M4 tree islands and 2007–2012 periods for M2 and M3 tree islands. Growth is expressed as absolute growth rate (AGR, in Equation 1), where

$$AGR_{\text{Initial-Final period}} = (\text{final biomass - initial biomass})/\text{time of growth in years}$$

where final and initial biomass estimates are derived from allometric equations on total height.

Hydrology is summarized as relative elevation, i.e., ground elevation in cm above or below the mean surface water adjacent to the island over the period from May 1, 2007–April 30, 2011. Chi-square and ANOVA are used to assess the effects of substrate on species survival and growth respectively. Tests of the effect of substrate type are restricted to trees planted in a high, flat 14-m wide central strip, because this is the only area underlain by limestone in islands of that type.

Results

Trees commonly found on frequently flooded sites in the Everglades (in blue) were generally less sensitive to water level than upland trees (in red) (**Figure 6-20**). Upland species needed to be 20 to 40 cm above mean water surface to have much chance of surviving.

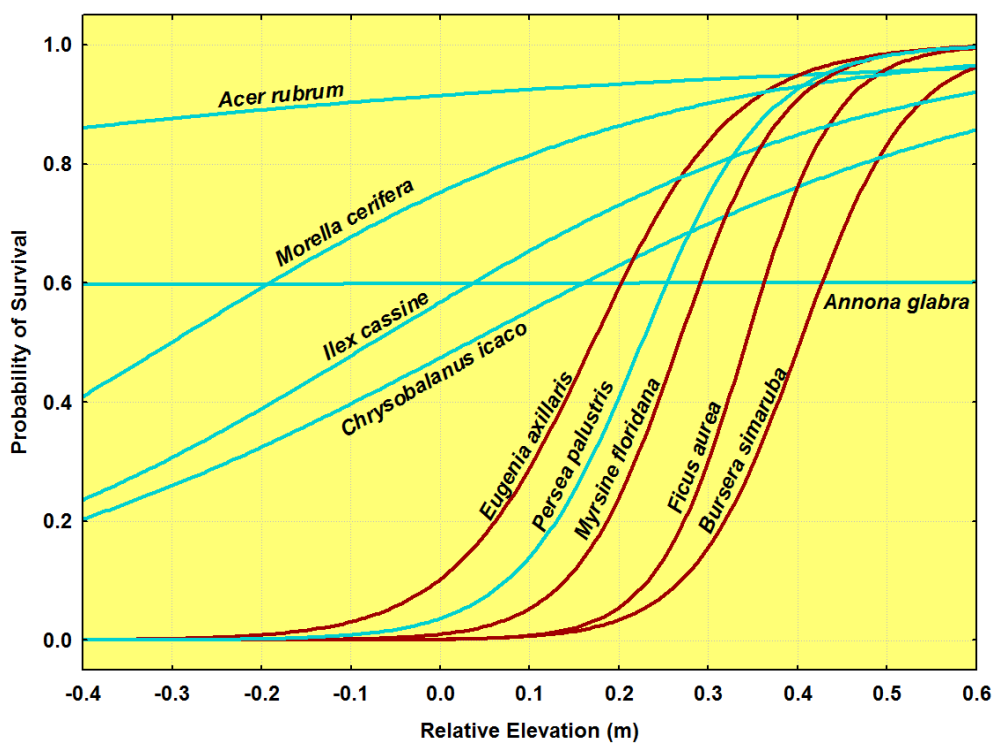

Figure 6-20. Logistic regression functions of all species survival with respect to relative elevation.

Besides the response to hydrology, tree survival showed a response to substrate type. For the majority of species, trees survived better on the limestone substrate (**Table 6-5**). *Myrica cerifera* and *Persea palustris* were the species with highest survival in limestone tree islands. The lowest survival corresponded to *Bursera simaruba* and *Ficus aurea*. Growth responses were broadly opposite to survival responses. Eight of 10 species displayed significant differences in growth on limestone and peat surfaces; all eight grew more rapidly on peat substrate, with differences ranging from ~1.2 to 6 times (**Table 6-5**).

Table 6-5. Tree survival and growth on limestone and peat substrates. [Note: kg – kilogram, NS – not sampled.]

Species	Survival (%)			Growth (kg/year)		
	Limestone	Peat	p-value	Limestone	Peat	p-value
Acer rubrum	83	99	<0.01	0.28	0.59	<0.01
Annona glabra	69	54	<0.05	0.58	0.84	<0.01
Bursera simaruba	43	27	NS	0.23	1.31	<0.01
Chrysobalanus icaco	78	64	<0.05	1.73	2.07	<0.01
Eugenia axillaris	84	75	NS	0.70	0.69	NS
Ficus aurea	60	30	<0.01	0.37	0.63	<0.01
Ilex cassine	86	71	<0.05	0.18	0.28	<0.01
Morella cerifera	94	87	NS	0.64	0.77	<0.01
Myrsine floridana	78	46	<0.01	0.15	0.19	NS
Persea palustris	90	85	NS	0.42	0.64	<0.01

Discussion

Several important trends in tree survival and growth in developing tree islands described in Stoffella et al. (2010) remained largely the same through five years. Tree survival and growth responses along a moisture gradient matched species distribution along natural hydrological conditions in the Everglades and species could clearly be characterized into flood-intolerant and flood-tolerant groups on the basis of early survival and growth. The assignment of species into those groupings can have important implications for both sustaining and restoring tree islands.

Relevance to Water Management

Knowledge of relative species tolerance could be useful in the selection of suitable species assemblages to replant damaged tree islands or to initiate new ones and could have profound implications for the restoration of existing landforms and artificial creation of tree islands. At early stages of development and especially during dry periods, limestone tree islands may provide a more beneficial environment for seedling survival, with less competition than peat tree islands. However, the latter seem to offer better conditions for growth. Nevertheless, both substrate types may be affected by flooding stress so that it becomes critical to anticipate any hydrological modification in that direction to avoid planting failure or tree island loss.

ECOSYSTEM ECOLOGY

Susan Newman, LeRoy Rodgers, Michael Manna, Mark Cook, David Black, Leonard Scinto[1], Alexandra Serna[1], Eric Cline and Thomas Dreschel

The initial narrative in this section focuses on areas of the Everglades that have been severely impacted by nutrient enrichment and presents preliminary results of two new active marsh improvement projects designed to restore ecosystem function to areas currently influenced by cattail (*Typha domingensis*) invasion. The second account describes the effort to develop a carbon budget for LILA.

ACTIVE MARSH IMPROVEMENT PROJECTS

Restoration of phosphorus (P) impacted regions of the Everglades requires not only a reduction in P loads and concentrations, but also active management efforts to reduce the resilience and resistance inherent to the cattail regime (Hagerthey et al., 2008). The Cattail Habitat Improvement Project (CHIP), a large-scale in situ study, successfully demonstrated that active management techniques can successfully rehabilitate slough habitat in cattail areas and create an alternate spikerush-SAV regime. As a result of the CHIP study, three important questions were identified regarding how to actively improve habitat conditions including (1) What are the hydrologic interactions on the vegetation community that facilitate cattail reinvasion? (2) How important is spatial heterogeneity of the habitat and vegetated edges for wading bird foraging? and (3) What is the limitation of using broad spectrum herbicides on vegetation succession?

As noted in last year's report, aerial reconnaissance indicated cattail reinvasion of the CHIP plot exhibited an east-west gradient, with extensive cattail coverage in the two eastern-most plots and less regrowth in the four western-most plots. The Water Depth Assessment Tool mapping of the sites indicated a west-east hydrologic gradient, with western plots experiencing a more rapid and greater degree of dryout, while eastern plots generally experienced longer hydroperiods and deeper water levels. However, before isolating this as the primary driver, it was important to rule out any change in nutrient status. As such, surficial soil and floc sampling were conducted in July 2012 and this verified that there was no east-west gradient in P concentrations and that the similarities in P concentrations between the open plots established during the active study period (2006–2009) were still accurate. Interestingly, during the 2006–2008 period, P concentrations in floc in open plots were greater than control plots, however the significantly lower P concentrations in open versus controls plots in 2012 confirmed a significant decrease in P concentrations observed in 2009 (**Figure 6-21**). This suggests the initial increase in P has been lost and open plots are now potentially accumulating lower concentration soils, likely due to lower storage in SAV versus cattail biomass. This is further supported by a greater concentration of inorganic (hydrochloric acid -extractable) P in open plots compared to controls (data not shown). This suggests that maintaining the habitat from one dominated by cattail to a mix of spikerush and open water/SAV slough can significantly change P cycling. Additional nutrient evaluation on a three- to five-year time frame would hopefully confirm this trend.

Based on the similarities in P concentration, hydrology is the likely driver of the east-west cattail reinvasion (Newman et al., 1996, 1998) and an important consideration in minimizing the amount of herbicide applied and the self-sustainability of habitat improvement strategies. In order to understand how local hydrologic conditions, both flooding and dryouts, influence the interaction between hydrologic stress and herbicide efficacy on cattail, continuously recording

water depth sondes (HOBO™) have been deployed in each open plot and depths and hydroperiods will be assessed throughout the year.

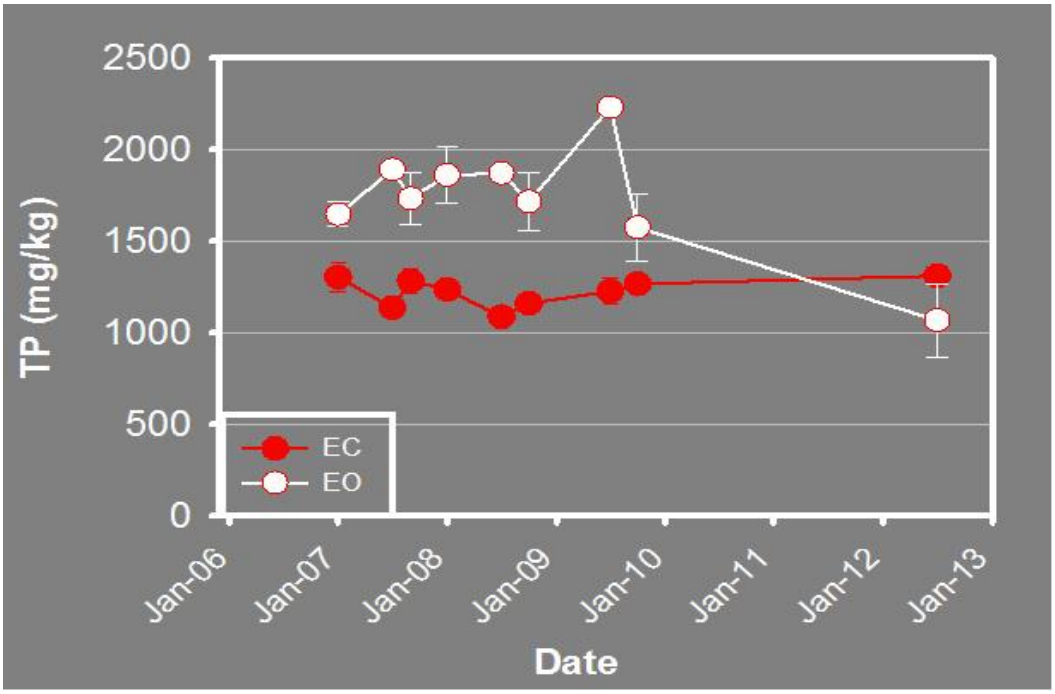

Figure 6-21. Total phosphorus mean ± standard error concentrations in milligrams per kilograms (mg/kg) determined in floc samples collected from Cattail Habitat Improvement Project enriched open (EO) and enriched control (EC) plots in 2006–2009, and most recently in 2012.

In 2011, there was a switch from using glyphosate and imazapyr for CHIP plant management to imazamox. Glyphosate and imazapyr are broad spectrum (i.e., non-selective) herbicides that effectively eliminated all the emergent vegetation and some SAV in the CHIP plots. However, imazamox is a selective systemic herbicide and cattail appears particularly sensitive to it (Rodgers and Black, 2013), thus allowing other desirable emergent species and SAV to continue colonizing the plots. At a rate of 32 ounces per acre [0.28 kilograms acid equivalent per hectare (kg ae ha^{-1}) imazamox provided excellent control of cattail in minimally invaded marsh and slough habitat, with minimal damage to emergent species or SAV (Rodgers and Black, 2013). Imazamox kills plants by binding to and inhibiting the activity of the acetolactate synthase (ALS) enzyme, causing a lethal decrease in the biosynthesis of branched chain amino acids (Shaner et al., 1984). Animals obtain branched chain amino acid from their diets and do not produce ALS, so they are unaffected by the chemical activity of imazamox (Hamel 2012). Human health and ecological risk assessments for imazamox support the conclusion that imazamox is a low-risk herbicide, unlikely to significantly bioaccumulate and is appropriate for some uses in natural areas (SERA, 2010). The greatest potential for environmental impacts is damage to non-target plant species. Therefore, several additional studies, including the optimum application rate and potential damage to native Everglades species not present in the Rodgers and Black (2013) study, needed to be undertaken before broad-scale application of the this herbicide is implemented.

The questions associated with the interaction of herbicide effectiveness and hydrologic conditions on plant growth, and habitat edge contributions to foraging wading birds, were incorporated into the experimental design of two large-scale studies. Because the primary objective was to facilitate landscape recovery/improvement in areas currently impacted by nutrients these projects were called Active Marsh Improvement (AMI). The AMI studies are the (1) ridge and slough landscape restoration study and (2) slough study. The study design and detailed methods are provided in Chapter 6 of the 2013 SFER – Volume I.

AMI-1: RIDGE AND SLOUGH LANDSCAPE RESTORATION STUDY

The large-scale AMI-1 Ridge and Slough Landscape Restoration Study was designed to build upon observations from the CHIP slough restoration study by conducting active marsh manipulation at a scale that encapsulates the larger ridge and slough landscape. The overarching question is: Can active marsh restoration techniques be employed to restore ridge and slough patterning and structure within nutrient enriched cattail areas? Larger plots allow a greater diversity of vegetation and habitats compared to the old CHIP plots such that the vegetation communities and the historical structural patterning of sawgrass ridges and open water sloughs are retained. Within this general framework, wading bird usage and the importance of edges for foraging as well as the significance of the west-east gradient in hydrology that may control the rate and extent of cattail reinvasion can be assessed. It was hypothesized that the rate and extent of cattail invasion would be significantly less in the western versus the eastern plots due to hydrologic stress caused by dryouts.

Methods

Landscape scale openings, two 750-by-750 m plots, were created for the AMI-1 project using the CHIP approach. This approach is a combination of herbicide and burning treatment, with the expectation that because imazamox was used, where CHIP initially used the broad spectrum combination of glyphosate and imazapyr, cattail will be disproportionately impacted allowing desirable vegetation recovery and succession following the burn to occur sooner than observed in CHIP. Plots were aerially sprayed in April 2011 with imazamox at a rate of 0.28 kg ae ha^{-1} and burned January 2012.

Results and Discussion

Aerial reconnaissance of the plots (June 2012, Rodgers and Newman, personal observation) indicated that while there was extensive sawgrass and other species present, both plots had experienced rapid regrowth of cattail. A recent study suggested that herbicide application is the most effective if plants are treated during greatest translocation of carbohydrate reserves to rhizomes (Linz and Homan, 2011). Additionally, in both AMI 2 (see below) and Rodgers and Black (2013) the herbicide treatment was applied later in the year (September/October) during active plant growth and successful cattail control was observed 12 months after treatment (MAT). Therefore, our preliminary conclusion was that rapid cattail regrowth in AMI 1 was due to time of year of treatment. As a result, AMI 1 plots were re-sprayed in January 2013 and aquatic birds and vegetation responses will be documented during and post cattail die-off.

AMI-2: SLOUGH STUDY

The objective of the AMI-slough study was to reduce the extent of the cattail expanse at the leading edge of the nutrient front in WCA-2A, thus 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 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-by-100 m plots, two herbicide treatments (0.21 or 0.28 kg ae ha; 24 and 32 ounces 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. Within each treated and control plot, individual plants representing a broad spectrum of the flora were tagged and rated in terms of herbicide control at 3, 6, and 12 MAT. Percent cover and species composition were assessed within 0.5-by-2 m quadrats in six ridge and six slough sampling sites in each plot.

Results and Discussion

At 3, 6, and 12 MAT each tagged plant was revisited and ranked according to the degree of herbicide damage. Herbicide damage ranking ranged from alive (normal growth with no visible phytotoxic effect), re-sprout/healthy (defoliated with healthy re-sprout), alive/injury (herbicide damage evident but plant alive) to dead (only dead leaves/cambium observed). Results from 12 MAT are presented in **Table 6-6**. These data indicate that cattail and arrowhead were the most sensitive to the herbicide treatments, with 74 and 45 percent death, respectively, in the highest dose. Logistical regression analysis on the effects of treatment on cattail indicated that Pr > ChiSq = 0.007, therefore overall the treatments--control, 0.21 and 0.28 kg ae $ha^{-1}$are significantly different. The odds ratios for control versus 0.21 kg ae ha^{-1}, control versus 0.28kg ae ha^{-1}, and 0.21 versus 0.28 kg ae ha^{-1}, were 32.49, 35.74 and 0.91, respectively. This indicates that control plants were 32 and 36 times more likely to be alive than plants in the 0.21 and 0.28 kg ae ha^{-1} treatments, while plants in the two herbicide doses had the same probability of being alive. For most other species, we were unable to meet the data assumptions to conduct the analyses.

Table 6-6. Evidence of herbicide damage on cattail and other more desirable native species observed 12 months after treatment. Values are percentage of tagged species.

	0.21 kg ae ha^{-1}			0.28 kg ae ha^{-1}		
Species	**Alive***	**Injury**	**Dead**	**Alive**	**Injury**	**Dead**
Cattail	31		69**	13	13	74
Muskgrass	100			80		20
Sawgrass	100			93	7	
Spikerush[1]	100			100		
Fragrant water lily	100			83		17
Arrowhead	100			55		45
Coastal plain willow	100			100		
Leafy bladderwort[2]	100			86		14

[1]*Eleocharis cellulosa*, [2]*Utricularia foliosa*.

*Alive = combination of alive + resprout/healthy.

** Cattail responses are significantly different for all treatments

The 12 MAT assessment of herbicide efficacy and plant community response also showed that, in general, those species exhibiting injury at 6 MAT had recovered by 12 MAT. For example, sawgrass, spikerush, arrowhead and coastal plan willow exhibited 21, 8, 8, and 38 percent injury, respectively, at a herbicide rate of 0.28 kg ae ha^{-1}, at 6 MAT, compared to 7 percent for sawgrass and zero for other species at 12 MAT. As expected, percent dead generally remained similar for most species, with the exception of cattail, which showed evidence of recovery from 6 to 12 MAT. Alive percent cattail increased from 24 to 31 percent at 0.21 kg ae ha^{-1} and from 0 to 13 percent at 0.28 kg ae ha^{-1}.

The proportional change in percent cattail cover from initial to 12 MAT was analyzed via analysis of variance with treatment comparisons made via Tukey's HSD test. Relative to initial cover, plots treated with herbicide saw a significant decrease in percent cover of 69 and 27 percent for 0.28 and 0.21 kg ae ha^{-1}, respectively. As a result, herbicide treated plots showed significant fragmentation of the vegetation community at 12 MAT (**Figure 6-22**). In contrast, control plots experienced a proportional increase of 64 percent.

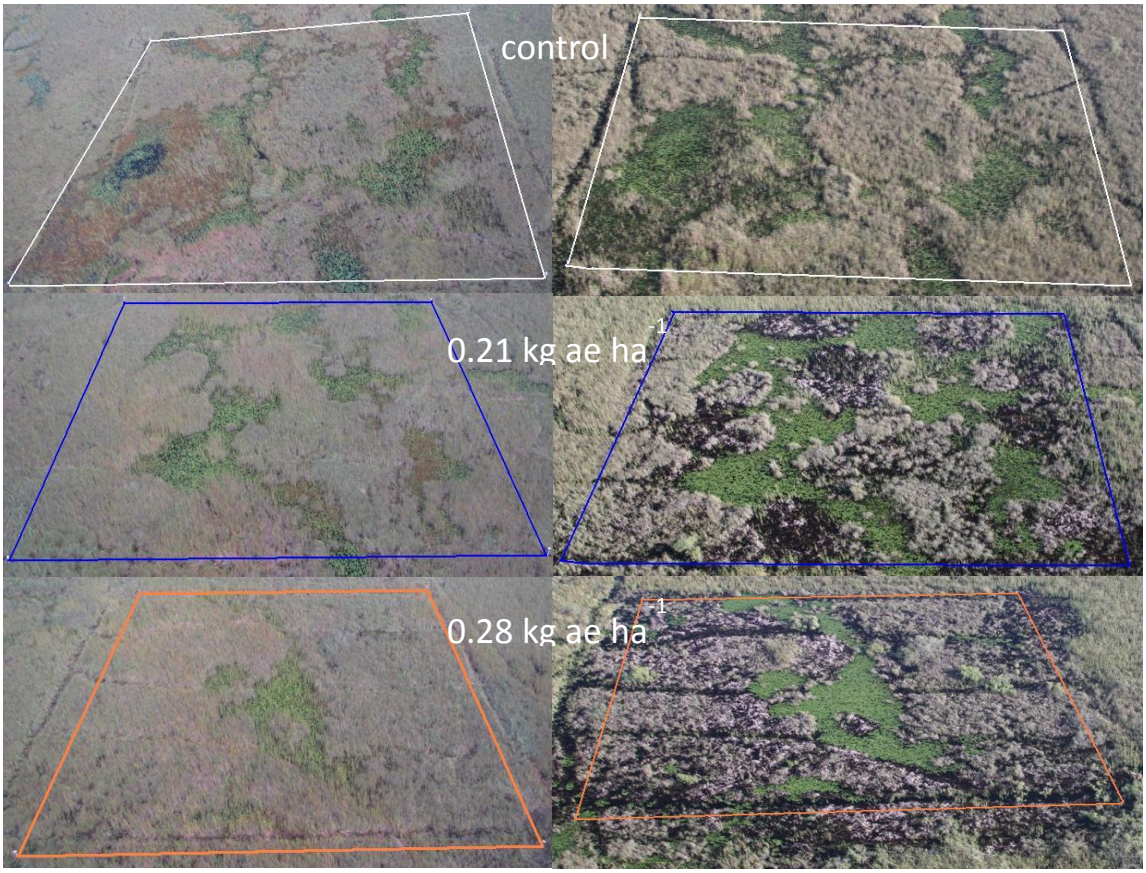

Figure 6-22. Evidence of herbicide damage on cattail in herbicide treated plots. Left panel indicates pretreatment conditions (October 2011), right panel is the same plot 11 months later (September 2012). Green color shows slough vegetation, water lily and spikerush. The tan color in the pretreatment and control photographs is a mix of sawgrass and cattail. The dispersed brownish/tan color in the treatment photographs is primarily sawgrass. [Note: kg ae ha^{-1} – kilograms acid equivalent per hectare.]

Relevance to Water Management

Nutrient loads to the Everglades have been significantly reduced; however, the downstream ecosystem is resilient and resists change. Active marsh improvement projects suggest that these areas may be able to be rehabilitated. Six years after CHIP implementation, a decrease in floc and surficial soil P concentrations was observed in open plots, while controls remained stable. This indicates that maintaining a spikerush/SAV habitat in an enriched ecosystem has the potential to modify P storage longer term. Active sampling of the CHIP plots was completed in 2009; however, these recent results suggest periodic monitoring of soil nutrients will provide essential information on this important P modification that will benefit maintenance of enriched areas in the natural ecosystem as well as within the stormwater treatment areas.

Based on the promising results of Rodgers and Black (2013), in 2011, two studies were initiated using imazamox, a herbicide that appears selective towards cattail, as part of the active marsh improvement strategy. Vegetation observations comparing the 12 MAT from AMI-2 with cattail regrowth observed in AMI 1 provided further support for the hypothesis that the time of year herbicide treatment is applied has a significant impact on subsequent cattail reinvasion. As the plots mature, the importance of spatial heterogeneity and habitat edges on wildlife usage will be explored. AMI projects provide managers with important information on how to optimize vegetation management and ecosystem restoration by documenting the selectively of imazamox, timing and frequency of application for large-scale management, effects of vegetation management on nutrient status on nutrient storage, and the relationship between hydrology, wildlife use, and cattail reinvasion.

SOIL ACCRETION AND CARBON BUDGETS FOR LILA TREE ISLANDS

The Everglades are composed of several key ecosystem components that contribute to its diversity and sustainability. The historical Everglades were characterized largely by a ridge and slough landscape punctuated by tree islands. Although tree islands comprise relatively little area, they are a numerous and vital element of the landscape. Tree islands provide the most terrestrial of habitats in the Everglades and are therefore important as “dry-land” refugia for wildlife and avian rookeries. Concentrations of soil total P have been shown to be as much as 100 times greater than that in the surrounding marsh, making some tree islands potential “biogeochemical hotspots” in an otherwise P-limited system. Despite their importance, hydrologic modifications to the system, since approximately the 1950s, have greatly altered the number, size, and distribution of tree islands in the Everglades. Rehabilitation or restoration of Everglades tree islands is now considered an important part of the continuing CERP.

The physicochemical and biological characteristics and processes in wetlands are largely determined by hydrology. The duration, frequency of flooding, and the rates of ground and surface water drainage (recession) and increase (ascension) directly alter chemical and physical processes such as nutrient cycling, organic matter accumulation, and anoxia. Organic matter decomposition plays a key role in nutrient cycling and soil accumulation and loss in wetlands (Newman et al., 2001). Peat accretes when the production of organic matter exceeds organic matter decomposition. Conversely, oxidation of peat occurs when decomposition rates exceed production rates. Therefore, tree island topography is considered in equilibrium with respect to the water surface when rates of organic matter decomposition and production are in equilibrium (Larsen et al., 2011). Changes in hydrology, amongst other factors, have been shown to influence rates of soil respiration of organic matter to carbon dioxide (CO_2) efflux (Davidson et al., 2000; Furukawa et al., 2005). Soil respiration is a combination of root respiration and microbial decomposition of carbon containing materials (Savage and Davidson, 2003), with CO_2/methane (CH_4) as gaseous end products (Raich and Schlesinger, 1992; Ryan and Law, 2005). Soil C efflux

measurements quantify the rate of gas exchange between the soil surface and atmosphere per area per time. Carbon (C) budget estimation on LILA tree islands consists of using litterfall and litter decomposition in conjunction with soil accretion/erosion and subsidence measurements and estimations of soil respiration of organic matter to CO_2 efflux (**Figure 6-23**).

The objective of this work was to determine the mechanisms by which vegetation, hydrology, and soil dynamics interact to establish viable self-organizing, sustainable tree islands. The restoration of a fully ecologically functioning tree island system may occur over longer time scales than the typical evaluation time frame of restoration projects. Therefore, this research was meant to evaluate response trajectories to determine if mechanisms thought to be responsible for tree (organic matter respiration), assuming no initial soil C (Amundson, 2001).

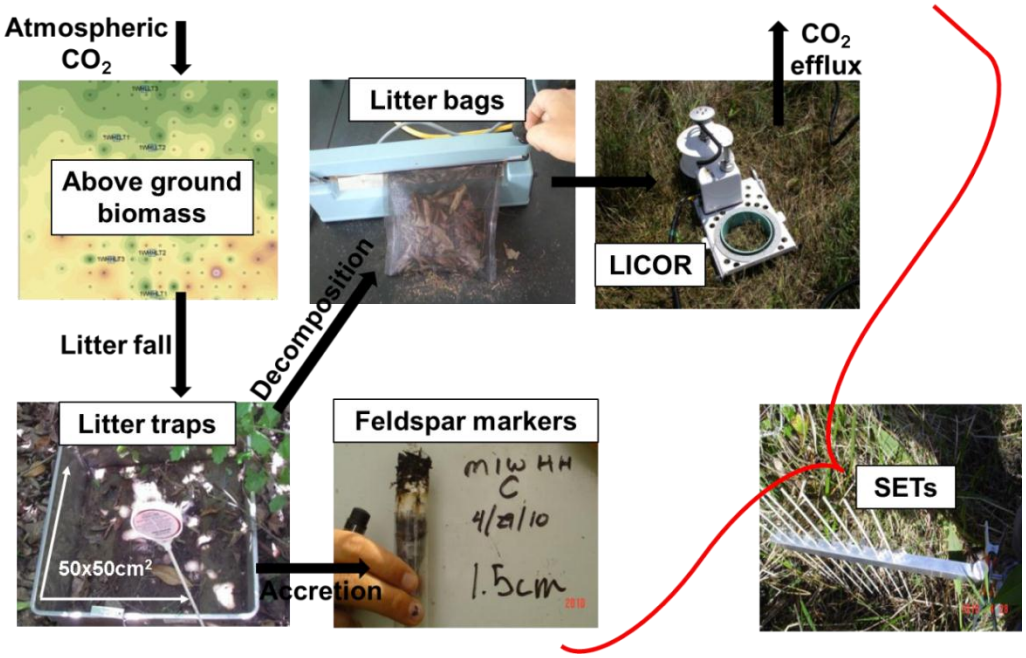

Figure 6-23. Simplified conceptual diagram of C cycling used in LILA tree islands.

Methods

Changes in tree island elevation, soil accretion, litterfall, CO_2 efflux, tree growth and biomass and surface and groundwater dynamics were measured over time and along hydrologic gradients on constructed tree islands in LILA. Ecosystem components in LILA represent the Greater Everglades ecosystem (GEE) tree islands, ridges, and sloughs. Our primary interest is in the dynamics of soil building on tree islands. Measurements have been conducted in two types of constructed tree islands; those where "peat" soils were sculpted to create topographic highs (top of tree island approximately 90 cm above slough soil surface), or where limerock cores were established and then covered to the same final elevations as the peat islands. These two core types are meant to represent tree islands from the northern and southern Everglades, respectively. Carbon budget determination and soil accretion/subsidence partially consisted of using litterfall and litter decomposition on the center portion (head high) and edge portion (head low) of LILA tree islands, in conjunction with surface elevation tables (SETs), marker horizon (feldspar) measurements, and estimations of soil respiration (C_i, e.g., CO_2 efflux) at georectified locations (**Figure 6-24**). High elevation plots were not inundated during the study period, whereas low elevation plots were saturated or flooded at least 140 days of the year.

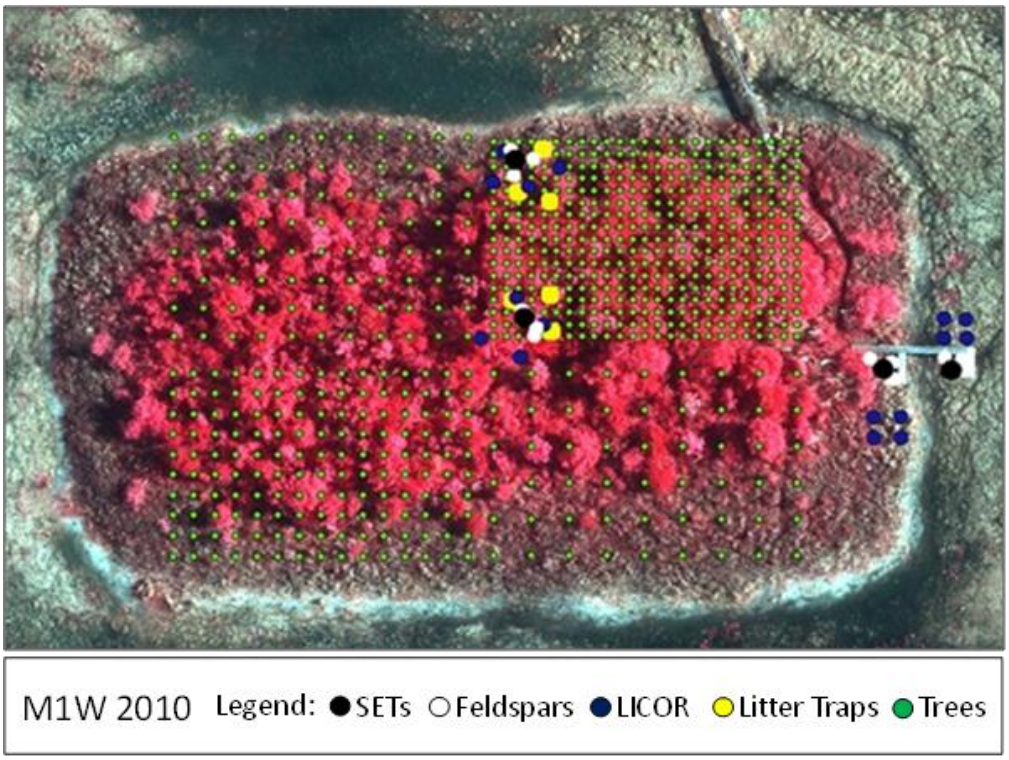

Figure 6-24. LILA Aerial photographs from 2010 of tree island M1W. Symbols indicate locations of SETs, feldspar markers, litter traps, and bags (western tree islands), and LI-8100 chambers in the tail of each island and within a high density tree plot. Georectified locations of instruments were determined by triangulation in April 2011.

Litterfall was collected every two months using litter traps installed at the heads (high and low elevations) of the western tree islands in July 2010. Spatial and temporal variation in litter production was obtained using steel wire fine-mesh (0.50-m x 0.50-m) litter traps placed within five meters of the SETs. Litter decomposition was determined using 0.2-m x 0.2-m litter bags constructed of 1.6-millimeter (mm) fiberglass window screening. Decomposition bags were attached to each trap in August 2010 and collected one month later for four events (30, 59, and 92 days), and then at two month intervals for two events (180 and 243 days), and at 4 months intervals for four events (367, 488, 606, and 732 days).

The SETs were measured annually after establishment (spring 2009) to determine overall changes in soil elevations. Each SET had associated feldspar markers (3 replicates) that yield long-term soil accretion measures due to litterfall and deposition as determined by the thickness (depth) of soil accruing above the feldspar layer over time. The relative positions of all sampling instruments and plots were determined using a geographic information system to facilitate coordination of measures.

Soil CO_2 efflux was measured using a LICOR LI-8100 Infrared Gas Analyzer (IRGA) and LI-8150 multiplexer with automated 104 long-term chambers (LICOR, Lincoln, NB) placed over 20-cm diameter collars installed in the proximity to the SETs.

Results and Discussion

There was an effect of both water depth and island core type on litter production (**Figure 6-25**). Litterfall, adding material to the soil surface, was significantly greater at high elevations [93.2 ± 60.2 grams per square meter (g m^{-2})] than at low elevations (49.4 ± 48.7 g m^{-2}, n = 287, p < 0.001, ANOVA). Litterfall was found to be significantly higher in the peat (113.9 ± 64.1 g m^{-2}) than in the limestone core tree islands (72.4 ± 48.2 g m^{-2}, n = 144, p < 0.001 ANOVA, **Figure 6-25**). Effect of island core type was evaluated only in the head high locations.

Plant litter decayed steadily and similarly in all tree islands and elevations (**Figure 6-26**). Comparisons of mass remaining in the litter bags after 732 days of decomposition in August 2010–2012 showed similar percentage of mass remaining at different elevations (n = 24, p = 0.133, Kruskal-Wallis test), and in both island core type (n = 12, p = 0.817, Kruskal-Wallis test). The average decomposition rate was 2.84, and ranged between 2.57 and 3.33 percent loss per month. The steady decrease of litter mass indicates low quality substrates to microbial communities and suggests significant amounts of recalcitrant material contributing to form soils. Decreased decomposition rates with increased water depth, due to less favorable aerobic conditions were expected. Though low elevation plots were flooded at least 140 days of the year there were no significant differences in decomposition rates relative to unflooded plots.

After three years (2009–2012), SETs data show an overall loss of tree island elevation (**Figure 6-27A**) with the tree islands head high experiencing a larger loss of elevation (-2.72 ± 2.01 cm) than the head low (-0.80 ± 1.90 cm); however, the difference was marginally significant (n = 16, p = 0.07, ANOVA). Peat tree islands experienced a larger loss of elevation (-3.84 ± 2.15 cm) compared to limestone islands (-1.59 ± 1.19 cm), however this difference was not statistically significant (n = 8, p = 0.115, ANOVA).

The feldspar markers showed soil accretion on all islands at all elevations. The thickness of soil accreting on top of the feldspar markers per year was generally small but obvious; leading to the conclusion that soil development in the young tree islands is a slow process (< 1 cm per year). After three years, the tree islands showed significantly greater soil accumulation at high (2.5 ± 1.1 cm) as compared to low elevations (1.8 ± 0.8 cm, n = 46, p = 0.037, ANOVA, **Figure 6-27B**), but soil accumulation in the peat islands (2.2 ± 0.8 cm) was not significantly different than in the limestone islands (2.6 ± 1.4 cm, n = 23, p = 0.422, ANOVA). Soil development was relatively more rapid at higher elevations and/or on peat islands where trees were maximally productive. Survival and growth of Everglades tree species planted on LILA tree islands improved with increasing elevation in both peat and limestone core islands, but trees response to substrate type showed lower survival and faster growth in peat-based than in limestone-based islands (Stoffella et al., 2010).

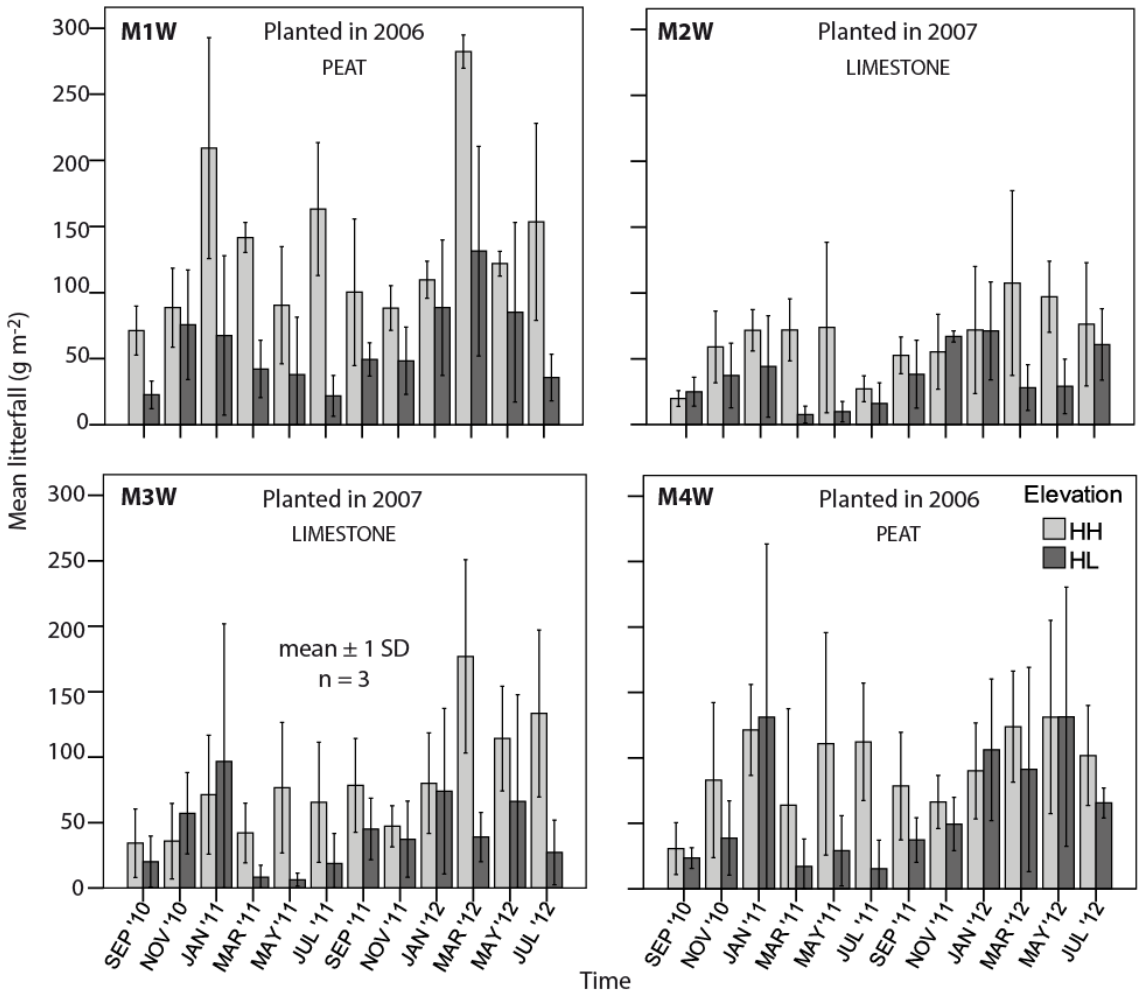

Figure 6-25. Mean [± 1 standard deviation (SD)] litterfall in the four western tree islands (M1W and M4W are peat core islands, and M2W and M3W are limestone core islands) heads at high (HH) and low (HL) elevations from September 2010 to July 2012.

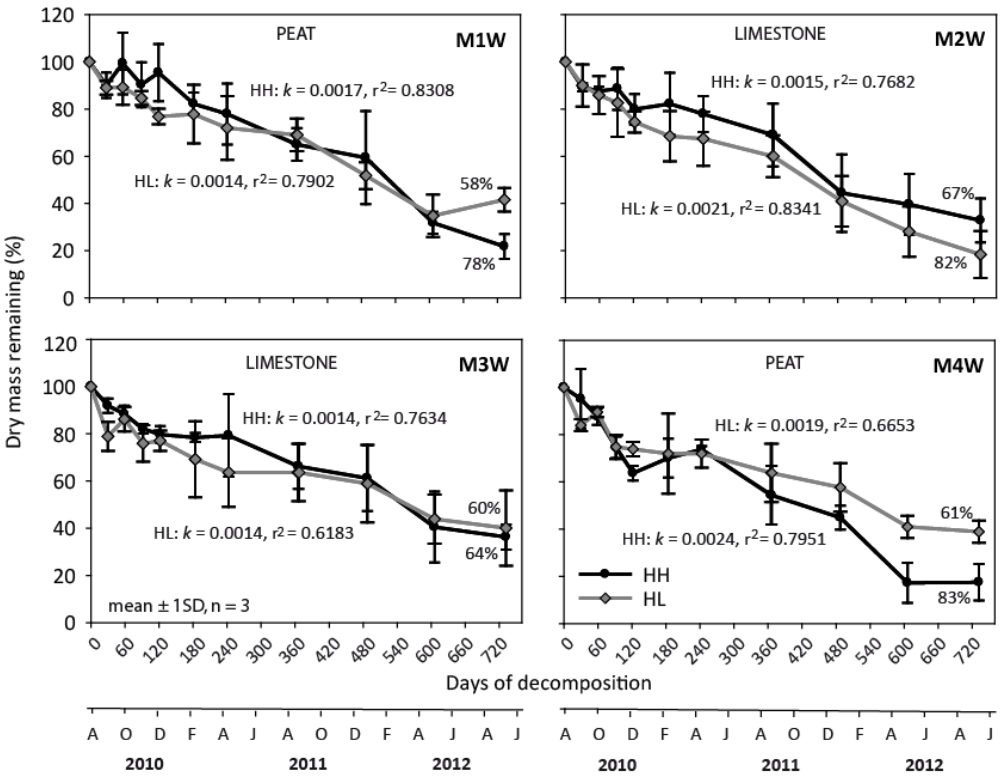

Figure 6-26. Decomposition expressed as percentage remaining mass of litter after 732 days of decomposition in the western tree islands at high (HH) and low (HL) elevations. Decomposition constants k (d^{-1}) are based on a decomposition model [$M_t = M_0 e^{-kt}$, where M_t is the mass remaining at time t and M_0 is the initial mass] and r^2 is from regression analysis. Values are mean ± 1 SD from triplicate bags (n = 3). Percentages of mass loss after 732 days of decomposition are also shown.

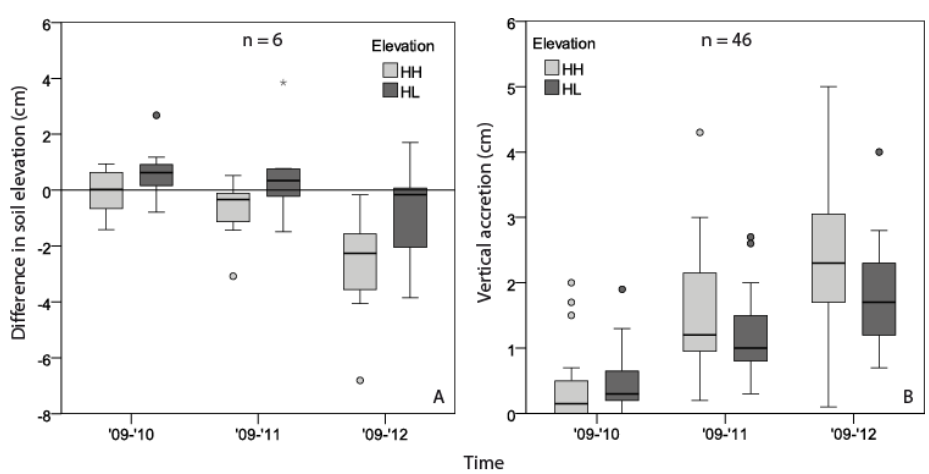

Figure 6-27. (A) Annual soil elevation differences of surface elevation tables (SETs) measurements and (B) soil accretion above feldspar markers located at high (HH) and low (HL) elevations of heads of eight peat and limestone core tree islands combined.

Within a tree island, the higher elevations generally produced higher biomass, litter production, and soil accretion. Peat core islands may favor a more productive tree island plant community, but peat islands tend to subside more rapidly than limestone islands. In the peat islands and at higher elevations, trees were maximally productive. Data of SETs suggest that subsidence occurs on the center of the tree islands leading to lower overall elevations and thus potentially longer periods of inundation. The centers of the tree islands seem to be losing elevation despite the fact that soil is being accreted at the greatest rate in these locations. Loss of soil elevation suggests a net loss of soil carbon (C) or an overall compaction since tree island creation. There are several possible reasons for the loss in elevation, including root decomposition, sediment compaction, and groundwater withdrawal.

Annual CO_2 soil efflux, as measured using a LI-8100 infrared gas analyzer, showed a significant negative linear relationship with relative water depth ($y = -6.92x + 3.72$, $r^2 = 0.21$, $n = 790$, $p < 0.001$) (**Figure 6-28**). Annual C losses estimated from soil CO_2 efflux measurements were significantly greater at high [1,203 to 2,250 and grams carbon per square meter per year (g C m^{-2} y^{-1})] than at low elevation plots (960 to 997 g C m^{-2} y^{-1}, $n = 790$, $p < 0.001$, Kruskal-Wallis test). Increasing CO_2 efflux was associated with shorter periods of inundation, confirming the effect of hydrologic conditions to soil respiration. Higher rates of CO_2 efflux (i.e., soil respiration) occurred in the head of the tree islands at high elevation (never flooded; **Figure 6-28**), coinciding with higher litter production and biomass. Furthermore, higher amounts of C inputs, and thus more labile C, have been shown to increase soil respiration rates (Allen et al., 2000; Trumbore, 2000; Bahn et al., 2008). Soil respiration measurements quantify root respiration and microbial decomposition of carbon containing materials; therefore it is important to determine the role of autotrophic respiration by live roots (not studied). Carbon balance estimates to date have been made on relatively young (~6 years old) LILA tree islands at preliminary stages of formation. These mechanisms (e.g., litterfall leading to soil accretion) are developing and it is expected that further development will change estimates of C dynamics.

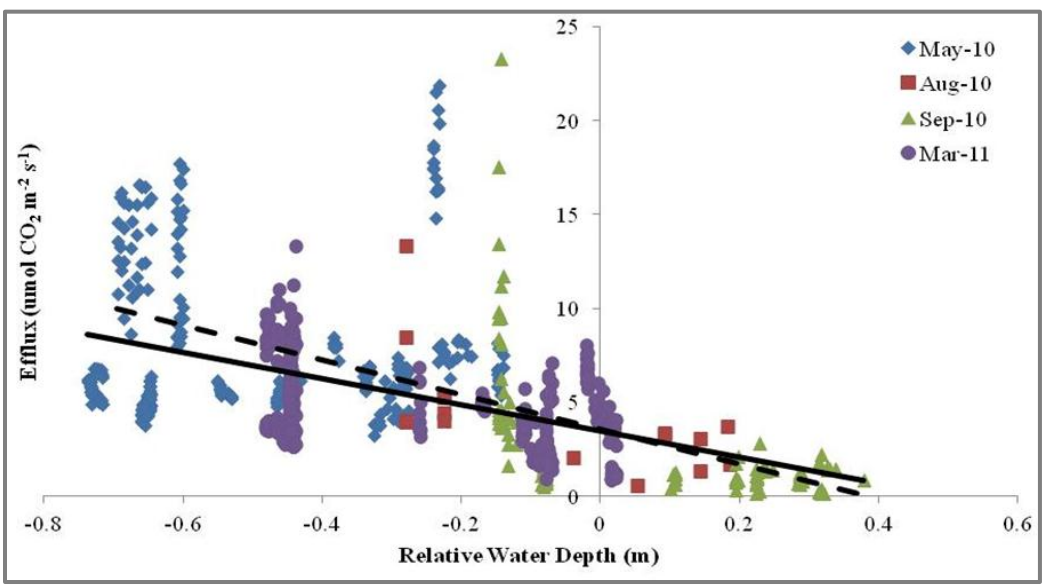

Figure 6-28. Measurements of carbon dioxide (CO_2) efflux in micromoles CO_2 per square meter per second (μmol CO_2 $m^{-2}s^{-1}$) from LILA tree island soils, based on relative water depth in meters (m). The dashed regression line includes efflux values from peat sections of tree islands ($y = -9.24x + 3.54$, $r^2 = 0.34$, $n = 624$, $p < 0.001$) and the solid regression line includes efflux values of the head of a limestone core tree island ($y = -6.92x + 3.72$, $r^2 = 0.21$, $n = 790$, $p < 0.001$).

Relevance to Water Management

This study documented the mechanisms of several tree island processes critical to the successful restoration and management of the Everglades, specifically concerning carbon dynamics of tree islands. Soil development (accretion) was relatively slow (< 1 cm per year) but more rapid at higher (drier) elevations where trees were maximally productive and where ET appears to concentrate nutrients from the groundwater (Sullivan et al., 2011). Regardless of soil accretion, SETs showed a net loss in elevation, which was likely due to subsidence. Understanding how Everglades tree island soil respiration responds to water depth fluctuations and type of island substrate, coupled with organic matter production and soil accretion, (C sequestration) can be used by managers to slow or reverse tree island loss. Restoration efforts that involve sculpting of landscape features (i.e., tree islands from levee removal) should consider the counteracting effects of subsidence and settling to rates of soil accretion. To date, this work has shown that production and soil accretion in nascent tree islands do not "build" topography at a rate to compete with settling/subsidence.

LANDSCAPE PATTERNS AND ECOLOGY

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The first part of this section summarizes sediment dynamics measured in marsh and canal habitats within the Decomp Physical Model (DPM). Results are reported from the baseline (pre-flow) period and show how current hydrologic conditions are insufficient to entrain and redistribute sediment, required for landscape restoration. In addition, research supporting the evaluation of the Florida Bay MFL rule is described as is the benthic vegetation and water quality of Florida Bay. Finally, the response of Florida Bay submergent aquatic vegetation to increased flow projected from the Central Everglades Planning Project (CEPP) is examined using simulation modeling.

SEDIMENT DYNAMICS IN THE DECOMP PHYSICAL MODEL: SYNTHESIS EXAMPLES OF RIDGE-AND-SLOUGH AND MARSH-TO-CANAL DYNAMICS

Introduction

The Decomp Physical Model (DPM) is a landscape-scale project designed to address key uncertainties associated with restoring the patterned and corrugated topography that once prominently defined the historical Everglades ridge and slough peatland. Before twentieth century drainage and impoundment, the system was characterized by sheetflow several times faster than current flow, resulting in linear sawgrass ridges and deep sloughs oriented parallel to flow (McVoy et al., 2011). It is widely recognized that restoring sheetflow is critical to rebuild these

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landscape features. Modeling studies indicate that water velocities greater than 2 cm per second (s^{-1}) are required to sufficiently entrain and redistribute sediment to build patterning and topography (Larsen et al., 2011). Scientific and engineering uncertainties remain over how rapidly the ridge and slough landscape will respond to restored sheetflow by altering entrainment and redistribution of sediment. Furthermore, even with restored sheetflow and levee removal, it is unknown to what extent the existing canals will hinder the restoration of the ridge and slough landscape. In summary, key restoration uncertainties for decompartmentalizing the current impounded system include (1) the extent to which canals must be backfilled to ensure the restoration of sheetflow and sediment redistribution and (2) the extent to which restored sheetflow conditions may facilitate the transport of high-nutrient canal sediments to areas downstream.

The DPM is located in the area between the L-67A and L-67C structures known as "the pocket" (**Figure 6-29**), where numerous hydro-ecological response variables are being monitored in a before-after-control-impact (BACI) statistical design. In all, twenty-three specific physical and biological hypotheses are addressed by the experiment and are detailed in the DPM Science Plan (DPM Science Team, 2010). DPM research questions can be summarized as follows:

- Sheetflow Questions: To what extent do entrainment, transport, and settling of sediments differ in ridge and slough habitats under high and low flow conditions? Does high flow cause changes in water chemistry and consequently changes in sediment and periphyton metabolism and organic matter decomposition?
- Canal Backfill Questions: Will canal backfill treatments act as sediment traps, reducing overland transport of sediment? Will high flows entrain nutrient-rich canal sediments and carry them into the water column downstream? To what extent are these functions altered by the various canal backfill options, including partial and full backfills?

The report presents a synthesis of findings describing the source, movement, and fate of sediment, the common currency linking all study components. As summarizing the entirety of the DPM data requires a larger venue, select sites are used to exemplify data that is being synthesized to address ridge-and-slough hypotheses and the canal-backfill hypotheses. As construction required for the project is still underway, baseline, low-flow conditions are reported. It is anticipated that subsequent reports will include syntheses of biogeochemical processes, integration of physical and biogeochemical processes on sediment and nutrient fluxes, and summaries of the effects of experimental sheetflow and canal-backfill treatments on hydrologic and ecological response variables.

Methods

To reproduce pre-drainage flow conditions, the DPM study includes construction of 10 gated culverts on the L-67A levee and a 3,000-foot gap in the L67C levee paired with three canal backfill treatments in the adjacent canal (**Figure 6-29**). The discharge capacity of the culverts is expected to generate water velocities of 2–5 cm s^{-1} in the flow-way, i.e., in the range needed to resuspend and redistribute sediment. The DPM utilizes a BACI experimental design, consisting of field monitoring of hydrologic and biological parameters under no flow (baseline) and high flow (impact) conditions in both impacted and non-impacted marsh and canal "control" sites. Due to water quality and flooding constraints, the operational window of the S-152 is limited to November–December. Construction is expected to be completed in summer 2013, in time for a first flow event in November 2013.

Water levels were measured continuously at RS1 by pressure transducers placed in fixed-elevation 1.5-inch PVC wells and operated continuously. The pressure transducers recorded water

level at 15-minute intervals. KPSI™ transducer sites were serviced and downloaded approximately monthly during the wet season. Data were corrected for drift according to common practices and procedures described in Kenney (2010). Transducers will remain operational for the duration of the project.

To define large-scale sheetflow patterns before operation of the L-67A culverts (S-152), an SF6 tracer release experiment was conducted at four DPM sites, including RS1 in 2011 (**Figure 6-28**). For the experiment, 5 liters of water saturated with sulfur hexafluoride 6 (SF6) was released as a point source. After injection, the tracer distribution was sampled each day using a high-resolution SF6 analysis system mounted on an airboat (Ho et al., 2009). Because of the high density of periphyton and sawgrass ridges in the study areas, tracer was sampled in a stop-and-go manner, where the airboat was stopped at one location and the pump intake lowered into the water. This sampling scheme ensured that the airboat did not break up periphyton mats and stir up sediments while the pumping unit was active. Analysis of the spatially explicit, time series data provided estimates of tracer heading (flow direction), advection rate (cm s^{-1}) and dispersion coefficients [square centimeters (cm^2) s^-] for each site (Ho et al., 2009; Variano et al., 2009).

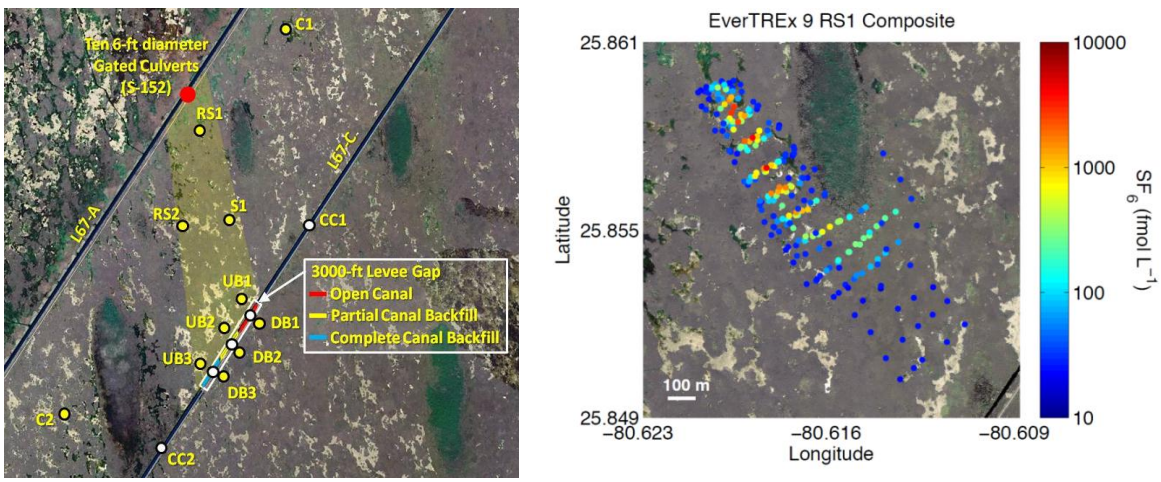


Figure 6-29. Map of the Decomp Physical Model (DPM) experimental site located between the L-67A and L-67C canal/levee structures, including impact and control sites (left). Sulfur hexafluoride 6 (SF6) tracer concentrations (four-day composite) sampled after initial injection at site RS1 (November 2011) (right).

To quantify water flow at the local scale, water velocity was measured at eight sites, using acoustic Doppler velocimeters (ADV). At each site flow speed and direction was measured at a fixed depth in the water column. The ADV approach measured flow velocity to a resolution of 0.01 cm s^{-1} with an accuracy of 1 percent of measured velocity (SonTek, 2001). Operating procedures and data filtering followed those described in Harvey et al. (2009), Riscassi and Schaffranek (2002), and SonTek (2001). Water velocity measurements were also made using a SonTek Handheld FlowTracker-ADV®. These provided additional information on the velocities at sediment trap locations (below). FlowTrackers were configured to measure velocities over a 120-second sampling period.

Water column total particulate and total particulate P concentrations were obtained in November 2010, 2011, and 2012. Water samples were collected mid-water column via a peristaltic pump, passed through a 500-micrometer (µm) Nitex mesh prescreen during collection, stored on ice and brought to the laboratory for processing. Immediately upon return to the laboratory samples were filtered through a 0.2-µm Pall™ membrane filter, the filters were oven-dried, weighed, and then digested and analyzed for total particulate P. Sediment critical

entrainment thresholds (CET: minimum velocity required to entrain sediments) were determined in situ using an annular benthic flume. The flumes are constructed of two cylinders that form a 0.1-m annular channel (Partrac 2005, 2006, 2008). The inner cylinder (radius 0.35 m), outer cylinder (radius 0.55 m), and watertight lid are constructed of Perspex™. Bed shear stress is created via a rotating lid affixed to the channel top. Lid rotation is by a geared direct current (DC) motor linked to a portable laptop computer which controls the start velocity, end velocity, step-wise rotation frequency increments, increment duration, and ramping rate between increments. An optical backscatter turbidity sensor is fixed at 5 cm above the sediment water interface such that the sensing zone is directed across the channel. Turbidity was recorded every 10 seconds. The flume was calibrated to derive the relationship between lid rotation and flow velocity at 5 cm above the sediment-water interface. CET is obtained by the relationship between flow velocity and turbidity. Entrainment velocities were measured within the slough at RS1 in October 2012 and March 2013.

Sediment transport and accumulation were measured using horizontal and vertical sediment traps, respectively. Horizontal traps were adapted from Phillips et al. (2000) and deployed mid-water column and parallel to flow. Traps were deployed in paired ridge and slough plots at RS1, RS2 and C1. To capture vertical sediment deposition in the canals, sediment traps were deployed in two canal control sites (CC1N, CC2S) and the three backfill treatments (CB1, CB2, and CB3) following a modified design from Kerfoot et al. (2004). Starting in 2011, traps were deployed for three weeks during the S-152 operational window (November–December) and six weeks immediately after the operational window (January–April). Canal deployments were suspended after November 2012 due to construction in the L-67C canal. Samples collected from sediment traps passed through 1-mm mesh sieves, and small particles were dewatered and collected using a settling (Imhoff) funnel. Samples were dried at 80º Celsius for dry weight determination. As median sediment particle size in Everglades wetlands is less than 100 µm (Noe et al., 2007), only the fluxes of small particles are reported here. Loading rates per frontal area were estimated from the horizontal traps and converted to loading per ground area based on the inner diameter of the inlet and outlet tubes (6.4 mm) and water column depth (surface to the floc layer). Vertical sediment accumulation in the canal was calculated from vertical traps based on the weight of recovered particles, trap inlet area (tube diameter), and deployment duration.

Results and Discussion

Synthesis Example 1: Ridge-and-Slough Sediment Dynamics

Data synthesis is achieved by examining relationships of multiple types of data that address common objectives or hypotheses. DPM data were synthesized by (1) comparing magnitudes and rates measured or inferred from different data sources, (2) comparing the consistency of findings in addressing DPM hypotheses, and (3) building a holistic understanding of sediment dynamics, highlighting important uncertainties. For the ridge and slough, an overview of data synthesis is presented in **Figure 6-30**, using site RS1 as an example.

While the spatial and temporal scales of SF6 and ADV measurements are quite different, both consistently showed that water flow in the baseline years is slow (< 0.5 cm s^{-1}), consistent with other Everglades studies (e.g., Harvey et al., 2009; Leonard et al., 2006). The SF6 tracer deployment at RS1 indicated an overall southeastern flow of 0.11 cm s^{-1} [±0.01, standard deviation (SD), **Figure 6-29**], which was lower but within the range of the mean and error of velocities measured by ADVs in the RS1 slough (0.31 ±0.29, SD) and ridge (0.32 ±0.17, SD) (**Figure 6-30**, panel b).

Sediment entrainment patterns were different during the two sampling events spanning 2012–2013 (**Figure 6-30**, panels b, e, f). Preliminary analysis of the CET in October 2012 suggests

entrainment occurred around 1.1–1.4 cm s^{-1} and then there was a gradual increase in turbidity values indicating continued entrainment and sediment suspension. In contrast, the CET determined in March 2013 appeared slightly lower, approximately 0.77 to 1.1 cm s^{-1}; however, the subsequent increase in turbidity was relatively rapid. A comparison of these data with additional information, such as total floc mass, chemistry, and biomarkers that identify floc sources, will help us understand the relative differences in floc characteristics and the potential for floc transport.

Sediment transport ranged from 0.4 to 44 grams per square meter per day (g m^{-2} d^{-1}), and in both years of sampling, sediment transport rates were highest in November and decreased nearly monotonically as water levels decreased (**Figure 6-30,** panel c). These trends were observed when transport was calculated per frontal area (independent of water depth) as well as per ground area (a function of depth). Although the CET of sediments decreased over time (October 2012–March 2013), flow velocities during this period remained below the CET. Water column particulates and sediment transport rates therefore were unlikely to be influenced by sediment resuspension. Sediment transport did not appear to correlate with the amount of floc available (**Figure 6-30**, panel c, d). That sediment transport mirrored water recession suggested a minor influence of resuspension and a stronger link to processes within the water column such as reduced periphyton and SAV biomass, productivity, and turnover during drydown.

Transport rates measured by sediment traps were expected to underestimate transport, as Phillips et al. (2000) observed 30–71 percent retention efficiency of these traps in estuarine systems. To quantify this potential bias, transport was calculated using site- and habitat-specific water column particulate concentrations and flow velocities. Mid-water column particulate concentrations within the RS1 slough were 0.61 and 0.45 milligram per liter (mg L^{-1}) in 2011 and 2012, respectively, and in the ridge, 0.49, and 0.02 mg L^{-1} in 2011 and 2012, respectively. A range in transport was calculated by using velocity estimates from both ADV and SF6 sources (as SF6 estimates were not habitat-specific, the same velocity was applied to both habitats). Transport calculated in this manner ranged from 18 to 98 g m^{-2} d^{-1} in November 2011 and 0 to 35 in November 2012 (**Figure 6-30**, panel c). In comparison, trap-based estimates ranged from 21 to 44 g m^{-2} d^{-1} in November 2011 and 17 to 38 in November 2012. Large variation the transport rates estimated by velocity and water column particulates largely reflect differences in mean velocity estimated by SF6 and the ADVs, and secondarily to differences in water velocity and particulate concentrations between ridge and slough habitats. Given the wide range in the calculated transport rates, we could not detect evidence that the sediment traps underestimate sediment transport. Taken together, these independent estimates of transport provide an envelope of uncertainty, to which the high flow treatment will be compared. Although the uncertainty appears substantial, the effect of high experimental flows is expected to be much greater. For example, given sediment stocks of 400 grams dry weight per square meter (DPM-wide average), even if only 1 percent of sediments were entrained under high flows, water particulate concentrations, and therefore sediment transport, would be expected to increase by at least one to two orders of magnitude.

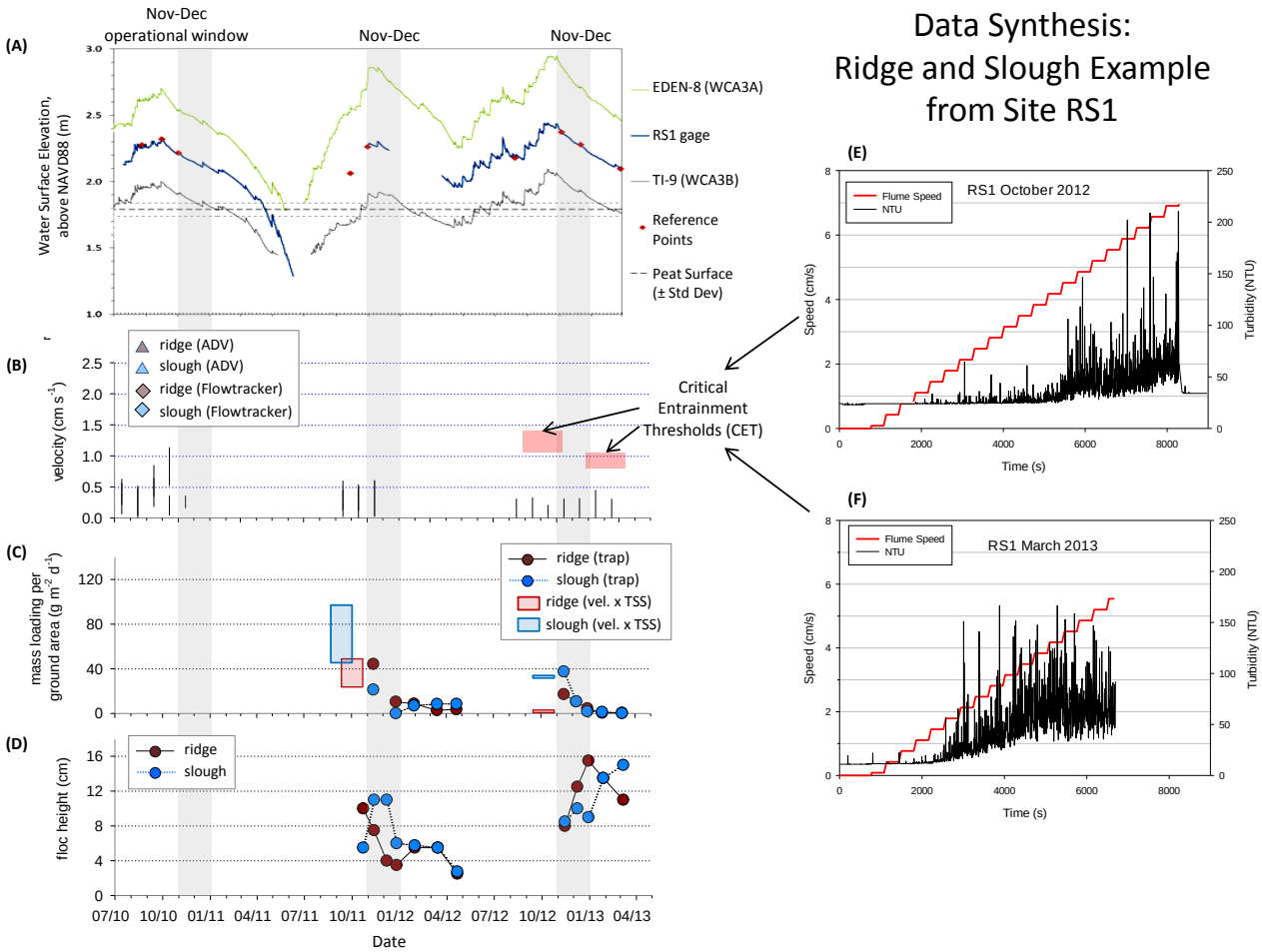


Figure 6-30. Data synthesis of hydrology and sediment dynamics, exemplified by field data collected at site RS1. (a) Water stage and peat elevation, (b) flow velocities, (c) sediment transport, (d) benthic sediment (floc) height, and (e, f) sediment entrainment velocities measured within a slough at RS1 in October 2012 and March 2013. Shaded bars in (c) represent the range in transport estimated by particulate concentrations x water velocity, using SF6-based velocities and acoustic Doppler velocity (ADV)-based velocities in November. The single bar in 2012 reflects that only ADV data was available that year.

Synthesis Example 2: Marsh-to-Canal Sediment Dynamics

To address canal backfill hypotheses, our central objective was to determine the extent to which sediment transport from the marsh interior contributed to accumulation in the canal during baseline, low flow conditions. An initial landscape sediment budget was presented previously in the 2013 SFER – Volume I (Sklar et al., 2013) and in this report build on those findings by examining more closely the temporal variation from November 2011 to January 2012 (**Figure 6-31**). During the operational window in 2011, marsh transport (ridge and slough average) ranged from 3 to 43 g m^{-2} d^{-1}, and canal accumulation ranged from 18 to 33 g m^{-1} d^{-1}. In November 2012, marsh transport and canal accumulation were 47 g m^{-2} d^{-1} and 43 g m^{-1} d^{-1}, respectively. While marsh transport rates decreased with drydown, canal accumulation showed the opposite effect, increasing to 112 and 102 g m^{-1} d^{-1} in March and April 2012, respectively. In previous reporting, our preliminary, annual budget showed canal accumulation (17.0 kg m^{-1} yr^{-1}) was much higher than marsh sediment transport alone (5.5 kg m^{-1} yr^{-1}). Here our data showed the magnitude of this missing source of canal sediments varied seasonally, increasing with drydown in the late wet

season. Comparing sediment nutrient and molecular biomarker signatures from sediment samples in interior and near-canal marshes and sediments accumulating in the canal will help identify the source of sediments accumulating in the canal during the drydown.

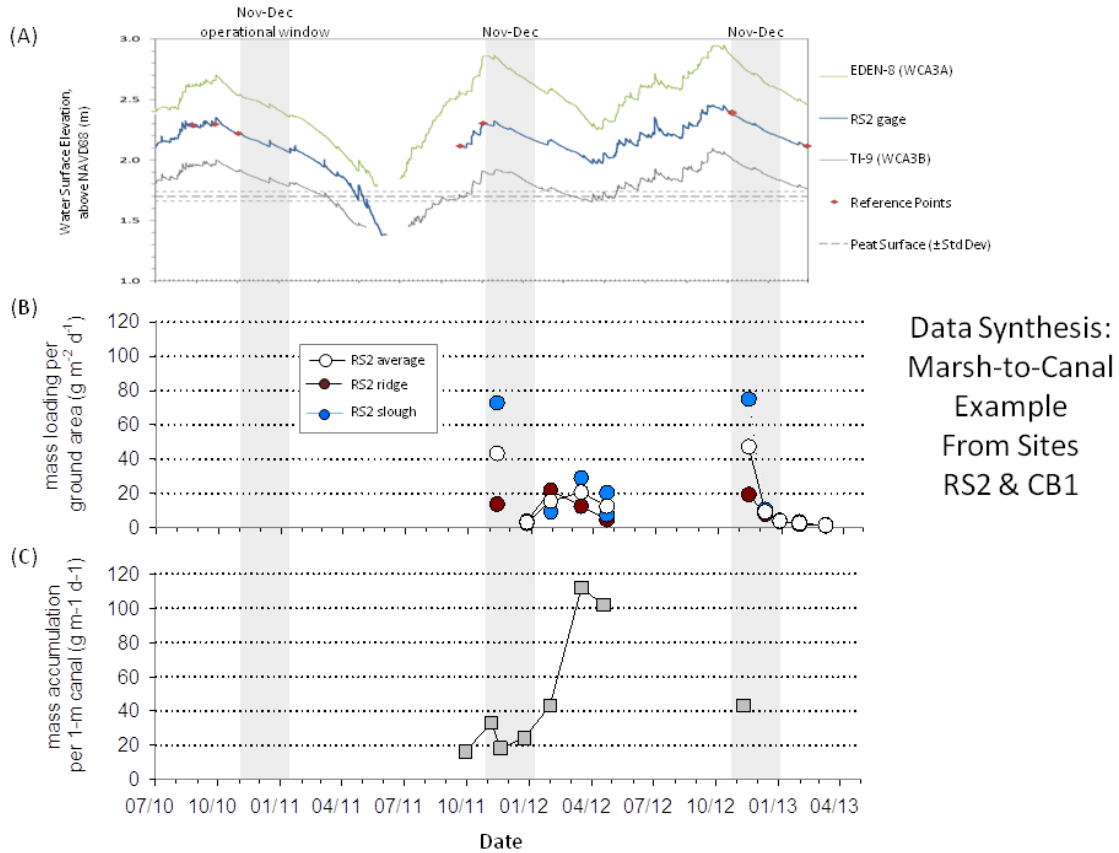


Figure 6-31. Data synthesis of sediment dynamics from marsh to canal, exemplified by field data collected at site RS2 and CB1. (a) Water stage and peat elevation, (b) sediment loading at RS2, and (c) sediment accumulation in the L-67C canal. Canal sediment accumulation rate is expressed per meter length of canal, calculated by multiplying the trap accumulation rate [grams per square meter per day ($g\ m^{-2}\ d^{-1}$)] by the average width of the L-67C canal (12 m).

Relevance to Water Management

Baseline data from the DPM confirm the conclusions from previous reporting—that in the current conditions of low water flow, restoration of the characteristic ridge and slough microtopography is unlikely. Water velocities above CET were required to resuspend and redistribute sediments. Study findings, however, do indicate that CET varies temporally. Future water management strategies to increase sheetflow or to use water pulse releases to redistribute sediments may vary in success depending on the seasonal changes in the CET of sediments.

The District continues to develop a sediment budget using alternate methods based on sediment traps, velocity measurements, and water column particulate concentrations. These two methods provide a means to compare transport rates and quantify the uncertainty underlying a budget model. This paired method may be used to evaluate sediment and nutrient spiraling in other water management efforts, including monitoring for the Everglades Stormwater Treatment Areas and the Central Everglades Planning Project.

RESEARCH IN SUPPORT OF EVALUATING FLORIDA BAY MINIMUM FLOWS AND LEVELS

Introduction

In 2006, the District developed the MFL rule for northeastern Florida Bay, one of the most important means by which water management can benefit the ecology of the downstream system. The MFL rule establishes the point at which water withdrawals would cause significant harm to the ecology of a priority water body. The MFL was based on the best available information at the time and a component of the rule requires periodic review and possible revision of the rule based on new science. An ongoing research program has focused on the effects of the rule on ecological conditions in the mangrove ecotone and the open waters of Florida Bay. The research has particularly addressed how patterns of hydrology and salinity affect the density, spatial extent and recruitment of SAV communities that form critical habitat in those areas.

The primary objective of the MFL rule for Florida Bay was to maintain a salinity profile that is protective of the ecology and biological resources in the bay including the upstream marshes, transition zone, and open waters of northeastern Florida Bay. The rule required the maintenance of salinity below a critical maximum threshold of 30 at a site (TR) in upstream Taylor River. Through modeling and water budgeting, this criterion was projected to protect downstream marine areas from exceeding higher levels (40) that would begin to compromise marine communities and upstream areas from exceeding low salinity thresholds that would harm fresher communities. *Ruppia maritima* (widgeon grass), nominally a low-salinity plant historically well established in the transition zone and whose range straddles fresh to marine salinities, was chosen as an indicator of the health of the ecosystem. The sensitivity of this species to high salinity serves as a sentinel for the transitional vegetative community of low salt tolerant and freshwater biota that managers desire to maintain in the transition zone [*R. maritima* and a consortium of freshwater plant species, *Chara hornemanii* (chara), *Najas* sp. (waternymph), *Utricularia* sp. (bladderwort)]. Achieving the target salinity profile in the transition zone was also designed to maintain an appropriate salinity profile that will reduce hypersaline events in the open bay and support a mixed *Thalassia testudinum* (turtle grass)-*Halodule wrightii* (shoal grass) community in the marine region of the estuary.

Since the establishment of the MFL in 2006, District research on salinity and its control of SAV response has included assessing the (1) temporal and spatial patterns of salinity in northeastern Florida Bay; (2) appropriateness of the salinity monitoring site in Taylor River; (3) relationship between SAV and salinity; (4) effect of salinity on *Ruppia* distribution and life history; (5) dependence of higher trophic levels including fish and birds on SAV; and (6) 30 salinity threshold as protective of the system. Summary highlights of the results of this comprehensive research program are presented here.

Methods

Water column salinity was measured at numerous sites in creeks throughout the transition zone and in open water Florida Bay. Salinity stations maintained by Audubon of Florida, Everglades National Park, SFWMD, and USGS provide long-term data sets. The relationship between *R. maritima* and salinity was investigated using average 30-day salinities, aligning with the calculation of the salinity criterion for the MFL rule (a 30-day average). To determine salinity effect on plant distribution, percent cover data for *R. maritima* were grouped into discrete categories (0–10, 10–20, 20–30, and > 30) and statistical differences among discrete categories were investigated using ANOVA and pair-wise t-tests. The variability of salinity was investigated as a possible factor contributing to differences among monitoring sites by comparing average *Ruppia* cover with the standard deviation of salinity.

Two ecological parameters help structure the MFL rule: (1) *R. maritima* and (2) prey-base fishes. A series of experiments measured *R. maritima* seed germination and seedling survival across a range of salinities (0–45) to examine the factors controlling the early life history, seed germination, and seedling survival. Seed densities were quantified and seed viability was measured in transects across the ecotone at sites where rapid expansion of *R. maritima* reproductive shoots was observed. The community of small prey-base fishes in Florida Bay's salinity transition zone is considered an excellent ecological indicator because it responds rapidly to changing hydrologic and habitat conditions and is important in the regional food web, especially the roseate spoonbill population (Trexler, 2005). Ongoing monitoring of the prey base has been was conducted eight times per year using 9-square meter drop traps at six sites in the ecotone from 2001 to 2013 to assess performance of Florida Bay MFL criteria. For these comparisons, prey fish density and biomass (summarized across all species) for six sites within the Taylor Slough and C-111 watersheds were compared by salinity (measured on the day of fish sampling) and frequency of occurrence for total SAV, i.e., proportion of SAV survey quadrats (percent) containing at least 5 percent total SAV cover.

Results

The salinity time series data at TR shows a clear annual cycle of increasing and declining salinity fluctuating inversely with precipitation (and freshwater flow) (**Figure 6-32**). The TR site, on which the Florida Bay MFL is based, showed that an exceedance occurred in the extremely dry year of WY2012 and an exceedance nearly occurred in early WY2013 (red line). Two pairs of consecutive exceedances within a 10-year period trigger an MFL violation. Through a combination of natural hydrology and District operations, no MFL violations have occurred since rule implementation. Comparisons of salinity patterns at the TR site with other sites within the MFL boundary (not shown) seems to confirm the efficacy of TR as a representative monitoring site for all basins within the MFL footprint.

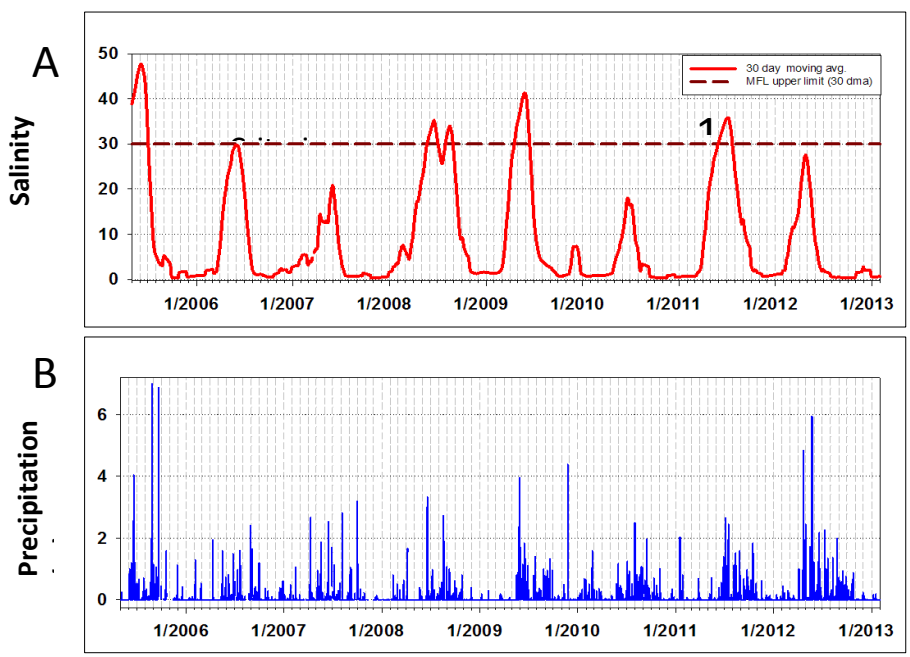


Figure 6-32. Salinity (upper) and daily precipitation (lower) at the Taylor River station showing an exceedance in May–July 2011 and nearly a second exceedance in April–May 2012.

ANOVA analysis shows that *R. maritima* mean cover is statistically different among salinity categories (**Figure 6-33**), with higher salinities significantly reducing the presence and cover of *R. maritima* ($F_{3,1105} = 7.67$, $p < 0.0001$). A pair-wise t-test identified that the > 30 category was significantly lower than the 0–10 and 10–20 categories ($p < 0.05$).

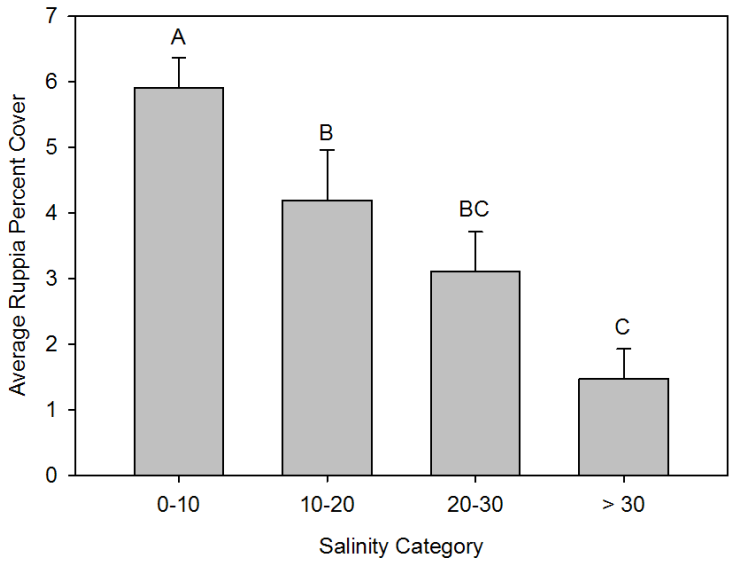


Figure 6-33. *Ruppia maritima* (widgeon grass) percent cover along the Joe Bay and Taylor River transects with respect to salinity category. Category C is statistically lower than categories B and A, and salinity in the range of 0–10 (Category A) is significantly more favorable for *R. maritima* than higher salinity categories.

Although *R. maritima* cover was generally correlated with mean salinity, the variability of salinity was found to increase downstream, with maximum variance nearest the bay. There was a negative correlation ($R = -0.815$, $p < 0.05$) between *R. maritima* cover and salinity variability (**Figure 6-34**). Low variability tends to characterize the upstream sites and high variability is more common at downstream sites where tide and wind action cause pulses of alternating fresh and salt water through the area.

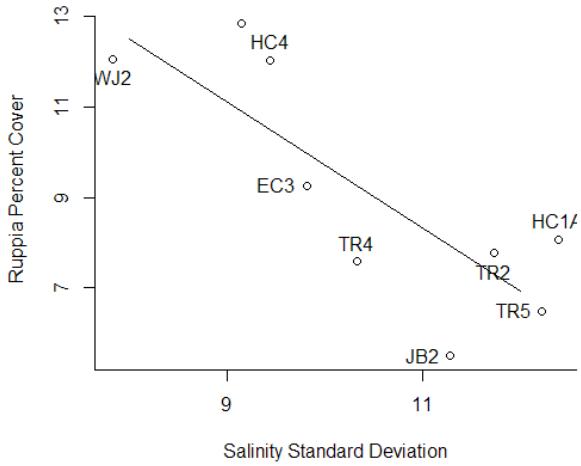


Figure 6-34. Relationship between salinity variability (standard deviation) and *R. maritima* cover ($R = -0.82$, $p < 0.05$). Analysis was limited to sites with > 5 percent average *R. maritima* cover. Site JB3, which had an exceptionally robust population, was excluded from this analysis.

Although ecological response to the salinity criterion for MFL is largely focused on *Ruppia*, the intent of the MFL rule is that if this indicator species is protected, other associated plant species will also be protected by the salinity regime established by the criterion. Long-term datasets demonstrate that an appropriate sequence of species occur in the transition zone in response to the salinity gradient established by the MFL criterion.

Optimal conditions for *R. maritima* habitat are low salinities in the wet season and low salinity variability in the dry season. It is important to know the conditions required to successfully germinate *R. maritima* seed and promote seedling survival to recruit new adult plants, which will affect the resiliency of the *R. maritima* community following a loss of plant cover. Research conducted to experimentally examine the factors controlling the early life history, seed germination, seedling survival, and recruitment of *R. maritima* showed that little germination occurred above 20 and of seeds that successful germinate, few seedlings survive above 10 (**Figure 6-35,** FB-MFL5). Therefore, even though adult plants can tolerate high salinity for extended periods, the population is limited on a recruitment basis by the requirement for low salinities that permit early life stages to survive.

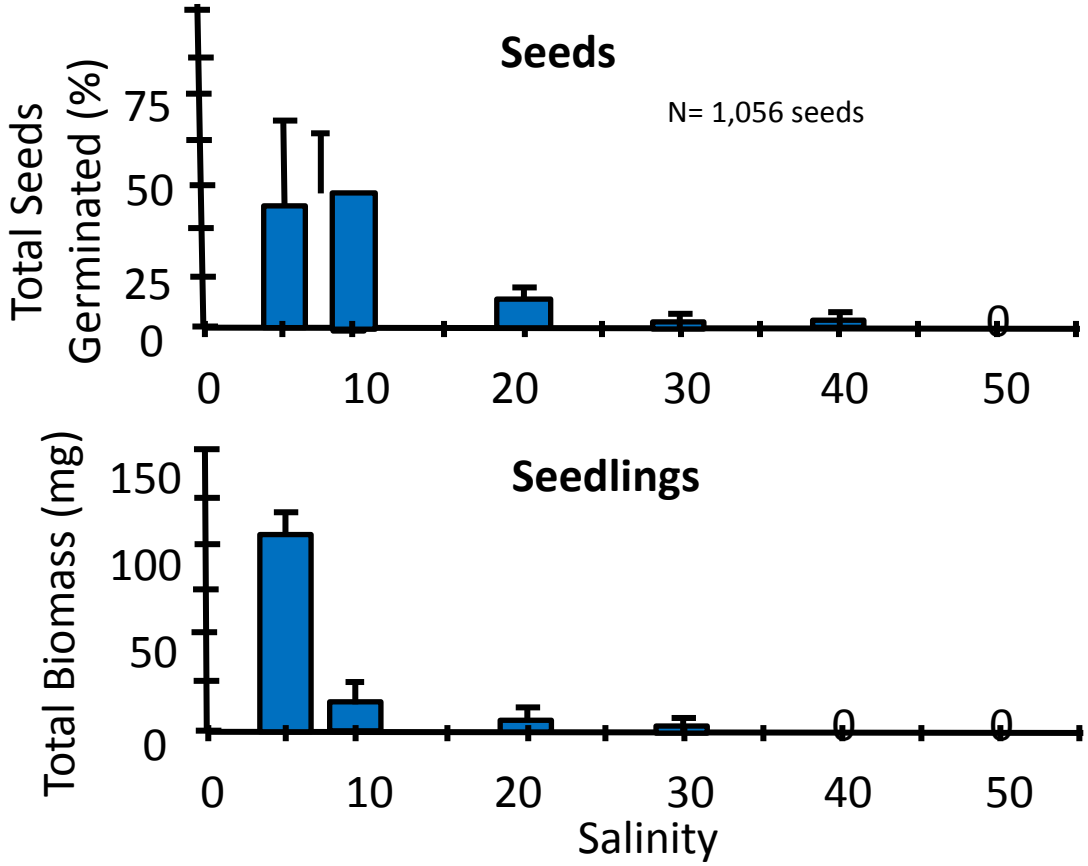


Figure 6-35. Total seeds germinated (upper panel) and seedling biomass (lower panel) under different salinity conditions.

An important consideration in determining relevance of the MFL criteria for vegetation is the benefit to higher trophic levels. Although many factors influence the population dynamics of fish and invertebrates, the association of higher trophic levels with seagrass habitat and low salinity is observed over a number of years and across a variety of conditions. Results of prey-base studies show that prey fish showed greatest density and biomass at lower salinities and increasing density with increasing SAV frequency (**Figure 6-36**).

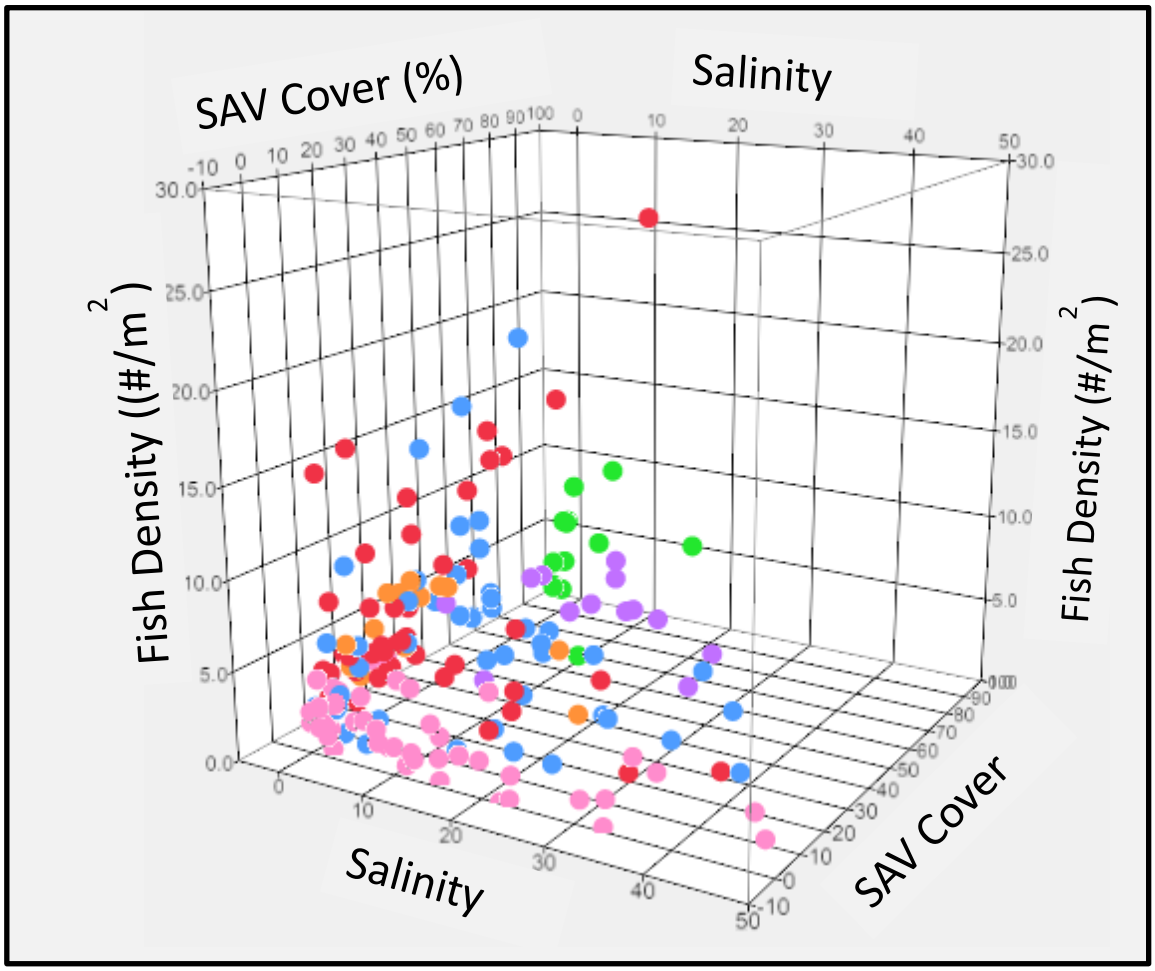


Figure 6-36. Depth-adjusted (stratified mean) prey-fish density (number per square meter) versus salinity and total SAV frequency of occurrence (percent, proportion of quadrats with minimum 5 percent total SAV cover, mixed species). Each bar represents a given fish sampling event, color-coded by site. [Note: psu – practical salinity unit, which is a unit of measure that is no longer used.]

Relevance to Water Management

Salinity level and variability affect the Florida Bay SAV community. Low salinities during the wet season with low seasonal salinity variability in the dry season are optimal conditions for desired *R. maritima* habitat. Although Florida Bay has recently experienced strong hypersalinity events (e.g., WY2012), in WY2013 *R. maritima* occupied a large number of sites throughout the transition zone, reflecting continued protection from harm. The MFL is set at an appropriate salinity level for protection in the transition zone and open waters of northern Florida Bay. Ongoing hydrologic restoration by the C-111 Spreader Western Features Project may improve compliance with the MFL in Taylor River although flow into the C-111 Basin may potentially be reduced. *R. maritima* and the freshwater consortium of the transition zone continue to be afforded effective protection by the MFL in WY2013.

BENTHIC VEGETATION IN FLORIDA BAY

Benthic vegetation, consisting of seagrass and benthic macroalgae, provides important habitat in Florida Bay and its associated creeks, ponds, and wetlands 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 the foundation for the current Florida Bay MFL rule, which is based on the salinity tolerance of widgeon grass (*Ruppia maritima*), and are used to provide ecosystem status updates for Restoration Coordination & Verification (RECOVER) efforts, assessment of District operations, and calibration and verification of the Florida Bay Seagrass Community Model (SEACOM).

Methods

Benthic vegetation is monitored in a randomized design where 0.25-square meter quadrats are assessed using indices of percent cover for benthic vegetation. Three separate monitoring programs cover different areas in Florida Bay. The South Florida Fish Habitat Assessment Program (FHAP) and the Miami-Dade Department of Permitting, Environment, and Regulatory Affairs 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 each May and Miami-Dade Department of Permitting, Environment, and Regulatory Affairs monitors the nearshore embayments of Florida Bay quarterly. Audubon of Florida monitors SAV using a point-intercept method every other month 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 is presented in the 2011 SFER – Volume 1, Chapter 12.

Results

Trends in SAV cover for WY2013 were divergent. During the wet season, below normal salinity facilitated an increase in the abundance of low salinity species such as *R. maritima* and the macroalga *C. hornemanii* in the ecotone. The areas of greatest increases in cover were upstream of Barnes Sound and along Highway Creek in the eastern C-111 Basin (**Figure 6-37**). A concomitant decrease in the abundance of high salinity species such as *H. wrightii* and *T. testudinum* was noted in these transects. Despite lower than normal salinities during the dry season, the gains of lower salinity species did not persist at all sites. In particular, *Chara* cover decreased at sites furthest upstream along the Taylor River and Highway Creek transects, and a large decline in *R. maritima* cover occurred in the Joe Bay transect (**Figure 6-37**) which continued a multi-year trend that began following record high cover in WY2011.

In WY2013, SAV cover in the open water areas of eastern Florida Bay changed little since WY2011. In the central bay, however, *H. wrightii* declined, in some cases significantly (**Figure 6-38**). Notably, in Rankin Lake, significant presence of *H. wrightii* (> 5 percent bottom occlusion) was observed in only 17 percent of the quadrats sampled in May 2012, as compared to in 52 percent in May 2011. Similarly, significant occurrence of *H. wrightii* in Whipray Basin decreased to 14 percent in May 2012 from 37 percent of quadrats sampled in May 2011. Rankin Lake also exhibited a decrease in *T. testudinum* cover, although an increase was observed in Whipray Basin. Importantly, researchers reported characteristics of seagrass die-off in this central bay area during May 2012 sampling, which had ceased by August 2012.

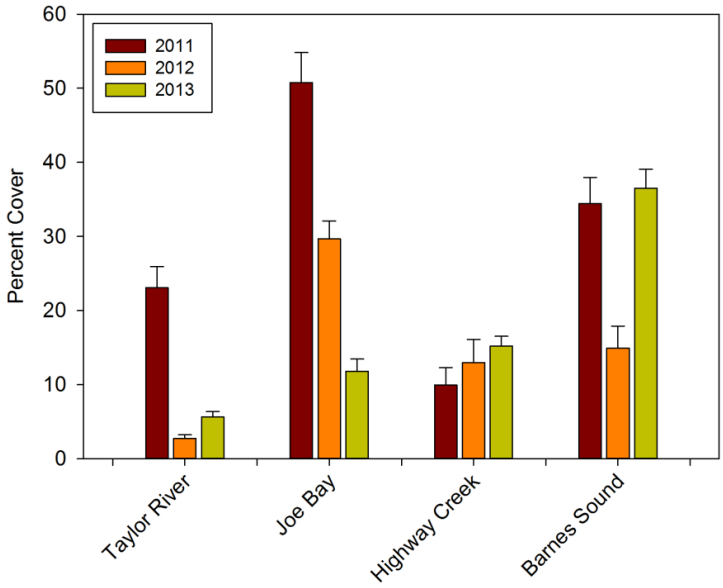


Figure 6-37. Average percent cover of *R. maritima* at the site with the maximum cover along each transect for WY2013 and WY2012. Error bars represent the variability of measurements at each site.

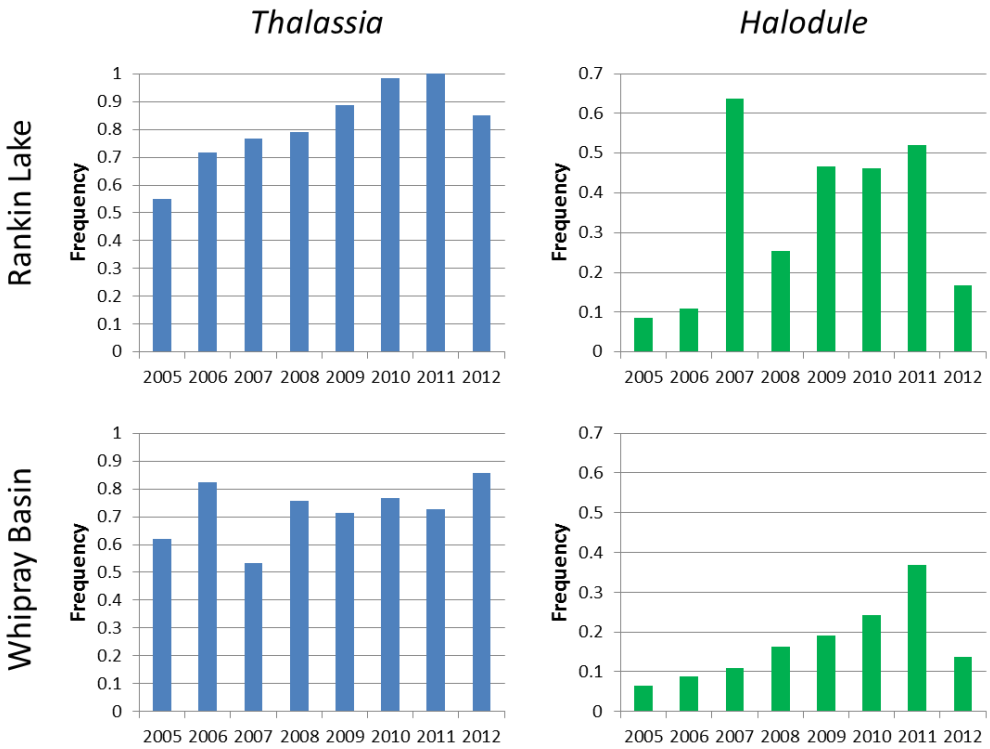


Figure 6-38. Frequency of occurrence at greater than 5 percent bottom occlusion for *Thalassia testudinum* (turtle grass) and *Halodule wrightii* (shoal grass) in two central Florida Bay basins: Rankin Lake and Whipray Basin. Data are collected in May of each year. Significant declines in *H. wrightii* were documented in May 2012 in comparison to May 2011.

Relevance to Water Management

Low salinity throughout the WY2013 wet season allowed the proliferation of fresh and low-salinity species of benthic vegetation in the ecotone upstream of Florida Bay. This response was similar to an event observed in WY2010–WY2011 although not as pronounced. The mixed patterns of SAV response in open water Florida Bay are more representative of the above average salinity of WY2012 rather than reflecting the low salinity of WY2013 because sampling occurred in May, prior to the period of maximum precipitation.

FLORIDA BAY WATER QUALITY CONDITIONS AND STATUS

Water quality in Florida Bay 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. A major CERP restoration project, the C-111 Spreader Canal Western Project, became operational during WY2013. The primary objective of the project is to minimize seepage from Taylor Slough toward the east and into the C-111 Basin. The retention of water in Taylor Slough is designed to facilitate more natural patterns of flow, timing, and freshwater distribution to sustain ecosystem structure and function in the southeastern Everglades and Florida Bay. These hydrologic modifications are not expected to alter downstream water quality, or to increase the magnitude, duration, or spatial extent of algal blooms downstream.

Water quality is assessed using both discrete fixed station sampling as well as synoptic mapping over large areas of southern Biscayne Bay and northern and central Florida Bay. The combination of fixed station sampling and synoptic mapping provides information on how well fixed-point measurements represent larger-scale water quality patterns. In addition, it gives insight into the influence of point source discharges on their receiving waters, permits detection of diffuse nonpoint sources, and reveals how upstream conditions affect the distribution of fresh water, nutrients, and Chl*a* downstream in Florida Bay. Results of water quality monitoring in Florida Bay, Whitewater Bay to the west, and Barnes Sound in Biscayne Bay to the east are reported here. These estuarine regions each have distinct water quality and ecological characteristics, in part, a consequence of the differential inputs of water and associated materials from the Everglades: Taylor Slough and the Everglades panhandle discharge to Florida Bay, Shark River Slough discharges into Whitewater Bay, and the C-111 canal discharges into Barnes Sound. Changing operations associated with implementation of the C-111 South Dade Project, Modified Water Deliveries to ENP (especially Tamiami Trail modifications), and the C-111 Spreader Canal Western Project will further change freshwater flow patterns and may alter water quality.

Methods

At the fixed point stations, water samples and physical parameters (temperature, salinity, conductivity, pH, and dissolved oxygen) are collected monthly in Barnes Sound and every other month at all other sites. Samples are collected at 0.5 m below the surface and processed according to the SFWMD Field Sampling Quality Manual (SFWMD, 2011) following Florida Department of Environmental Protection (FDEP) protocols. Physical parameters are collected with a calibrated sonde following SFWMD protocols. Samples are processed on site, stored on ice, and shipped overnight to the SFWMD Analytical Lab in West Palm Beach for analysis according to SFWMD Chemistry Laboratory Quality Manual (SFWMD, 2012) following FDEP protocols. All sample results are quality assured before being uploaded to the District's DBHYDRO database. Water quality mapping is conducted using high speed, ultra-high resolution (1 m) mapping technology, termed data flow (Madden and Day, 1992), at least quarterly. Five data flow surveys

were conducted in WY2013. This data flow device is a portable, self-contained flow-through instrument containing sensors and fluorometers for continuous sample acquisition and high speed real time in vivo measurement of a suite of water quality parameters including temperature, conductivity, salinity, pH, dissolved oxygen, turbidity, Chl*a* fluorescence and colored dissolved organic matter (CDOM) fluorescence. Additionally, a C-6 Multi-sensor Platform (Turner Designs) consisting of six Cyclops-7 sensors and fluorometers that measure in vivo turbidity and Chl*a*, CDOM, phycoerythrin (blue-green algae pigment), phycocyanin (blue-green algae pigment), and optical brighteners in relative fluorescence units is modified for operation in the flow-through system. A global positioning system provides location coordinates for each data point.

Results and Discussion

The discrete water quality samples analyzed for this report are Chl *a*, total phosphorus (TP), total nitrogen (TN), total organic carbon (TOC), dissolved inorganic nitrogen (DIN), and turbidity. The annual averages of all parameters for all basins were similar across both water years and were lower than the period of record averages with a few exceptions. The WY2013 annual averages of Chl*a* in east and central Florida Bay and Whitewater Bay, TN in the central bay and Whitewater Bay and DIN in Barnes Sound and Whitewater Bay were above their period of record (POR) averages. In addition, many of these parameters have stabilized somewhat, indicated by little to no interannual concentration changes, during the last four years compared to the POR (**Figure 6-39**). This could be attributed to many factors including the lack of storm/hurricane disturbance, increased SAV coverage resulting in stabilized sediments, or system reaching equilibrium after the 2004 and 2005 hurricanes.

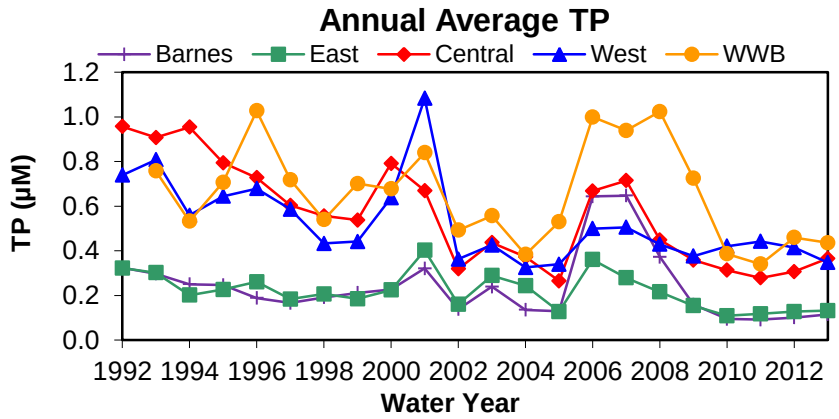
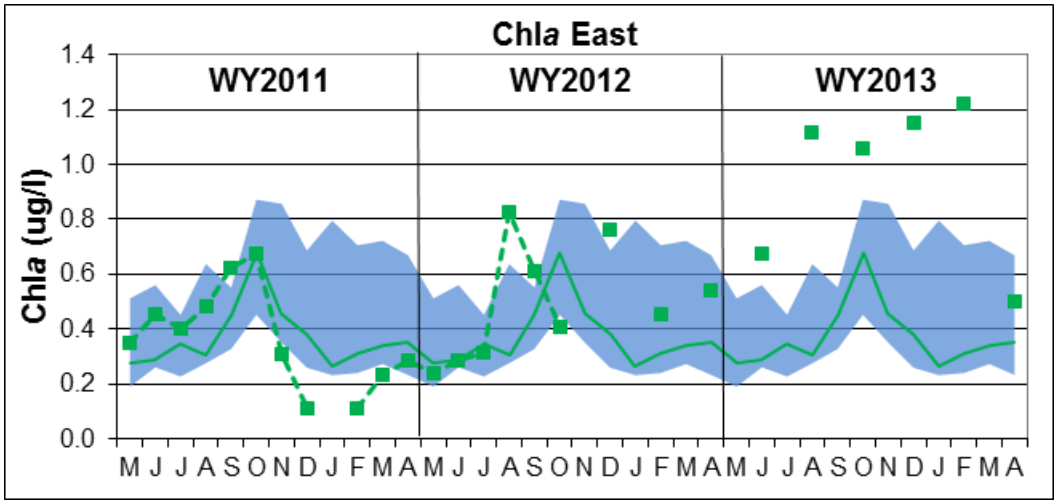


Figure 6-39. Annual average total phosphorus (TP) concentrations in micromoles per liter (µM) in all regions showing similar concentrations during the last four water years compared to the entire period of record in each region. [Note: WWB – Whitewater Bay.]

TP, TN, turbidity, and TOC exhibited similar seasonal patterns in WY2012 and WY2013 in all basins (data not shown). Chl*a* and DIN followed similar patterns in WY2012 and WY2013 in central and western Florida Bay and Whitewater Bay but not in Barnes Sound or the eastern bay. Both Chl*a* and DIN in Barnes Sound were slightly lower during WY2013 than WY2012. In the eastern bay, a significant increase in Chl*a* was measured in WY2013 compared to both WY2012 and the long-term average during the months of August, October, and December 2012, and February 2013. Chl*a* during these four months was approximately 2.7 times higher than the

long-term mean, while DIN was approximately 2.4 times lower during the same period (**Figure 6-40**, green squares).

It was determined that a single site, at the mouth of Little Madeira Bay was driving the Chl*a* increase in the eastern bay, although the pattern of lower DIN was regional. The cause of the elevated Chl*a* is unknown, but it was localized to Little Madeira Bay and the nearby area where Chl*a* was somewhat elevated for part of the wet season. Record discharge from Taylor River likely displaced the water mass into Florida Bay proper where the water quality monitoring site is located. Synoptic mapping confirmed that the elevated values were limited to the immediate area surrounding the mouth of Little Madeira Bay during June and August (**Figure 6-41**) and levels rapidly declined to the historical mean within a short distance from Little Madeira Bay.



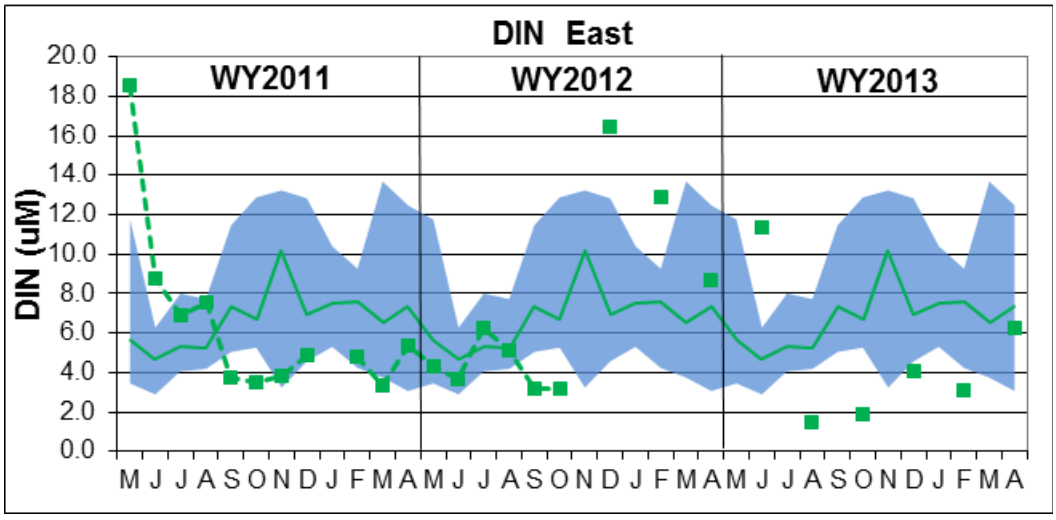


Figure 6-40. Chlorophyll *a* (Chl*a*) concentrations in micrograms per liter (µg/L, upper) and dissolved inorganic nitrogen (DIN) concentrations in micromoles per liter (µM, lower) in the eastern region of Florida Bay during WY2011 through WY2013 (solid symbols) compared to the temporal median of the monthly spatial means and the interquartile range for the entire period of record, WY1992–WY2010 (solid line and blue shading). Dashed line becomes points after October 2011 because sampling was then conducted every other month.

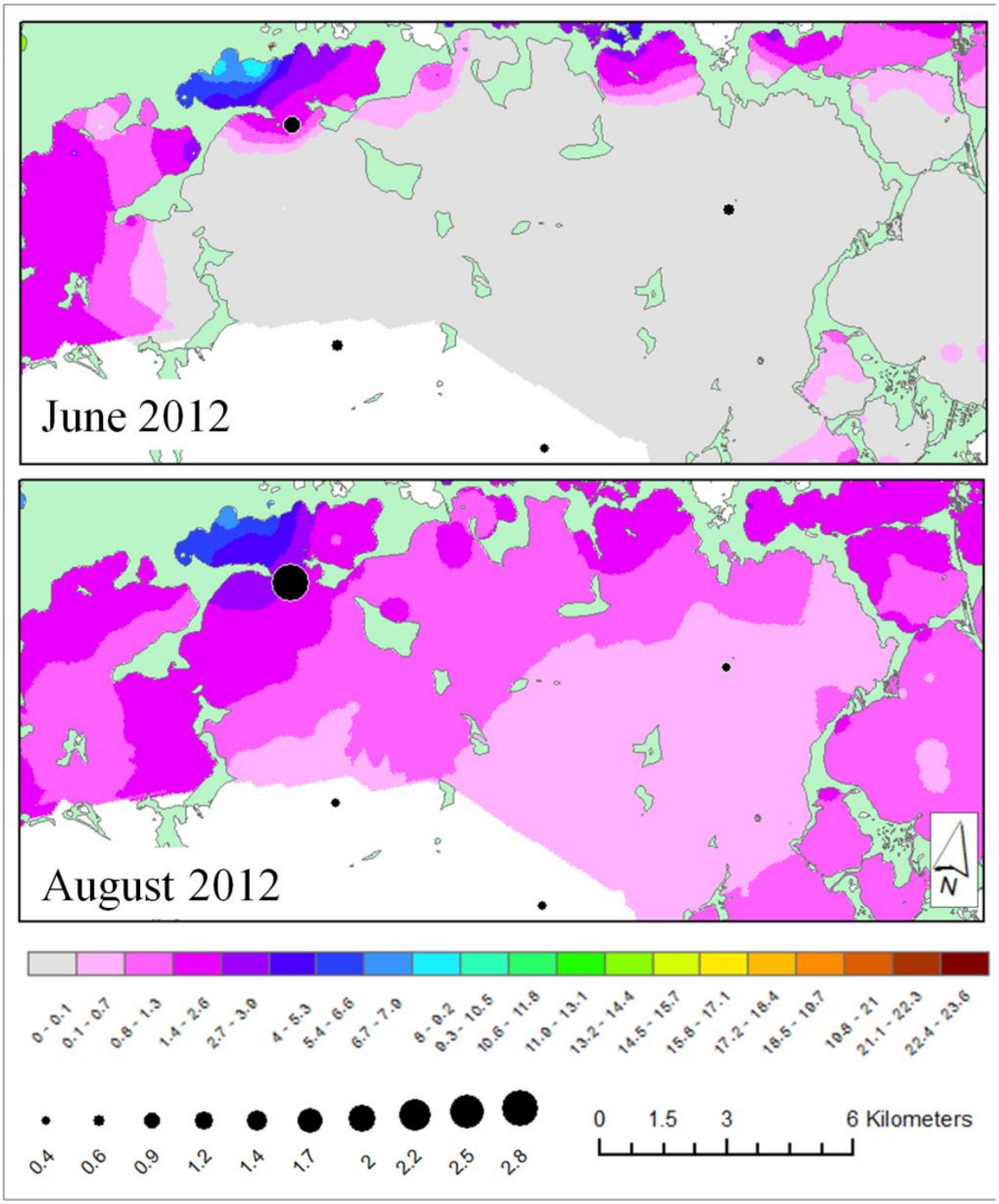


Figure 6-41. Chl*a* in µg/L interpolated maps from June (upper panel) and August (lower panel) 2012. Discrete samples are represented by black circles.

Relevance to Water Management

Water quality assessment is used to document the effects of recent changes in the quantity, timing, and quality of water delivered to the southern Everglades wetlands and the Florida Bay estuary. Specifically, it enables detection of any unusual conditions and provides information on the movement of fresh water, nutrients, and organic matter from the S-332 structures and the C-111 canal through the mangrove wetlands of the southern Everglades and Florida Bay. The elevated Chl*a* observed in Little Madeira Bay during WY2013 is hypothesized to be due to the displacement of water into Florida Bay due to the record discharges from Taylor River. Several factors likely contributed to the observed flow pattern, including high rainfall in the local sub-watershed, the installation of a hydrologic seepage barrier on the eastern border of Taylor Slough, and operational flows through the C-111 project features. Continued long-term data collection will enable determination of impacts of the C-111 project in the context of interannual variability in precipitation.

SIMULATION MODELING TO EVALUATE CENTRAL EVERGLADES PLANNING PROJECT ALTERNATIVES AND EFFECTS ON FLORIDA BAY SUBMERGED AQUATIC VEGETATION

The Central Everglades Planning Project (CEPP) consists of a system of water management features and operations designed to move additional water from Lake Okeechobee and other sources to provide restoration benefits to the Everglades and Florida Bay. In order to evaluate the effects of various CEPP design alternatives on Florida Bay SAV communities, the District's SEACOM model was used to predict trajectories of Florida Bay seagrass populations under five CEPP restoration alternatives, historical conditions based on the Natural System Model (NSM), the existing condition baseline (ECB), and the future without project (FWO). The desired outcome of restoration of freshwater flows is a more diverse, mixed SAV community than present, characterized by expanded *R. maritima* habitat in the northern sites and mixed *T. testudinum-H. wrightii* in sites farther from freshwater sources. SAV biomass and species composition was generated by SEACOM for Little Madeira Bay near the mangrove ecotone at the outflow of the Taylor River site and for the Whipray Basin site in the central bay, about 25 kilometers distant from the freshwater discharge at Taylor River. Output is presented here for ALT 4R, a likely preferred alternative, and is compared to the FWO to determine benefits of the project to Florida Bay. SEACOM (Madden and McDonald, 2010; Madden, 2013) outputs biomass and species composition for the three dominant seagrasses in northern Florida Bay.

Methods

SEACOM (Madden and McDonald, 2010, Madden, 2013) outputs biomass and species composition for the three dominant seagrasses in northern Florida Bay. Hydrologic output was generated by the Distict's Regional Simulation Model and a multiple linear regression algorithm was used in post-processing to generate salinities for downstream locations at critical points in Florida Bay to be used as input to SEACOM. The SEACOM model was run with a time step (dt) of 0.1 day for a simulation period of 40 years after model stabilization and was initialized as follows: average year conditions (the standard model conditions) for model runs for several Florida Bay locations were calculated from salinity, temperature data (ENP continuous monitoring platforms, computed daily), and water column nitrogen and P data (Southeast Environmental Research Center, Florida International University marine monitoring network, computed monthly) from 1996 to 2005. The standard salinity and temperature model was calculated as the average value for each day across all years in the POR (e.g., the January 1 value equals the average of values on January 1 from 1996–2005) and the standard nutrient model was calculated as the monthly average for TN and TP across 1996–2005. The monthly average

nutrient value was applied to each day of the month, yielding a step function. For each 40-year scenario run, the salinity simulations were provided from the Regional Simulation Model-multiple linear regression output and run with the standard model temperature and nutrients. The final seagrass values provided by the equilibrated model were applied as initial conditions for each of the scenario runs.

Results

The SEACOM output for the Taylor River site TR, representative of coastal lakes in northern Florida Bay, site TR under Natural Systems Model hydrology reflects that, historically, a diverse mix of SAV species under wetter conditions resulted from greater freshwater flows in the pre-drainage Everglades (not shown). *T. testudinum* was reduced due to lower salinities, and *H. wrightii* and *R. maritima* were abundant compared to current conditions. For CEPP planning, ALT 4R produced the most favorable outcome for restoring Florida Bay SAV at Taylor River, resulting in mixed stable communities of three SAV species relative to the FWO alternative. *T. testudinum* under ALT 4R (**Figure 6-42**) was reduced by 0 to 17 percent relative to FWO for an average reduction in biomass of about 8 percent. *H. wrightii* responded positively to the decrease in salinity due to additional fresh water provided by ALT 4R (**Figure 6-43**), increasing in biomass by up to 33 percent during the simulation period, with largest gains occurring in dryer years. *R. maritima*, which was not appreciably present in any year of the FWO scenario (**Figure 6-44**), increased significantly under ALT 4R, particularly during the latter 10 years of the simulation, establishing a persistent presence presumably due to both the simulated seed bank being built up and baseline salinity being lower than the average for the simulation period.

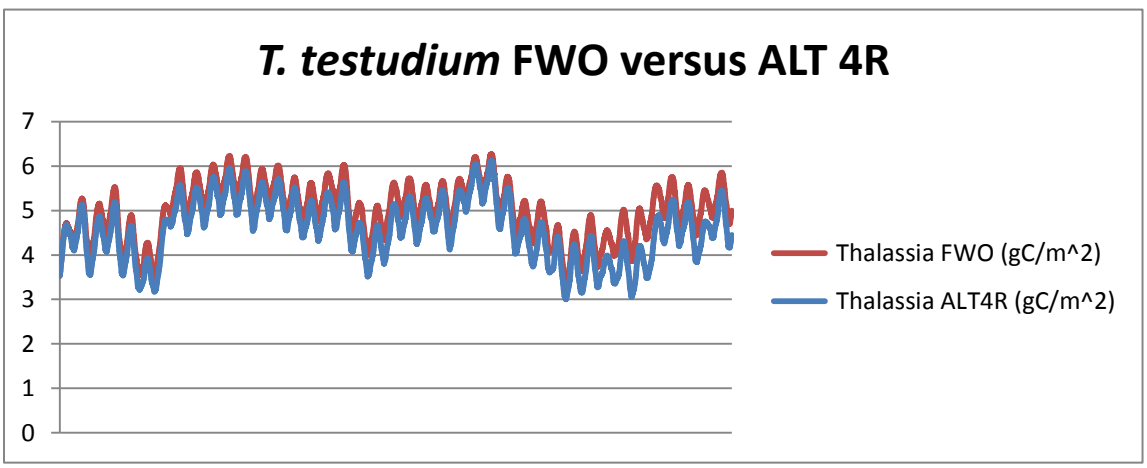


Figure 6-42. *T. testudium* biomass at Taylor River site TR for a 40-year simulation comparing Alternative 4R (ALT 4R) and the future without project (FWO.) [Note: gC/m^2 – grams carbon per square meter.]

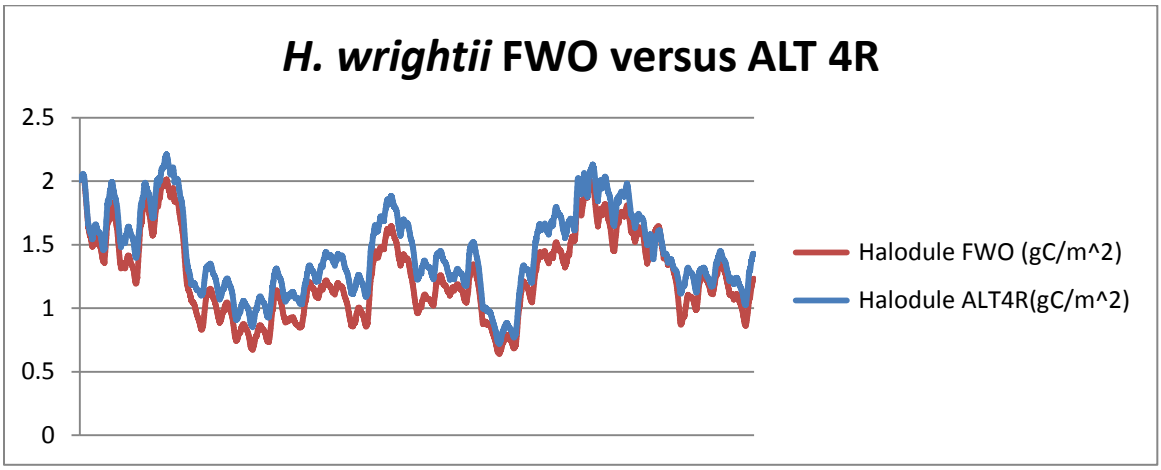


Figure 6-43. *H. wrightii* biomass at Taylor River TR site for a 40-year simulation comparing ALT 4R and FWO.

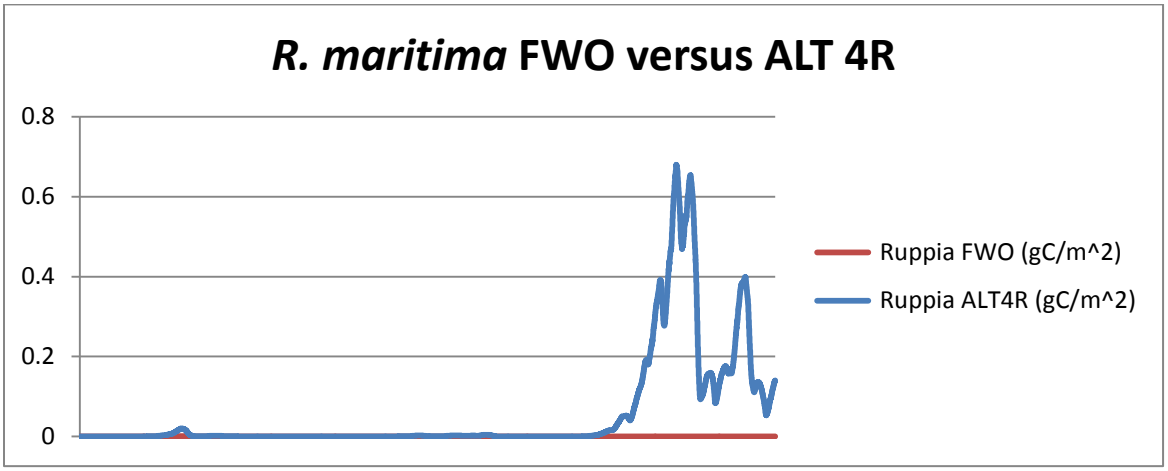


Figure 6-44. *R. maritima* biomass at Taylor River TR site for a 40-year simulation comparing ALT 4R and FWO.

Runs for Whipray Basin (not shown) indicated that no CEPP alternative had much impact on SAV. No *Ruppia* was present in NSM, FWO, or CEPP scenarios. ALT 4R generated a slight decrease in *T. testudinum* of less than 0.5 percent and an increase in *H. wrightii* in some years of up to 2 percent. These results indicate little difference between historical pre-drainage conditions and current conditions at that site, which is 30 kilometers distant from freshwater sources in the central bay ecotone.

Relevance to Water Management

The modeling evaluation demonstrated that CEPP alternatives provided benefit to the seagrass community in nearshore Florida Bay, particularly the ecotone and regions of the northern bay, decreasing the monospecific characteristics of the community and allowing expansion of *R. maritima* into the nearshore lakes of Florida Bay. The overall outcome was that alternative ALT 4R created a more mixed SAV community, with reduced dominance by *T. testudinum*, increased species richness, and higher overall productivity for co-dominant species, trending toward historical conditions projected by NSM.

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