Chapter 6: Ecology of the Everglades Protection Area

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SUMMARY

The studies and findings discussed in this chapter of the *2011 South Florida Environmental Report* (SFER) – *Volume I* are presented within five conceptual groupings: (1) hydrologic and climate trends, (2) wildlife ecology, (3) plant ecology, (4) ecosystem ecology, and (5) landscape processes. Programs of study were based on the short-term operational needs and long-term restoration goals of the South Florida Water Management District (SFWMD or District), including large-scale and regional hydrologic needs in relation to regulation schedules, permitting, the Everglades Forever Act [Section 373.4592, 11 Florida Statutes (F.S.)] mandates, and the Comprehensive Everglades Restoration Plan (CERP). An overview of projects and results, along with related mandates, is presented in **Table 6-1**.

HYDROLOGIC AND CLIMATE TRENDS

In terms of historical trends, the hydrologic environment for Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) in the Everglades was somewhat of a flip-flop. The wet season did not get as wet as it normally does and the dry season did not get as dry. The end result was a net annual precipitation that was only about 5 inches greater than normal, but had a seasonal pattern where large fluctuations and reversals occurred in the wet season, and where water depths were too great during the dry season to support foraging by wading birds. The hydrology in Water Conservation Area 1 was the most representative example of this pattern.

A homogeneity study on the large-scale, long-term climate regimes of South Florida was also conducted in WY2010. Examining these trends provides a useful first step in anticipating climate influences on hydrology at spatial scales relevant to water management. Gradients in precipitation and temperature over spatial scales of 10–100 kilometer (km) are important to understanding the smaller spatial-scale heterogeneities in the response of South Florida's climate to variability in teleconnection patterns. This work suggests that each of three climate indices has seasonally variable impacts across relatively small spatial scales (10–100 km) on time scales from inter-annual to multi-decadal. Study findings indicated the need to downsize coarse spatial-scale global circulation models and create predictive climatic indices better suited for the District's region.

WILDLIFE

Wading bird nesting was not successful for most species in calendar year 2010. Large abandonments occurred throughout the system especially during March and April 2010. In the few places that wood storks (*Mycteria americana*) attempted to nest, all nests failed. The

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relatively unsuccessful nesting season was probably a consequence of the direct effects of cold weather early in the fledgling season when temperatures dropped below 40 degrees Fahrenheit for extended periods of time and hydrology on foraging success. In addition, these factors likely had indirect effects on prey production.

Everglades tree islands may have a unique connection to wildlife, and not just as critical habitat and centers of biodiversity, but also as central depositories for the accumulation of nutrients, especially phosphorus. It may be that without this enrichment, tree health would decline, the peat accumulation rates would not be enough to keep islands dry during critical mating periods, and the tree islands would become marsh. Several pathways leading to nutrient enrichment in tree islands have been proposed, one of which is the contribution of guano from wading birds nesting on tree islands.

The contribution of heavy nitrogen in tree island soil organic matter from wading bird guano was evaluated with nitrogen stable isotopes, which indicated that the marsh soil and various primary producers (plants) were depleted in ^{15}N, while the consumer (animal) tissues were enriched in ^{15}N. This may explain why the soil $\delta^{15}N$ value fell from 3–5 parts per thousand (‰) for 15 tree islands and was greater than 5‰ for seven islands, suggesting a food web where wading birds prey on invertebrates and fish from the marsh and excrete nutrients as guano onto the vegetation and soils of tree islands, thereby enriching the soils. Nitrogen was chosen for study since there is a scientific basis for traceability to ecological source, and because nitrogen and phosphorus are closely linked within food webs.

Unfortunately, wildlife now also refers to invasive species. Five invasive plant species [Australian pine (*Casuarina equisetifolia*), Brazilian pepper (*Schinus terebinthifolius*), melaleuca (*Melaleuca quinquenervia*), Old World climbing fern (*Lygodium microphyllum*), and shoebutton ardisia (*Ardisia elliptica*)] and seven invasive animal species [Argentine black and white tegu (*Tupinambis merianae*), Cuban treefrog (*Osteopilus septentrionalis*), Burmese python (*Python molurus bivittatus*), island apple snail (*Pomacea insularum*), Nile monitor (*Varanus niloticus*), redbay ambrosia beetle (*Xyleborus glabratus*), and sacred ibis (*Threskironis aethiopicus*)] found in the Everglades Protection Area (EPA) are assessed in this chapter. Biological scientists and land managers familiar with the Everglades evaluated each of these 12 species for (1) distribution, (2) known and possible impacts on native systems, (3) status and effectiveness of control programs if any, (4) the potential effects of the species on restoration efforts, and (5) recommended actions for each species in light of its possible effects on Everglades restoration, operations, and conservation.

PLANTS

The three projects discussed in this chapter focus on plants associated with tree islands in the Everglades. First is a description of the surveys that are used to identify the early infestations of the invasive Old World climbing fern and an analysis that suggests that the hydrologic conditions on a tree island two years prior to surveys can serve as an indicator of the probability of finding *Lygodium*.

Second is a description of an important ecophysiological measurement, sap flow, in tree species on islands with differing hydrologic regimes as a way to identify plant stress. Although most of the species in this study were more flood tolerant than upland hammock tree island species, the trees evaluated still showed a significant response to hydrologic conditions. Sap flow rates were highest at the beginning of the wet season (June–October) when water levels were beginning to rise and the leaves in the canopy were fully expanded.

Studying the (1) germination, establishment, growth, survival, and recruitment of woody species, (2) ecological processes that maintain a healthy forest structure and, over time, (3) tree island spatial extent, composed the third project. It is reported here that woody species successfully colonize, become established, and survive on tree island sites where the hydroperiod is short and soil nutrients are high. In addition, the presence of small elevated sites, such as fern tussocks, small hummocks, and tree stumps create conditions that enhance seedling growth and survival.

ECOSYSTEM

Two ecosystem-scale projects focus upon mechanisms to accelerate the recovery of cattail-infested marsh and one focuses upon the use of plant fossil seeds to determine historic hydrologic regimes. Past SFERs have presented data on the impacts of fires on cattail recovery and phosphorus release. The 2011 SFER describes a wetland ecosystem model (WED) used to better understand the effect of longer-term application of repeated fires on the rate of phosphorus depletion from the soils in enriched regions of the Everglades. In this simulation, the cattails grow back to approximately the same biomass every year using the phosphorus reserves in the soil. The outcomes of the WED simulation, based on four seasonal and hydrological scenarios suggest that fires under low-water depth (< 10 cm) could result in a 14 percent reduction in soil phosphorus from an impacted area over 20 years. Water depth was found to be the most critical factor for effects of fire on phosphorus removal, the post-fire phosphorus pulse, and downstream effects.

An update on the Cattail Habitat Improvement Project (CHIP) used to better understand the effect of removal of cattail using herbicides is also provided. CHIP was designed to assess whether creating openings in dense cattail areas will sufficiently alter trophic dynamics such that wildlife diversity and abundance increase and determine to what extent these created open areas' functions compare to the natural Everglades. Preliminary findings indicate that these created openings have higher wildlife diversity and are sustainable in the short term — and with minimal effort and cost may be sustained long term. These openings also compare favorably with natural functions and may provide both operational flexibility and significant environmental benefits in a region where currently neither one exists.

Paleoecological analyses of Everglades soil cores used fossil seeds and other proxies to quantify vegetation changes at the multi-century to millennial-scale. Everglades fire regimes and paleoclimate drivers suggest that natural climate variability (i.e., pronounced southward shifts in the Inter-Tropical Convergence Zone) can effectively change a sawgrass-water lily, ridge-and-slough landscape to a fire-dominated, tree island-forming, charophyte (water-plant dominated) landscape. While observations of widespread charophyte-dominated portions of the Everglades landscape are lacking in the modern system, experimental results from the CHIP experiment — of charophyte dominance after large-scale vegetation disturbances — may provide key insights about the ecosystem drivers that triggered this state change in the past and the internal feedbacks that contributed to its inherent, long-term stability.

LANDSCAPE

Four landscape projects, designed to help the SFWMD manage water in a more holistic manner while providing data for system-wide performance measures, are included in this SFER.

1. For the first time, the SFER includes the characterization of "ghost" tree islands in Water Conservation Area 2A (WCA-2A). Although most tree islands in WCA-2A are gone and converted to ghost tree islands, they appear to have formed across a broader spectrum of geomorphological conditions than previously thought, including on pinnacle rock, bedrock depressions, and even a flat plain topographic surface. As a possible indicator of extreme degradation, peat bulk density was low at nearly all sites and increased down-core but remained low, similar to the marsh.

2. The mapping and analysis of tree island and vegetation changes in Water Conservation Area 3 (WCA-3) continues. The WY2010 update, from aerial photos taken in 2004, shows that the number and overall hectares (ha) of tree islands continues to decline. There was a net loss of 519 acres from the WCA-3 community of tree islands, between 1995 and 2004.
3. A WCA-3 vegetation map was completed from 2004 imagery. This new map, compared to a 1995 WCA-3 baseline vegetation map, found that sawgrass/shrub areas increased approximately 48 percent from 3,871 to 5,738 ha, broadleaf marsh increased 30 percent, and floating marsh decreased by 37 percent.
4. A new digital aerial sketch mapping (DASM) technique was introduced in WY2010. This region-wide mapping effort documented the spatial extent and dominance patterns of four priority invasive plant species within the Everglades Protection Area. Given its relatively low cost, low turnaround time, and acceptable mapping accuracy, DASM has great potential for numerous invasive plant mapping applications across the vast Everglades landscape.

Table 6-1. Summary of Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) Everglades research findings in relation to operational mandates.

Projects	Findings	Mandates
Hydrologic Patterns for Water Year 2010	Abnormally high rainfall in May 2009 helped to make WY2010's rainfall amount in the Everglades Protection Area 10–26 percent greater than the 15-year historical average. Water depths were never high enough to threaten the health of tree islands; however, recession rates and water depths throughout the Everglades during the dry season (November–May) did not support extensive or intensive wading bird foraging or nesting.	ROS, MFLs
Climate Gradients Across South Florida	Climate teleconnection patterns have variable influence on South Florida climate over short distances.	CERP, MFLs, FEIM
Wildlife		
Wading Bird Monitoring	There was a significant decrease in nesting effort relative to WY2009 and the decadal average. The lack of successful nesting may be attributed largely to cold weather during early spring and related rainfall-reversal events that resulted in poor foraging and nesting conditions.	ROS, CERP, MFLs, FIEM
Potential Faunal Contributions to Tree Island Phosphorus Cycling	The total phosphorus (TP) content in the soil of tree islands may be due to faunal contributions as guano. This hypothesis is supported by the high stable nitrogen isotopes (^{15}N) in tree island soils, which reflect organic matter from organisms at high trophic levels. These organisms with enriched ^{15}N are represented by consumers such as wading birds which feed on aquatic animals. Decreases in soil TP concentrations in the tree islands since Water Conservation Area impoundment took place in the 1950s have also been observed.	EFA, CERP, FIEM
Invasive Nonindigenous Species in the Everglades Protection Area (EPA)	The status of 12 priority invasive taxa (five plant, seven animal) were assessed for the Greater Everglades region. The prognoses for invasive species impacts on Everglades restoration vary from significant to minimal to unknown. Recommendations for continued research, monitoring, and management efforts are provided for each species.	CERP, EFA, AWCA, INPA
Plants		
Tree Island Old World Climbing Fern Habitat Suitability Analysis	Original expectations were that adjacency to infestations of Old World climbing fern (*Lygodium microphyllum*) would indicate risk for new infestations. However, analysis revealed that tree islands with *Lygodium* are located in areas where water depths and depth variability are significantly lower; adjacency to other infested tree islands seemed to be unimportant.	FEIM, MFLs, CERP, the RECOVER Monitoring and Assessment Plan, and the Interim Operational Plan/Combined Structural and Operational Plan

Table 6-1. Continued.

Projects	Findings	Mandates
Plants (*continued*)		
Seasonal and Spatial Pattern of Sap Flow in Tree Island Woody Species: An Ecophysiological Indicator of Tree Species Health	Findings on how sap flow data can be used to assess plant community responses to changes in hydrology indicate that woody species that are acclimated to longer hydroperiods are less sensitive to seasonal changes in hydrology. The seasonal pattern of xylem sap flow for willow (*Salix caroliniana)*, pond apple (*Annona glabra*), and cocoplum (*Chrysobalanus icaco*) followed very closely canopy leaf area development. Although most tree island species are flood tolerant, these woody species showed significant response to flooding variability.	ROS, CERP, EFA
Tree Island Seedling and Sapling Recruitment as a Function of Hydrology and Soil Nutrient Resources	The survivorship rate at the seedling and sapling stage was driven by the hydropattern that characterized the tree islands under study. Woody species successfully colonized, established, and survived on sites where the hydroperiod was short and soil TP was high. However, along the nutrient-hydrology gradient that characterized both tree islands, it was the hydrology that played a major role in driving recruitment and survivorship rates (higher on sites where hydroperiod was short). An important finding associated with seedling survivorship is that small elevated sites (e.g., fern tussocks, small hummocks, and tree stumps) create conditions that enhance seedling growth and survivorship on tree islands where the hydroperiod is longer. Thus, variation in microtopography and microenvironment allows seedling and saplings to survive under long hydroperiods and poor nutrient conditions.	ROS, CERP, EFA
Ecosystem		
Cattail Fire Model	A wetland ecosystem model (WEM) predicted that repeated application of fire alters the TP dynamics in surface and porewater, and soil. Fires under low-water-depth conditions generated stronger negative effects on TP concentration in water and soil regardless of season. July fires generated similar but larger increases of TP in surface and porewater than February fires regardless of water depth. The WEM showed that repeated fires suppress cattail aboveground biomass.	LTP
Cattail Habitat Improvement Project	Submerged aquatic vegetation, principally the macroalga, *Chara*, remained the dominant component of vegetative biomass in open plots. Cattail invasion of open plots remained at less than 30 percent almost three years after the last herbicide treatment and without additional management. Open plots consistently supported higher wading bird foraging than the surrounding cattail habitat. All these characteristics indicate that active management has created a regime shift that benefits wildlife within enriched and transitionally enriched areas of the Everglades.	LTP, ROS

Table 6-1. Continued.

Projects	Findings	Mandates
Ecosystem (*continued*)		
Using Plant Fossil Seeds to Determine Historic Hydrologic Regimes	Paleoecological evidence shows that relatively large ecosystem state changes in the Everglades likely coincided with past multi-decadal droughts, due to pronounced southward shifts in the Inter-Tropical Convergence Zone at 3.8, 3.4, 3.0, and 2.8 thousand years ago (ka). The first and most significant of these (3.8 ka) coincided with a replacement of a sawgrass-and-water lily landscape with a *Chara*-dominated one, which subsequently endured over 2,000 years.	CERP, EFA, ROS, MFLs
Landscape		
Tree Islands in Water Conservation Area 2A: Microtopography and Vegetation Patterns	Tree islands in WCA-2A formed over pinnacle rock, bedrock depressions, and even over a flat topographic surface. Peat depths ranged from 1–2 meters and increased from south to north of the WCA. The elevational difference between a marsh and a tree island was greatest in southern WCA-2A. Peat bulk density was low at nearly all sites and increased down-core but nonetheless remained low, similar to the marsh. Vegetation on “ghost” islands was fairly depauperate, with only a few woody species dominating the heads of what remained of the former tree islands.	EFA, CERP, MFLs
Water Conservation Area 3 Tree Island Map Update	Numbers and hectares (ha) of tree islands have declined since a previous comparison mapping of tree islands for the 1940s–1995 period, which documented a 61 percent decline of tree islands within this impoundment. The WY2010 analysis also suggests that cypress (*Taxodium* spp.) tree islands have differing driving metrics for change as opposed to strand tree islands, which appear to be changing more rapidly.	CERP, EFA
Vegetation Trends within Water Conservation Area 3 from 1995–2004	The 2004 WCA-3 vegetation map resulted in 939,415 photointerpreted 50 x 50 meter grid cells or 234,854 ha of land surface mapped. Overall map accuracy was 90.8 percent. Exotic species were again a small (35 ha) overall component of the conservation area. The most significant finding may be the change in cattail cover since 1995. Analyzing each grid cell for any amount of cattail showed a 63 percent increase from 19,871 ha in 1995 to 32,349 ha in 2004.	EFA
Quantifying Region-Wide Invasive Nonindigenous Plant Infestations Using Digital Aerial Sketch Mapping (DASM)	The District and partners mapped invasive plant infestations in the entire Everglades Protection Area during spring 2009 (northern half) and spring 2010 (southern half). DASM is proving to be a cost-effective means of rapidly obtaining information on invasive plant distributions.	EFA, INPA

AWCA–Florida Aquatic Weed Control Act (Section 639.20, F.S.)
CERP–Comprehensive Everglades Restoration Plan
EFA–Everglades Forever Act [Section 373.4592, Florida Statutes (F.S.)]
FEIM–Florida Everglades Improvement and Management
INPA–Invasive Nonnative Plants Act (Chapter 369.251, F.S.)
LTP–Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area
MFLs–Minimum Flows and Levels
RECOVER–Research Coordination and Verification
ROS–Regulation and Operational Schedules
USEPA–U.S. Environmental Protection Agency

HYDROLOGIC AND CLIMATE TRENDS

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HYDROLOGIC PATTERNS FOR WATER YEAR 2010

The amount of rain in the Everglades Protection Area (EPA) for Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) was substantially more than WY2009 and significantly different, in terms of seasonality, from historical averages. WY2010 rainfall amounts also varied little from region to region as shown in **Table 6-2**. In Everglades National Park (ENP or Park), the rainfall was 5.3 inches more (9.6 percent) than the historical average and 17.9 inches more (32.4 percent) than WY2009. In Water Conservation Area 3 (WCA-3), the rainfall was 9.2 inches more (9.6 percent) than historical average and 16.3 inches more (36.8 percent) than WY2009. In Water Conservation Areas 1 and 2 (WCA-1 and WCA-2), the rainfall was 13.6 inches more (26.3 percent) than historical average and 18.2 inches more (38.4 percent) than WY2009. (See Chapter 2 and related appendices of this volume for a more detailed description of rain, stage, inflows, outflows, and historic databases). (See Chapter 1, **Figure 1-1**, for a map of the region).

Table 6-2. Average, minimum, and maximum stage [feet National Geodetic Vertical Datum (ft NGVD)] and total annual rainfall (inches) for WY2010 in comparison to historic stage and rainfall. Average depths were calculated by subtracting elevation from stage.

Area	WY2010 Rainfall	Historic Rainfall	WY2010 Stage Mean (min; max)	Historic Stage Mean (min; max)	Elevation
WCA-1	65.6	51.96	16.33 (13.81; 16.99)	15.63 (10.0; 18.16)	15.1
WCA-2	65.6	51.96	12.32 (9.45; 13.56)	12.53 (9.33; 15.64)	11.2
WCA-3	60.6	51.37	9.90 (5.83; 11.06)	9.55 (4.78; 12.79)	8.2
ENP	60.5	55.22	6.15 (4.19; 6.85)	5.99 (2.01; 8.08)	5.1

As one would expect from these above-average precipitation values, regional water depths were also above average. The average depth in the ENP for WY2010 was 1.1 feet (ft), which was 0.2 ft above the historical average, but interestingly was 0.1 ft less than in WY2009. This may be due to the fact that the total inflows into the ENP were about 37,000 acre-feet (ac-ft) less than WY2009 (see Chapter 2 of this volume) but the difference was most likely due to the very low stages at the beginning of WY2010. The average depth in WCA-3 for WY2010 was 1.7 ft, which was 0.4 ft above the historical average, but again interestingly, was 0.4 ft less than last year. In this case, total inflows were about 259,000 ac-ft more than WY2009. This difference is clearly due to the very low stages at the beginning of WY2010 relative to WY2009. The average depth in WCA-2 for WY2010 was 1.1 ft, which was 0.2 ft above the historical average, and greater than last year. The average depth in WCA-1 for WY2010 was 1.2 ft, which was 0.7 ft above the historical average, and greater than WY2009.

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The greatest difference between WY2010 and WY2009 can be found by looking at the month of May 2009 (**Table 6-3**) and the dry season recession rates (**Figures 6-1** through **6-7**). May 2009 is mentioned because of its tremendous deviation from the norm (high rainfall that caused reversals in most regions) and its significance to the fledging of wading birds (reduced success) at the end of the 2009 nesting season. **Table 6-3** summarizes the statistics for rainfall just in May 2009 compared with rainfall in the month since 1932. Notice that May is typically a transition month (from the dry to wet season) and has a very high mean range. Despite this wide range of historical values, May 2009 had one of the highest precipitation rates of any May on record for the WCAs and tied the overall record for the entire South Florida Water Management District (SFMWD or District).

Table 6-3. Average, minimum, and maximum total monthly rainfall (inches) for the Everglades Protection Area (EPA) in comparison to May 2009 (Ali et al., 1999; MacVicar, 1983).

Area	May 2009 Rainfall	Average May Rainfall	Historic May Rainfall (min; max)	Historic Period for min and max (n)
WCAs-1 & 2	9.15”	5.22”	(0.38”; 14.60”)	1957–2009
WCA-3	9.00”	5.25”	(0.94”; 10.90”)	1963–2009
Entire SFWMD	9.04”	4.66”	(1.26”; 9.04”)	1932–2009

The following hydropattern figures (1) highlight the average stage changes in each of the WCAs for the last two years in relation to the recent historic averages, (2) flooding tolerances for tree islands, (3) drought tolerances for wetland peat, and (4) recession rates and depths that support both nesting initiation and foraging success by wading birds. These indices were 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 (MFLs) in the Everglades (SFWMD, 2000).

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 categories based upon foraging observations in the Everglades (Gawlik, 2002).

- A red label ➡ indicates conditions of hydrologic reversal due to recession rates that are too fast (greater than 0.6 ft per week) or too slow (less than 0.04 ft for more than two weeks), or when the average depth change for the week is positive rather than negative.
- A yellow label ➡ indicates poor conditions due to a slow recession rate of 0.04 ft for a week or a rapid recession between 0.17 ft and 0.6 ft per week.
- A green/good label ➡ is assigned when water depths decreased between 0.05 ft and 0.16 ft per week.

Although these labels are not indicative of an appropriate depth for foraging, they have been useful during high water conditions to highlight recession rates that can lead to good foraging depths toward the end of the dry season (April and May).

Water Conservation Area 1

WY2010 started with the second wettest May in the history of the SFWMD, but less so for WCA-1. On May 1, 2009, there were still about 4 inches of water across the impoundment (**Figure 6-1**). After an exceptionally smooth and steady recession rate from November 2008 until May 2009 that fostered record-breaking nesting and foraging by wading birds in WCA-1, water levels rose about one foot over a two-month period; this was not an extreme rehydration rate, but just enough to bring the 2009 wading bird nesting season to an end. Water depths in WCA-1 continued to rise during the wet season and reached a peak of around 2.0 ft in October 2009, but never posed a flooding problem for tree islands.

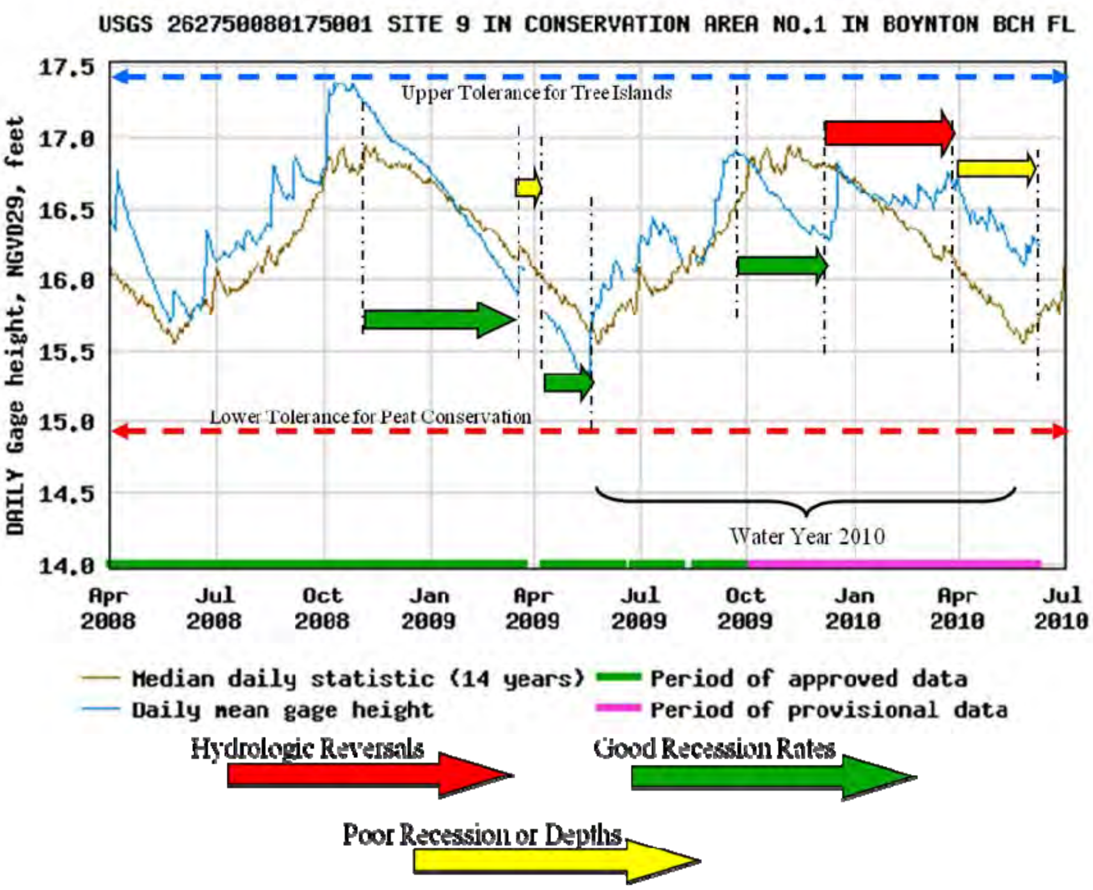

Figure 6-1. Hydrology in Water Conservation Area 1 (WCA-1) in relation to the 14-year median stage and indices for tree island flooding, peat conservation, and wading bird foraging.

The water level changes during the WY2010 dry season and wading bird nesting season was almost a perfect opposite to that in WY2009. At first, recession rates were excellent and it appeared that there could be a hydrologic pattern to support early nesting by wood storks (*Mycteria americana*), a goal of Comprehensive Everglades Restoration Plan (CERP) restoration. However, in late December 2009 there was a rapid water level rise to average conditions, where levels hovered for almost four months. Recession rates in support of wading bird foraging started up again around April 2010, but depths stayed more than one foot for the rest of the dry season — not an optimum situation for short-legged wading birds. WCA-1 had the longest duration of good nesting and foraging of any region in the EPA for the previous four years. For WY2010, hydrological conditions were merely marginal everywhere in the Everglades, including WCA-1.

Water Conservation Areas 2A and 2B

For the last four water years in WCA-2A, the stage levels during the wet season have exceeded the upper flood tolerance for tree islands for one to two months, which is not considered enough time to cause any tree island damage (Wu et al., 2002). In WY2010, despite a huge water level increase of almost 4.0 ft from May–July, water levels did not exceed the upper flood tolerance for tree islands for even a day (**Figure 6-2**). WCA-2A and 2B continue to be the most hydrologically variable regions in the entire EPA. Future efforts to restore WCA-2A tree islands will require a closer examination (i.e., frequency analysis) to see if this kind of hydropattern can enhance the return of woody tree species to these marshes.

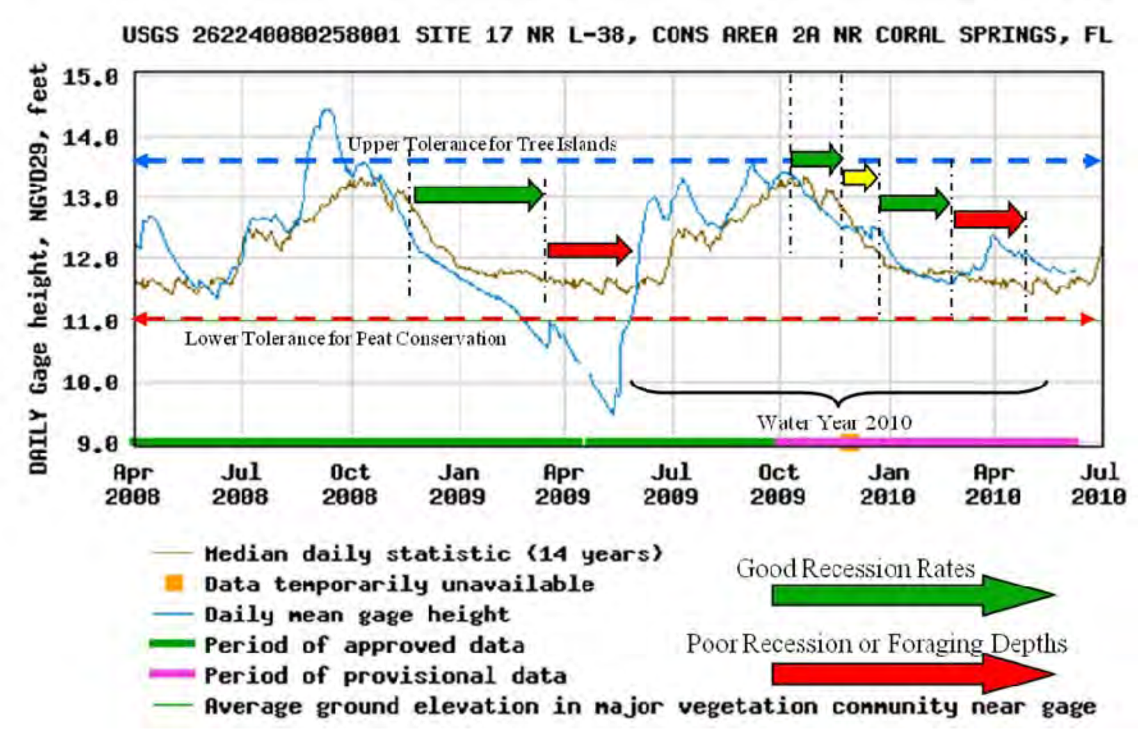

Figure 6-2. Hydrology in Water Conservation Area 2A (WCA-2A) in relation to the recent 14-year average, with indices for tree islands, peat conservation, and wading bird foraging.

Wading birds frequently forage in WCA-2B during droughts because it tends to stay deeper and maintain water for longer periods than the rest of the Everglades Protection Area (EPA). This was particularly true in WY2006 when dry season water levels went below ground in WCA-2A and the wading birds moved to the wetter habitat of WCA-2B. In 2009, large flocks of wading birds were observed foraging in WCA-2B in April and May because recession rates were excellent and depths were near optimum. In WY2010, like everywhere else, May rainfall was remarkable; stage readings at structure S-99 went from 7.1 ft to 10.6 ft in two months (**Figure 6-3**). Water depths stayed above 3 ft for almost the entire dry season and as a result, very few wading birds were observed foraging in WCA-2B in WY2010.

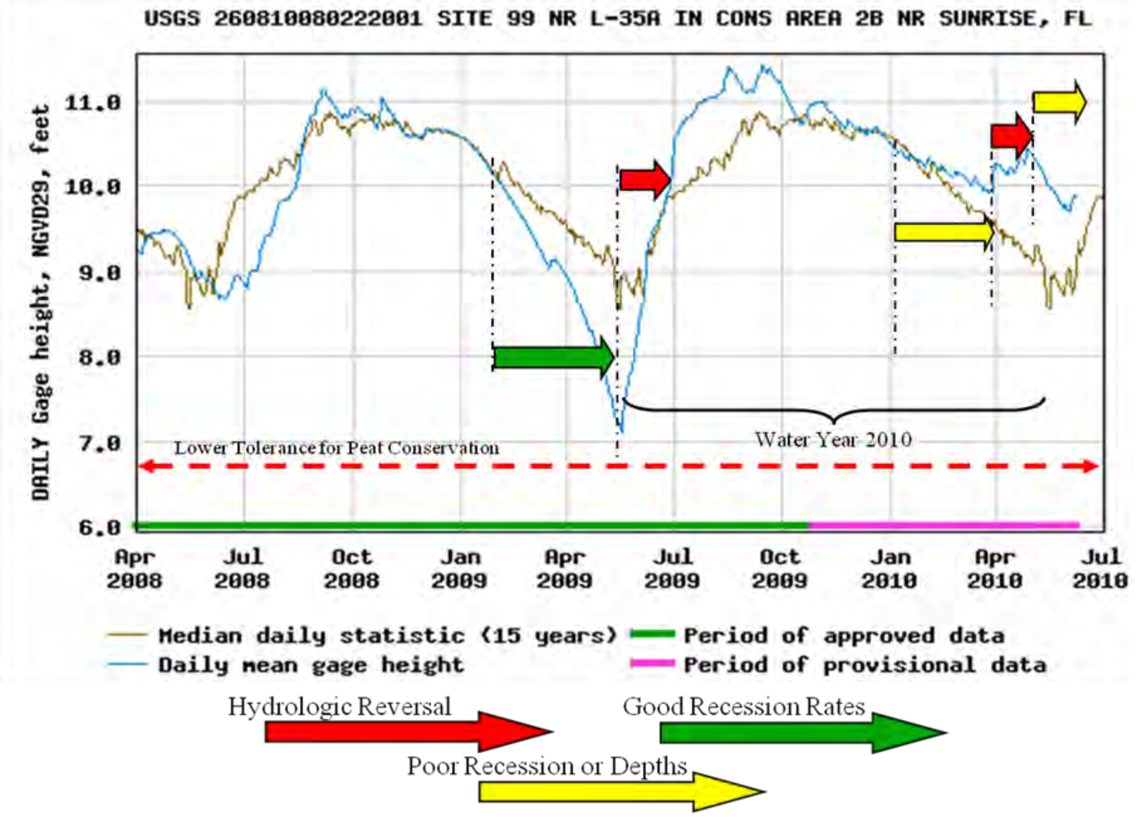

Figure 6-3. Hydrology in northeast Water Conservation Area 2B (WCA-2B) (gauge 63) in relation to the recent 15-year average with indices for tree islands, peat conservation, and wading bird foraging.

Water Conservation Area 3A

In the northeastern region of WCA-3A (gauge 63), WY2009 began relatively well in June 2008 with steady rehydration rates and a long wet season with a hydroperiod capable of rejuvenating the prey base for the region's large wading bird rookery (Alley North) where annual nesting during the past decade has frequently exceeded 20,000 nests. Optimum recession rates in this important northeast section of WCA-3A began around December 2008 and continued uninterrupted until water levels went below ground in April 2009. Soil moisture became critically low and posed a muck fire threat to the Alley North colony. Fortunately, there were no muck fires and the May 2009 downpours very quickly removed the fire hazard in the region. After the May rainfall, water levels exceeded tree island tolerances for two short periods and then in October began to decline, but too steeply to support wading bird foraging (**Figure 6-4**). By December, there was a reversal, followed by no recession, followed by another reversal, which combined marked a four-month period of very poor wading bird foraging habitat.

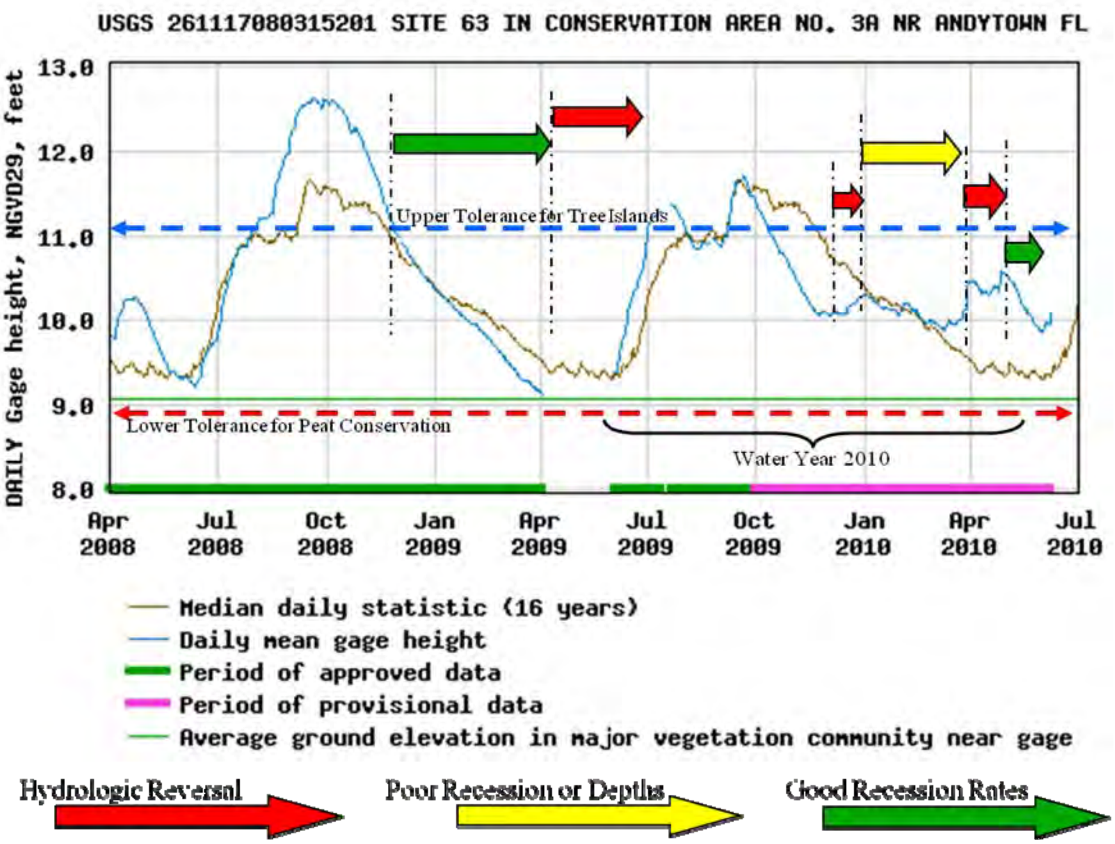

Figure 6-4. Hydrology in northeast Water Conservation Area 3A (WCA-3A) (gauge 63) in relation to the recent 16-year average with indices for tree islands, peat conservation, and wading bird foraging.

The hydrologic pattern during WY2009 in central WCA-3A (gauge 64) was extremely conducive for wading bird foraging. Good recession rates that supported maximum foraging behavior and nesting lasted for a full five months beginning in December 2008 and ended abruptly in May 2009 (see **Table 6-2**). WY2010 was very different (**Figure 6-5**). Water levels barely got high enough to rehydrate tree islands and recession rates were poor for almost the entire wading bird nesting season. However, despite relatively high water, wading birds did manage to successfully forage in the central Everglades during the periods of good recession rates (March and June).

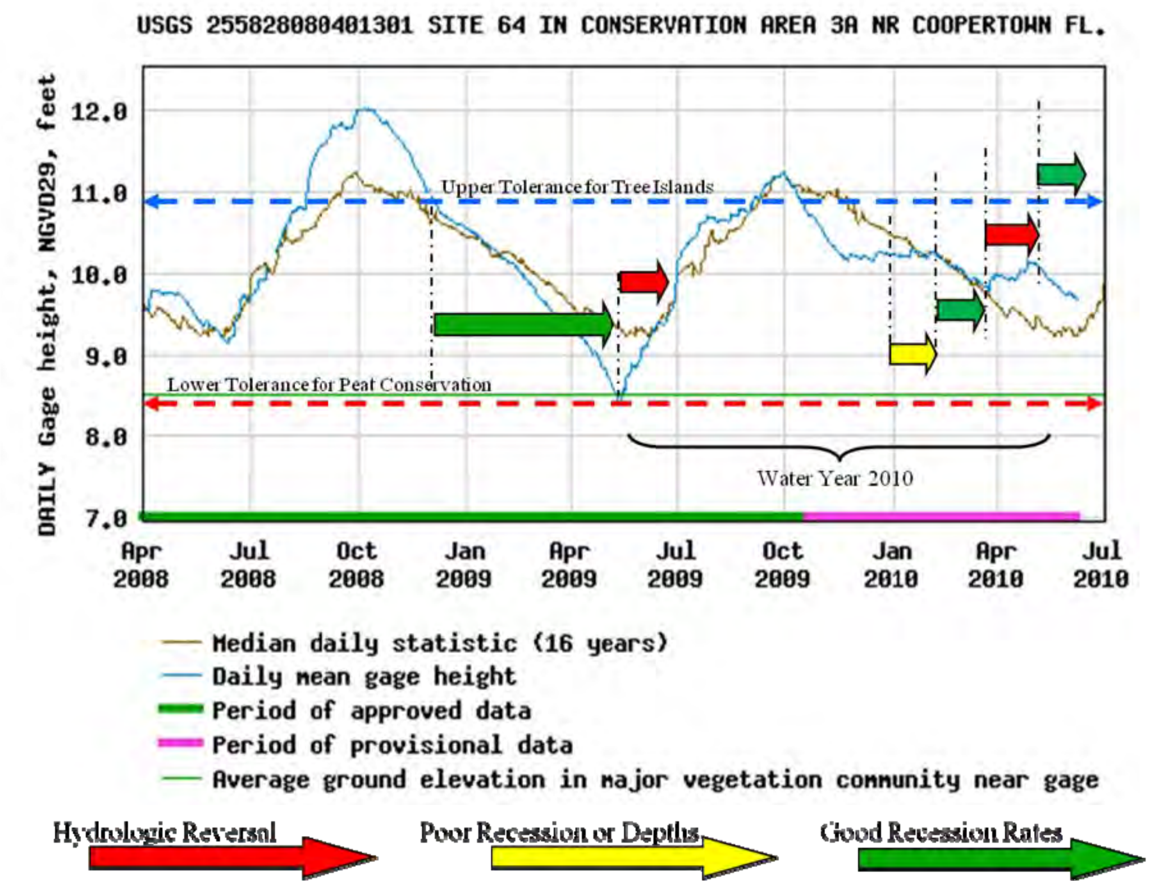

Figure 6-5. Hydrology in central WCA-3A (gauge 64) in relation to the recent 16-year average with indices for tree islands, peat conservation, and wading bird foraging.

Water Conservation Area 3B

In 2008, rising water levels in WCA-3B during the wet season followed the 12-year average almost exactly and the upper tolerance for tree islands was barely reached. Then, in November, water levels fell at an almost perfect 0.10 ft per week during the dry season. The setup for optimum March and April 2009 foraging by wading birds could not have been better. WY2010 was a very different story (**Figure 6-6**). Like everywhere else in the EPA, there was an abrupt water level rise in May and June 2009, followed by a dry season with numerous reversals and very poor recession rates. Survey flights over this region were very sparse, but it would seem fair to say that extensive use by large flocks was not likely with the prevailing hydrological conditions in the area.

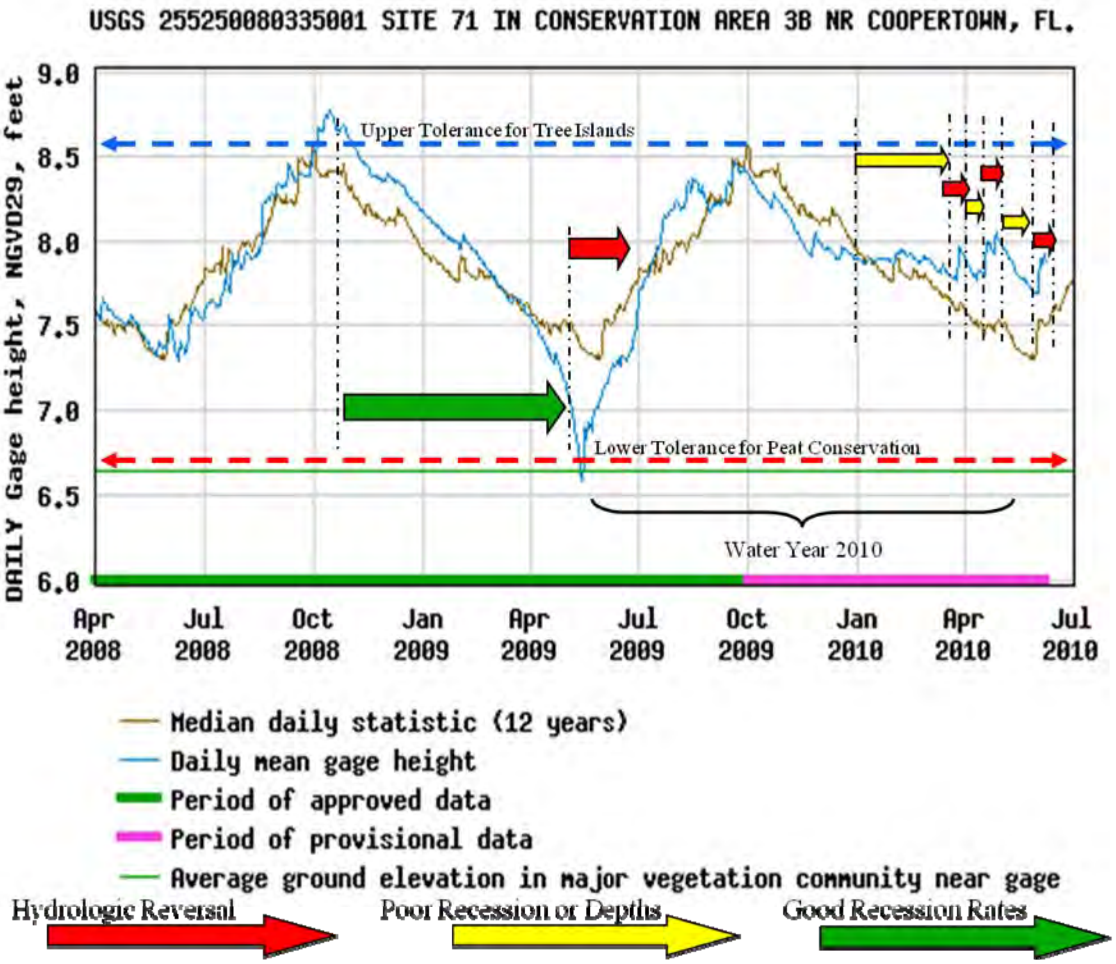

Figure 6-6. Hydrology in central WCA-3B (gauge 71) in relation to the recent 12-year average and indices for tree islands, peat conservation, and wading bird foraging.

Northeast Shark River Slough

For three years in a row (WY2007–WY2009), this region of the Park experienced very dry conditions and violations of the MFLs (Sklar et al., 2009). Despite this trend, WY2009's water levels began dropping in December and good recession rates in support of very good wading bird foraging and nesting remained until April 2009. Like everywhere else, the May rainfall created a dramatic beginning to WY2010 because in two months (May and June) the stage increased by 2.5 ft (**Figure 6-7**). The WY2010 dry season had good recession rates for one month (January). The rest of the time, and despite the relatively good water depths, the water levels in Northeast Shark River Slough did not decrease, did not support wading bird foraging and, in fact, increased.

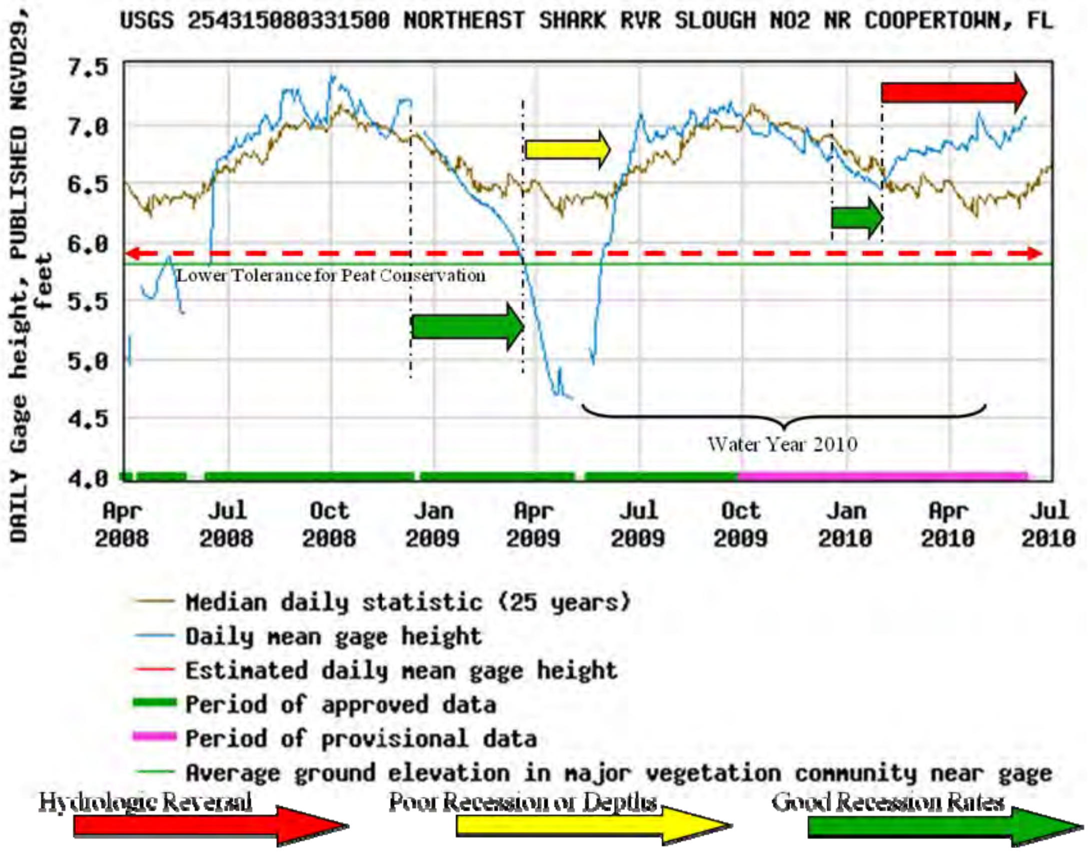

Figure 6-7. Hydrology in Northeast Shark River Slough in relation to the recent 25-year average with indices for tree islands, peat conservation, and wading bird foraging.

CLIMATE GRADIENTS ACROSS SOUTH FLORIDA

South Florida is often portrayed as having a uniform climate over relatively broad scales of 100–300 kilometers (km) in literature addressing large-scale climate phenomena such as the El Niño-Southern Oscillation (ENSO; Donders et al., 2005; Ropelewski and Halpert, 1986) or the Atlantic Multi-decadal Oscillation (AMO; Enfield et al., 2001) indices that are based on sea surface temperature (SST) anomalies. However, literature addressing weather patterns, rather than climate, shows considerable differences in precipitation and temperature over short distances (Henry et al., 1994). These gradients in precipitation (**Figure 6-8**) and temperature over spatial scales of 10–100 km were investigated to better understand the smaller spatial scale heterogeneities in the response of South Florida’s climate to variability in teleconnection patterns.

Methods

Monthly precipitation and air temperature were compiled from two datasets for South Florida; web links used for this study were available as of August 2010. Data for Everglades (EVER), Miami International Airport (MIA), Royal Palm (RP), Flamingo (FLAM), and Tavernier (TAV) were obtained from the National Oceanic and Atmospheric Administration-National Climate Data Center (NOAA-NCDC) via the Florida Coastal Everglades Long-Term Ecological Research climate data portal: http://fcelter.fiu.edu/data/climate/FCE/. Data for Ft. Myers (FTM), Belle Glade (BG), West Palm Beach (WPB), Ft. Lauderdale (FLL), and Key West (KW) were obtained from the NOAA-NCDC Global Historical Climate Network (GHCN) v.2: http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/index.php. The time interval covered in common by all 10 stations was January 1951–March 2006. The WPB station was used for precipitation analysis, but was dropped for air temperature analysis due to unacceptable amounts of missing temperature data.

The AMO index (**Figure 6-9**) used here was calculated on North Atlantic SST anomalies after Enfield et al. (2001): http://www.cdc.noaa.gov/Timeseries/AMO/index.html.

The ENSO time series used was the multivariate ENSO index (MEI) based on the first principle component of six weighted variables as described by Wolter and Timlin (1998): http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/.

The Pacific Decadal Oscillation (PDO) index for this study was based on north Pacific SST anomalies (Mantua and Hare, 2002; Mantua et al., 1997): http://jisao.washington.edu/pdo/PDO.latest.

Data processing and statistical analyses for this work were performed using MATLAB® (R2009b). With the exception of KW, which had an uninterrupted time series, all other stations had small data gaps, each missing 2.1 percent (± 1.1 percent) of the monthly values. Gaps were filled using the corresponding monthly climatology calculated for each station.

Data was compiled into three-month seasonal composites for analysis, as dry season [winter; December–January–February (DJF)] and wet season [summer; July–August–September (JAS)]. The seasonal composites excluded the early and late months of the typical regional wet and dry seasons, minimizing wide precipitation or temperature variances associated with the transition between these periods.

The statistical significance of each correlation was tested at the 95 percent confidence interval at $p = 0.05$, using a phase-randomization method based on Ebisuzaki (1997) which accounts for non-zero autocorrelations. Spatial gradients were interpolated at 0.02 degrees using two-dimensional natural neighbor interpolation, producing grid cells of approximately 2.01 km wide east-to-west, by 2.22 km tall north-to-south ($n = 6,841$).

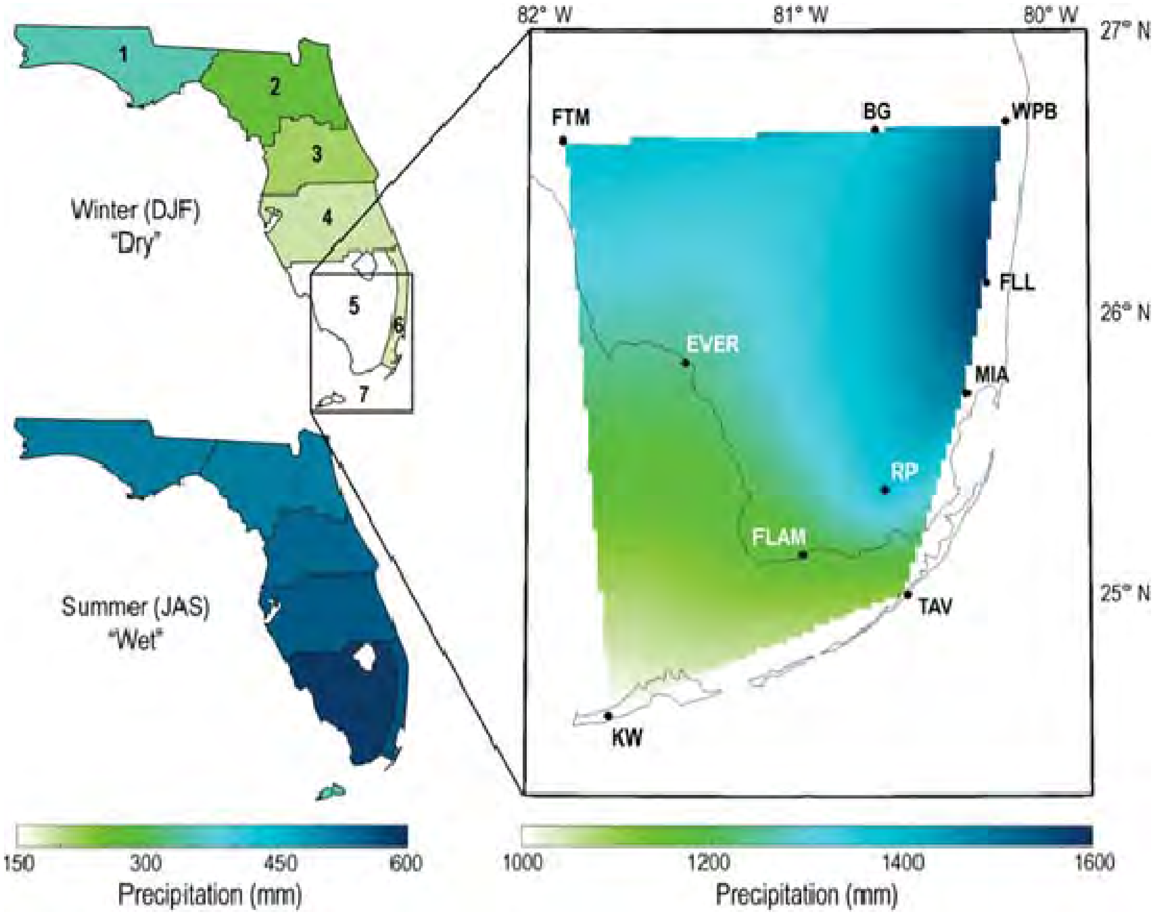

Figure 6-8. Seasonal patterns of precipitation in millimeters (mm) in Florida by the National Weather Service (left). Mean annual precipitation (mm) in South Florida interpolated across the 10 stations used in the study (right).

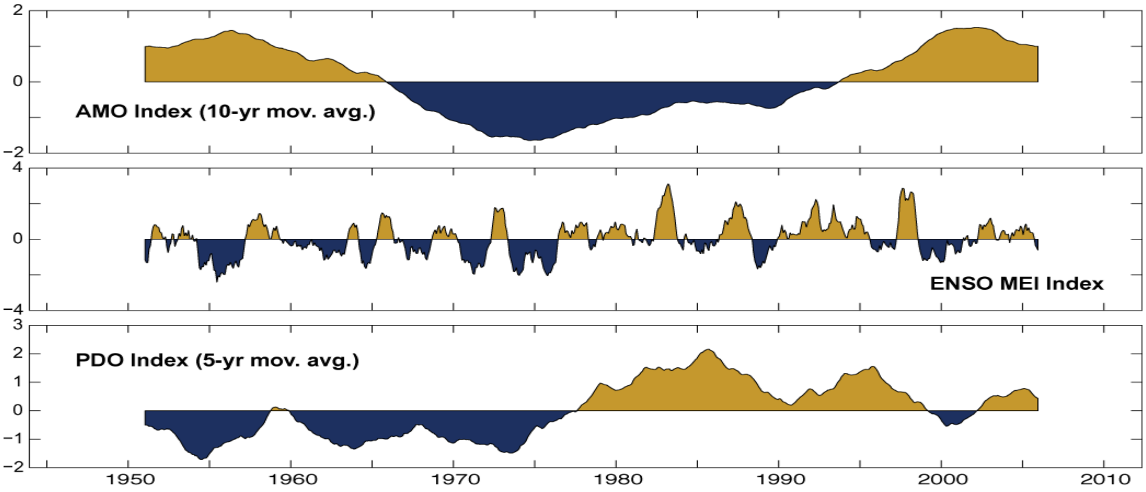

Figure 6-9. The Atlantic Multi-decadal Oscillation (AMO), El Niño-Southern Oscillation (ENSO), and Pacific Decadal Oscillation (PDO) shown for January 1951–March 2006. Index values are in deviations from the mean.

Results and Discussion

Winter precipitation showed no significant correlation to the AMO over the study period. However, summer precipitation at FTM, BG, WPB, RP, and TAV displayed a significant positive correlation to the AMO (**Figure 6-10**) at the 95 percent confidence interval or higher, and the AMO accounted for 7–15 percent of the summertime precipitation variance at these sites. The southwest coastal and southwest interior portions of the Everglades in the vicinity of Shark River Slough showed no correlation between summer precipitation and the AMO.

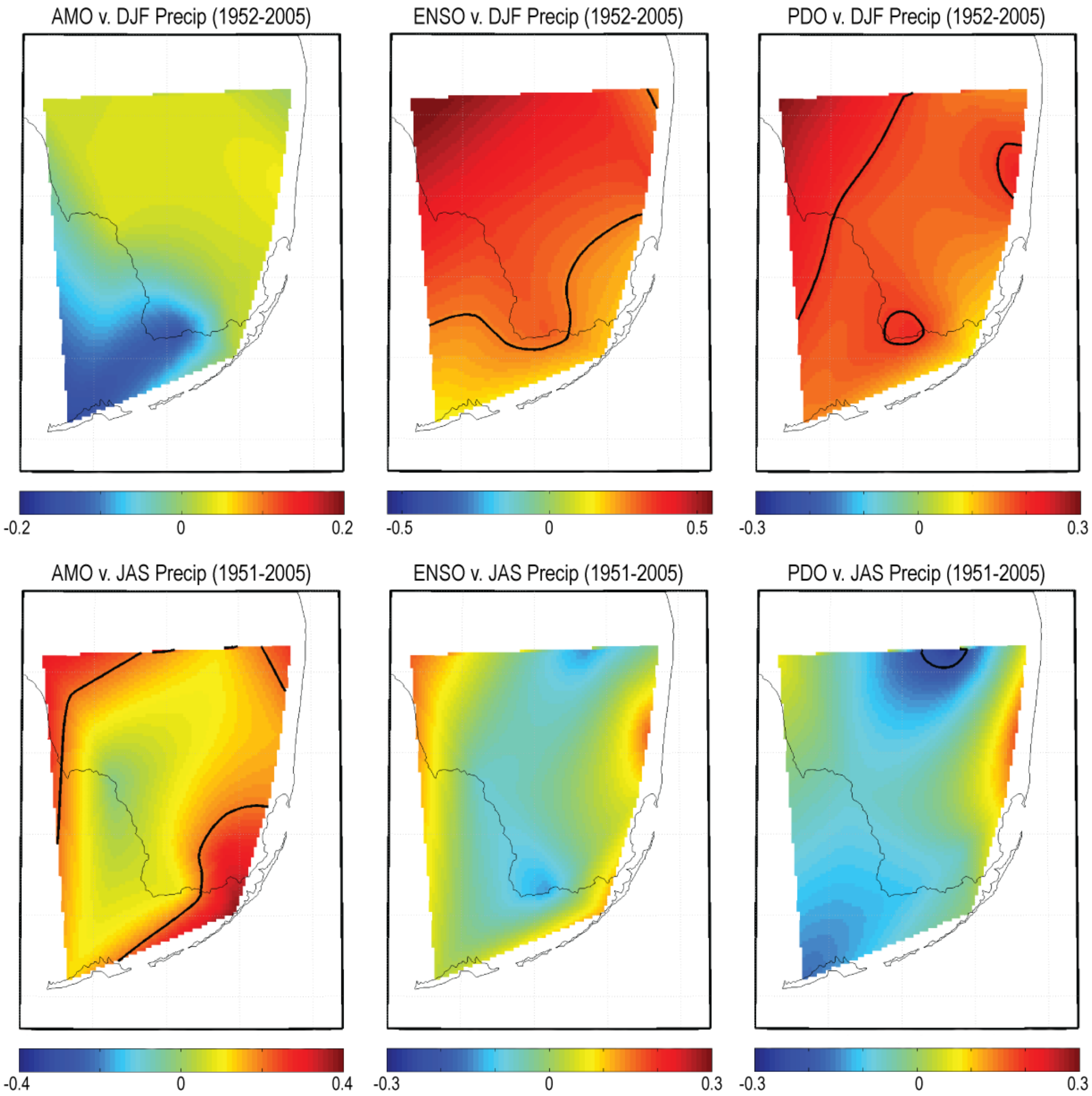

Figure 6-10. Spatial correlation between seasonal precipitation and climate indices across South Florida. Colors indicate correlation coefficients. Solid black lines indicate the 95 percent significance level for the correlation. Geographic scope is identical to the zoomed map in **Figure 6-8**.

Winter mean daily high temperatures do not show any correlation with the AMO at the 95 percent confidence interval, but TAV winter temperatures were significantly negatively correlated at the 90 percent confidence interval (**Figure 6-11**). As with precipitation, the AMO influence was seen more in the summer, with temperatures expressing a positive significant correlation at MIA, FLL, and BG, and further showing correlations at the 90 percent confidence interval at FLAM, EVER, and KW stations. The summer influence of the AMO on daily high temperatures at these locations was expected since these stations do not have increased JAS precipitation which would cool the afternoon daily high temperature during a positive phase of the AMO.

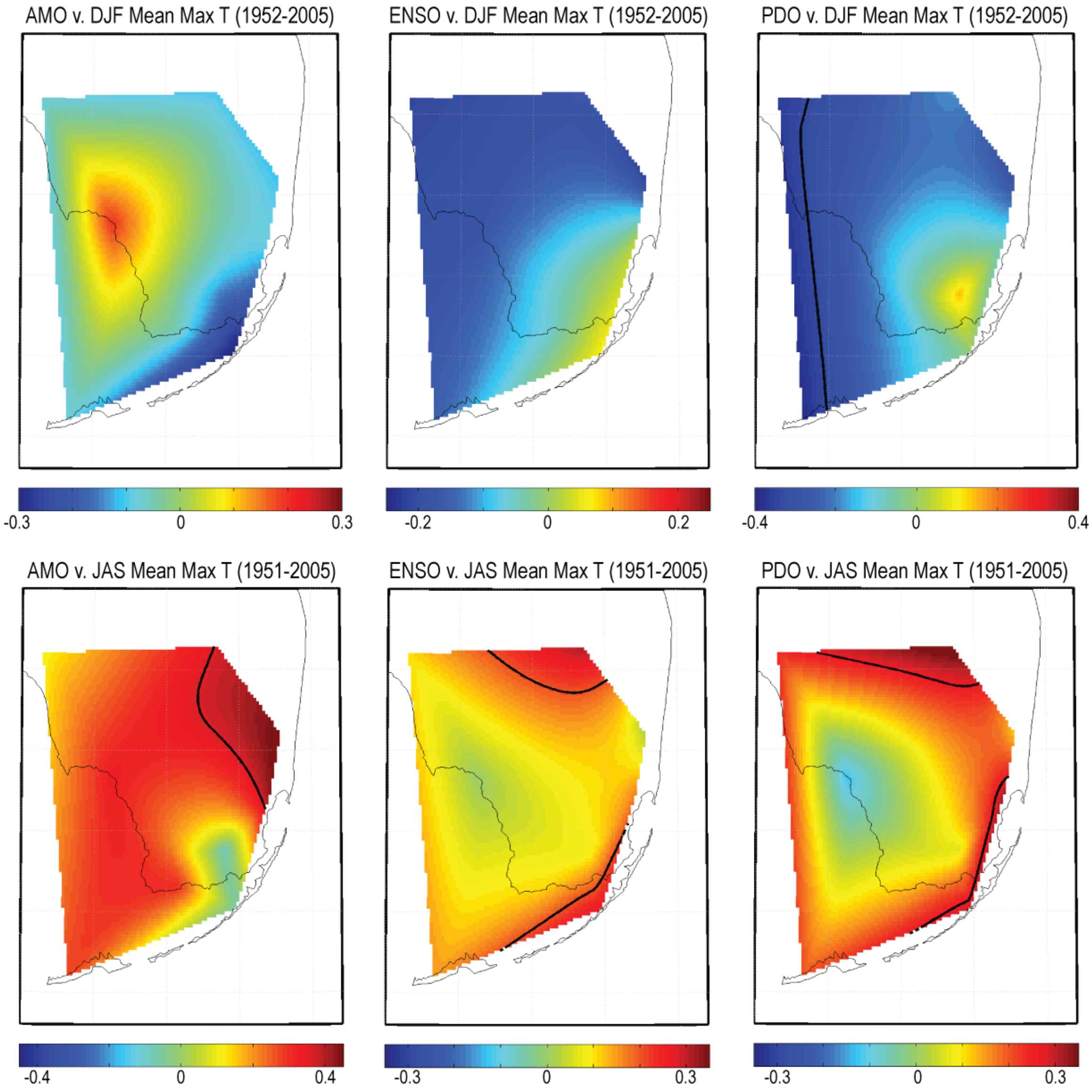

Figure 6-11. Spatial correlation between seasonal mean daily high temperatures and climate indices across South Florida. Colors indicate correlation coefficients. Solid black lines indicate the 95 percent significance level for the correlation. Geographic scope is identical to the zoomed map in **Figure 6-8**.

Since the natural (pre-20th century) drainage basin for the Everglades extends northward into the Kissimmee River drainage (Steinman et al., 2002), it is likely that the AMO does have a substantial impact on the ecology and hydrology of the Everglades. As Enfield et al. (2001) demonstrated, the AMO is significantly correlated with rainfall in this area, and thus, in the absence of urban development, diversions, and water management, was probably more significantly connected to the natural water budget of the Everglades than indicated through the current study's correlations with modern precipitation alone.

For half the stations in this study (FLL, BG, FLAM, EVER, and FTM), winter precipitation had a significant positive correlation with ENSO, supporting previous observations (Ropelewski and Halpert, 1986). ENSO explained as much as 34 percent of the variance in DJF precipitation at the stations where it was significantly correlated. Winter mean daily high temperatures in the Everglades demonstrated a pronounced negative relationship with ENSO, but the relationship was not statistically significant. Some wet season mean daily high temperatures did have a significant positive correlation to ENSO indicating that in the summer, both TAV and BG were warmer during El Niño events and cooler during La Niña events.

A significant positive correlation between ENSO and DJF precipitation indicates wetter winters during El Niño years and drier winters during La Niña years with a frequency of occurrence of about once every three to seven years. The 50 percent or more increase in dry season precipitation during El Niño events can thus substantially influence the hydroperiod of the Everglades region. A combination of non-significant correlation between Taylor Slough area precipitation and ENSO and the anthropogenic modulation of surface inflows implies that the freshwater inflows to northeastern Florida Bay, and by extension local salinity values, are not as clearly impacted by ENSO teleconnections as some previous work has suggested.

While the entire region expressed a positive correlation with the PDO, only FTM, FLL, and FLAM demonstrated a significant positive correlation between winter precipitation and the PDO. The PDO explained up to 9 percent of the variance in wet season precipitation at the stations where it was significantly correlated. As with ENSO, summer precipitation only showed a significant relationship to the PDO at BG, which had a significant negative relationship. FLL, only ~60 km away, had a significant positive relationship at the 90 percent confidence interval between summer precipitation and the PDO. These correlations to winter precipitation agree with previous evidence of teleconnections between the PDO and the paleohydrology of South Florida (Donders et al., 2005), implying that selection of paleoproxy data sample sites within the Everglades region are possibly sensitive to climate heterogeneities over small distances.

Winter mean daily high temperatures had significant negative correlation with the PDO along the Gulf coast at FTM and KW. EVER and FLL also had a negative relationship at the 90 percent confidence interval. During the dry season, the PDO accounted for about 15 percent of the variance in the daytime high temperatures. In the wet season, the pattern was similar to ENSO with BG, MIA, and TAV expressing a significant positive correlation to the PDO.

Conclusions

This study increased understanding of climate gradients over short distances, and especially in light of the differential patterns of water management, development, and land use practices in the South Florida region. While previous work has indicated various degrees of connectivity between the AMO, ENSO, and the PDO with South Florida precipitation and temperature, those often broad-scale observations do not uniformly apply at smaller spatial scales. The current study suggests that each of these three climate indices has seasonally variable impacts across relatively small spatial scales (10–100 km) in South Florida on time scales from inter-annual to multi-decadal.

Relevance to Water Management

These climate gradients in correlation to major climate indices have noteworthy implications for modern water management, and offer context for spatial variation in South Florida paleoclimate and paleohydrology studies. They provide a useful first step for anticipating climate influences on hydrology at spatial scales relevant to water management, including the major sub-basins of the Everglades watershed. Additional implications include the need to downsize coarse spatial-scale global circulation models and create predictive climatic indices better suited for the District's region. The recognition of such high spatial resolution gradients in teleconnections presents another layer of challenges for the restoration of wetlands and the Everglades ecosystem.

WILDLIFE ECOLOGY

Mark Cook, Binhe Gu, LeRoy Rodgers, Sharon Ewe[3],
Donny Smoak[4], Colin Saunders
and Carlos Coronado-Molina

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 over-drained estuarine region to the more ponded interior marshes
- A marked decrease in the frequency of exceptionally large aggregations of nesting white ibises
- Delayed nest initiations of wood storks by a few months (from November/December to February/March), resulting in poor nesting success

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 better understanding the putative mechanistic 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 by recasting these data into practical spatially explicit tools it can be used 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 during the 2010 breeding season (WY2010–early WY2011) and reports on the contribution of guano from wading birds nesting to tree island soil nutrient enrichment. In addition, assessment of major invasive species impacting the Everglades has been included [such as the Argentine black and white tegu (*Tupinambis merianae*), Cuban treefrog (*Tupinambis merianae*), giant constrictor snakes, island apple snail (*Pomacea insularum*), Nile monitor (*Varanus niloticus*), redbay ambrosia beetle (*Xyleborus glabratus*), and sacred ibis (*Threskironis aethiopicus*) among others].

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WADING BIRD MONITORING

Wading birds are excellent indicators of wetland ecosystem health and have a central role in the CERP. Nesting figures for CERP performance measures are restricted to colonies in the Greater Everglades Region, i.e., the WCAs and the 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-drainage (1930–1940) wading bird nesting patterns are evaluated using the following parameters (Ogden et al., 1997; Frederick et al., 2009):

- Increase and maintain the total number of pairs of nesting birds in mainland colonies to a minimum of 4,000 pairs of great egrets, 10,000–20,000 combined pairs of snowy egrets and tricolored herons, 10,000–25,000 pairs of white ibises, and 1,500–2,500 pairs of wood storks.
- Shift in timing of nesting in mainland colonies to more closely match pre-drainage conditions. Specific recovery objectives would be for wood storks to initiate nesting no later than January in most years and for ibis, egrets, and herons to initiate nesting in February–March in most years.
- Return of major wood stork, great egret, 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.
- Reestablish historical distribution of wood stork nesting colonies in the Big Cypress Basin and in the region of mainland mangrove forests downstream from the Shark Slough and Taylor Slough basins. Increase the proportion of birds that nest in the southern ridge and slough marsh–mangrove ecotone to greater than 50 percent of the total for the entire EPA.
- For wood storks, restore productivity for all colonies combined to greater than 1.5 chicks per nest.
- Return to an interval between exceptional white ibis nesting events, defined as greater than 70th percentile of annual nest numbers for the period of record.

Summary of Nesting Year 2010

The information reported in this section represents a compilation of data collected by a variety of institutions which includes, but is not limited to, Florida Atlantic University (FAU), University of Florida (UF), the ENP, and the Audubon Society. It should be noted that the population estimates reported here are simply the totals of independent surveys and are not adjusted according to comprehensive 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 South Florida region. The period covered by this report is the nesting season from January–July, 2010. For further details on independent sampling methods see Cook and Kobza (2010).

The estimated number of wading bird nests in South Florida in 2010 was approximately 21, 426. This is a 72 percent decrease relative to the 76,791 nests of 2009, which was the best nesting year on record in South Florida since the 1940s, and 53 percent less than the average of the last 10 years (**Figure 6-12**). All species of wading birds suffered significantly reduced nest numbers relative to the past 10 years. Wood stork nesting started relatively early but was very much reduced relative to the record number of nests in 2010 and most colonies eventually failed. White ibis numbers were 79 percent of 2009 and 62 percent of the past 10 years. Roseate spoonbill nest numbers were the lowest since records began. The 2010 season had few wading bird nests relative to the past 10 years and to pre-drainage years.

Approximately 19,875 wading bird nests were initiated in the Greater Everglades during 2010. The Park historically supported the largest number of nests in the system, but in recent decades most nesting has occurred in the WCAs. CERP’s goal is to restore the hydrologic conditions that will re-establish prey densities and concentrations 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 2010, the ENP supported the most nests (38 percent) followed by WCA-1 (34 percent), while WCA-3 supported the lowest number of nests (28 percent). This spatial distribution of nests contrasts with the general pattern over the past decade when either WCA-1 or WCA-3A held the greatest proportion of nests in the Everglades and the ENP was relatively unattractive for nesting (an average of 10 percent of nests over the past decade). The Park appears has been relatively more attractive to nesting birds in recent years, with the proportion of nests increasing to 20 percent in 2006 and 21 percent in 2009, then jumping to over 40 percent in 2010. However, 2010’s increase remains below the 50 percent CERP target and was likely due to a temporary decline in nesting conditions in the WCAs rather than a marked improvement in habitat conditions along the marsh–mangrove ecotone. Wood stork nesting in the Everglades was restricted to colonies in the ENP which contrasts with 2009 when approximately one-third of observed stork nests were in the WCAs.

Nest success varied considerably by species with early nesting species such as wood storks, roseate spoonbills (*Ajaja ajaja*), and great egrets faring particularly poorly. Wood storks initiated nesting relatively early in 2010 (January), possibly as a result of the rapid recession rates in most areas from October through December 2009, but all nests subsequently failed. The unusually high rainfall and persistent cold temperatures from January through March 2010 were likely responsible for these abandonments (Cook and Kobza, 2010). Both rainfall and cold temperatures are known to limit the availability of aquatic prey, which likely had a strong influence on nest success, but the direct effects of climatic conditions on the adults of this tropically distributed species may have also played an important role.

Later nesting egrets, herons, and ibises were relatively more successful at rearing young, and from a sample of 90 nests (mixed species) in WCA-3A, approximately 75 percent of nests produced at least one fledgling per nest. The later-nesting species were more successful probably because they avoided the majority of the reversals and cold weather. Recession rates in WY2010 were largely classified as “poor” and stages were generally too deep in the WCAs for effective wading bird foraging (see the *Hydrologic and Climate Trends* section of this chapter). Moreover, the annual monitoring of prey densities during the seasonal drydown reveal that WY2010 experienced reduced aquatic prey production relative to WY2009 (Dale E. Gawlik, Florida Atlantic University, Boca Raton, FL, personal communication), probably due to the dry conditions at the end of the 2009 dry season. More suitable hydrologic conditions in the ENP during the course of the 2010 nesting season likely contributed to the increase in the number of nests and nest success of this region relative to WCA-3A and WCA-1.

Three of the four species groups met the numeric nesting targets proposed by the South Florida Ecosystem Restoration Task Force when averaged over two nesting seasons (**Table 6-4**). Two other targets for Everglades restoration are 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 (Ogden, 1994). The 2010 nesting year did show an improvement in the timing of wood stork nesting and a general shift of colony locations to the coast.

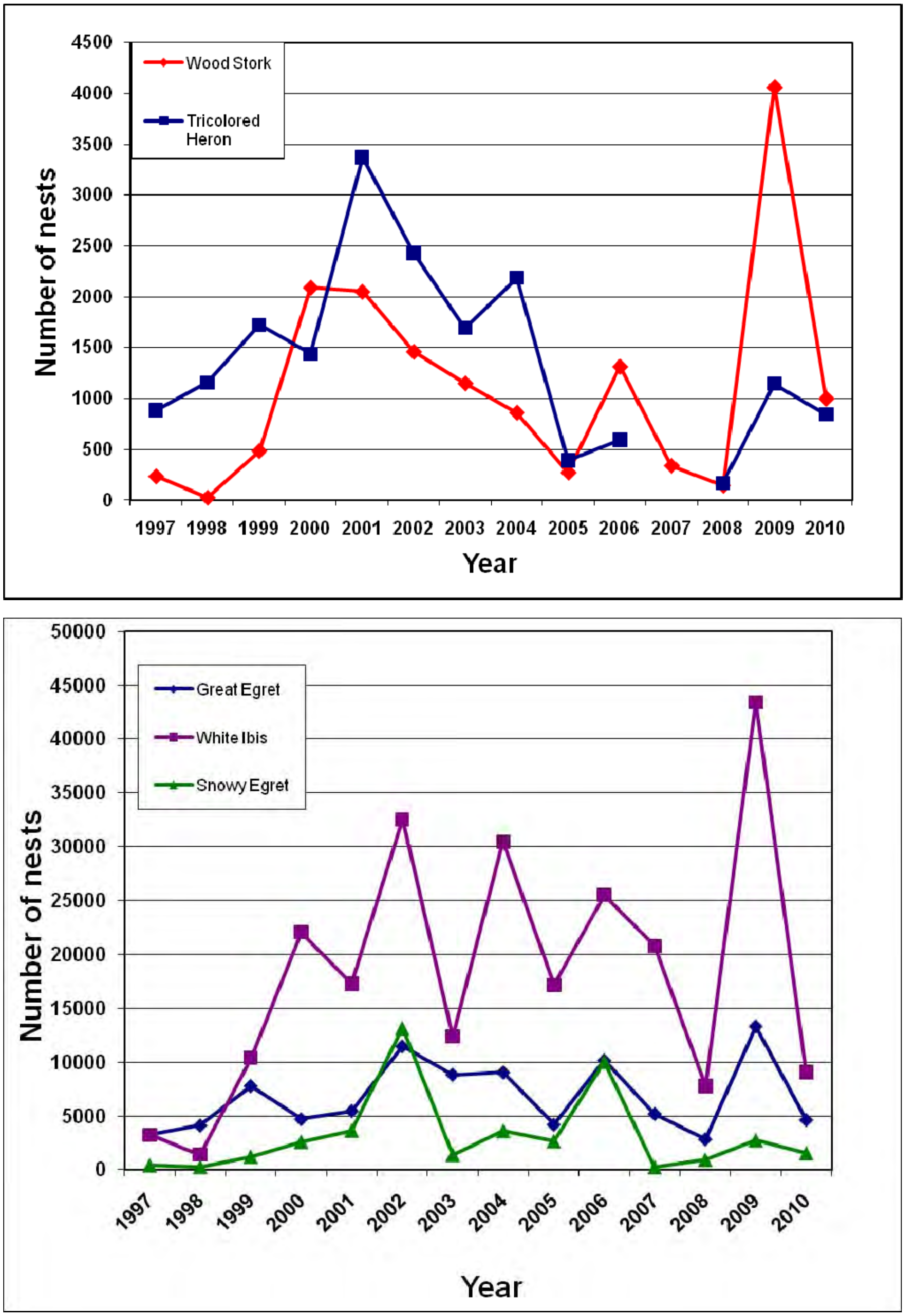

Figure 6-12. Historical wading bird nesting numbers in the Everglades for individual species since 1997.

Table 6-4. Numbers of wading bird nests in the Water Conservation Areas (WCAs) and Everglades National Park (ENP or Park) compared with Comprehensive Everglades Restoration Plan (CERP) targets and historical ranges. Target numbers are based on known numbers of nests for each species during the pre-drainage period 1930–1940, and which were summarized by Ogden (1994).

Species	1998-2000	1999-2001	2000-2002	2001-2003	2002-2004	2003-2005	2004-2006	2005-2007	2006-2008	2007-2009	2008-2010	Target
Great Egret	5,544	5,996	7,276	8,460	9,656	7,829	8,296	6,600	5,869	6,956	6,774	4,000
Snowy Egret/ Tricolored Heron	2,788	4,270	8,614	8,088	8,079	4,085	6,410	4,400*	3,778	1,723	2,442	10,000-20,000
White Ibis	11,270	16,555	23,983	20,758	24,947	20,993	24,926	21,133	17,541	23,953	20,081	10,000-25,000
Wood Stork	863	1,538	1,868	1,596	1,191	742	800	633	552	1,468	1,736	1,500-2,500

Note: great egret - *Casmerodius albus*, snowy egret - *Egretta thula*, tricolored heron - *Egretta tricolor*, white ibis - *Eudocimus albus*, and wood stork - *Mycteria americana*

POTENTIAL FAUNAL CONTRIBUTIONS TO TREE ISLAND PHOSPHORUS CYCLING

Tree islands are a unique landscape feature in the Everglades and important centers of biodiversity. Recent research indicates that tree islands are nutrient hotspots which sequester a large amount of phosphorus entering the central Everglades (Wetzel et al., 2009). Therefore, in addition to supporting a diverse biota, tree islands may also play an important role in reducing nutrients from the marsh and helping to maintain the oligotrophic state of the Everglades. Recently, Wetzel and colleagues (2005) proposed several pathways leading to phosphorus enrichment in tree islands, one of which is guano from wading birds nesting on tree islands. Wading birds prey on invertebrates and fish from the marsh and excrete nutrients as guano onto the vegetation and soils, thereby enriching the soils with phosphorus and nitrogen. Previous studies have demonstrated that seabird guano is an important source of phosphorus in coastal areas (Smith, 1979; Baxter and Fairweather, 1994).

Stable isotope analysis is a powerful tool for tracing sources and sinks of major biogenic elements in ecosystem studies (Peterson and Fry, 1987). Unfortunately, there are no phosphorous stable isotopes, so nitrogen stable isotopes are used by many researchers to follow phosphorus cycling because both elements are closely linked in soil and water and within food webs. Guano consists of both nitrogen and phosphorus in various forms including ammonia, uric, phosphoric, oxalic, and carbonic acids. McColl and Burger (1976) reported large increases in nitrogen and phosphorous concentrations in water concomitant with a colony of Franklin's gulls nesting in the cattail area at the Agassiz National Wildlife Refuge, northern Minnesota. In this study, nitrogen stable isotopes for soil and various biota were measured to track potential sources of phosphorus in tree islands in the Everglades. The nitrogen element consists of two stable isotopes, ^{14}N (99.63 percent) and ^{15}N (0.37 percent). The ratio of ^{15}N to ^{14}N (termed as $\delta^{15}N$, with a unit of parts per thousand or ‰) in inorganic and organic compounds are typically carried on the signature of their source and influenced by major biogeochemical processes. There is a stepwise isotope (^{15}N) enrichment along food chains, with an average of 3.4‰ per trophic transfer from animal feeding and assimilation (Post, 2002). Therefore, wading birds that feed on crayfish (*Procambarus* spp.), mosquitofish (*Gambusia* spp.) and other aquatic animals have higher $\delta^{15}N$ than their prey. The isotope composition of the animals' waste is somewhat lower than that of animal tissues due to isotope discrimination during protein metabolism (Minagawa and Wada, 1984). However, the preferential loss of $^{14}NH_3$ during volatilization leaves proportionally more ^{15}N in animal droppings (Mizutani et al., 1986).

Methods

During 2006–2009, surface soil samples [typically the top 5 centimeters (cm)] were collected on and around 36 tree islands, with most samples being obtained from WCA-3. These soil samples were taken from the head, near tail, and far tail of each tree island. Leaves were collected from the dominant plant species on the tree islands and slough. Animal droppings were collected from several tree islands in WCA-1 and WCA-3. All samples were cleaned, dried and ground to fine power prior to isotope analyses. The total phosphorus content in soil was determined following standard methods (APHA, 1998). Stable isotope data on aquatic consumers were provided by Gu and Kendall (in revision).

Results and Discussion

The results of sampling on and around tree islands indicate that the marsh soil and various primary producers (plants) are depleted in ^{15}N, with a range from -1–3‰, whereas the consumer (animal) tissues are enriched in ^{15}N, with a range from 4–9‰ (**Figure 6-13**). The average $\delta^{15}N$ value of all surface soil from tree islands was 3.8±1.6‰, but was equal to or less than 3‰ in 14 islands. The soil $\delta^{15}N$ value was 3–5‰ in 15 islands and was greater than 5‰ in seven islands. The $\delta^{15}N$ values of the terrestrial plants from tree islands averaged 2.2‰ and varied from -2.2‰ [wax myrtle (*Morella cerifera*)] to 2.8‰ [cocoplum (*Chrysobalanus icaco*)]. The $\delta^{15}N$ of the mammal droppings averaged 5.3‰ with a range from 2.3 (wild pig droppings) through 9.0‰ (bear droppings). The $\delta^{15}N$ of guano samples collected from two tree islands in WCA-1 and WCA-3, respectively, ranged from 7.7 to 9.0‰ (n = 4). These enriched values are likely the results of wading birds feeding on invertebrates and fish from the marsh. Nitrogen cycling processes that can significantly affect soil $\delta^{15}N$ include ammonification and denitrification which cannot significantly alter the isotope ratio of the organic pool. Therefore, the high $\delta^{15}N$ of the soil organic matter was attributed to the contribution of wading bird guano. Other sources of nitrogen could not have lead to the observed ^{15}N enrichment in the soil due to their low $\delta^{15}N$ tree leaves and herbivore droppings (**Figure 6-13**) or the small population size of representatives of higher trophic levels (e.g., bears).

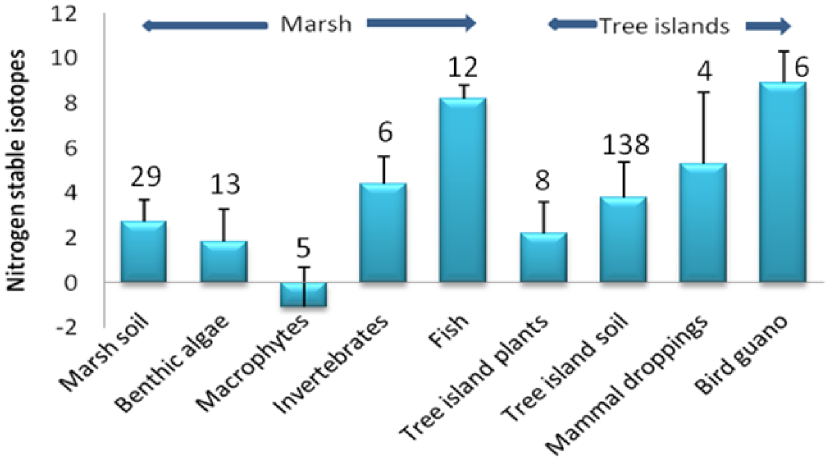

Figure 6-13. Nitrogen stable isotopes in various organic pools from marsh and tree island locations. Values above each column are the number of samples for soil and guano, and the number of species for biota. The error bar represents one standard deviation.

The head of a tree island is an area that contains semitropical hardwoods and upland plants. The near tail is a wet region of the head with a vegetation community consisting of ferns, shrubs, aquatic plants, and tropical hardwood that are able of tolerate various degrees of flooding. The tail is occupied by a mixture of flood-tolerant ferns, shrubs, sedges, and sawgrass, while the far tail is dominated by sawgrass (*Cladium* sp.) (Sklar and van der Valk, 2002). The data reveal a pattern of decreasing TP concentrations from the head to the far tail of the tree islands sampled. For example, the TP concentrations at the head of tree islands 3AS3 and Nuthouse were two orders of magnitude higher than concentrations in the near tail and far tail regions (**Table 6-5**). Similarly, the $\delta^{15}N$ values from a tree island head are on average 2 to 5‰ higher than those in the tail region.

This suggests that the head of the tree islands was the preferred site for wildlife use. For example, the high concentration of TP at an average of nearly 4 percent at the head of Nuthouse island (**Table 6-5**) is similar to the phosphorus level in pure guano, suggesting that the head of this tree island might have been used by wading birds intensively.

There were also large variations in soil $\delta^{15}N$ from the same region across tree islands (**Table 6-5**). These variations are likely attributed to the differences in wading bird use because not all tree islands served as wading bird rookeries or are occupied by similar numbers of wild animals.

The use of tree islands by wildlife, including wading birds, is also evident by the presence of uric acid in the soils (**Table 6-5**). Similar to TP and δ^{15}N, urea concentrations were also higher on the island head than the tail, suggesting a link of these parameters to wildlife ‘fertilization’ of tree islands. To establish a link between δ^{15}N and phosphorus enrichment in the soil, soil TP data plotted against δ^{15}N display a strong positive relationship ($r^2 = 0.59$, $p < 0.001$, $n = 243$).

The historic changes in δ^{15}N and TP on tree islands were investigated. Two cores from the head of tree islands 3AS5 and 3AS3 in central WCA-3A displayed a trend of decreasing δ^{15}N and TP since the completion of the WCAs in the 1950s. One explanation for these declines is the reduction of wading bird nesting on these tree islands due to increasing water depth and consequent decreasing prey accessibility.

Table 6-5. Distribution of total phosphorus (TP), urea, and nitrogen isotopes (mean and standard deviation) in the top 5–30 centimeters (cm) of soil from three tree islands and surrounding marshes in WCA-3.

Tree Island/ Parameter	Unit	Head	Near tail	Far tail	Marsh
3AS5					
TP	mg/kg**	899(451)	487(130)	379(95)	225(68)
Urea	mg/kg	1.61(2.31)	0.59(0.86)	0.60(1.02)	0.54(0.76)
δ^{15}N	‰***	5.1(1.6)	3.6(1.2)	3.1(0.8)	3.0(0.4)
Nuthouse					
TP	mg/kg	38,075(2,397)	285(106)	349(490)	96(21)
Urea	mg/kg	2.76(1.58)	2.35(2.16)	1.31(1.63)	0.22(0.88)
δ^{15}N	‰	10.2(1.0)	5.6(1.0)	4.7(0.6)	4.1(0.5)
3AS3					
TP	mg/kg	44,490(31,786)*	293(188)	ND	122(40)
δ^{15}N	‰	6.6(1.3)*	4.4(0.7)	ND	3.0(0.7)

*18 cm only

**mg/kg–milligrams per kilogram

***‰–parts per thousand

Conclusions

This study suggests that one of the possible mechanisms for high TP contents in the soil of tree islands is faunal contribution as droppings. This is supported by the high stable nitrogen isotopes in the soil, which reflect organic matter from organisms at high trophic positions. Preliminary results suggest that the phosphorus enrichment may be, in part, the result of the presence of wading bird guano in tree islands, especially in the head region. Historic changes in TP concentration in tree islands may be due to changes in wading bird density and distribution in South Florida. Further data collection will help provide a better understanding of the relative contribution of wading bird guano to phosphorus enrichment on tree islands and the role of wading birds in maintaining tree island productivity and the oligotrophic state of the marsh.

Relevance to Water Management

This study suggests that a loss of phosphorus accumulation on tree islands has occurred since changes in water management (impoundment) in the 1950s. This suggests, in turn, that impoundment might have been detrimental to wading bird feeding and nesting. The corresponding decreases in TP and $\delta^{15}N$ in the soil since impoundment might indicate decreasing wading birds and other wild animals' utilization of tree islands.

INVASIVE NONINDIGENOUS SPECIES IN THE EVERGLADES PROTECTION AREA

This section presents an evaluation of priority nonindigenous, invasive species that occur within the Greater Everglades region. The goal of this evaluation is to identify the potential negative effects of each species on Everglades conservation and restoration. In addition, recommendations for future research and management actions related to these species are provided. The species discussed here do not represent all nonindigenous species documented to occur in the EPA. Rather, included are the top priority species falling in one of several categories: (1) established species requiring long-term management, (2) newly detected species requiring rapid response to eradicate or contain, and (3) potentially invasive species requiring continued monitoring and risk-assessment research.

District biological scientists and land managers familiar with the Everglades, with additional input from scientists from the ENP, Florida Fish and Wildlife Conservation Commission (FWC), University of Florida, U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers assessed five invasive plant species and seven invasive animal species. Each species was evaluated for:

- Current distribution within the restoration project area
- Known and possible impacts on native systems
- Current status of existing control programs if any
- Availability of effective control methods
- The potential effects of the species on restoration efforts

Recommendations were then made for what actions, if any, should be taken for each species in light of its possible effects on the Everglades restoration efforts. Chapter 9 and Appendix 9-1 of this volume provide additional information about invasive species in South Florida. Additional information on spatial distributions for invasive plants is given in the *Quantifying Region-Wide Nonindigenous Plant Infestations Using Digital Aerial Sketch Mapping Section* of this chapter.

Priority Invasive Plants

Australian Pine (Casuarina equisetifolia and C. glauca)

- Australian pine is a large, fast-growing tree that readily colonizes freshwater marsh, pine rocklands, and other moist inland habitats (Morton, 1980). Australian pine infests an estimated 2,338 ha within the Greater Everglades region, primarily in coastal wetlands and to a lesser extent in sawgrass (*Cladium jamaicense*) marshes in eastern reaches of the ENP.
- Once established, the tree forms dense stands, eventually excluding native plants.
- Australian pine threatens key habitat for the endangered Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis),* which requires the short-hydroperiod marl prairies of the southeastern Everglades for nesting.

***Prognosis for Restoration Impacts*:** Systematic control efforts to restore sparrow nesting habitat invaded by Australian pine are successfully reducing this once widespread invasive tree to maintenance levels in many areas. If control efforts in the eastern Everglades and southeastern coastal wetlands remain on track, region-wide maintenance control should be achieved by 2018. At low densities, Australian pine is expected to have negligible impacts on restoration. Potentially affected restoration performance measures include *Freshwater Vegetation Mosaics, Marl Prairie Cape Sable Sparrow Habitat* as presented in RECOVER (2007).

***Recommendations*:** (1) Continue funding for systematic control in remaining impacted areas, with an emphasis on coastal wetlands and sawgrass marshes in the eastern and southeastern sections of the Greater Everglades; (2) promote private lands initiatives for Australian pine control in close proximity to Everglades conservation lands as a means to reduce propagule pressure; (3) refine aerial spot-spraying techniques to improve control of outlier populations in remote areas with minimal damage to native plant communities.

Brazilian Pepper (*Schinus terebinthifolius*)

- Brazilian pepper is widely distributed throughout the Greater Everglades region, invading mangrove swamps, tree islands, hardwood hammocks, cypress savannas, and disturbed habitats (Doren and Jones, 1997). Recent aerial mapping shows that that this aggressive invasive tree is established in at least 27,282 ha within the Greater Everglades (see the *Quantifying Region-Wide Nonindigenous Plant Infestations Using Digital Aerial Sketch Mapping* section of this chapter). During January 2010, record cold temperatures in the southwestern coastal regions of the ENP caused widespread frost damage to mangrove species, especially buttonwood (*Conocarpus erectus*) (Rodgers and Pernas, unpublished manuscript). But Brazilian pepper was not noticeably affected. Decreased competition is expected to result in further expansion of Brazilian pepper in this region.
- Once established, Brazilian pepper severely reduces native plant and animal diversity (Workman, 1979; Curnutt, 1989) and alters food web dynamics (Maffei, 1997), soil accretion rates (Gordon, 1998) and fire behavior (Wade et al., 1980, Loope and Dunevitz, 1981).
- Until recently, operational control for Brazilian pepper was limited to the ENP's Hole-in-the-Donut restoration project. The District and FWC have recently increased control efforts in WCA-2 and WCA-3 by systematically removing large infestations in tree islands and disturbed areas (e.g., levees).

***Prognosis for Restoration Impacts*:** Brazilian pepper poses a significant threat to habitat stability and diversity in Everglades tree islands and mangrove swamps. A sustained integrative management program that includes herbicidal, biological, and mechanical controls — coupled with restoration of historic hydropatterns — is necessary reduce impacts of this invasive tree to acceptable levels. Successional trajectories following Brazilian pepper removal may be unpredictable and lead to undesired restoration outcomes (Matthews and Endress, 2010). Potentially affected restoration performance measures include *Freshwater Vegetation Mosaics; Ridge and Slough Community Sustainability* as presented in RECOVER (2007).

***Recommendations*:** Continue resource allocation to control and monitoring efforts in tree islands and other affected habitats, while promoting research to develop biological control agents for Brazilian pepper. Research is also needed to understand recovery dynamics in previously infested tree islands and evaluate potential restoration tools to facilitate recovery to targeted outcomes.

Melaleuca (*Melaleuca quinquenervia*)

- Melaleuca occupies an estimated 41,938 ha within the Greater Everglades region where it readily invades moist, undisturbed pine flatwoods, disturbed sites, sawgrass-dominated communities, cypress swamps, mangroves, savannas, and wet prairies (Serbesoff-King, 2003). Once established, melaleuca transforms open-canopied, diverse plant communities into closed-canopy melaleuca forests with sparse understory and low structural diversity (O'Hare and Dalrymple, 1997).
- Although systematically removed and under maintenance control in WCA-2 and WCA-3, it remains widespread throughout WCA-1. Additionally, a successful biological control program has reduced its rate of spread (see Chapter 9 of this volume).

***Prognosis for Restoration Impacts*: With continued systematic implementation of integrated management in the region, melaleuca will continue to trend toward region-wide maintenance control. The biggest threat to this management trajectory is loss of sustained funding. Potentially affected restoration performance measures include *Freshwater Vegetation Mosaics; Ridge and Slough Community Sustainability; Marl Prairie Cape Sable Sparrow Habitat* as presented in RECOVER (2007).

***Recommendations*:** Continue regional integrative management to maintain lowest feasible levels. Promote control efforts on adjacent lands to reduce propagule pressure.

Old World Climbing Fern (*Lygodium microphyllum*)

- Old World climbing fern occupies an estimated 2,338 ha within the Greater Everglades region where it aggressively overtakes tree island plant communities. Once established, Old World climbing fern substantially alters tree island canopy structure and species composition (Brandt and Black, 2001) (see also the *Tree Island Lygodium Habitat Suitability Analysis* section of this chapter).
- Control tools are limited to herbicides, although biological control development shows early promise with the successful establishment of one agent (Boughton and Pemberton, 2009).

***Prognosis for Restoration Impacts*:** Old World climbing fern infestations represent a major threat to the biodiversity, structure, and function of Everglades tree islands. Potentially affected restoration performance measures include: *Freshwater Vegetation Mosaics; Ridge and Slough Community Sustainability* as presented in RECOVER (2007).

***Recommendations*:** Continue with a restrained program of aerial spraying (to limit damage to non-target native species), combined with proactive ground treatment of selected infestations to avoid losses of wetland tree species. Critical research and monitoring needs include improvements to herbicide translocation to rhizomes (Hutchinson et al., 2010), improved herbicide efficacy in standing water, continued research toward development of effective biological control agents, ground-based monitoring for incipient populations, and restoration techniques for heavily impacted tree islands.

Shoebutton Ardisia (*Ardisia elliptica*)

- Shoebutton ardisia is a shade-loving shrub closely related to the native marlberry (*A. escallonioides*). Unlike marlberry, shoebutton ardisia forms dense, monotypic stands in tree islands and tropical hammocks. Severe infestations typically occur in transitional areas between short-hydroperiod wetlands and hammocks (Koop and Horvitz, 2005), often eliminating understory plant communities (Doren et al., 1997). Shoebutton ardisia is most abundant in southeastern sections of the ENP and the South Dade Wetlands region, but appears to be expanding into tree islands within the WCAs.

- Detection of this species is difficult given its close resemblance to marlberry and understory concealment from aerial reconnaissance.
- Management options are limited to chemical and mechanical controls. Costly mechanical biomass removal is typically required for dense infestations.

Prognosis for Restoration Impacts**:** Shoebutton ardisia poses a significant threat to habitat stability and diversity in Everglades tree islands and hardwood hammocks. Potentially affected restoration performance measures include *Freshwater Vegetation Mosaics; Ridge and Slough Community Sustainability* as presented in RECOVER (2007).

Recommendations**:** Continue with a systematic program of ground-based detection and herbicide and mechanical treatments. Critical research and monitoring needs include improvements to herbicide efficacy and selectivity, ground-based monitoring for incipient populations, and restoration techniques for heavily impacted habitats.

Priority Invasive Animals

Argentine Black and White Tegu (*Tupinambis merianae*)

- A large, omnivorous lizard filling a niche similar to that of the Nile monitor (*Varanus niloticus*). In its native range, the Argentine black and white tegu prefers savannas and other open grassy areas and nests in burrows (Winck and Cechin, 2008). Two established populations are documented in Florida: west-central Florida and South Florida, near Florida City and the ENP. Recent ad hoc monitoring efforts suggest that the population near the ENP is expanding (Tony Pernas, National Park Service, personal communication), but systematic surveys are needed to validate these observations.
- The tegu is an emerging threat and little information is available on species or ecological impacts in Florida. As an egg predator, the tegu now threatens shorebirds and sea turtles on the island of Fernando de Noronha where it was intentionally released to control rats (Ramalho et al., 2009). If the tegu spreads into the Everglades and other natural areas, it could prey upon the eggs (and hatchlings) of the American crocodile (*Crocodylus acutus*), the Cape Sable seaside sparrow (*Ammodramus maritima mirabilis*) (Kevin Enge, unpublished data), as well as all other ground nesting birds and reptiles.
- The Argentine black and white tegu is a priority species for early detection and rapid response by regional invasive species biologists. Interagency members of the Everglades Cooperative Invasive Species Management Area (Everglades CISMA) have initiated monitoring, assessment, and control efforts, but a there is lack of dedicated funding and staffing resources. Given the increasing likelihood that this species is well-established on the eastern boundary of the ENP and that control tools are not yet developed, eradication from Florida may soon be unachievable (Kevin Enge, Florida Fish and Wildlife Conservation Commission, personal communication).

Prognosis for Restoration Impacts**:** The spread of this species has the potential to significantly impact restoration efforts by increasing predation on threatened and endangered species. Potentially affected restoration performance measures include *Juvenile Crocodile*

Survivorship; Juvenile Alligator Survivorship; Marl Prairie Cape Sable Sparrow Habitat as presented in RECOVER (2007).

***Recommendations*:** The District and other agencies should allocate resources to increase rapid response efforts and fund applied research to develop effective control tools. State wildlife regulators should accelerate rapid assessments to determine appropriate regulatory tools to minimize additional introductions.

Cuban Treefrog (*Osteopilus septentrionallis*)

- Cuban treefrogs are large predatory treefrogs that invade pine forests, hardwood hammocks, swamps, and rural developed areas throughout Florida (Johnson, 2007).
- Cuban treefrogs consume a variety of invertebrates and native treefrog species (Maskell et al., 2003). It is likely that Cuban treefrogs become dominant over native anurans through some combination of predation and competition for prey (Knight et al., 2009; Waddle et al., 2010).
- No formal control efforts are in place, although the University of Florida has recently begun educating the public and encouraging humane euthanization of Cuban treefrogs captured by homeowners.

***Prognosis for Restoration Impacts*:** The species disrupts and displaces native species in natural habitats (Hardin, 2007; Waddle et al., 2010) and therefore is viewed as a potential problem for restoration of native herpetofaunal communities in the Greater Everglades region. No viable control tools are currently available for large-scale implementation.

***Recommendations*:** Control options for this species should continue to be explored.

Giant Constrictor Snakes

- Established South Florida populations are documented for three giant constrictor species — Burmese python (*Python molurus bivittatus*), northern African python (*P. sebae*), and common boa (*Boa constrictor*). The Burmese python is the most widely distributed of the three, currently documented throughout the Southern Everglades as far north as WCA-3.
- The Burmese python is a top predator known to prey upon more than 20 native Florida species (Snow et al., 2007a, 2007b), including the federally endangered Key Largo woodrat (*Neotoma floridana smalli*) and wood stork.
- Invasive species biologists continue research to develop control tools and gather data on the natural history of pythons in Florida. The development of a trap capable of capturing free-ranging pythons represents a significant milestone toward implementing region-wide management programs (Cherkiss et al., 2009), but effective attractants must still be developed. The District and other agencies have formed search teams that routinely survey roads and levees by sight for pythons.
- From January 2–11, 2010, sustained record low temperatures caused widespread mortality of Burmese pythons in South Florida (Mazzotti et al., 2010), suggesting a reevaluation of predicted range expansions in temperate climates (Avery et al., 2010). Although Burmese pythons continue to be observed in the wild, sightings were down marginally during spring 2010 compared to recent years (Bob Hill, SFWMD, personal communication). However, from July 11 through October 1, 2010, 24 hatchlings were removed from in and around ENP. This is on par with

the number of hatchlings found during the previous summer (Skip Snow, National Park Service, personal communication). At the time of this report, a total of 246 Burmese pythons had been removed in and around the Greater Everglades region from January–October 2010. This compares to 291 pythons removed in the previous reporting period by October 2009.

Prognosis for Restoration Impacts**:** The spread of constrictor snakes has the potential to significantly impact restoration efforts by increasing predation on threatened and endangered species and altering trophic dynamics by competing with native species for habitat and food. Potentially affected restoration performance measures include *Wading Bird Nesting Patterns and American Alligator Distribution, Size, Nesting and Condition* as presented in RECOVER (2007).

Recommendations**:** Continued research toward the development of effective control tools is necessary. These include the development of (1) effective attractants for trapping, (2) technology to improve detection in the field, (3) use of satellite tags for enhanced telemetry, (4) use of trained dogs for detection, and (5) genetic testing to examine python population structure, diversity, and size of the effectively breeding population. Additional resources should also be allocated to expand established control programs. Focused monitoring and removal efforts should be implemented in wading bird rookeries to address potential threats to wading bird populations. Increased coordination to complete and implement a strategic regional management plan is also needed. An interagency team, coordinated by the Everglades CISMA, is preparing to implement a region-wide monitoring, control, and training program in late 2010. This program will focus on three components of python management in South Florida: (1) training for python search teams, (2) monitoring and rapid response efforts at the population’s expansion front, and (3) suppressing the core population in the southeastern Everglades region.

Island Apple Snail (*Channeled Apple Snail*) (*Pomacea insularum*)

- The island apple snail is a large freshwater snail found in canals and long-hydroperiod wetlands throughout the South Florida region.
- This recent invader competes with the native apple snail (*P. paludosa*), which is found to decline or disappear after invasion by the island apple snail (Rawlings et al., 2007). Decreased capture and feeding rates for the larger island apple snail by juvenile Everglade snail kites (*Rostrhamus sociabilis plumbeus*) may negatively impact the federally endangered kite’s survival (Cattau et al., 2010).
- The ENP and Miccosukee Tribe monitoring results indicate that this species’ abundance is increasing in many canals near or within the Everglades (e.g., Tamiami Trail Canal) and distributions may be expanding into open marsh.

Prognosis for Restoration Impacts**:** This species has the potential to reduce abundance of the native Florida apple snail, the primary food source of the federally endangered snail kite (Conner et al., 2008).

Recommendations**:** Monitoring efforts should be continued and expanded to determine the extent of invasion within the Everglades, especially critical snail kite habitat. Research to evaluate potential control tools is needed.

Nile Monitor (*Varanus niloticus*)

- The Nile monitor is a large, predatory lizard known for its intelligence and adaptability (Bennett, 1998). Established populations are documented in and around Cape Coral in Lee County (Enge et al., 2004) and Homestead Air Force Base in Miami-Dade County. This species has the potential to establish in any habitat where permanent water bodies exist.

- Nile monitors are generalist feeders (Losos and Greene, 1988) and commonly prey on crocodile eggs and hatchlings in Africa (Lenz, 2004). Their impact on Florida fauna is unknown, but their potential to eliminate or significantly reduce native species through competition and predation is high (FWC, 2003).

Prognosis for Restoration Impacts**:** The spread of this species has the potential to significantly impact restoration efforts. The Nile monitor has the potential to prey on threatened and endangered species and alter trophic dynamics by competing with native predators for habitat and food. Potentially affected restoration performance measures include *Juvenile Crocodile Survivorship; Juvenile Alligator Survivorship* as presented in RECOVER (2007). Evidence that Burmese python preys on juvenile American alligators (*Alligator mississippiensis*) (Snow et al., 2007) suggests a dual threat to alligator survival and population growth by giant constrictors and large predatory lizards should the abundance and distribution of both invasive reptiles increase.

Recommendations**:** Continued monitoring of the Homestead population and research toward development of effective control tools are necessary. As control tools are developed, resource allocation toward eradication efforts should be increased. Research to determine the current and potential long-term impacts of the Nile monitor on Everglades restoration objectives should also be pursued.

Redbay Ambrosia Beetle (*Xyleborus glabratus*)

- Laurel wilt is a disease caused by a fungus (*Raffaelea* sp.), which is carried into host trees by the nonindigenous redbay ambrosia beetle (*Xyleborus glabratus*). The beetle attacks native red bays (*Persea borbonia*) and other closely related species (Hanula et al., 2009), causing up to 90 percent mortality of red bay in areas where it is established (FDACS, 2008). Laboratory tests confirm pathenogenicity of the wilt fungus on swamp bay (*P. palustris*), an important Everglades tree island species.
- Laurel wilt is not documented in the Everglades as of WY2010. However, it was detected in Martin County in 2009 (Dixon and Smith, 2010) and found in Miami-Dade County infecting an avocado tree in March 2010 (FDACS, 2010), immediately adjacent to the Bird Drive Basin and less than 5 km from WCA-3B. There is currently no feasible method for controlling this pest or its associated disease.

Prognosis for Restoration Impacts**:** The potential spread of laurel wilt into the Everglades landscape represents a major threat to the structure and diversity of Everglades tree islands. Potentially affected restoration performance measures include *Freshwater Vegetation Mosaics; Ridge and Slough Community Sustainability* as presented in RECOVER (2007).

Recommendations**:** Continue regional trap monitoring. Critical research areas include:

- *Persea* resistance
- *Persea* species seed/genetic conservation efforts
- Potential chemical or biological control tools
- Impacts on plant community structure and function in Everglades tree islands
- Impacts on the Palamedes swallowtail butterfly (*Papilio palamedes*) and other host-specific commensals

Sacred Ibis (Threskiornis aethiopicus)

- The sacred ibis is a large omnivorous wading bird with life cycle requirements similar to those of egrets, herons, and wood storks in Florida (Rodgers et al., 1996).
- This opportunistic feeder consumes insects, fish, molluscs, crustaceans, small mammals, bird eggs, and refuse (Clergeau and Yésou, 2006). The sacred ibis is known to raid nests of threatened shorebirds, at times destroying whole nesting colonies (Yésou and Clergeau, 2005). Recent gut analysis indicates that anthropogenic refuse is the principal component of the South Florida population's diet (Calle, 2010).
- Interagency eradication efforts, organized by the Everglades CISMA, are producing promising results with only two unconfirmed reports in 2009–2010 (John Humphrey, U. S. Department of Agriculture, personal communication).

***Prognosis for Restoration Impacts*:** The sacred ibis is a potential threat to native water bird populations. Given the success of the current eradication, this species is less likely to impact restoration efforts. Potentially affected restoration performance measures include *Wading Bird Nesting Patterns* as presented in RECOVER (2007).

***Recommendations*:** Continue focused eradication efforts.

PLANT ECOLOGY

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Plant studies form an important basis for evaluating restoration success, and three studies are discussed for WY2010. This section evaluates the invasive Old World climbing fern (*Lygodium microphyllum*) to determine the conditions under which it is likely to become established. In addition, this section examines the physiology of tree species using sap flow as an indicator of tree health or stress, and the recruitment of tree seedlings and dependencies upon hydrology. Both sap flow and seedling recruitment studies are long-term projects that will provide relevant information to water management, including the impacts of high and low water events.

TREE ISLAND *LYGODIUM* HABITAT SUITABILITY ANALYSIS

Tree islands are an ecologically important component of the Everglades landscape, serving as biodiversity centers in the Everglades (Hoffman et al., 1994). They have decreased greatly in number since 1940 (Patterson and Finck, 1999; Sklar et al., 2007). Everglades tree islands are being further degraded by colonization of invasive exotic plant species, a problem affecting South Florida ecosystems that has been documented extensively (e.g., Doren and Ferriter, 2001; FLEPPC, 2006; Ferriter et al., 2007). Eradication of invasive nonindigenous species is mandated by a number of federal and state laws and statutes including the Everglades Improvement and Management Statute, MFLs, CERP, the Research and Coordination Verification (RECOVER) Monitoring and Assessment Plan, and the Interim Operational Plan (IOP) for Protection of the Cape Sable Seaside Sparrow (see Volume III, Appendix 5-2). Old World climbing fern is considered to be the greatest threat of all invasive plant species to the Everglades (Rodgers et al., 2010). This species is classified as a Category 1 Noxious Weed in Florida by the Florida Exotic Pest Plant Council (FLEPPC, 2009).

Old World climbing fern is native to Asia, Africa, and Australia and escaped cultivation after being imported originally as nursery stock (Langeland and Hutchinson, 2005). The viability of Everglades tree islands is being threatened especially by *Lygodium* because this climbing fern eventually overtops the tree canopy, shading and choking out trees and understory species. Damage to tree islands caused by *Lygodium* includes (1) loss of important wildlife habitat, (2) loss of endangered species of native orchids and bromeliads co-occurring with the forests (Langeland and Hutchinson, 2005), and (3) increasing fire extent by elevating fire into tree canopies (Volin et al., 2004) and crossing wetland areas (Langeland and Hutchinson, 2005). Its spores are now ubiquitous (Langeland and Hutchinson, 2005) and populations of the vine are abundant in WCA-1, eastern Big Cypress Preserve, and the northern ENP immediately south of Tamiami Trail. Consequently, its expansion into WCA-3A and WCA-3B is of major concern for maintaining tree island health and preventing further loss of forests on the tree islands. Volin and others (2004) have predicted that the population traits of this species predispose it to becoming widely established in the Everglades.

Identifying *Lygodium* before it reaches the canopy and causes major ecological damage requires on-the-ground surveys of the tree islands by knowledgeable field staff. These surveys

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require a large investment of time and resources as well as follow-up for treatment. Original expectations were that tree islands located near others with *Lygodium* would be at highest risk of infestation, but recent survey results have shown that adjacency is not a reliable predictor of the presence of *Lygodium*. Habitat conditions of *Lygodium* that have been found suggest that habitat moisture may be a significant factor. Therefore, hydrologic conditions have been identified that may improve the search efficiency for *Lygodium* on tree islands in WCA-3.

Methods

The SFWMD has been funding ground surveys to identify *Lygodium* populations on tree islands in WCA-3A and WCA-3B for several years (Rodgers et al., 2010). From 2008 through early 2010, 104 tree islands in WCA-3 were surveyed for the presence or absence of the fern. The surveys were concentrated in central and southern WCA-3A, WCA-3B, but did include seven tree islands in northern WCA-3A. The survey methodology included a series of east-west transects across the tree islands spaced 20 meters (m) apart, extending from the tree island head to the near tail. The tree islands were classified by total area as small (0-4 ha), medium (4-8 ha), and large (8 ha) or larger. The surveys include tree islands from all three size classes, and the number of transects per tree island were adjusted to these sizes.

When *Lygodium* was found, its location and more detailed site conditions, such as surrounding vegetation communities and water depths, were documented. These locations were then also reported for treatment by the SFWMD. Tree islands previously identified with *Lygodium* were revisited to assess treatment success. Of the 107 tree islands, 24 had *Lygodium* individuals or populations identified (**Figure 6-14**).

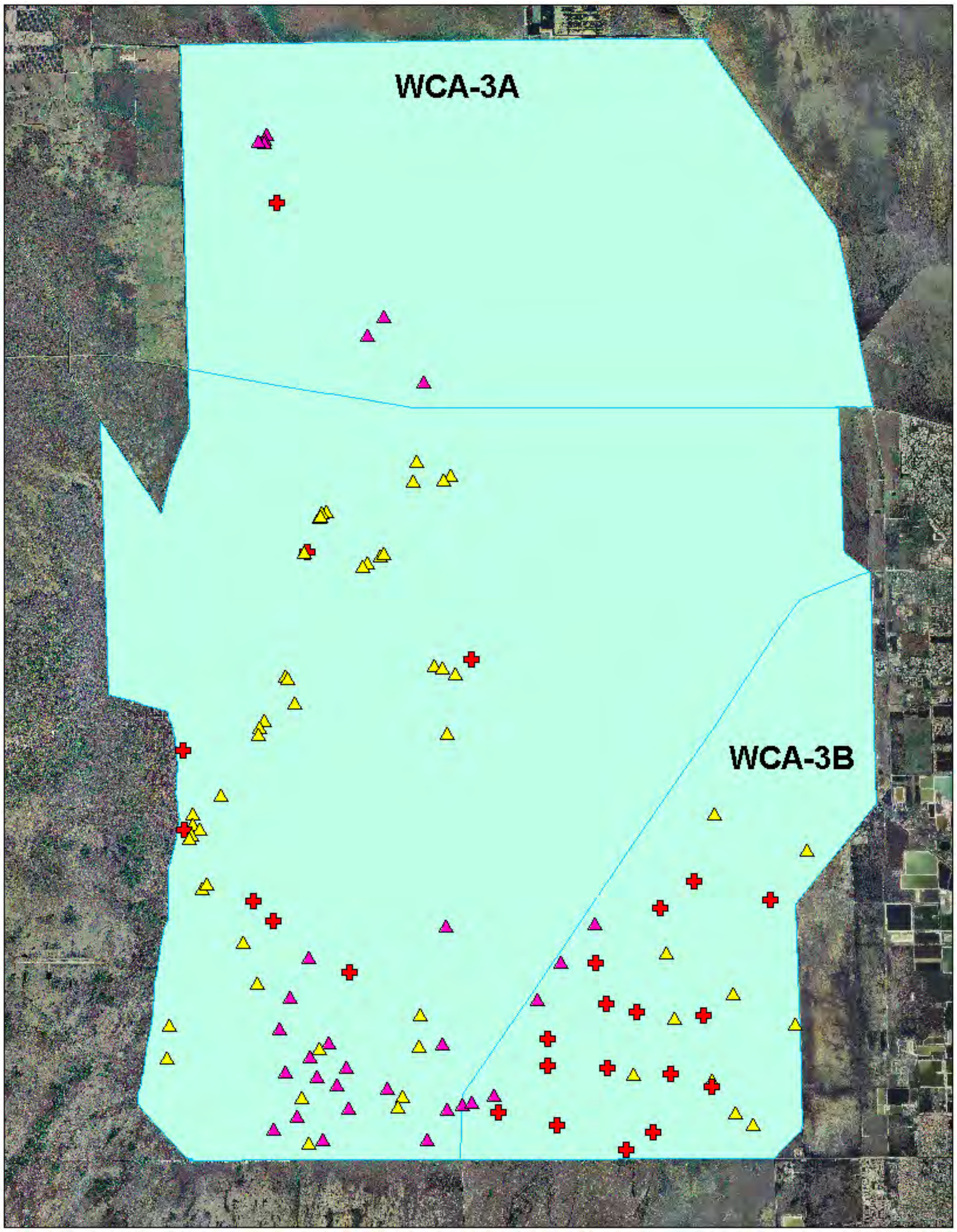

Figure 6-14. Locations of tree islands surveyed in 2008 and 2009. Red crosses indicate the locations of tree islands where Old World climbing fern (*Lygodium* sp.) was found. Triangles indicate locations of tree islands without *Lygodium* that were surveyed during 2008 (yellow) and 2009 (pink) (Ewe, 2009a; Ewe, 2009b; Ewe and Vega, 2010).

Original expectations were that there would be relatively high infestation rates adjacent to source populations of *Lygodium* in the ENP and in Big Cypress Preserve as surveyed by Wu et al. (2006), but these expectations were not confirmed by the 2008 and 2009 surveys (Ewe, 2009a; Ewe and Vega, 2010). Instead, unexpectedly high infestations were found in WCA-3B, away from most other source populations. Subsequent surveys confirmed that adjacency to other infested areas did not predict Old World climbing fern's presence on tree islands in WCA-3A or WCA-3B (Ewe, 2009a; Ewe, 2009b; Ewe and Vega, 2010). Nearly all the *Lygodium* plants were found on elevated sites out of the water on fern mounds, on logs, and on tree or shrub branches up to 0.4 meter above the ground; they were rarely rooted in the ground (Ewe, 2009a; Ewe, 2009b; Ewe and Vega, 2010). This observation led to a reconsideration of the prediction that *Lygodium* infestation was related to adjacency to other populations. Instead, it was hypothesized that tree islands in areas with drier hydrologic conditions were more likely to support *Lygodium* populations than those experiencing wetter conditions. It was assumed that hydrologic conditions on a time scale of monthly or longer time periods govern the establishment and maturation of *Lygodium*; the elevations of tree islands was not considered, so results do not reflect inundation.

To test this hypothesis, recent (up to two years previous) hydrologic regimes of tree islands with and without *Lygodium* were compared. Water stages and depths for the surveyed tree islands were available through the U. S. Geological Survey's Everglades Depth Estimation Network (EDEN) (http://sofia.usgs.gov/eden/). Hydrologic data in EDEN are for grids 400 m x 400 m in size. Daily water depths were retrieved for the grid where each tree island was located; monthly mean slough depths were calculated from these data by year and by month. Monthly mean water depths for two calendar years prior to the survey year were used for the hydrologic analysis (e.g., 2008 survey results used 2006 and 2007 water depths). Months were classified into wet and dry seasons (June–October and November–May, respectively). The presence or absence of *Lygodium* defined the two tree island populations.

Hydrologic information for the analyses included mean, minimum, maximum, and range of monthly water depths for the two preceding calendar years and for the wet and dry seasons one and two years before the surveys. Data were analyzed using an analysis of variance (ANOVA) adjusted for the unequal sample sizes and unequal variance structures of the two populations, followed by a comparison of population means.

Results

Results of the analyses indicated that tree islands with *Lygodium* were located in areas where water depths were significantly shallower and where depth variability was lower than for tree islands lacking *Lygodium*. **Table 6-6** reports the results of the analysis for the tree islands with (L_y) and without (L_n) *Lygodium* in 2008 and 2009. Ten annual and seasonal variables differed significantly ($p < 0.05$) between the two populations. Maximum annual depths, wet season maximum depths, and the range of water depths one and two years prior to the survey differed between islands with and without *Lygodium*. The previous year's mean wet season depth, wet and dry season ranges and maximum depths also differed significantly. Values presented in **Table 6-6** for one or two years preceding the tree island survey were determined based upon the survey year (one year: 2007 or 2008; two year: 2006 or 2007).

Figure 6-15 illustrates the differences in water depths between the tree islands without and with *Lygodium.* Only variables showing significant differences ($p < 0.05$) in **Table 6-6** were plotted in **Figure 6-15**. Significant depth differences ranged from as little as 2.6 inches to 5.6 inches between populations.

Table 6-6. Significance of hydrologic variables in differentiating 107 tree islands without (L_n) (n = 83) and with (L_y) (n = 24) *Lygodium.* “Dry” and “wet” indicate dry and wet seasons, respectively. Depth differences in inches were calculated as L_n-L_y.

	Two Years Before Survey		One Year Before Survey	
Variable	**Student’s t-test**	**L_n-L_y (inches)**	**Student’s t-test**	**L_n-L_y (inches)**
Mean dry	0.5609	1.04	0.1994	2.35
Mean wet	0.2045	1.55	0.0175	3.83
Minimum dry	0.8844	-0.30	0.5675	1.17
Minimum wet	0.2645	1.34	0.1640	1.73
Maximum dry	0.1916	2.11	0.0171	4.41
Maximum wet	0.0089	2.57	0.0156	5.21
Range dry	0.0585	2.41	0.0015	3.24
Range wet	0.2799	1.23	0.0194	3.48
Minimum	0.9939	0.02	0.6088	0.98
Maximum	0.0057	2.88	0.0106	5.59
Range	0.0139	2.86	0.0010	4.61
Mean	0.4133	1.25	0.1042	2.97

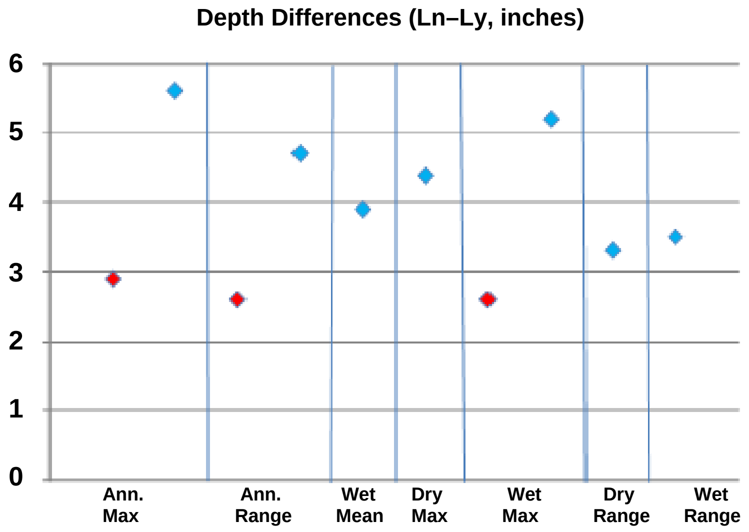

Figure 6-15. Hydrologic variables with significant differences ($p < 0.05$) between water depths surrounding the tree islands with and without *Lygodium* populations (L_y-L_n) identified by surveys. Water depths are in inches; red diamonds represent water depths two years prior to survey; blue diamonds are one year prior.

Conclusions

Tree islands with *Lygodium* experienced lower annual water depths and annual depth differences than those where *Lygodium* was not observed. Mean depths and ranges during wet and dry seasons and wet season mean depths were also lower for infested tree islands.

The hydrologic variables here may be surrogates for soil moisture through peat hydration and perhaps microsite moisture (within 40 cm of the surface of the ground), which appear to relate indirectly to elevation. In contrast to mineral soils, peat is known to wick and hold moisture, and this property may better relate to ground surface moisture and microsite moisture than elevation alone. Restoration of a more natural hydroperiod (deeper water and greater variability in depths) appears to reduce habitat suitability on tree islands for *Lygodium* in WCA-3 and therefore contributes to restoration of tree islands.

Relevance to Water Management

Restoration of more natural hydroperiods in the Everglades may decrease the risk of *Lygodium* infestations through elevated water depths and greater ranges of depths. Identification of the specific conditions that facilitate *Lygodium* propagation at a landscape scale is needed. Restored hydropatterns may improve the health of tree island plant communities, increasing their resistance to invasive species, and decreasing the suitability of tree islands for *Lygodium* invasion. Continued tree island surveys, combined with existing results, contribute to developing risk indicators for tree island infestation by *Lygodium*.

SEASONAL AND SPATIAL PATTERN OF SAP FLOW IN TREE ISLAND WOODY SPECIES: AN ECOPHYSIOLOGICAL INDICATOR OF TREE SPECIES HEALTH

Transpiration, the loss of water vapor from plants, is a physiological process that is affected by the structure of the plant (i.e., stomata response) and the environment (i.e., temperature and hydrology). Transpiration is a dominant factor in the soil-plant water relationship because transpiration produces a gradient that causes movement of water through the plants (Kozlowski and Pallardy, 1997). Measuring sap flow is a technique used to estimate the transpiration rate, which is dependent on the energy balance of the canopy, the physiological control of stomata, the temperature and humidity of the air, and the supply of water (Jarvis, 1981; Whitehead and Jarvis, 1981). In some species, variations in transpiration are governed by tree size and hydraulic architecture (Meizner et al., 2001).

Sap flow measurements are versatile because spatial heterogeneity does not limit their applicability; therefore, sap flow measurements are very well suited for determining species effects that occur in highly heterogeneous environments (Barret et al., 1996). Thus, different sap flow and transpiration rates can be expected in trees that are under extreme hydrological conditions, poor soil-nutrient conditions, or diminishing physical components (i.e., reduced canopy). Therefore, sap flow and transpiration rates can be used as an ecophysiological indicator of woody species responses to changing hydrology in forested wetlands.

The purpose of this study was to compare seasonal and spatial sap flow patterns in woody tree species experiencing different hydrological conditions on a tree island located WCA-3A. Determining the temporal and spatial characteristics of sap flow was expected to provide a better understanding of the optimum hydrological requirements of woody species living on tree islands. Three dominant woody species were chosen: a deciduous willow (*Salix caroliniana),* a semi-deciduous pond apple (*Annona glabra*), and an evergreen cocoplum (*Chrysobalanus icaco*). Since hydrology is significantly different between the dry season (characterized by low water level and short hydroperiod) and wet season (characterized by high water level and long hydroperiod), it was hypothesized that during the dry season, sap flow rates would be low due to smaller leaf areas resulting in less canopy demand for water. In contrast, during the wet season when leaf area is fully expanded, the demand for water would be high, resulting in higher sap flow rates. Spatially, it was hypothesized that sap flow rates on the head would be higher due to higher leaf areas, resulting in a greater canopy demand for water.

Methods

Sap flow measurements were conducted on tree island 3AS3 located in WCA-3. The hydrologic pattern along the central axis of this island varied from low water levels and a short hydroperiod of one month on the head to high water levels and a long hydroperiod of 12 months on the near tail during the study period (see Sklar et al., 2010).

Tree sap flow probes were installed on 14 adult trees located on the head and 15 adult trees located on the near tail. Five individuals of each dominant species (willow, cocoplum, and pond apple) were instrumented. Continuous heated probes consisting of two needles were horizontally inserted into the sapwood of each tree. The upper needle was continuously heated while the lower needle was not heated. The difference of temperature between the two needles is inversely correlated with sap flow density, which is the sap flow in kilograms per unit of sapwood area kg/m^2/s (Granier, 1987). Measurements of sap flow were made using commercially available thermal dissipation probes (Model TDP-30, Dynamax Inc., Houston, TX) that operate on the constant power principle designed by Granier (1987). Two cylindrical probes, each 30 millimeters (mm) in length were inserted 30 mm into the sap wood of the tree at about 1.5 m from the ground. Sap flow data were collected every minute from June 10, 2009 through April 10, 2010. Thirty-minute mean values were stored on a data logger (CR 1000, Campbell Scientific, Inc., Logan, UT).

Results

During the onset of the wet season (June–September 2009) maximum sap flow rates were recorded from 1:00 p.m.–2:00 p.m. for trees on both the head and near tail. During the onset of the dry season (December 2009–April 2010) maximum sap flow values were recorded from 3:00 p.m.–4:00 p.m. Seasonal differences in maximum flow rates are related to the solar irradiance seasonal pattern that peaks earlier during the summer time (1:00 p.m.–2:00 p.m.) and later during winter time (4:00 p.m.).

The three tree species showed a strong diurnal variation with the high maximum values occurring during the mid-afternoon and the lowest occurring early in the morning (**Figures 6-16**, **6-17**, and **6-18**). On the head, willow had a maximum sap flow value of 0.03 and 0.002 kg/m^2/s during the wet and dry seasons, respectively (**Figure 6-16**, panel A). On the near tail, maximum values were 0.04 and 0.002 kg/m^2/s during the wet and dry seasons, respectively (**Figure 6-16**, panel B). Maximum sap flow values on the head for pond apple were 0.09 and 0.018 kg/m^2/s during the wet and dry season, respectively. Max sap flow on the near tail was lower at 0.058 and 0.005 kg/m^2/s during the wet and dry season, respectively (**Figure 6-17**). As for cocoplum, sap flow maximum values on the head were 0.042 and 0.008 kg/m^2/s during the wet and dry seasons, respectively. On the near tail, maximum sap flow values were 0.046 and 0.01 kg/m^2/s during the wet and dry season respectively (**Figure 6-18**).

The seasonal pattern of xylem sap flow for both willow and pond apple were very similar with highest sap flow values being observed during the peak of the wet season but with a steady decrease from the wet season through the dry season when both species had their lowest maximum sap flow values (**Figures 6-16** and **6-17**). This seasonal pattern was observed at both the head and near tail regardless of the air temperature (it did not seem to affect the sap flow rate of these two species); however, on the head the lowest maximum sap flow values had a short period and lasted from December–January and from February–March for willow and pond apple, respectively. On the near tail, the lowest maximum values lasted from January–March for both willow and pond apple. In contrast to the sap flow seasonal pattern observed for willow and pond apple, cocoplum did not show any significant seasonality or spatial variability as sap flow rates held steady around 0.04 kg/m^2/s through the entire study period, except with a short period during January when values decreased to between 0.009 and 0.01 kg/m^2/s (**Figure 6-18**). This decreased is attributed to the cold snap that occurred in January when air temperatures decreased to as low as 5° Celsius.

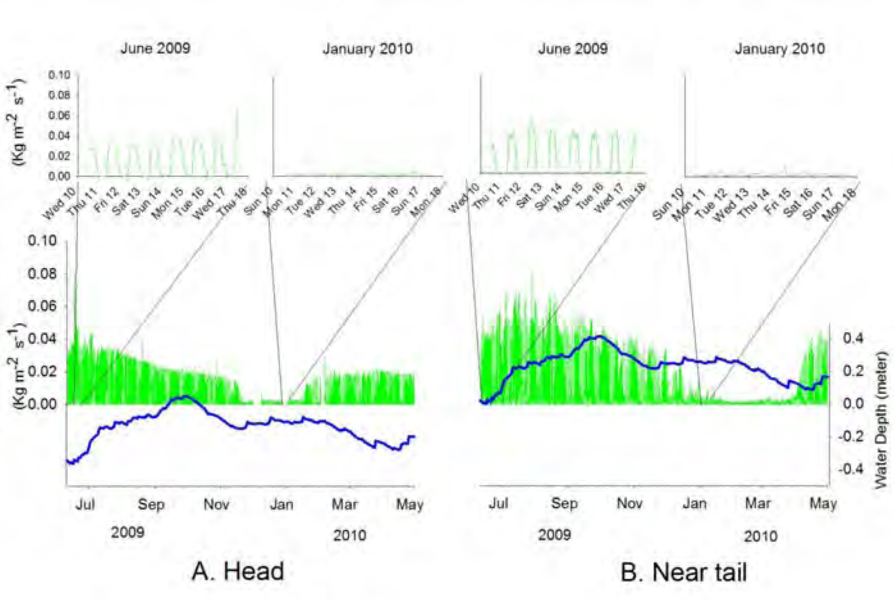

Figure 6-16. Spatial and temporal pattern of sap flow rates of willow (*Salix caroliniana*) on both the head (A) and near tail (B) of tree island 3AS3. Sap flow measurements were taken daily from June 2009–April 2010. Upper panels show the diurnal sap flow pattern during the wet (June 2009) and dry (January 2010) seasons while lower panels show the monthly sap flow pattern.

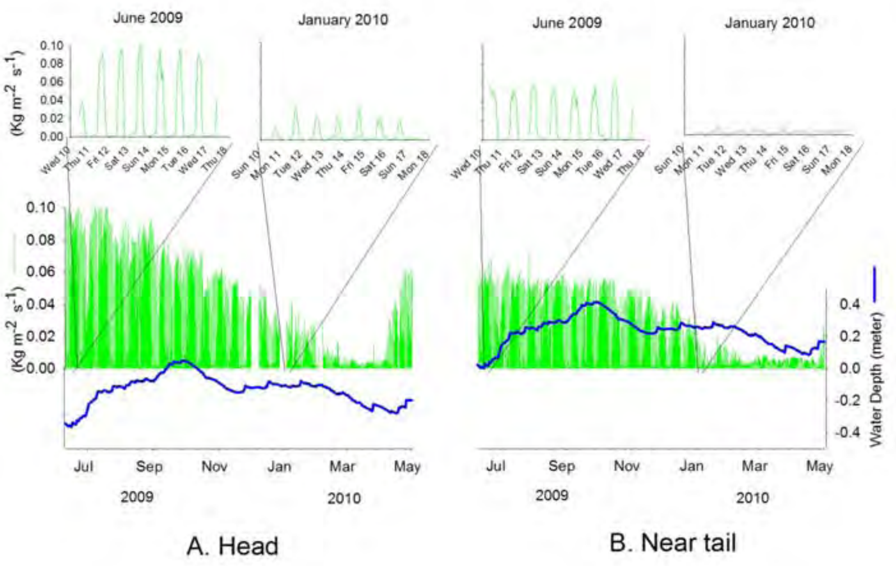

Figure 6-17. Spatial and temporal pattern of sap flow rates of pond apple (*Annona glabra*) on both the head (A) and near tail (B) of tree island 3AS3. Sap flow measurements were taken daily from June 2009 to April 2010. Upper panels show the diurnal sap flow pattern during the wet (June 2009) and dry (January 2010) seasons while lower panels show the monthly sap flow pattern.

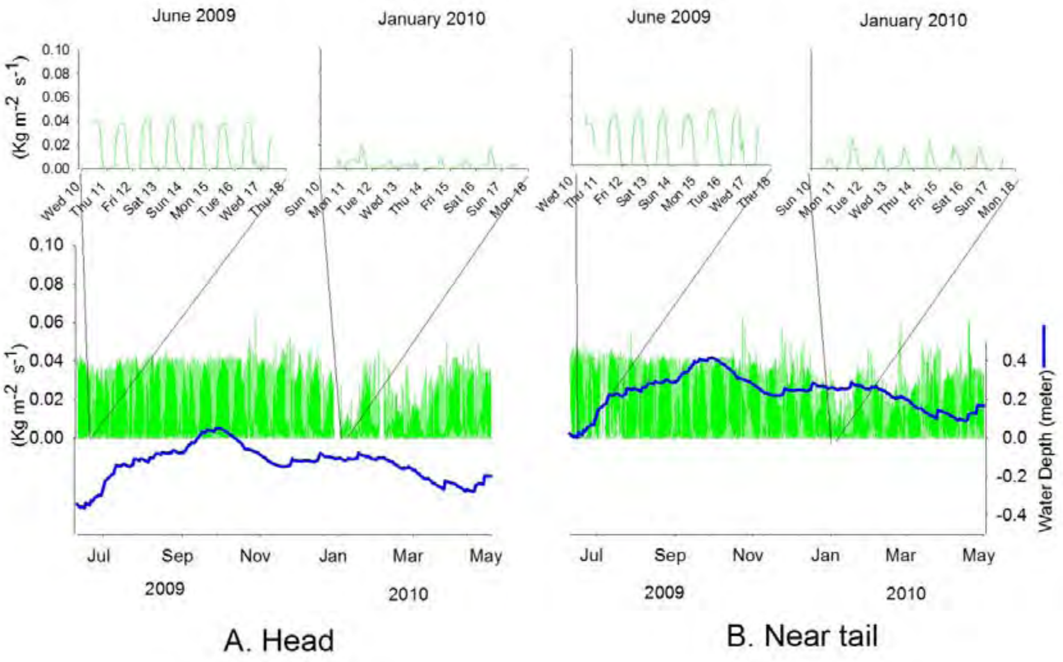

Figure 6-18. Spatial and temporal pattern of sap flow rates of cocoplum (*Chrysobalanus icaco*) on both the head (A) and near tail (B) of tree island 3AS3. Sap flow measurements were taken daily from June 2009–April 2010. Upper panels show the diurnal sap flow pattern during the wet (June 2009) and dry (January 2010) seasons while lower panels show the monthly sap flow pattern.

Discussion

It has been shown that woody tree species located on islands that experience wetter than normal conditions are physiologically stressed, especially during extreme environmental events, either very dry or very wet conditions (Kozlowski, 1997; Sklar and van der Valk, 2002). Studies have shown that the dry season tends to be more favorable for leaf level gas uptake; conversely, the wet season seems to be a time of year when leaf level water demand coupled with higher water levels induces a physiological stress on whole-plant water balance (Sklar et al., 2010).

Initial findings on how physiological parameters, such as sap flow, can be used to assess plant community responses to changes in hydrology indicate that adult woody species acclimated to longer hydroperiods are less sensitive to seasonal changes in hydrology. Results from this study indicate that the seasonal pattern of xylem sap flow for adult trees of willow, pond apple, and cocoplum was in sync with canopy leaf area development and daily solar radiation. Canopy leaf development, measured as litterfall production, indicates that both deciduous and semi-deciduous species drop their leaves during the peak of the dry season (January–March) (Coronado-Molina et al., unpublished data), which is precisely the time when sap flow rates were the lowest for both willow and pond apple. Similarly, both species have fully expanded leaves during the wet season, which was the time when sap flow rates were the highest. In contrast, cocoplum, an evergreen species, does not show any seasonality in leaf development because the tree produces new leaves all year (Coronado-Molina et al., unpublished data), a pattern that was closely followed by the measured rates of sap flow. Although most of the species in this study are more flood tolerant relative to the upland hammock tree island species, these woody species showed a significant response to hydrologic conditions. Sap flow rates for these species are highest at the beginning of the wet season when water levels are beginning to rise and the leaves in the canopy are fully expanded.

Conclusions

Even though leaves are fully expanded during the onset of the wet season, sap flow rates start decreasing when water is deepest. This seasonal pattern indicates the sensitivity of sap flow rates to water depth and extent of inundation on tree islands, suggesting that sap flow is an excellent tool to measure stress of woody species subjected to long hydroperiods.

Relevance to Water Management

The desired restoration conditions for Everglades tree islands are to improve the health of Everglades tree islands considered to be stressed or degraded and to prevent areal reductions of tree islands due to exposure to long hydroperiods. Developing tools to measure tree island health is needed for restoration purposes. Sap flow is being tested as a potential tool to measure stress on tree island woody plant communities as one index of tree island health.

SEEDLING AND SAPLING RECRUITMENT AS A FUNCTION OF HYDROLOGY AND SOIL NUTRIENT RESOURCES

With their sensitivity to water levels, the health of tree islands is a good indicator of successful hydrological management of the Everglades. Determining the causal mechanisms for the current forest structure will help predict how plant dynamics, such as seedling establishment and recruitment, will respond to alterations of the hydrologic system. The germination, establishment, growth, survival, and recruitment of woody species are ecological processes that determine community structure and diversity and, over time, tree island spatial extent. At the same time, seed dispersal and germination are dependent on many environmental factors, such as hydrology, soil moisture levels, light conditions, temperature fluctuations, redox (reduction oxidation reaction) and soil properties (Kozlowski and Pallardy, 2002; Rice, 1984). Furthermore, it has been found that long hydroperiods can inhibit seed germination and seedling establishment, promote negative growth responses, and even cause selective mortality of woody species that are less tolerant to high water levels (Hosner and Boyce, 1962; Harms et al., 1980; Megonigal and Day, 1992; Conner, 1994, Jones et al., 2006). Thus, the successful recruitment of seedlings into the adult population depends not only on seedling establishment and subsequent survival, but also on the availability of suitable germination microsites to enhance the probability of survival under adverse or diverse environmental conditions. Thus, to restore forested wetlands that are subjected to high water levels and long hydroperiods, it is important to understand how environmental factors, such as hydrology, light, and soil properties affect the recruitment processes.

The main objective of this study was to determine how local hydrological conditions and soil properties influence recruitment, growth, and survivorship along a natural hydrologic-nutrient gradient on tree islands. It was hypothesized that long hydroperiods and nutrient-poor soils restrict the regeneration of the tree island forests by adversely effecting seedling growth and recruitment. In contrast, short hydroperiods along with nutrient-rich soils were thought to be most suitable for seedling germination, recruitment, growth, and survivorship.

Methods

To accomplish the main objective, two tree islands located in WCA-3A were chosen because they are characterized by contrasting flood regimes (short or long hydroperiods) and contrasting soil properties (nutrient-rich soils or nutrient-poor soil). For instance, tree island 3AS2 is a tropical hammock island with an elevated head that is characterized a short hydroperiod and high TP [average 9,600 milligrams per kilogram (mg/kg)] and low total nitrogen (TN) (average 10,000 mg/kg). This island is dominated by low-water tolerant species, such as white stopper *(Eugenia axillaris*) and satin leaf (*Chrysophyllum oliviforme*) on the head and by high-water tolerant species, such as cocoplum (*Chrysobalanus icaco*) and sweetbay (*Magnolia virginiana*) on the near tail. In contrast, tree island 3AS5, a low-elevation island, is characterized by a long hydroperiod and low TP (average 631 mg/kg) and high TN (average 35,000 mg/kg) at both the head and near tail. The forest structure is dominated by willow (*Salix caroliniana*), buttonbush (*Cephalanthus occidentalis*), and sweetbay (*Magnolia virginiana*) throughout the entire island. On both islands, two parallel north-to-south 100-m transects were set up in March 2008. Along each transect, four 5 x 5 m plots were established; within each plot, five 1 x 1 m subplots were randomly selected to facilitate the measurement of seedling and sapling density. Specifically, plots were located at the head (plot 1), 25 m south of the head (plot 2), then 75 m south (plot 3), and 100 m south (plot 4). Visual inspection of the plots showed that most seedlings were established on slightly elevated microsites, including hummocks and tussocks; estimating the microtopographic variability within the subplot soil elevations was done by measuring the water level within the subplots and relating these measurements to the water levels at the benchmark in closest proximity to the study island. Flat-pool was assumed, meaning that the water level at benchmark and all locations within 2 or 3 miles of the benchmark is the same. This approach ensured that the benchmark [North American Vertical Datum 1988 (NAVD88)] was used to determine the elevations of the subplots. In March 2008, all seedlings and saplings located within the subplots were identified and tagged, allowing for tracking their recruitment and survival. All tagged seedling and saplings were measured again in June 2008, January 2009, and January 2010. In addition, any newly recruited seedlings within the five recruitment subplots were identified and included in the study to provide an estimate of the rate of new recruitment. Aboveground and belowground water surfaces were estimated for each plot from regional stage recorders, tree island elevation measurements, and the U. S. Geological Survey's Everglades Depth Estimation Network (EDEN) (Telis, 2006).

Results

Due to its elevated head relative to the near tail, tree island 3AS2 was characterized by a short hydroperiod on the head with less than a month of inundation at a water depth of 20 cm during the study period. In contrast, the near tail plots were characterized by a long hydroperiod, experiencing eight to nine months of inundation at water depths of 30–40 cm (**Figure 6-19**). Similarly, on the head, TP averaged 9,600 mg/kg with an average nitrogen-to-phosphorus ratio of (N:P) 1.0. On the near tail, TP averaged 731 mg/kg and the N:P averaged 35. On this tree island, there was a high density of seedlings and saplings in the head plots. Seedling composition was dominated by cocoplum and white stopper (**Figure 6-19**, panel A) but the density decreased along plots located in the near tail where seedling composition was dominated by buttonbush and cocoplum (**Figure 6-19**, panels B–D). Seedling survivorship was significantly higher on the head plots where 50 percent of the seedlings survived during the study period. On the head, the highest seedling mortality occurred during the high-water period of July 2008 and February 2009, when approximately 50 percent of seedlings died (**Figure 6-19**, panel A). In contrast, in the near-tail plots, seedling survivorship rate was very low, particularly at plots 2 and 4 where only 20 percent of the seedlings survived during the study period (**Figure 6-19**, panels B–D).

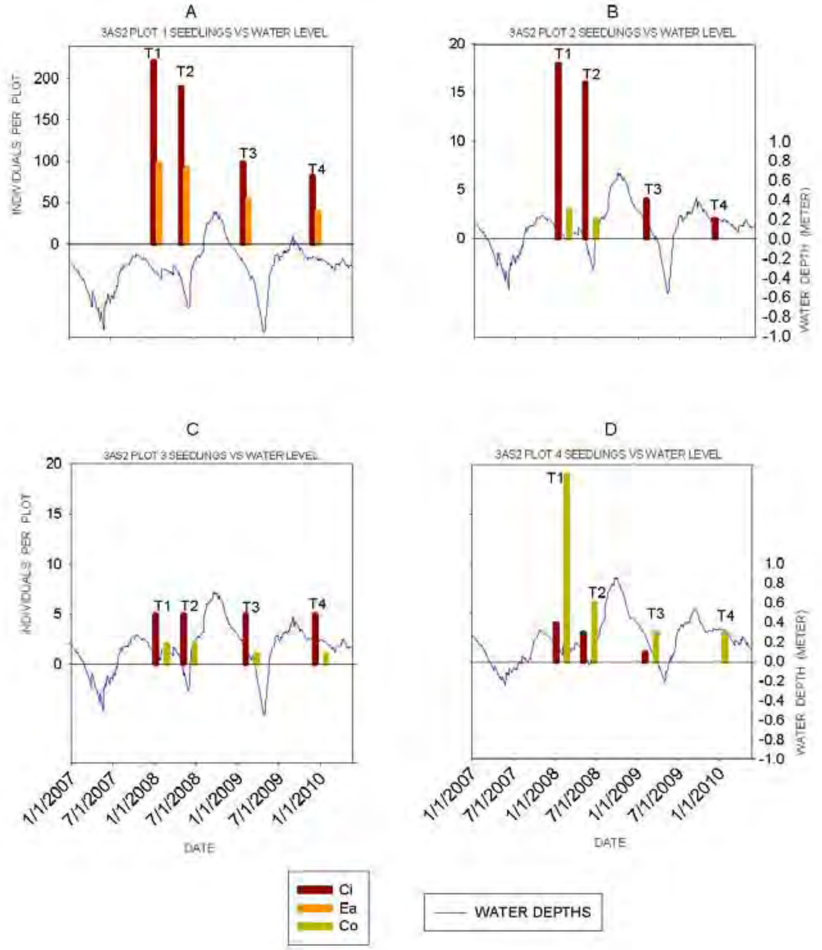

Figure 6-19. Seedling recruitment (stems per plot) and water level (cm) along a 100-meter (m) long head-to-tail transect at tree island 3AS2. T1 = January 2008; T2 = May 2008; T3 = February 2009; T4 = January 2010. Species: (Ci) = *Chrysobalanus icaco*, (Co) = *Cephalanthus occidentalis*, and (Ea) = *Eugenia axillaris.*

Due to its low elevation at both the head and near tail, tree island 3AS5 was characterized by a long hydroperiod along the seedling transects. Seedling plots remained inundated nine to 10 months per year, with a water depth ranging from 20 to 60 cm during the study period (**Figure 6-20**). Soil nutrient properties were similar along the transect where TP averaged 631 mg/kg and the N:P averaged 45. Seedling density was relatively low and dominated by species that were water tolerant, including dahoon holly (*Ilex cassine)*, swamp bay (*Persea palustris*), pond apple (*Annona glabra*), willow (*Salix caroliniana*), wax myrtle (*Morella cerifera*), and buttonbush (*Cephalanthus occidentalis*) (**Figure 6-20**). Even though seedling density was low, the survivorship rate was relatively high at 40 to 50 percent. Survivorship was particularly high in plot 2, which was characterized by the presence of fern tussocks (**Figure 6-20**, panel B).

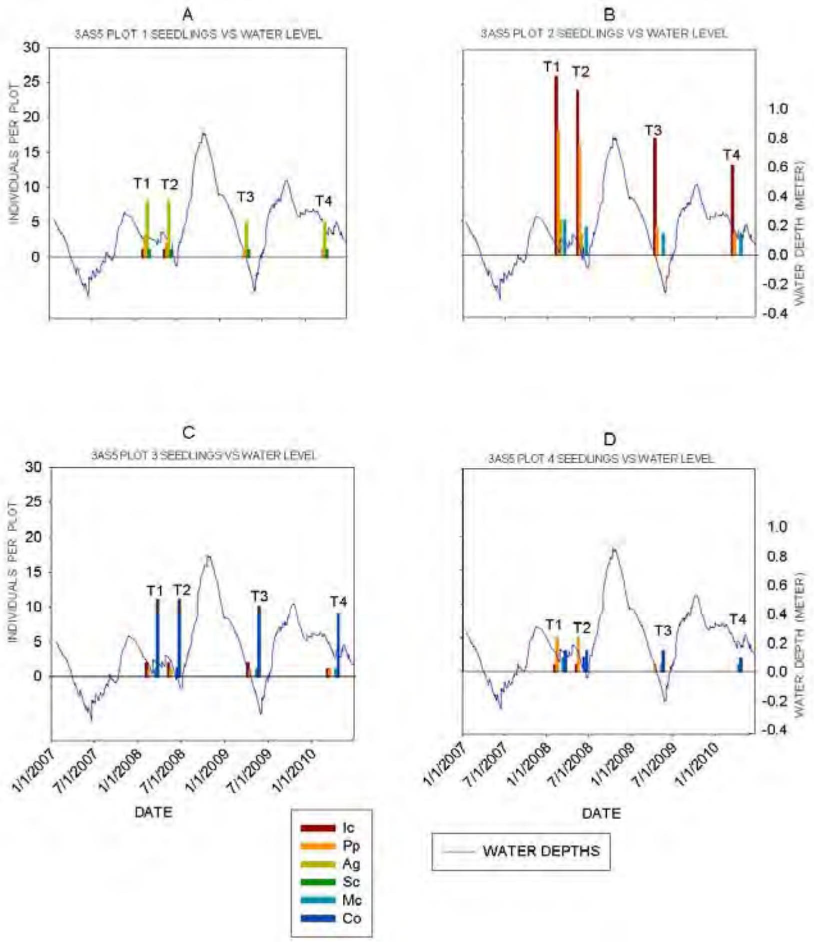

Figure 6-20. Seedling recruitment (stems per plot) and water level (cm) along a 100-m long, head-to-tail transect at Tree Island 3AS5. T1 = January 2008; T2 = May 2008; T3 = February 2009; T4 = May 2010. Species: (Ag) = *Annona glabra*, (Co) = *Cephalanthus occidentalis*, (Ic) = *Ilex cassine*, (Mc) = *Morella cerifera*, (Pp) = *Persea palustris*, and (Sc) = *Salix caroliniana.*

Discussion

The survivorship rate at the seedling and sapling stage does appear be driven by hydropattern (i.e., a short hydroperiod on 3AS2 versus a long hydroperiod on 3AS5). Recruitment and survivorship rates were higher on sites where the hydroperiod was short. The importance of hydrology in driving survivorship rates was more evident on the head of 3AS2, where an increase in the hydroperiod during the wet season of 2008 was sufficient to increase mortality by almost 50 percent, a pattern that was less evident on the near tail, where the hydroperiod was longer during the study period. As a resource, soil nutrients played a smaller role as there was no obvious relationship between seedling recruitment and survivorship and TP gradients on an island or differences in TP between islands.

Conclusions

These results indicate that woody species successfully colonize, become established, and survive on sites where the hydroperiod is relatively short and soil nutrients are high. However, the presence of small elevated sites, such as fern tussocks, small hummocks, and tree stumps create conditions that enhance seedling growth and survivorship on tree islands where hydroperiods are long. It seems that variations in biologically created microtopography plays an important role in creating micro-environments where seedling and sapling of woody species survive under long hydroperiods and poor nutrient conditions.

Relevance to Water Management

Short hydroperiods allow woody tree species to germinate large numbers of seedlings. However, long hydroperiods do not completely eliminate the germination and establishment of woody tree species on an island. This resilience gives flexibility to the management of hydrologic regimes in the Everglades, but still does not provide the frequency thresholds for high and low water events that are needed to constrain the number and duration of extreme floods and droughts.

ECOSYSTEM ECOLOGY

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The focus on areas of the Everglades that have been severely impacted by nutrient enrichment continued with the application of a prescribed fire model created under the Accelerated Recovery on Impacted Areas (FIRE) Project and the maintenance of openings in dense cattail (*Typha domingensis*) stands for ecosystem restoration under the Cattail Habitat Improvement Project (CHIP). More detail on past studies completed within these projects in presented in Sklar et al. (2010). In addition, a project is described which involved the paleoecological analysis of soil cores used to study changes in the historic landscapes of the Everglades.

CATTAIL FIRE MODEL

The FIRE Project is a research component of the Long-Term Plan, designed to evaluate prescribed fires as a management tool for accelerating the recovery of phosphorus-enriched areas of WCA-2A. A four-year field study was conducted during which time two fires occurred at both a highly phosphorus-enriched plot and a moderately phosphorus-enriched plot. To understand the effect of longer-term application of repeated fires in the two areas, a wetland ecosystem model was developed. Using this model, fire's effects on TP concentration in water and soil under different seasons and hydrological scenarios was examined. Specifically, the objectives of this study were:

- To evaluate the effects of single and multiple fires on phosphorus dynamics
- To evaluate the effects of fires under contrasting hydrological conditions and in different seasons on phosphorus dynamics in water and soil
- To identify the best fire scenario for reducing phosphorus storage in the systems

The FIRE Project hypothesized that repeated application of prescribed fires would remove phosphorus from the ecosystems and reduce phosphorus storage.

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Methods

A wetland ecosystem model (WEM) was compartmentalized into four main modules: vegetation, soil, water chemistry, and fire (**Figure 6-21**). The vegetation module simulated plant growth, carbon (C) cycling, and nutrient uptake and accumulation in plants. The soil module simulated the dynamics of C, nitrogen (N) and phosphorus (P) in soil, as well as other physical and chemical properties (e.g., soil temperature) to a depth of 30 cm, as this depth was considered the active root zone. The water chemistry module was used to simulate the water budget and consisted of water input from rainfall and upstream inflow; and water losses from evapotranspiration (ET) and downstream outflow. The fire module considered biomass burning and nutrient (mainly as ash) deposition into the ecosystem as the key nutrient recycling processes, and the diffusion and downwind transport of ash as a main nutrient export processes from the experimental plot. Fauna were neither considered in this model nor monitored during the field study. Details regarding the equations for each model can be found in Tian et al. (2010).

Data for the model simulation included climatic conditions [air temperature, rainfall, solar radiation, and photosynthetically active radiation (PAR)], inflow water, and associated nutrient dynamics. These data were retrieved from the District's hydrometeorologic database (DBHYDRO). All climate data were measured at site WCA-2 F4, which was less than 5 km away from the highly enriched plot. Water level data were measured at site WCA-2 E1, less than 1 km away, and were used as a control for the water depth dynamics in the simulations. Both nitrogen and phosphorus atmospheric depositions were assumed to be invariable throughout the study due to their small contribution to total cycling and the unknown nature of future deposition trends. Other model data including vegetation, water chemistry, and soil parameters were obtained from the FIRE Project or the literature.

The WEM was calibrated using field data from the unburned control plot monitored by the FIRE Project, and then validated against field data from the burned plot for both the highly-enriched and moderately-enriched areas. Two scenarios were modeled: a burned scenario simulating the ecosystem dynamics after a fire (July 25, 2006, for highly enriched and February 20, 2006, for moderately enriched); and an unburned scenario that assumed no fire during the simulation period. The differences between these two scenarios were regarded as the fire impacts. The model was first iterated for 50 years, followed by a transient run covering the period 1998–2008 for model validation. It was then used to forecast system responses to prescribed fires conducted biannually in either July or February under high water depth or low water depth. The model operated at a daily time step for all simulations. The cell size for the simulation was set at 9 hectare (ha) to be consistent with the layout of the FIRE Project field experiment (Miao et al., 2009, 2010).

Five simulations were run to determine the effect of hydrology and season on phosphorus dynamics post-fire. One control simulation without any fires was set up for comparison purposes (S-1). The first scenario (S1) consisted of low water depth (relatively dry) conditions in 2006, and wet conditions (higher depths) from 2008–2024 when the last fire was simulated. The second scenario (S2) was under low water depth conditions for all fires (2006, 2008–2024). Scenarios S4 and S5 were under the same conditions as S1 and S2 respectively, except that the fires occurred in February. (Note: The S3 simulation , representing low water in 2006, high water in 2008, and low water from 2010–2024, is not presented with these results due to the complexity of the hydrologic scenarios simulated.) Models were run using low water depth conditions to mimic the actual conditions during the first fires (2006). The first water depth was depth at time of fire. The second water depth was the three-month post-fire water depth, after which water depth varied according to the Everglades wet/dry seasons. Scenarios S1 and S4 are referred to as high water, while S2 and S5 are referred to as low water (**Table 6-7**). All results presented here are model simulation results.

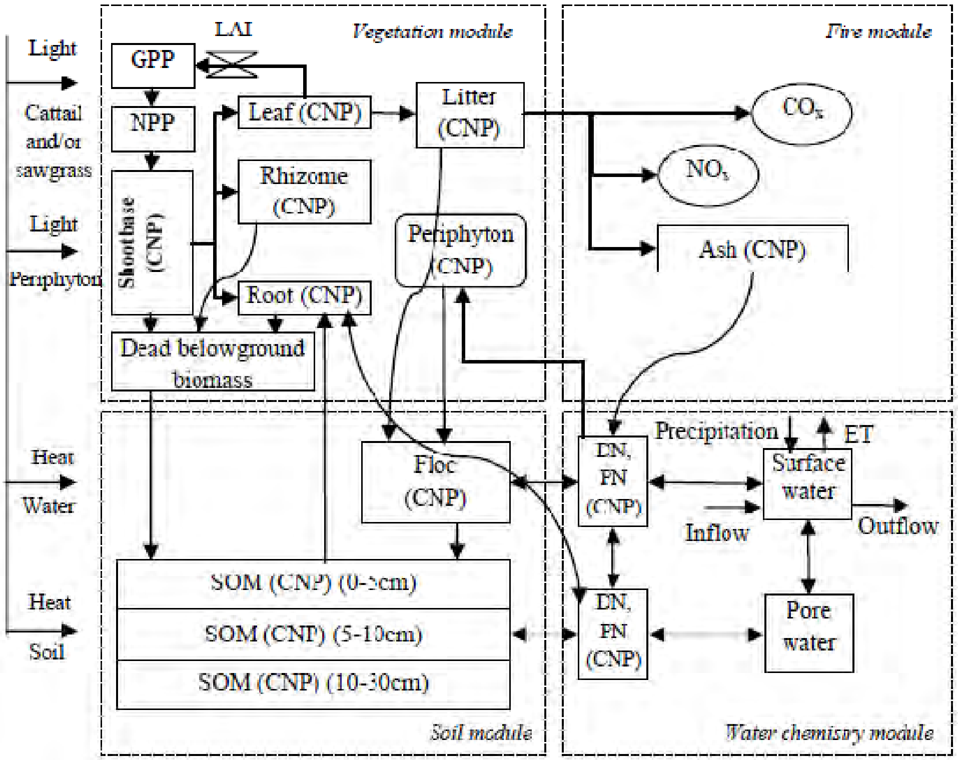

Figure 6-21. Conceptual diagram of the wetland ecosystem model after Tian et al. (2010). (DN) = Dissolved nutrients, (PN) = particulate nutrients, (SOM) = soil organic matter, (GPP) = gross primary production, and (NPP) = net primary production, C = carbon, P = phosphorus, N = nitrogen.

Table 6-7. Detailed information of five combinations of hydrological and seasonal simulated scenarios. The first water depth was depth at time of fire. The second water depth was the three-month post-fire depth, after which water depths varied according to wet or dry seasons.

Simulations	Characteristics	Year	
		2006	2008–2024
S-1	No burn (Control)		
S1	Burn month	July	July
	Burn water depth (m)	0.1 & 0.1	0.5 & 0.5
S2[b]	Burn month	July	July
	Burn water depth (m)	0.1 & 0.1	0.1 & 0.1
S4[c]	Burn month	February	February
	Burn water depth (m)	0.1 & 0.1	0.5 & 0.5
S5[d]	Burn month	February	February
	Burn water depth (m)	0.1 & 0.1	0.1 & 0.1

[a] low water depth (2006); high water depth (2008–2024)
[b] low water depth (2006); low water depth (2008–2024)
[c] low water depth (2006); high water depth (2008–2024)
[d] low water depth (2006); low water depth (2008–2024)

Results

Surface water TP concentrations in the highly enriched plot were highest after the initial July fire; subsequent high-water and low-water fires producing decreased peaks until 2014 when post-fire peaks stabilized. Peaks were higher under low water conditions than high water conditions. When the fires were simulated for February, the surface TP response to fires was higher under low water depth than under high water depth conditions. In the moderately enriched plot, July fires under high water depth generated lower peaks than low water depth, but both stabilized during the 2016–2024 fires. During February fires, under the high water depths, the TP peak was constant during 2012–2024 fires. However, under the low water depth scenario, the TP peak decreased each year after eight fires.

Porewater phosphorus concentrations in the highly enriched plot, under both high water depth and low water depth conditions were approximately 600 micrograms per liter (µg/L) for 2006 July fire, decreased to 420 µg/L for the 2008 July fire, and remained relatively constant during 2010–2024. Low water depth fires produced decreasing peaks after 2010. The February fires were similar for fires under high and low water depths. In the moderately enriched plot, the porewater peak TP concentration stabilized after eight fires for both the high water depth and low water depth fires in July. In February, the peak TP concentration under both scenarios was approximately 398 µg/L after the first fire and continued decreasing each.

Soil TP concentration in the highly enriched plot, regardless of hydrological conditions, decreased under the July fires scenario (**Figure 6-22**). However, fires under low water depth scenarios generated a stronger decrease in soil TP, compared to high water depth condition. February fires also resulted in a long-term decrease in soil TP. As with the July fires, low water depth fires resulted in greater decreases in soil TP concentration than high water depth fires. Fires in the moderately enriched plot produced similar responses.

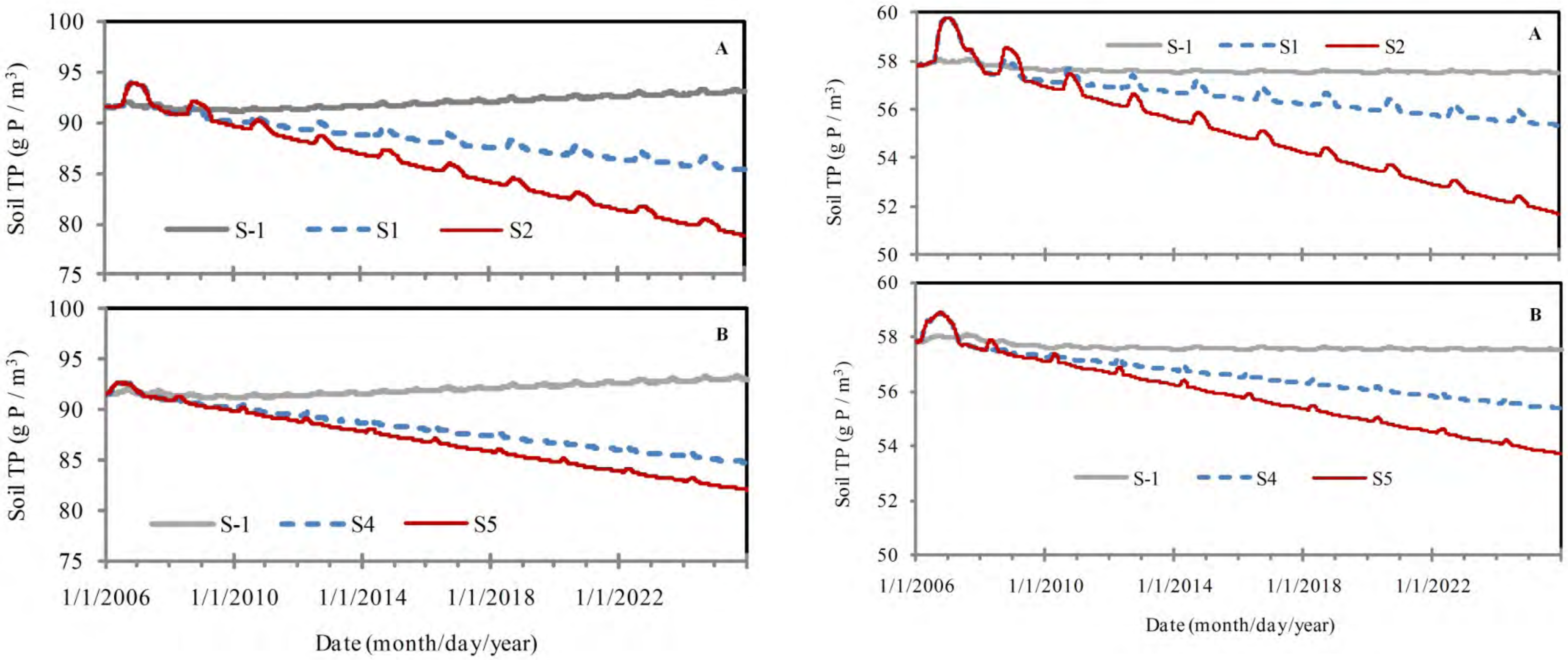

Figure 6-22. Modeled dynamics of soil TP in response to multiple July and February fires for the highly enriched cattail (*Typha* spp.) ecosystem (left) and the moderately enriched cattail ecosystem (right). [Note: S-1: control simulation; S1: July fires under high water depth; S2: July fires under low water depth; S4: February fires under high water depth; S5: February fires under low water depth.]

Cattail aboveground biomass in the highly enriched plot decreased by 508 grams per square meter (g/m^2) after the initial July fire in 2006 (**Figure 6-23**). Two years later, the cattail aboveground biomass had not recovered completely to pre-burn conditions. Low water depth fires decreased biomass more than high water fires in the simulations. The first February fire in 2006 caused a reduction of approximately 264 g/m^2 in cattail aboveground biomass with no full recovery after two years. July fires caused a higher reduction than February fires, regardless of hydrological conditions; and fires under low water depths caused a higher reduction than those under high water depths.

Similar to the highly enriched plot, the initial July fire in the moderately enriched plot caused a 455 g/m^2 decrease in cattail aboveground biomass, so low water depths caused a greater reduction in biomass than high water depth fires in these plots as well. The first February fire in 2006 caused a reduction of approximately 360 g/m^2 in cattail aboveground biomass. Similar to the fire effects for the highly enriched wetland, July fires caused a higher reduction than February fires; fires under low water depths caused a higher reduction than those with high water depths.

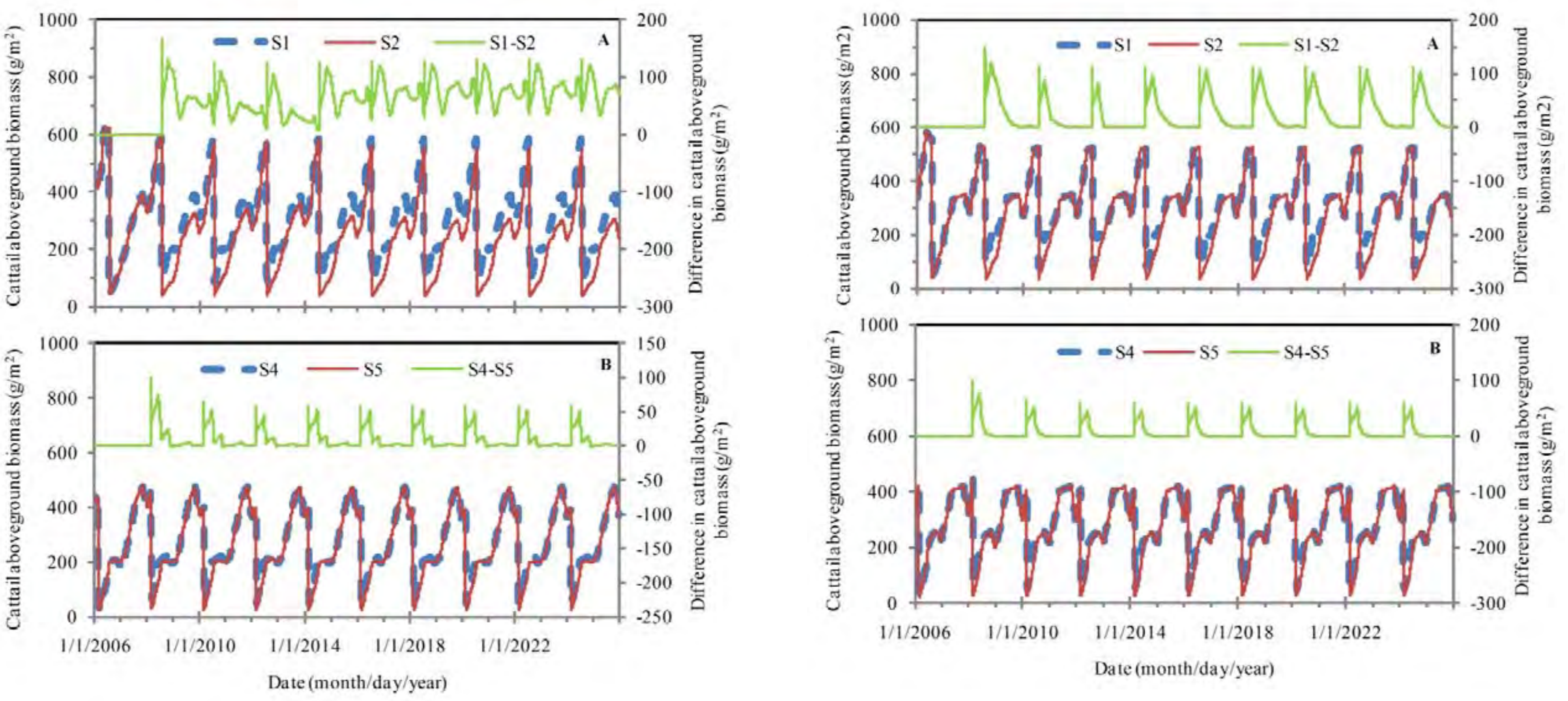

Figure 6-23. Modeled dynamics of cattail aboveground biomass in response to multiple July and February fires for the highly enriched cattail ecosystem (left) and the moderately enriched cattail ecosystem (right), [Note: S-1: control simulation; S1: July fires under high water depth; S2: July fires under low water depth; S4: February fires under high water depth; S5: February fires under low water depth.]

Discussion

Fires significantly altered the TP concentration in surface and porewater in the short-term, with peaks in concentration immediately following the fire and decreasing concentrations over time in all of the experimental scenarios. Fire occurring under low water depth conditions yielded higher pulses of TP in surface and porewater for both July and February fires. This is probably because the July fire consumed more plant biomass and dead mass and provided more ash to the water column, thus providing more particulate phosphorus, the major source of TP in surface water (Salas et al., 2003). The porewater TP concentration was directly controlled by surface water TP for the short-term, so it exhibited a similar response to July and February fires. The hydrological effects on fire impacts were similar for both highly enriched and moderately enriched wetlands.

Regardless of which season the fire occurred, lower water depth enhanced the decrease in soil TP concentration with fire. July fires caused slightly stronger effects on the decline in soil TP concentration compared to February fires. The decline in soil TP concentration with fire was indirectly the result of biomass burning and removal, which caused plants to access more soil TP for regrowth.

Fires directly consumed cattail aboveground biomass, but the effects varied with hydrological conditions. The July fire caused stronger suppression effects on plant biomass due to the higher plant biomass in July relative to February. Low water depths enhanced a fire’s effect on plant biomass, so the fires under low water depths caused a higher reduction in cattail aboveground biomass than those under high water depths.

Conclusions

Repeated application of fire alters the TP dynamics in surface water and porewater and in soil. In summary, regardless of season, the fires under low water depth hydrological conditions generated stronger negative effects on TP concentration in water and soil. Regardless of the hydrological condition, the July fires generated similar effects, but with a larger magnitude, on the increases of TP in surface and porewater than February fires. Meanwhile, repeated fires may suppress the effects on cattail aboveground biomass. July fires under low water depths appear to be the fire regimes that make the greatest contribution to the reduction in cattail aboveground biomass.

Relevance to Water Management

The outcomes of the model simulation, based on five seasonal and hydrological scenarios (four burn and one control), provided useful information for fire application in the Everglades. The results suggested that late summer fires under low water depth (< 10 cm) conditions would result in the greatest system reduction in phosphorus. Water depth is a critical factor for fire effects on phosphorus removal, the post-fire phosphorus pulse, and downstream effects.

CATTAIL HABITAT IMPROVEMENT PROJECT

Eutrophication of the Everglades has resulted in a regime shift from the ridge-and-slough landscape to large areal expanses of cattail (Hagerthey et al., 2008). To accelerate the recovery of phosphorus-impacted regions, restoration requires not only a reduction in the supply rate of phosphorus, but also active management efforts that reduce the resilience and resistance inherent to the cattail regime. CHIP is a large-scale in situ study comprising 15 6.25-ha plots to test the ability to rehabilitate cattail areas by creating an alternative submerged aquatic vegetation (SAV) regime. The ultimate objective of CHIP was to accelerate the ecological rehabilitation of the phosphorus-enriched, emergent macrophyte Everglades marsh. The approach was to induce a regime shift by applying commonly used management options to create and sustain an SAV/periphyton-dominated habitat. It was hypothesized that by switching primary production to the water column, compared to emergent macrophyte biomass, then (1) biogeochemical cycling among the dominant carbon pools would be altered, and (2) there would be a change in food quality by reducing the amount of structural carbon (i.e., cellulose and lignin).

Using a combination of herbicides and fire, open areas were created in enriched and moderately enriched areas of WCA-2A in July 2006. The numerous hypotheses, experimental design, and rationale behind this research project were described in Sklar et al. (2007, 2008) and Newman et al. (2009, 2010) while the detailed project description and methodologies can be found at (www.sfwmd.gov/evergladeswatershed). WY2010's report compares the initial intensive sampling event, after the plots had been allowed to equilibrate from the disturbance (January 2007), and the final sampling event from September–November 2009, to assess the stability and sustainability of the created regime. For all results, sites are delineated based on their location; enriched (E), transitional (T), reference (UC) and whether or not they were burned, open (O), or controls (C).

Methods

The open plots were created using a combination of herbicides and burning, and subsequently maintained with herbicide application as necessary. Specifically, glyphosate was applied in May 2006 and the plots were burned on July 20–21, 2006. It was determined that glyphosate alone was not sufficient to control cattail regrowth; thus, an additional spray was conducted in August 2006, using a combination of glyphosate and imazapyr. Some vegetative strips remained, and a partial respray occurred in September 2006. Two additional sprays to maintain the openings were done in March and November 2007. No further herbicide application has since occurred.

Water samples were collected using both grab and automatic samplers and analyzed using standard methods. Grab samples reflected time periods that corresponded with pre- and post-foraging by wading birds, while automatic samplers captured the flux of soil nutrients to the overlying water column at the initiation of the wet season, as well as concentration effects during drydown. Environmental conditions, wind speed, air temperature, water temperature, relative humidity, and PAR were measured at 30-minute intervals using HOBO® weather stations. Water depths were recorded at 30-minute intervals using HOBO® water level loggers. High frequency measurements of dissolved oxygen (DO), pH, water temperature, and specific conductivity were obtained using Hydrolab multi-parameter datasondes (Hach®) deployed for five-day increments about once a month throughout the study. Both soil and vegetation were sampled from three locations within each plot and composited. Soil and floc samples were collected using 10-cm, thin-walled stainless steel coring tubes and analyzed using standard methods. Vegetative biomass and species composition were obtained from 0.25 square meter (m^2) quadrats.

Results

Over the four-year study period, water depths ranged from complete drydown (< 0 cm) to approximately 1 m (**Figure 6-24**). TP and total Kjeldahl nitrogen (TKN) were consistently greater at the beginning of the wet season following initial marsh inundation and then rapidly declined (**Figure 6-24**, panels A and B, respectively). As flow at the onset of wet season differed among years, the initial spike in nutrients at the beginning of wet seasons was likely regulated more by flux from the soils rather than external nutrient loads through the S-10 structures. In 2006, mean daily flows during the onset of the wet season averaged 247 cubic feet per second (cfs) over 22 days of operation, 0 cfs in 2007 with no days of operation, 1,163 cfs in 2008 over 31 days of operation, and 1,749 cfs in 2009 over 28 days of operation. Similar TP and TKN concentrations were generally observed between open and control plots, and as expected, TP concentrations declined from the enriched sites to the reference sites.

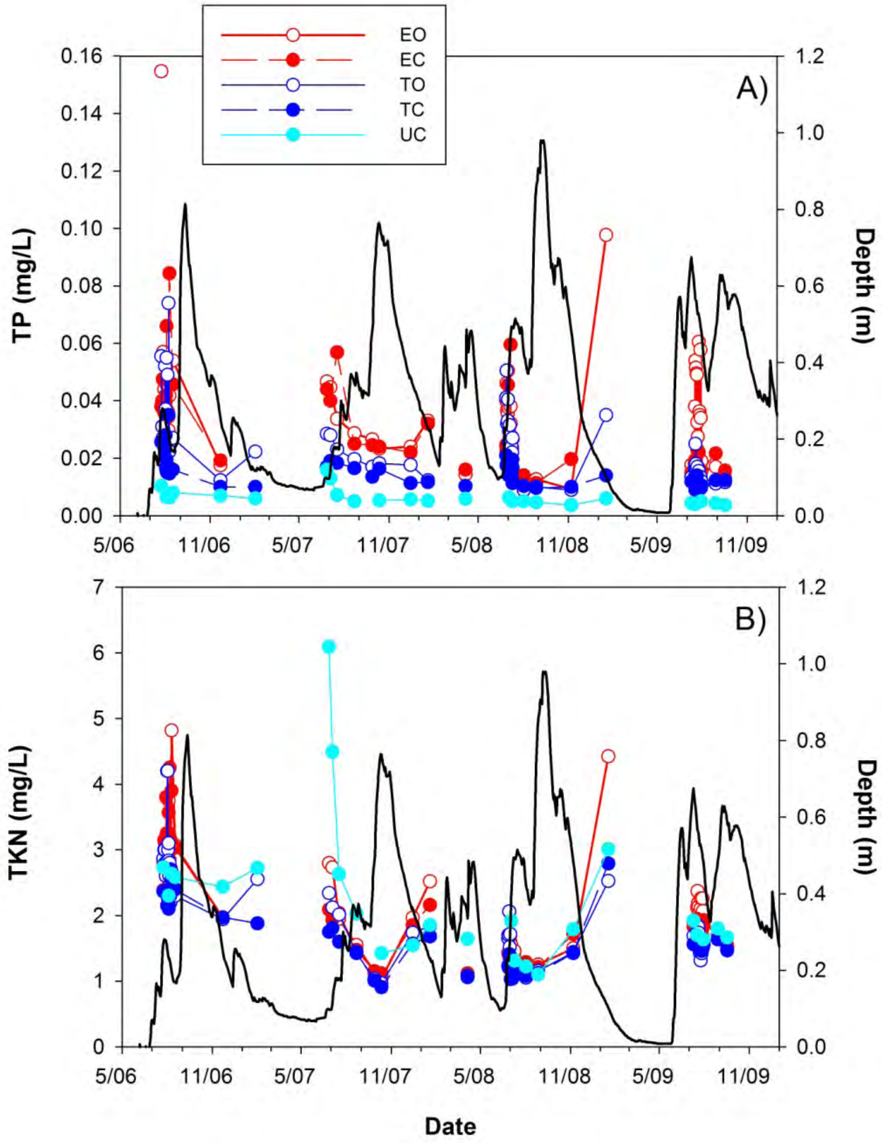

Figure 6-24. Water depth (black line) and mean surface water TP and total Kjeldhal nitrogen (TKN) concentrations collected throughout the project duration. Plots were EO = enriched open, EC = enriched closed (control), TO = transitional open, TC = transitional closed, or UC = reference.

TKN concentrations did not show consistent patterns among treatments. Annual TP and TKN concentrations within a treatment did not exhibit distinct trends over time.

The implemented treatment, i.e., removal of vegetation, significantly affected environmental conditions within plots (**Table 6-8**). The open plots, with limited emergent vegetation, were characterized by greater PAR, water temperatures, and wind speed relative to the paired control.

The concomitant increases in SAV and periphyton photosynthesis and reaeration from greater wind speeds resulted in significantly greater dissolved oxygen (DO) concentrations, DO percent saturation, and pH ($p < 0.05$).

Table 6-8. Environmental [mean ± standard deviation (S.D.)] conditions for the two created openings (EO and TO), control site (EC), and reference conditions (UC), throughout the duration of the study. Sample size (n) is denoted in the parentheses. Data reflect high-frequency measurements obtained by sensors and data loggers, therefore values for each treatment were paired with the corresponding control to enable direct comparisons.

	EO	EC	TO	TC	UC
Dissolved Oxygen (mg/L)	3.9±3.6 (4,338)	1.4±1.0 (4,338)	4.2±3.1 (4,307)	1.9±1.3 (4,307)	6.8±2.5 (4,337)
Temperature (ºC)	23.7±5.1 (4,338)	22.3±4.9 (4,338)	23.6±5.2 (4,307)	22.8±5.1 (4,307)	25.1±6.1 (4,337)
Wind Speed (m/sec)	1.6±1.5 (4,338)	0.1±0.1 (4,338)	1.7±1.4 (4,307)	0.2±0.3 (4,307)	1.7±1.5 (4,337)
PAR (µmol/m^2/sec)	449±598 (10,521)	168±291 (10,521)	457±602 (7,938)	334±475 (5,292)	420±580 (85,749)
DO % Saturation	44±37 (713)	14±8.8 (713)	43±24 (713)	20±11 (713)	81±22 (713)
pH	7.7±0.4 (713)	7.4±0.4 (713)	7.5±0.3 (713)	7.2±0.2 (713)	8.0±0.3 (713)
Specific Conductivity (µS/cm)	948±325 (713)	900±356 (713)	717±273 (713)	713±277 (713)	810±87 (713)

mg/L – milligrams per liter
ºC – degrees Celsius
m/sec – meters per second
PAR – photosynthetically active radiation
µmol/m^2/sec – micromoles per square meter per second
DO – dissolved oxygen
µS/cm – microseimens per centimeter

Treatment effects were most dramatic when comparing diel cycles (**Figure 6-25**). As previously reported (Newman et al., 2010), significantly different water column diel DO patterns were evident within three weeks of the burn (**Figure 6-25**, panels A and B) and persisted throughout the duration of the study (**Figure 6-25**, panels C and D). Dissolved oxygen concentrations in control plots were typically < 1 mg/L and did not exhibit strong diel fluctuations (**Figure 6-25**, panels A and C). In contrast, strong diel fluctuations in DO concentrations, range < 1 to > 12 mg/L, were recorded in open plots (**Figure 6-25**, panels B and D).

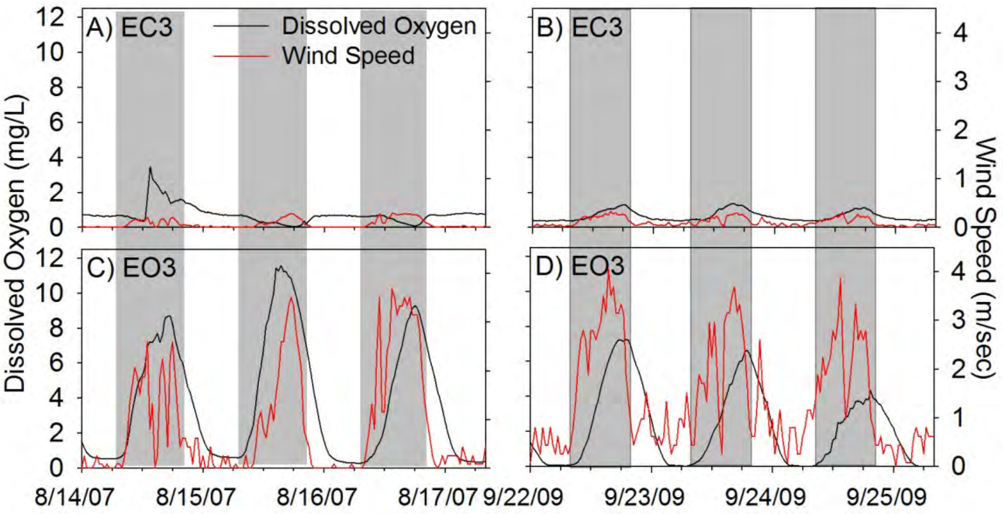

Figure 6-25. High-resolution (30-minute intervals) patterns of dissolved oxygen and wind speed at selected sites EC3 and EO3 for early (August 2007; panels A and C) and later (September 2009; panels B and D) periods of the Cattail Habitat Improvement Project (CHIP) measured using Hydrolab multiparameter sondes (Hach®). White and gray boxes indicate day and nighttime, respectively.

Treatment responses were generally more apparent in the floc compared to the soil layer. With greater aeration of open plots, and changes in microbial communities, increased decomposition was previously reported (Newman et al., 2010) and is evidenced by significant decreased carbon contents in open plots relative to controls. Throughout the study, TP and TN concentrations tended to be greater in the open plots relative to the controls. In general, there were no trends in nutrient contents within a treatment from the beginning to the end of the project (**Figure 6-26**).

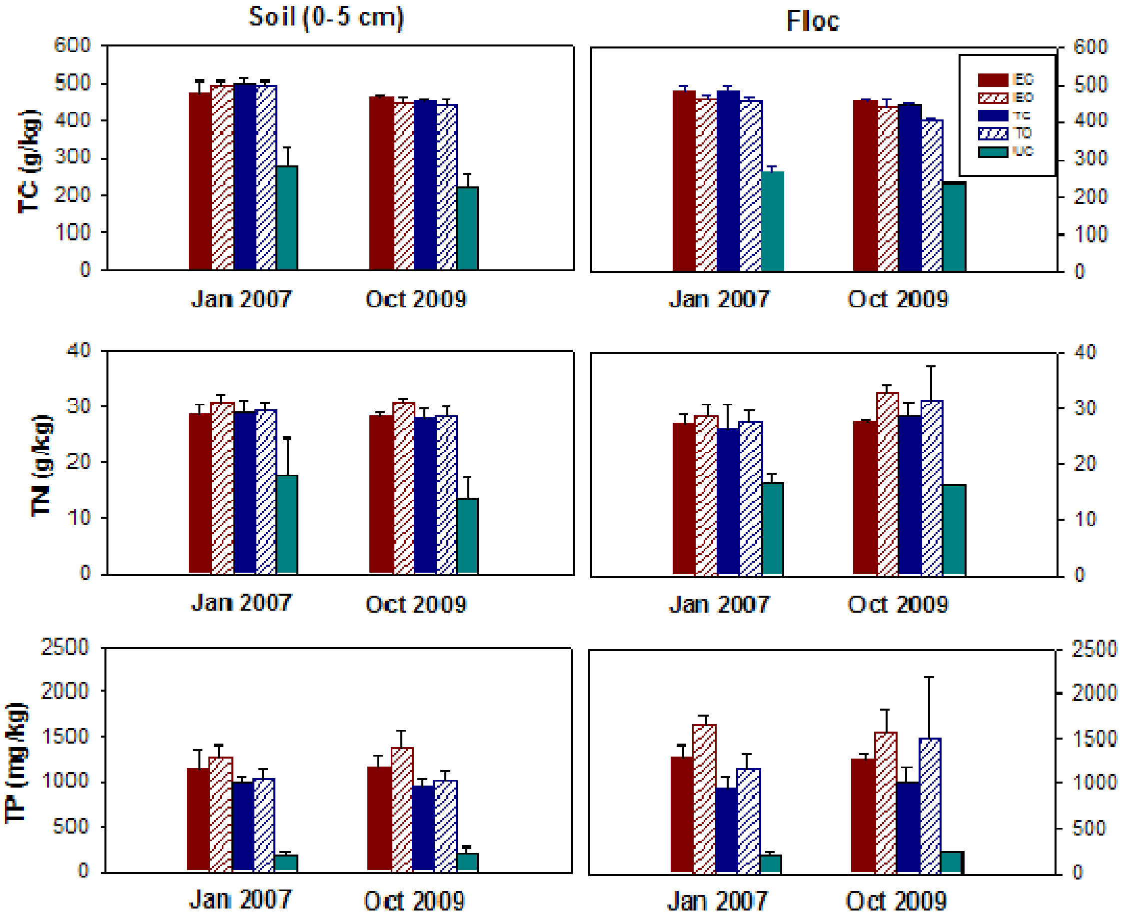

Figure 6-26. Mean (± S.D.) nutrient contents determined in surface soils (0-5 centimeters) and floc at the beginning (post-equilibration) and end of the project.

Live aboveground biomass was similar between controls in 2007 and 2009, averaging 960 and 890 grams per square meter (g/m^2) in enriched plots, and 685 and 736 g/m^2, in transition plots, respectively (**Figure 6-27**, panel A). The emergent macrophytes, cattail and sawgrass (*Cladium jamaicense*), comprised the majority of biomass. In contrast, biomass increased in open plots from < 5 g/m^2 in 2007 to > 520 g/m^2 in 2009, with the macroalga, *Chara* sp., comprising the majority of biomass. The effective switch from an emergent macrophyte to an SAV-dominated ecosystem was further evident by the sustained lack of live belowground biomass in the open plots (**Figure 6-27**, panel B).

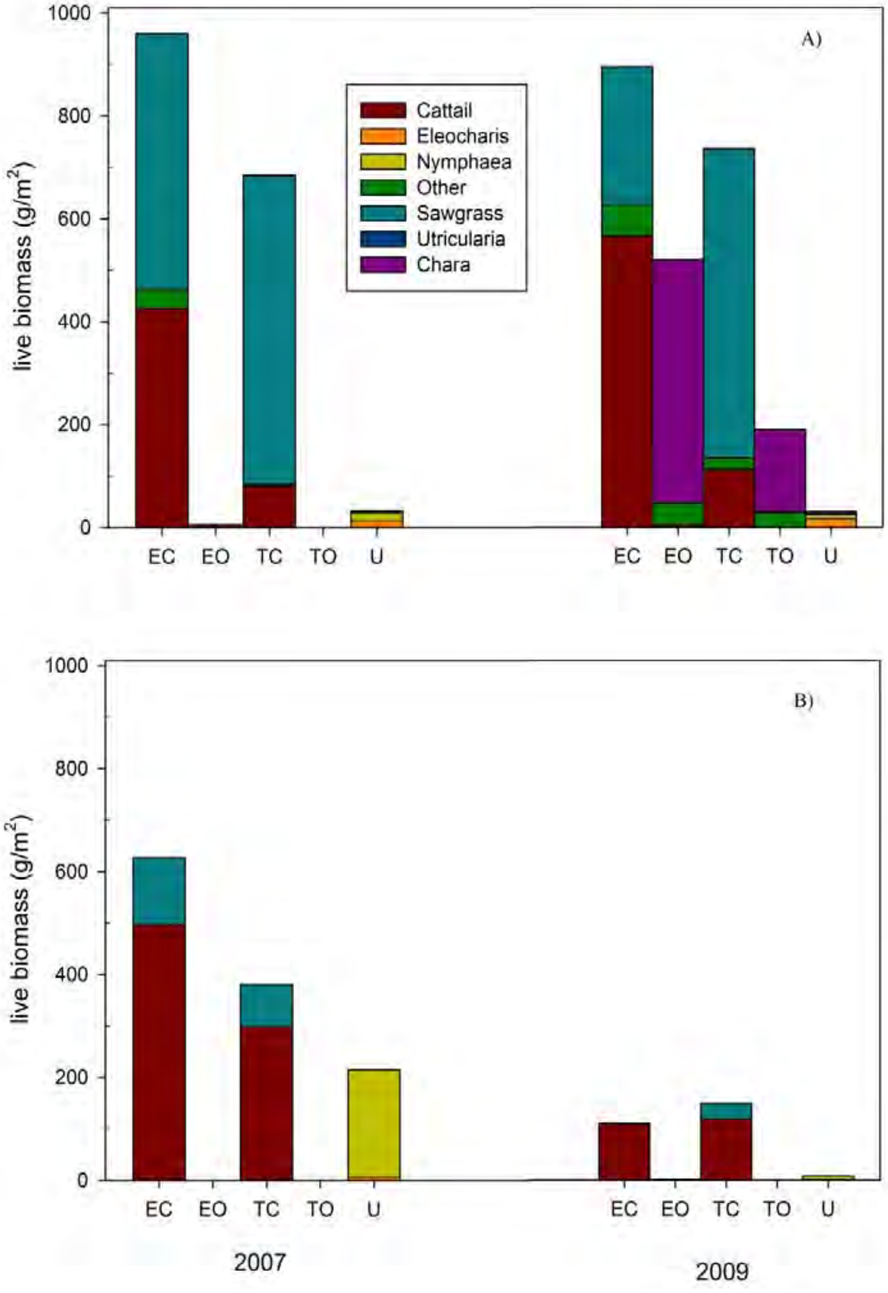

Figure 6-27. Average live aboveground (A) and belowground (B) biomass obtained in January 2007 and September 2009.

Recent aerial reconnaissance demonstrated the combined effectiveness of herbicide application followed by burning, and limited maintenance, in the creation of a potentially sustainable regime shift beneficial to wildlife (**Figure 6-28**).

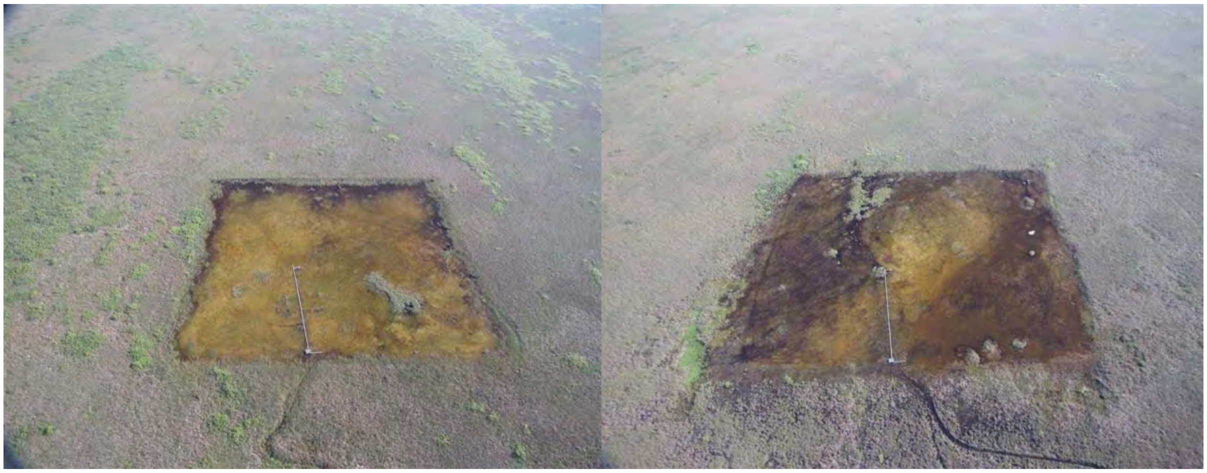

Figure 6-28. Aerial photographs of vegetation communities in open plots EO1 (right) and TO2 (left) in May 2010. Extensive brown areas are dense submerged aquatic vegetation (SAV), primarily *Chara* sp.; small grey-green patches are cattail (photos by the SFWMD).

Discussion

The combination of DO concentrations, floc and soil nutrient content, and macrophyte species composition support the hypothesis that biogeochemical cycling is different between open and control plots. More importantly, similarity between 2007 and 2009, as well as 2008 (Newman et al., 2010), indicate the relative stability of this shift. Furthermore, the most recent aerial photography (**Figure 6-28**) clearly shows that for over 925 days since the last herbicide application, and 1,406 days since the burn, this alternative regime has been sustained in an otherwise cattail-dominated region of the Everglades. Reestablishment of cattail within the six open plots is patchy, ranging < 5–30 percent cover. It is likely that with no further maintenance, the plots will ultimately revert back to emergent marshes; however, high soil phosphorus content and recruitment from the surrounding cattail stands makes the time frame for this reconversion unknown. Although reductions in surface water and soil phosphorus levels were not observed over the four-year study period, this is not unexpected, given that the regime was in its infancy. However, with minimal further active management, these plots could be sustained and dramatic shifts in phosphorus storage would likely be observed.

Relevance to Water Management

In previous SFERs, high fish biomass and extensive use of the open plots by foraging wading birds were documented. This most recent study shows that these created openings are sustainable in the short-term and, with relatively minimal effort and cost, could be sustained in the long-term. Densely vegetated areas tend to be located in high-nutrient areas, which have higher elevations due to greater peat accretion. These areas are also in close association with inflow structures. As a result, they tend to be rewetted sooner and have shallower conditions than downstream ridge-and-slough areas. This has significant ramifications for wildlife in the Everglades, by providing an effective habitat to encourage and sustain early foraging and, hence, breeding, as well as serving as habitat buffers to mitigate the effects of hydrologic reversals. For example, increased wood stork numbers is a critical CERP performance measure; however, key factors limiting successful wood stork reproduction are the delayed onset of breeding and nest abandonment during reversals. Implementing CHIP at a larger scale might provide both operational flexibility and significant environmental benefits in a region where currently none exist.

USING PLANT FOSSIL SEEDS TO DETERMINE HISTORIC HYDROLOGIC REGIMES

Key goals for CERP include the restoration of ecosystem attributes that typify the predrainage Everglades ridge-and-slough landscape. To accomplish these goals, it is vital to have accurate predrainage hydrologic and vegetation targets. Paleoecological analyses of Everglades soil cores (e.g., Winkler et al., 2001; Bernhardt and Willard, 2009) use fossil pollen, diatoms, seeds, and other proxies to quantify vegetation changes, and by inference the hydrologic conditions resulting from modern water management. Paleoecological data are often required to answer these questions because the quantifiable period of record is not long enough.

Paleoecological studies also provide information about ecosystem responses to natural climate change (Cronin et al., 2002; Willard et al., 2002). The interdependence of climate patterns across large distances (thousands of kilometers) is known as a “teleconnection.” One important teleconnection for South Florida climate is the control of dry season rainfall in South Florida by the El Niño-Southern Oscillation (ENSO; see Chapter 2 of this volume). This teleconnection is known to impact Everglades ecosystem functions, such as fire frequency and severity (Beckage et al., 2003). Because minimum water level criteria (MFLs) for the Everglades are established to protect peat-forming wetland soils from fire oxidation, improved knowledge about climate teleconnections and their impacts on natural fire regimes will ultimately benefit the ongoing development and review of MFLs. By examining time periods from several centuries to millennia, paleoecological studies provide longer-term datasets for more rigorously quantifying linkages between Everglades climate (and ecosystem responses) and global climate drivers. Donders et al. (2005), for instance, have proposed a link between South Florida climate and increasing ENSO intensity over the late Holocene (the last 6,000 years), corroborating results from central Florida and generally the eastern Atlantic Coast (e.g., Watts, 1971). Several researchers suggested that broad links existed between the South Florida climate with periodic southward migrations of the Intertropical Convergence Zone (ITCZ) starting approximately 4,000 years ago (4 ka) to present (Winkler et al., 2001; Gleason and Stone, 1994). Southward migrations of the ITCZ signify reduced rainfall in the Caribbean region (Haug et al., 2001).

For the current study, an analysis of soil macrofossils (mainly seeds and plant fragments) from Everglades ridge-and-slough cores to quantify millennial-scale Everglades ecosystem responses to climate drivers was used. The central hypothesis is that Everglades paleohydrologic regimes are a result of teleconnections with both Atlantic and Pacific climate indices including ENSO, the Pacific Decadal Oscillation (PDO), Atlantic Multi-decadal Oscillation (AMO), and Intertropical Convergence Zone (ITCZ). It was hypothesized that from 5 ka to present, increasing ENSO intensity has generally resulted in increasing Everglades slough and decreasing Everglades ridge vegetation. It was hypothesized that drying events associated with more extreme southern migrations in the ITCZ generated a temporary expansion of sawgrass ridges into deeper sloughs, mirroring modern examples due to drainage in the ENP and elsewhere. Relationships of Everglades vegetation with AMO, however, is not examined here, given that the best available data for past AMO cycles is < 500 years and the temporal resolution of soil cores is too poor.

Methods

Modified piston-corers 10 cm in diameter were used to collect soil cores to bedrock or a maximum of 1 m depth in adjacent sawgrass ridges and sloughs. Study sites (**Figure 6-29**) spanned the central flow path of historic Shark River Slough, from the most upstream region (site

WCA3B), to the northeast and central portions of Shark River Slough (sites NESRS1 and SRS-2), and downstream in southwest Shark River Slough at Rookery Branch (site SRS-3), the latter three sites in the ENP (sites SRS-4, 5, and 6).

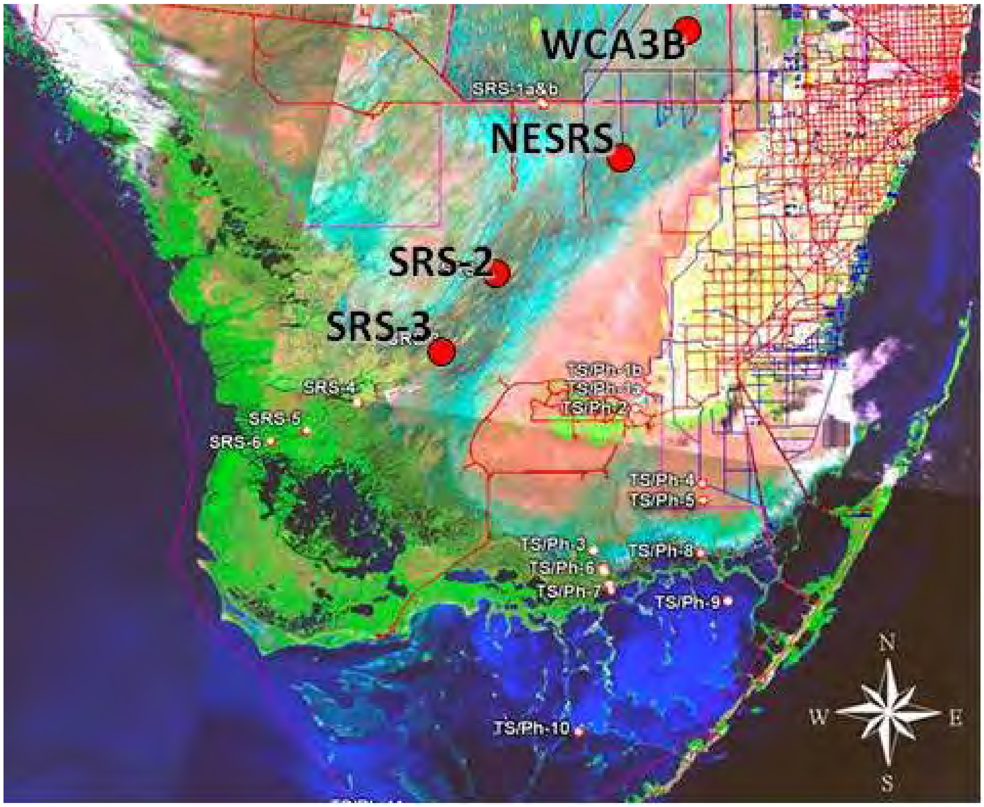

Figure 6-29. Location of coring sites along the historic flow path of Shark River Slough.

Deep cores were analyzed for radiometric dating, bulk density, macrofossils, and in one case, charcoal (SRS-3). Cores were extruded in the lab at 1-cm intervals, and then subsampled for radiometric analysis, bulk density, macrofossils, and charcoal. All soil intervals were accompanied by a stratigraphic description to provide additional context for paleovegetation chronologies.

Macrofossil analyses involved washing soil samples with 1 mm, 500 micrometer (µm), and 63 µm screens. Preliminary analyses showed particles collected in the 1 mm and 500 µm mesh sieves contained abundant and identifiable (under 30X magnification) seeds and seed fragments and other identifiable macrofossils (shells, arthropod exoskeletons, and characteristic plant leaf or root tissues). In the 63 µm size class, particles consisted of fragments that were unidentifiable and not analyzed further. Fossil seeds were identified based on the characteristics of seeds from live plants collected in the field and from fossil seeds collected from surficial soils (0–4 cm) from calibration studies, as described in Saunders et al. (2008). For Accelerated Mass Spectroscopy (AMS) dating of seeds, depths where seed abundance was relatively high were selected. In some cases, seeds were composited over 2–3 cm intervals to obtain the minimum mass required for AMS dating (2–5 mg dry weight). Seeds were carefully recovered from selected soil samples, extracted with forceps, and cleaned with three rinses of deionized water to reduce contaminating carbon sources.

Both lead^{210} (210Pb) and carbon^{14} (14C) data were used to generate soil age models that covered the entire time span (from ~5 ka to present) of each core. Radiometric 14C dates were obtained from bulk soil and 14C-AMS dates were obtained for fossil seeds. A standard acid/alkali pre-treatment of soil and seeds (except 1 marl sample in an NESRS sawgrass core) were performed prior to analysis; all radiometric and AMS analyses were performed by Beta Analytic, Inc. (Miami, FL). Carbon^{14} ages were converted from radiocarbon years to calibrated years before present. Radiometric analyses of soil using 210Pb and cesium^{137} (137Cs) was employed for dating the last 100 years. Lead^{210} profiles of ridge-and-slough cores were analyzed with a Constant Rate of Supply (CRS) model (Appleby and Oldfield, 1978). The CRS model was used instead of assuming a constant accretion rate because hydrologic changes over the past century likely caused accretion rates to vary over this time period (Bernhardt and Willard, 2009). First-order errors of age calculations for the CRS model followed the method detailed in Binford (1990). A locally weighted regression function was used to generate soil age models for all cores, based on age estimates from all available 210Pb, 137Cs, and 14C data (Lynch et al., 2004). This regression incorporates both the mean and 95 percent confidence intervals for each age. In the case of the 14C ages, however, the median probability age was used in place of the mean value, which is more sensitive to potential outliers portions of the 95 percent confidence interval of the calibrated 14C age.

Macrofossil-based vegetation chronologies were compared with paleoclimate proxies for ITCZ and ENSO. While AMO and PDO climate events influence on Everglades dynamics are possible, only the ITCZ and ENSO climate proxies have existing paleorecords that are long enough (> 5,000 years) for comparing century-scale variability.

Results

Soil age models and paleoecological evidence collected thus far indicate substantial changes in the vegetation, fire regime, and possibly accretion that occurred during the time interval of 4–3 ka. In general, soil age models (**Figure 6-30**) indicated the greatest temporal resolution in the top- and bottom-most layers of the cores, corresponding to the last 200 years and from ~3.0–5.0 ka, respectively. A linear interpolation based on a single 14C date of 2014 +/-150 at 23 centimeters was used to provide an approximate age model for SRS-2.

Macrofossil evidence completed thus far on three cores (**Figure 6-31**) shows that at both WCA-3B and NE-SRS, a ridge-and-slough landscape was dominant prior to 4 ka, as inferred from abundant water lily (*Nymphaea* spp.) seeds with intermittent intervals of sawgrass. The sharpest vegetation changes after 4 ka are observed in the NESRS slough core. Starting at 3.8 ka, the ridge-and-slough landscape was replaced by a charophyte-dominated landscape; the change occurring within the span of about 80 years. Peak charophyte oospore concentrations were observed at roughly 300–400 year intervals: 3.7 ka, 3.3 ka, and 2.9 ka. Although the time resolution between 2.9 ka to ~0.5 ka is too coarse to indicate additional peaks, the high abundance of charophytes continued until the most recent centuries (~0.2 ka). The short core from SRS-2 also indicated high charophyte abundance since at least 2 ka. The NESRS core also showed that water lily increased after ~2 ka, indicating a return to wetter conditions. At WCA3B, water lily seed concentrations were reduced after 3.5 ka, indicating a shift to drier conditions, but generally, vegetation changes were less striking than at NESRS.

Although the SRS-3 sawgrass core only covered ~3.5 ka through present, the macrofossil and charcoal evidence is consistent in showing alternating environmental conditions between 3.5 ka to 2 ka, spaced at ~300–400 year intervals. Peak concentrations of sawgrass seeds occurred at 3.1 ka, 2.7 ka, 2.3 ka, and the most notable charcoal peaks were observed at 3.5, 3.1, and 2.7 ka. After 2.0 ka, increased water lily and reduced baseline charcoal accumulation indicate a return to wetter conditions. Charcoal peaks still occurred after 2.0 ka, although at longer (~600–700 year) intervals: 2.0, 1.3, and 0.7 ka.

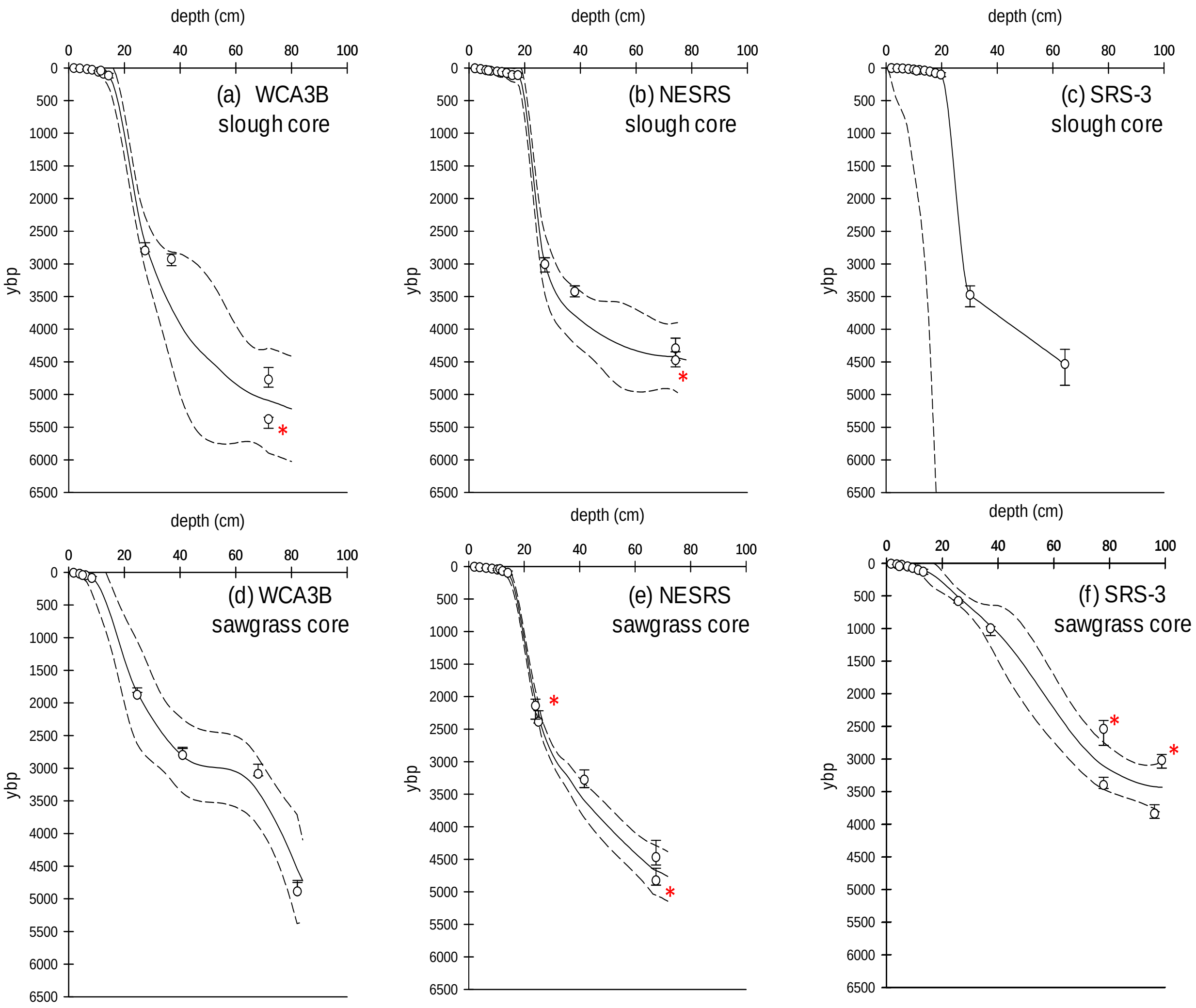

Figure 6-30. Soil age models constructed for sawgrass and slough cores from sites WCA3B, NESRS, and SRS-3. Models (solid line: mean; dashed lines: 95 percent confidence intervals) are weighted regressions based on average age and 95 percent confidence intervals of radiometric dates (white circles) including lead^{210} (210Pb) (constant flux model), depth of carbon^{137} (137C) peak concentration, and carbon^{14} (14C) dates of bulk soil and fossil seeds (the latter indicated with red asterisks).

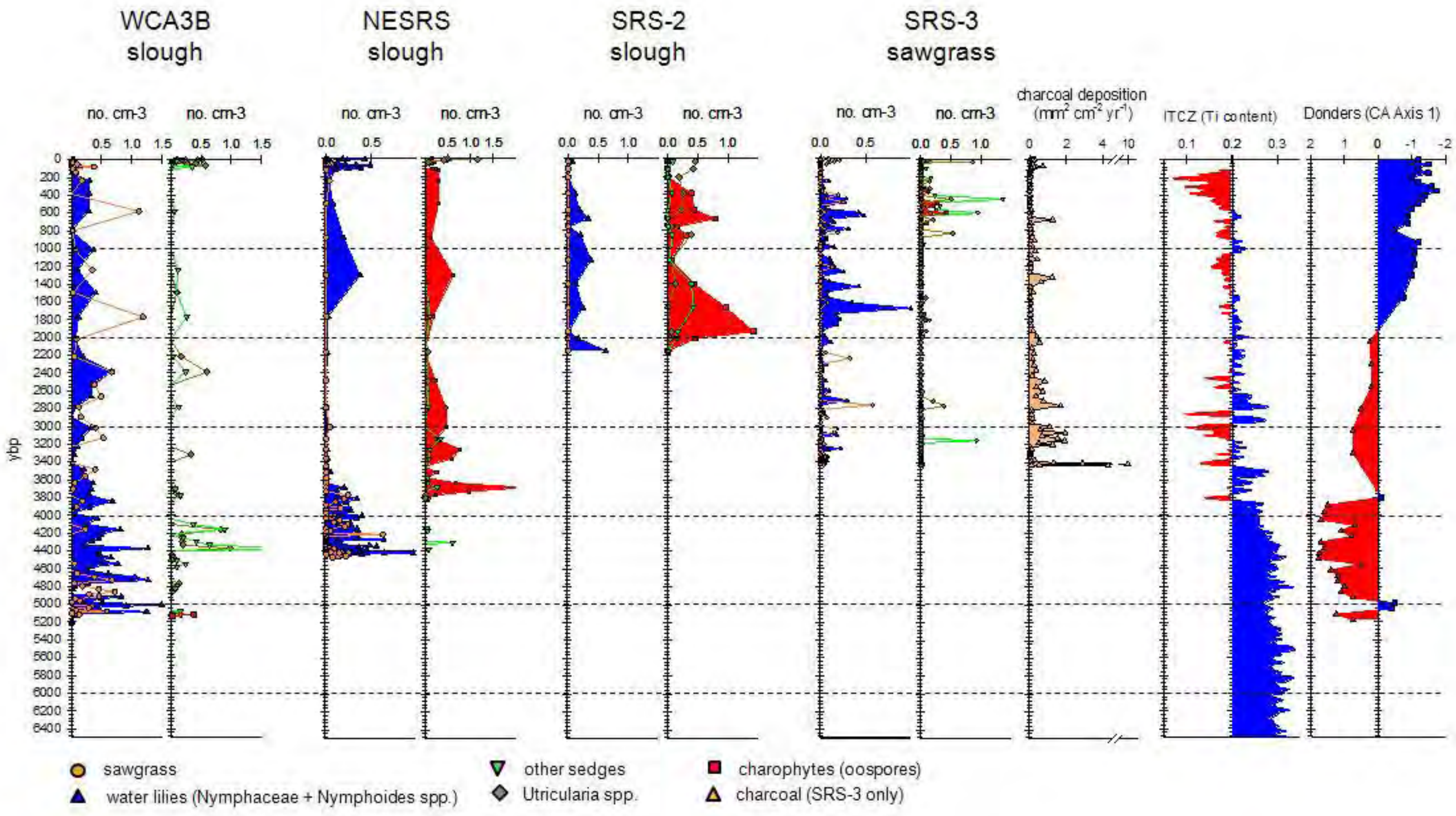

Figure 6-31. Changes in vegetation and fire regimes over the past 5,000 years as inferred from profiles of fossil seed/spore concentrations (all sites) and charcoal deposition (SRS-3 only), respectively. Paleoclimate indices from the Cariaco Basin (proxy for ITCZ position, Haug et al., 2001) and Fakahatchee Strand (CA Axis 1 from Donders et al., 2005) are shown on the right for comparison with paleovegetation and fire regime changes. Coloration of climate-indices from the Cariaco Basin and Fakahatchee Strand are used to indicate drier (red) versus wetter (blue) conditions for the Caribbean region and South Florida, respectively.

Discussion

Between 4,000 and 3,000 years ago, major ecosystem changes occurred across the historic Shark River Slough landscape. At ~3.8 ka, in what is now northeast Shark River Slough, there is evidence of an ancient charophyte landscape that effectively replaced (within ~80 years) the ridge-and-slough landscape. This coincided with periods of increased fire activity in the southwestern part of the region. Previous paleostudies indicate that drier conditions occurred across the Everglades starting at 3 ka, interrupted by a wet period from 2 ka to 1 ka (Altschuler et al., 1983; Gleason and Stone, 1994). The latter findings are based on dates associated with marl embedded in peats; the current results suggest that changes were likely under way several centuries prior to the switch from peat to marl accumulation.

Major shifts in climate over the past 10,000 years in the southeastern U.S. and Caribbean regions, influenced by Atlantic and Pacific climate drivers (Hoddell et al., 1991; Rodbell et al., 1999; Haug et al., 2001; Donders et al., 2005), have been proposed to broadly underlie the dry periods inferred from Everglades paleoecological data (Winkler et al., 2001; Bernhardt and Willard, 2009). Willard et al. (2002) proposed that widespread droughts in the Caribbean region, corresponding to southward ITCZ shifts, influenced tree island development in the Everglades over the last 2,000 years. Current results lend further support that this link applies to the southward shifts in the ITCZ prior to 2 ka. While our examination of the correspondence between Everglades paleoecological variables and climate proxies is still in the preliminary stages, periodic increases in fire activity (3.5 ka, 3.1 ka, and 2.7 ka) and charophyte abundance (3.7 ka, 3.3 ka, and 2.9 ka) suggest a similar periodicity with the timing of southward shifts in the ITCZ at 3.8 ka, 3.4 ka, 3.0 ka, and 2.8 ka as noted by Haug et al. (2001) (**Figure 6-31**). More refined soil-age models will confirm whether Everglades shifts have been in phase with the ITCZ migrations; however, increased fires and reduced water lily abundance over the 3.8–2 ka period suggest dry conditions in the circum-Caribbean region during southern ITCZ migrations (Haug et al., 2001; Hodell et al., 1991; Higuera-Gundy, 1999) and also hold true for the Everglades.

This study adds to a growing body of literature linking Everglades vegetation and hydrology to regional climate drivers; however, discrepancies remain. For instance, along the west coast of South Florida (Fakahatchee Strand), soil cores show a nearly monotonic shift from pine to bald cypress forest over the past 4.5 ka (**Figure 6-31**). This evidence points to the influence of a steadily strengthening ENSO over the past 5,000 years (Rodbell et al., 1999; Riedinger et al., 2002), effectively increasing dry season rainfall in South Florida (Beckage et al., 2003). An increasing influence of the El Niño phenomenon explains the general trend toward wetter conditions after 2 ka in the current study as well; thus a lessening influence of southward ITCZ shifts. Nonetheless, the strong periods of dry conditions between 3.8–2 ka in the Everglades appears to be in opposition to the hydrologic trajectories inferred strictly from El Niño patterns and the Fakahatchee Strand data (**Figure 6-27**). A study in the *Climate Gradients Across South Florida* section of this chapter demonstrated that there are spatial gradients in the strength of ENSO teleconnections within the South Florida climate. The finding that ENSO more strongly and significantly influences dry season rainfall in the west (nearer Fakahatchee) but not to the east (i.e., Everglades) may reconcile the two lines of paleoecological evidence.

Conclusions

The paleoecological data from Shark River Slough, though preliminary, point to global and regional climate drivers as governing local hydrologic regimes, and thus ecosystem dynamics, in the Everglades. The influence of strengthened ENSO events after 2 ka agrees with generally wetter conditions indicated by the macrofossil and charcoal data. However, that the system also experienced periodic drying from 3.8 to 2.0 ka suggests the importance of southward shifts in the ITCZ in influencing the South Florida climate. While it is intuitive that fire patterns are linked with drier climate, these data strengthen the link between ancient (multi-century to millennial-scale) Everglades fire regimes and paleoclimate drivers. Additionally, as these data suggest, this natural climate variability can effectively change a ridge-and-slough landscape to a charophyte landscape. This change is unprecedented in the modern record, can persist for several centuries to multiple millennia, and can establish within a human lifetime (~80 years).

Relevance to Water Management

A key goal of CERP is to restore the predrainage structure and functioning of the ridge-and-slough landscape. Paleoecological data benefit CERP efforts by refining the picture of the predrainage ridge-and-slough landscape. Continued efforts are aimed at quantifying ridge-and-slough landscape responses to past climate variation, both as a prologue for expectations about the pace of recovery of the current degraded system, and also for understanding the potential range of responses to natural climate variation, including ecological surprises such as the widespread replacement of the ridge-and-slough landscape with the ancient charophyte landscape. Charophytes have been proposed as alternative, stable states in lakes (van Nes et al., 2002), in part due to high spore production and germination rates, and dense propagule banks (Bonis and Grillas, 2002). Dense *Chara* spore-banks observed in the cores sampled here could have contributed to the long-term persistence of the ancient charophyte landscape in Shark River Slough.

Data indicate that the loss of the ancient charophyte landscape in NESRS occurred as recently as the late 19th century, and may have implications for altered ecosystem structure and function. Charophytes are known to be the preferred food source of herbivorous wading birds in Lake Veluwemeer (the Netherlands) (Noordhuis et al., 2002), and they support higher densities of invertebrates than other macrophytes (Hargeby et al., 1994). The potential of charophytes to preferentially support secondary producers in the freshwater Everglades is unknown at this time; however, the implications for altering nutrient cycling, aquatic foodwebs, and higher trophic levels (and CERP restoration success) may be of interest for future studies. It is notable that the key findings of the CHIP experiment included a rapid rise and sustained dominance of charophytes as a result of large-scale vegetation disturbances. Such observations represent the first documented example of a charophyte-dominated Everglades landscape and could provide an opportunity to further understand the triggers, internal feedbacks and resilience, and trophic implications of the ancient charophyte landscape observed in NESRS.

Understanding teleconnections between South Florida climate and global drivers such as ENSO, ITCZ, and the AMO can be used to help water managers better anticipate droughts or flooding associated with climate cycles (Abtew and Trimble, 2010). The analyses of paleoecological data gathered here are being used to improve the District’s understanding of linkages between climate drivers from multi-century cycles. Despite the long-term periods of these cycles, these cycles may have had dramatic effects on local climate and ecosystem responses, including fire regimes. Minimum water level criteria for the Everglades are based on protecting the peat-forming wetland soils from fire oxidation. Given the direct impact of ENSO-related dry periods on fire frequency and severity in the ridge-and-slough landscape (Beckage et al., 2003), knowledge of climate teleconnections and their impacts on fire regimes provides a potentially important source of information to help guide District mandates such as MFLs.

LANDSCAPE PROCESSES

Ken Rutchey, Binhe Gu, LeRoy Rodgers, Ted Schall,
Sharon Ewe[2], Jennifer Vega[2] and Yuncong Li[14]

Tree island research and mapping activities continued with the characterization of "ghost" tree islands in WCA-2A and the mapping and analysis of tree island and vegetation changes in WCA-3. In addition, the application of a technique for mapping exotic plant invasions is described.

TREE ISLANDS IN WATER CONSERVATION AREA 2A: MICROTOPOGRAPHY AND VEGETATION PATTERNS

Tree islands serve as critical habitat for wildlife (Hoffman et al., 1994) and as potential nutrients sinks (Orem et al., 2002). These functions, however, have likely been compromised because up to 60 percent of tree islands that once existed in the 1940s have disappeared (Patterson and Finck, 1999). Water management practices in the 20th century altered the plant community and the size of the tree islands in the Everglades (Willard et al., 2006). Moreover, a considerable number of tree islands in WCA-3 and WCA-2 have been converted to marsh due to changes in water depth and hydroperiod (Patterson et al., 1999; Sklar and van der Valk, 2002). Of current Everglades regions, tree islands in WCA-2A have suffered the most damage; over 95 percent of the original tree islands have disappeared (Hofmockel et al., 2008).

Tree islands that have lost elevation and most of their woody vegetation are called ghost tree islands. Ghost tree islands have disappeared from the landscape horizon and can be located only as scars seen in aerial photographs. Very little information is available on the physical, chemical and biological changes these tree islands have undergone since their state change. One of the goals of this work was to determine the current status of these islands. Specifically, this work was to (1) identify the patterns of peat and bedrock microtopography between the island and surrounding marsh; (2) assess the differences in soil bulk density between and within the ghost islands using short (0-30 cm) and long (0-60 cm) soil cores; and (3) determine vegetation species composition and coverage across and within islands across the landscape. This information is needed before successful restoration plans can be implemented.

Methods

Site Selection

Ten tree islands distributed from north to south within WCA-2A and representing a broad range of sizes (35 x 10^3 m^2 to 1,750 x 10^3 m^2) and hydrologic regimes were selected for this study (**Figure 6-32**). Eight ghost islands, one live island, and a transitional island were sampled. Islands in the south have a longer and deeper flooding regime compared to islands in northern WCA-2A.

Microtopography (Soil and Depth to Bedrock)

Microtopography was assessed along multiple transects, extending from the marsh on the east and the west of each island. Soil surface elevation was measured using a sounding rod at 10 m intervals along the transects. Depth to bedrock was assessed using a stainless steel probing rod at

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20 m intervals along transects. Peat depth was calculated from the difference between peat and bedrock measurements.

Soil Core and Bulk Density

Fifteen short soil cores (30 cm) were collected in east-west transects across the head, mid-island, and near tail of each island. On each of the three east-west transects, cores were collected both from the island and from the surrounding marsh. Upon return from the field, short soil core samples were sectioned at intervals of 2.5 cm for the top 10 cm soil and 5 cm for the bottom 20 cm soil. Wet and dry weights were used to calculate bulk density.

Vegetation Structure and Composition

Vegetation structure was assessed at two levels on each island. The first assessment (primary level) was meant to be a coarse, rapid-level evaluation of the island as seen from the airboat. The secondary assessment (secondary level) was a more detailed measure of vegetation structure using similar protocols to the invasive exotics survey currently being conducted in WCA-3 (see the *Tree Island Lygodium Habitat Suitability Analysis* section of this chapter).

Microtopography

Peat depth in the island and surrounding sloughs ranged from 1–2 m for all the islands; the shallowest soils were observed at 2A-14-2 (1.29 m), 2A-15-6 (1.33 m), and 2A-12-6 (1.38 m) while the deepest soils were encountered at 2A-22-28 (2.00 m) and 2A-22-27 (1.99 m). Soils in the north also tended to be deeper than in the south (**Table 6-9** and **Figure 6-32**). Peat topographic variability was greater within the head of the island relative to the mid-island or near-tail transects (**Table 6-9**). For each transect on an island, peat depth from the slough to the highest point ranged from 106 cm at the head of 2A-15-6 to 12 cm at the near tail of 2A-14-2.

Since impoundment, the hydrology in WCA-2A has experienced a high degree of variability, with a tendency for high water depth in the southern region. Islands in the northern part of WCA-2A do not encounter the extreme seasonal changes in water level and have had shorter hydroperiods and flooding levels than in the southern portion of WCA-2A. With higher peat depth and greater tree survival, the less severely impaired live tree islands in the northern region are likely the reflection of more appropriate hydrology. The shallower peat depth in tree islands of the southern region may be explained by a slower soil accumulation rate due to the loss of vegetation under extreme hydrological conditions.

The maximum bedrock depth was observed at the head of 2A-11-1 (3.10 m) while the shallowest peat depth was observed at 2A-12-6 (10 cm at the near tail). There did not appear to be a landscape-scale pattern of island formation as there was neither a pattern of bedrock formation within the head of the islands (i.e., pinnacle rock, flat surface, or depression) nor a clear pattern in the landscape-scale distribution of these island types within WCA-2A (**Figure 6-32**). Five of the islands appear to have developed over pinnacle rock at the head while four islands appear to be over a flat bedrock surface. One island (2A-14-2) appears to have developed within a bedrock depression (**Figure 6-32**). On some of the islands, the pinnacle rock extends up to a meter in height from the surrounding bedrock; however, on 2A-14-2, the bedrock depression is only approximately 30 cm deep (Ecology and Environment, Inc., 2009).

The greater elevational differences observed between the island and slough for the head relative to the mid-island and near tail of the southern islands (**Table 6-10**) is potentially a function of the hydrologic conditions of the southern half of the WCA-2A landscape; heads of the southern islands had overall deeper peat relative to mid-island and near tails (**Table 6-10**). Although some of the northern islands showed evidence of fire (i.e., fires scars visible from SFWMD imagery, 2009), peat depths were significantly greater in this area and island-slough differences were reduced. These findings indicate that it is possible that the sloughs in northern WCA-2A, despite being burned and exposed to shorter hydroperiods, have had higher rates of peat production and filling in relative to the tree islands. This finding is further supported by anecdotal evidence of woody species [i.e., willow (*Salix caroliniana*) and wax myrtle (*Morella cerifera*)] growing beyond the historical boundaries of the ghost islands, invading the surrounding marsh. Thus, the shorter hydroperiod sloughs in northern WCA-2A might be undergoing transition to a drier state.

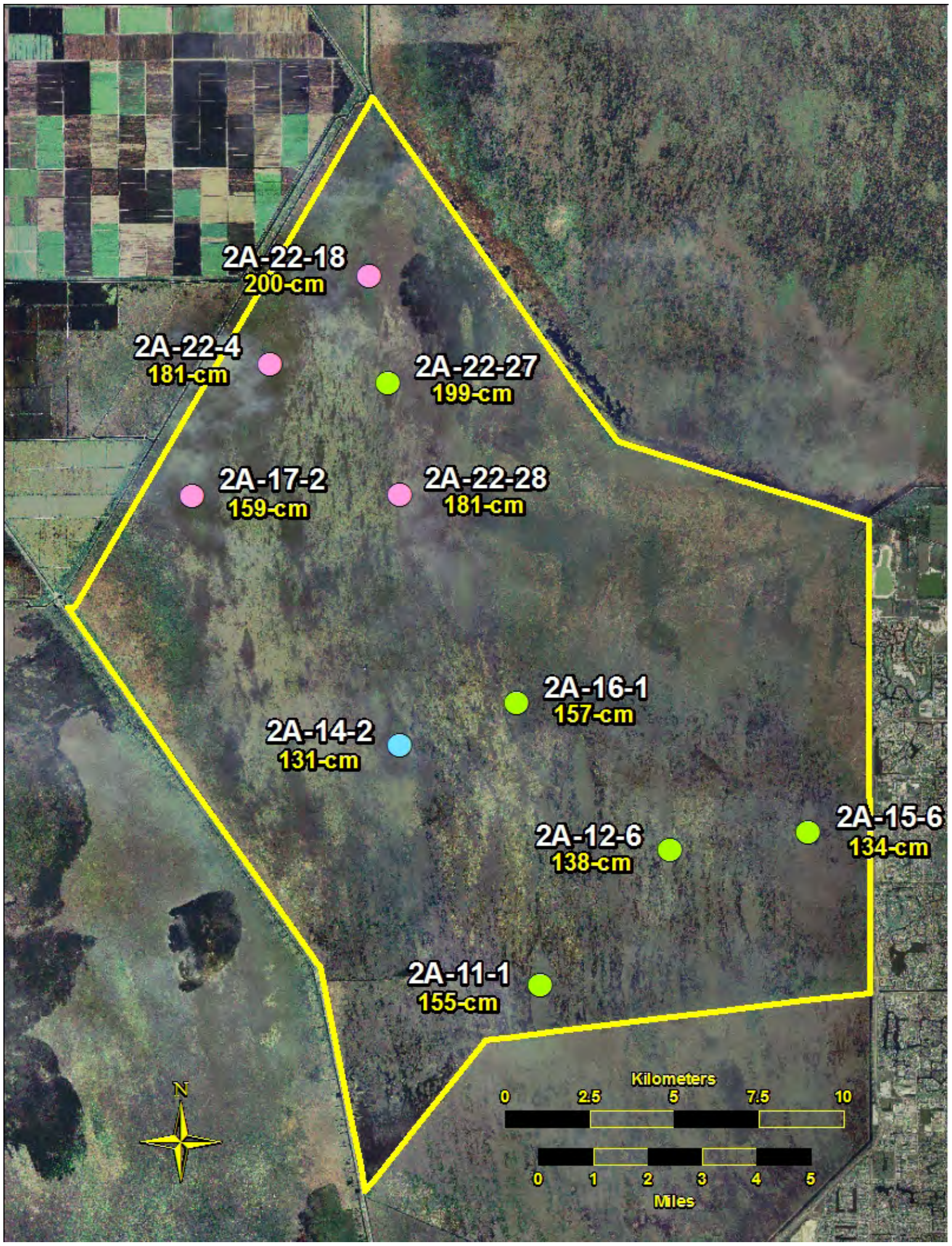


Figure 6-32. Tree islands sampled in WCA-2A. One live island (2A-22-18), one severely degraded (transitional) island (2A-22-4), and eight ghost islands were sampled. Average peat depth around and each island is shown below the island name. Five islands had pinnacle rock over the head (green), one island head was in a depression (blue), and four islands heads were over a flat bedrock surface (pink).

Table 6-9. Peat depth characteristics in 10 tree islands from WCA-2A. Average (Avg) depth and the standard deviation (σ) are also presented.

Tree Island	Location	Peat Depth (cm) Min	Max	Avg	σ	Tree Island	Location	Peat Depth (cm) Min	Max	Avg	σ
2A-11-1	Head	118	310	208	72	2A-17-2	Head	128	231	149	22
	Mid	93	268	156	61		Mid	117	191	151	18
	Near tail	104	188	145	25		Near tail	112	220	167	24
2A-12-6	Head	49	192	139	37	2A-22-4	Head	108	230	195	26
	Mid	103	180	131	25		Mid	142	210	183	17
	Near tail	10	242	144	50		Near tail	145	209	175	15
2A-14-2	Head	89	214	128	34	2A-22-18	Head	180	228	195	13
	Mid	91	172	120	22		Mid	168	240	204	17
	Near tail	108	177	139	18		Near tail	151	264	201	24
2A-15-6	Head	63	254	129	43	2A-22-27	Head	114	247	187	28
	Mid	99	213	138	28		Mid	183	240	213	18
	Near tail	95	202	133	27		Near tail	167	227	197	15
2A-16-1	Head	85	200	139	32	2A-22-28	Head	167	209	179	17
	Mid	123	270	164	40		Mid	133	207	178	21
	Near tail	66	310	169	65		Near tail	146	216	185	20

Table 6-10. Differences in island-slough water depths for the 10 islands from south to north. Regardless of type (i.e., live or ghost), islands were classified as either being in the northern or southern half of WCA-2A for analysis. Greater values indicate a larger difference between average island elevations relative to average slough depths.

Island	Location Classification	Average Island-Slough Difference (cm) Head	Middle	Near tail
2A-11-1	South	27	17	10
2A-12-6	South	28	14	15
2A-14-2	South	17	8	2
2A-15-6	South	27	19	14
2A-16-1	South	20	11	16
2A-17-2	North	11	9	6
2A-22-4	North	6	5	6
2A-22-18	North	6	11	8
2A-22-27	North	3	6	5
2A-22-28	North	9	10	4

Soil Bulk Density Patterns

Average soil bulk density of the ghost islands in grams per cubic centimeter (0.10 ± 0.01 g/cm^3) was similar to the surrounding slough (0.08 ± 0.01 g/cm^3), which were similar to Newman et al. (1997) who found that bulk density of the marsh in WCA-1 (0–20 cm) was approximately 0.06 g/cm^3. Bulk density from the ghost islands, however, was significantly lower than live tree islands in WCA-3A (0.3–0.6 g/cm^3) (Coronado-Molina et al., SFWMD, unpublished data). Low bulk density on these ghost tree islands relative to the live islands likely indicates reduced structure and function. Vegetation on mid-islands and near tails was primarily dominated by sawgrass, an observation reflected by lowered bulk densities and values similar to marsh samples.

Vegetation Patterns

Tree island vegetation patterns are an indication of tree island ecosystem health (**Table 6-11**). In general, canopy cover and height were highest on the heads of these islands, and decreased toward the near tails. Lowered canopy heights at the middle and near tails of the islands were due to presence of sawgrass and the limited number of woody species at these sites.

Most of the islands had very limited woody vegetation at the mid- and near-tail transects. The most common species was sawgrass as a canopy and herbaceous species. The dominant woody species on the islands was willow, followed by wax myrtle. Leather fern (*Acrostichum danaeifolium)* and cattail were observed on a few islands but were not dominant. The middle transects of the live and transitional islands had woody species, but the plants were sparse and had limited cover. The near tails of these islands were similar to the ghost islands and dominated by sawgrass.

The absence of other woody species within the tree islands and the dominance of sawgrass was an indication of the depauperate nature of the ghost islands. The smallest island in this survey, 2A-22-27, had no canopy but instead consisted of short wax myrtles (< 2 m) and sawgrass. These patterns are indicative of either shrub re-invasion into a previously wooded island or the continued degradation and loss of the original vegetation on this island.

In the living (2A-22-18) and transitional (2A-22-4) islands, woody vegetation at the near tails has been replaced by sawgrass while the middle and head of the islands appear to be more sparse than previously observed in 1940 imagery (SFWMD, unpublished photos). There was also a species composition shift from dahoon holly (*Ilex cassine*) to willow at the head of 2A-22-18, with a loss of vegetation cover and shift to sawgrass toward the near tail of the island. These observations confirm the slow degradation and concurrent shift from a more upland vegetation type (i.e., dominated by dahoon holly) to more flood-tolerant monospecific canopy of willow.

Table 6-11. Canopy and herbaceous species height range, cover, and average height for the heads, mid and near tails of all the islands measured. Values followed by the same superscript do not differ at the $p < 0.05$ level.

	Canopy			**Herbaceous**		
	Height Range (m)	**% Cover**	**Height (m)**	**Height Range (m)**	**% Cover**	**Height (m)**
Head	0.0 – 6.2	25.3 ± 3.1^a	2.7 ± 0.3^a	0.0 – 1.8	35.0 ± 4.1	1.0 ± 0.1^a
Mid-island	0.0 – 2.3	10.3 ± 2.5^b	1.2 ± 0.2^b	0.0 – 1.9	34.9 ± 4.4	1.1 ± 0.1^b
Near tail	0.0 - 2.4	2.3 ± 0.9^c	0.4 ± 0.2^c	0.0 – 1.8	34.2 ± 3.3	1.4 ± 0.1^b

Conclusions

Tree islands in WCA-2A could have been formed over pinnacle rock, bedrock depressions, or over a flat topographic surface. Bedrock topography did not appear to be related to the topography of the surface peat. Peat depth ranged from 1–2 m deep and increased from south to north of the WCA. The elevational difference between the marsh and the island was greatest in southern WCA-2A and decreased for islands in the north. These patterns indicate that microtopography may be a function of island location within the landscape and hydrologic regime. Peat bulk density was low at nearly all sites and increased downcore — but nonetheless remained low, similar to the marsh. The peat distribution pattern, low soil bulk density and the virtually complete disappearance of woody vegetation for ghost tree islands are somehow related and a consequence of altered hydrology, climate, and local ecology. Vegetation and soil samples from this survey are being analyzed for nutrients, especially total phosphorus, Pb210, charcoal, metals and stable isotopes to gain more insight.

Relevance to Water Management

Water management practices in the 20th century created impoundments in the Everglades that, in turn, somehow altered the plant community and both size and dimension of tree islands. Over 95 percent of the original tree islands in WCA-2A have disappeared. Information on the current status of the tree islands in WCAs is needed to better understand how future water management can restore these critical Everglades habitats.

WCA-3 TREE ISLAND MAP UPDATE

This section provides an update and analysis of trends in data for tree islands located in WCA-3. WCA-3 is a 234,853-ha impoundment located in the central portion of the remnant Everglades. This area is the focus of the CERP Decompartmentalization and Sheet Flow Enhancement Project (DECOMP). This project is expected to reestablish the ecological and hydrologic connection of WCA-3 and the ENP and provide more natural sheetflow and hydroperiod for the region. More details on DECOMP are available at www.evergladesplan.org.

The mapping of tree islands through time provides for an evaluation of the historical trends and insights into the key hydrologic needs for tree island restoration and successful implementation of DECOMP. The WY2010 update used 1:24,000-scale color-infrared aerial photography collected from December 2003–January 2004 to document and update the trends determined from previous tree island mapping efforts within WCA-3.

Methods

The WCA-3 tree island mapping update relied on the stereoscopic analysis of 1:24,000-scale color-infrared positive transparencies (23 x 23 cm format) flown during the period from December 15, 2003 through January 21, 2004. These data were digitally scanned and geo-referenced into the Florida State Plane Coordinate System East Zone (901) North American Vertical Datum of 1983 High Accuracy Reference Network (HARN). The photointerpretation of tree islands was conducted using DAT/EM Summit Evolution digital photogrammetric workstations, which provided sufficient magnification capability to accurately identify and delineate tree/shrub species in a virtual three-dimensional (3-D) rendered landscape. Vegetation height was an important component in delineating the tree islands. The workstations provided stereo superimposition capability, which allowed the delineated line work to be projected onto the digital aerial photography as it was being created. Delineations of tree islands were done as distinct groupings of trees and/or shrubs that were larger than a 1-ha minimum mapping unit. The outer boundary of a tree island was defined as the outermost extent of a continuous grouping of trees and/or shrubs with at least 5 percent ground cover. Small inclusions of marsh species may be present within the tree island polygons and thus classified as part of the tree island. These rules were consistent with the historical WCA-3 tree island trend maps created by Patterson and Finck (1999).

The Patterson and Finck (1999) study combined all types of tree islands. For this study, an attempt was made to discriminate between cypress and strand tree islands. Strand tree islands are typically fixed, teardrop-shaped features oriented northwest to southeast with the tallest trees typically located in the head (northern portion of island) with an elongated tail to the south that is typically composed of shrubs and/or marsh species. The hypothesis is that different types of tree islands may be evolving differently within the landscape through time. It can be argued that the growth morphology and formation or fragmentation of cypress islands may be very different from strand tree islands that have evolved under similar hydrological conditions.

The Patterson and Finck (1999) 1995 tree island data map was used as an initial base. The 2004 tree island polygons were updated by editing the 1995 tree island polygons utilizing the new 2004 digital aerial photography. Tree islands were categorized into cypress and strand tree island classes for both the 1995 and 2004 tree island data. The areas (ha) and numbers of tree islands were calculated and summed for each of the classes found in the 1995 and 2004 datasets. Loss or gain in tree island area and number was calculated by subtracting the 2004 from the 1995 tree island summary calculations for each of the tree island classes. Areas and numbers of tree islands for each class were also calculated for islands with no change in area, and for those exhibiting a loss in area, or those with a gain in area.

Results and Discussion

Table 6-12 shows that 15.2 percent of strand tree islands (209.9 ha) were lost from 1995 through to the 2004 mapping as opposed to a loss of only 0.5 percent or 0.3 ha for cypress tree islands during this same time period. Total loss of all tree islands was 9.6 percent. **Table 6-13** shows that cypress tree islands are relatively stable as opposed to strand tree islands. Strand tree islands showed no change in area on 29 islands, a gain in area (241.9 ha) on 103 islands, and a loss in area (451.8 ha) on 215 islands (**Table 6-13** and **Figure 6-33**). A qualitative scanning of the WCA-3 landscape using the 3-D rendering application indicated no new islands during the 1995–2004 time interval.

Table 6-12. Area and number of tree islands found in 1995 and 2004 and loss/gain for strand (TI) and cypress (CTI) island categories. Note: Nine strand tree islands merged with other islands so total loss in numbers is 55 (-64 + 9 = 55).

	CTI	TI	Total
# of tree islands – 1995	**219**	**356**	**575**
Hectares	754.1	2,728.1	3,482.2
Acres	1,863.4	6,741.1	8,604.5
# of tree islands – 2004	**218**	**293**	**511**
Hectares	753.8	2,518.2	3,272.0
Acres	1,862.6	6,222.4	8,085.0
Loss/Gain	**-1**	**-63**	**-64**
Hectares	-0.3	-209.9	-210.2
Acres	-0.7	-518.7	-519.5

Table 6-13. Area [hectares (ha)] and number of tree islands found that had no change in area, a loss in area, and a gain in area for the strand (TI) and cypress (CTI) island categories.

Islands Without Change in ha	CTI	TI	Total
# of tree islands	**213**	**29**	**242**
Hectares (ha)	738.0	127.2	865.2
Acres	1,823.7	314.3	2,137.9
Islands that lost ha	**CTI**	**TI**	**Total**
# of tree islands	**3**	**215**	**218**
Hectares	1.3	451.8	453.1
Acres	3.1	1,116.5	1,119.6
Islands that gained ha	**CTI**	**TI**	**Total**
# of tree islands	**3**	**103**	**106**
Hectares	1.0	241.9	242.9
Acres	2.4	597.7	600.1

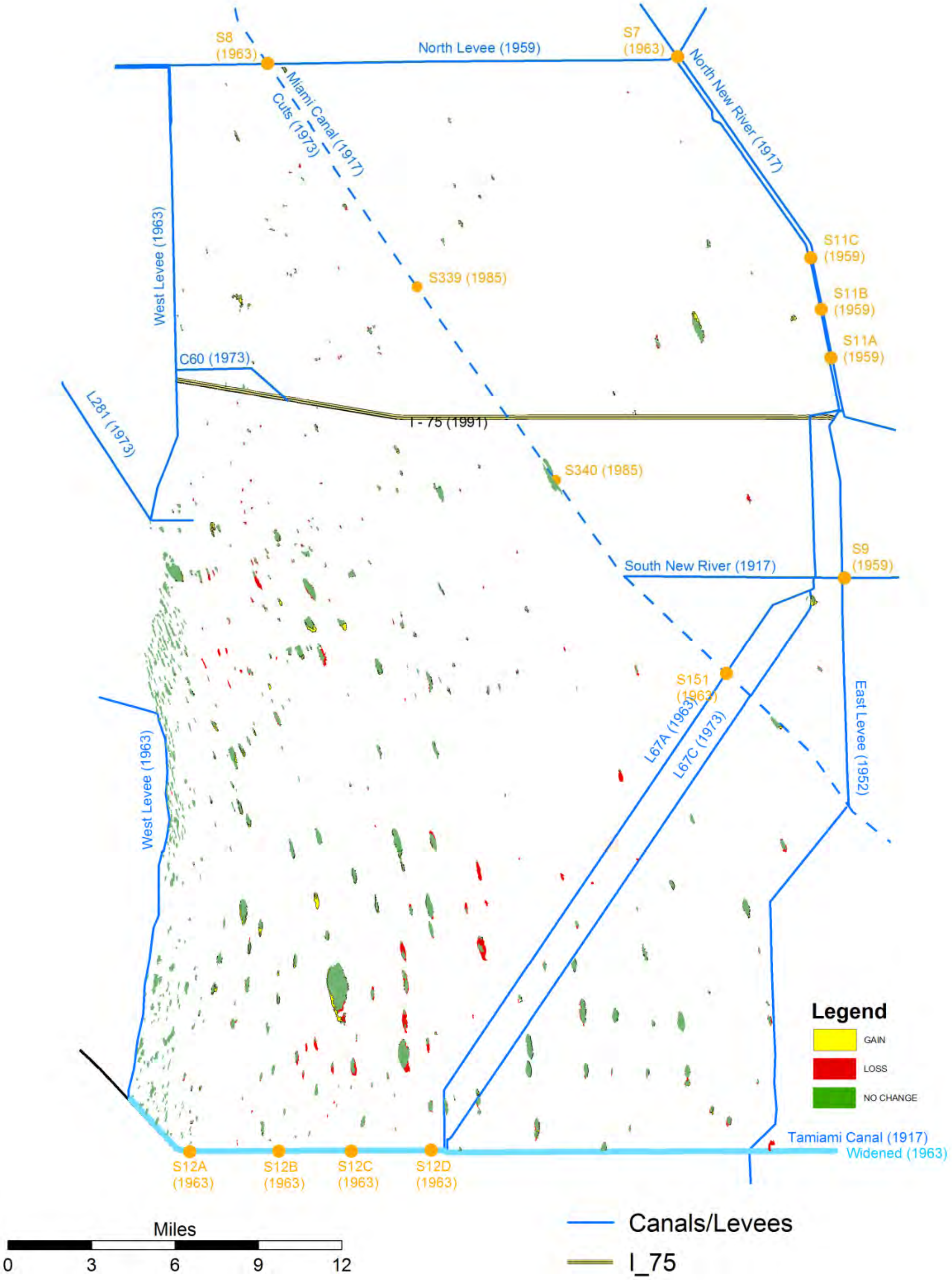
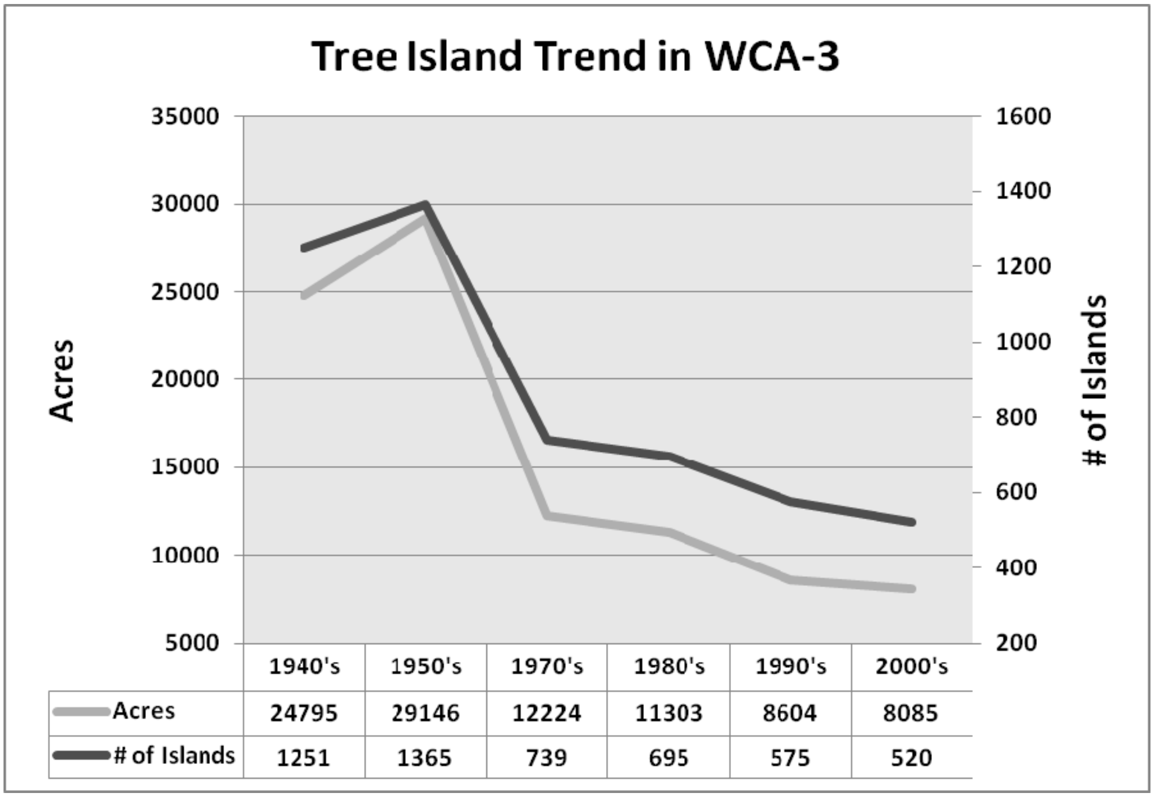


Figure 6-33. Tree island changes in WCA-3 from 1995–2004.

Conclusions

There was a net loss of 210.2 ha (519 acres) from the WCA-3 community of tree islands. This would appear, at first, to be minor compared to the 3,482.2-ha loss observed in 1995 since the 1940s. However, tree islands are expected to have a long life and be stable due to the nature of tree growth and the paleoecological record (Gleason, 1994; Willard et al., 2001; Willard et al., 2002).

These data establish a base from which future tree island map products can be compared. The 1995 data used in the current study are from an earlier study (Patterson and Finck, 1999), which depicted change in tree island numbers and extent from the 1940s to 1995. That study determined that there was a decline of 61 percent in tree islands greater than 1 ha on aerial photography during that time period. The WY2010 update shows that the trend of numbers and ha of tree islands continues to decline within this impoundment (**Figure 6-34**). It appears that cypress tree islands have differing driving metrics or ranges under which they undergo change as opposed to strand tree islands, which appear to be changing more rapidly. Although these data show a continuing trend, further study and analysis are needed to correlate these findings to other metrics including hydrology and topography.



	1940's	1950's	1970's	1980's	1990's	2000's
Acres	24795	29146	12224	11303	8604	8085
# of Islands	1251	1365	739	695	575	520

Figure 6-34. Updated 2004 tree island numbers and acres in relation to the 1940s–1990s tree island trend maps created by Patterson and Finck (1999).

Relevance to Water Management

Previous SFERs and the current study have shown that woody tree/brush species in the Everglades are sensitive to depths and duration of inundation. This new data indicates that current operating conditions are interacting to continue to foster the loss of tree island habitat in WCA-3. It is important to understand these interactions considering WCA-3 is currently the focus of DECOMP. Analyses of these data are being conducted to quantify correlations to hydrology, topography, and island-specific species composition. Results from these analyses should strengthen operational strategies that are conducive to stopping the loss of tree and brush species on tree islands and provide for the successful restoration and implementation of DECOMP.

VEGETATION TRENDS WITHIN WCA-3 FROM 1995–2004

The RECOVER program is designed to organize and provide the highest quality scientific and technical support during CERP implementation (RECOVER, 2004a). RECOVER has developed a system-wide Monitoring and Assessment Plan (MAP), which is designed to document how well CERP is performing (RECOVER, 2004b). The Water Resources Development Act of 2002 authorized CERP as a framework to restore the Everglades and established the U.S. Army Corps of Engineers (USACE) together with the District as co-sponsor agencies responsible for MAP implementation. One component of the MAP is vegetation mapping, since a critical element of any wetland restoration program is reliably documenting temporal changes in the spatial extent, pattern, and proportion of plant communities within the landscape. These types of mapping efforts establish baseline conditions for comparison to future mapping efforts or document changes. Collectively, these mapping efforts play a critical role by allowing state and federal agencies to track ecological restoration.

Methods

Vegetation mapping started in 2004 with the collection of approximately 320 color-infrared aerial photographs at 1:24,000-scale, covering all of WCA-3. These data were geo-referenced to the Florida State Plane East coordinate system. Vegetation mapping was conducted by overlaying a one-quarter hectare (50 x 50 meter) grid within the boundaries of WCA-3, resulting in 939,415 grid cells. Advantages of grid system mapping include greater time and cost efficiency, and the unique ability to classify vegetation within the same quarter hectare grid cells from this analysis and during past and future mapping efforts. In addition, the grid system more accurately depicts the overall heterogeneity of Everglades vegetation than using a vector approach (Rutchey et al., 2008; Rutchey and Godin, 2009). Each grid cell was labeled according to the majority vegetation community as described in the Vegetation Classification System for South Florida Natural Areas (Rutchey et al., 2006). The classification approach allows for classes of particular interest, such as exotics and cattail, to be identified with an additional density class. The density classes are:

- Monotypic (≥ 90 percent)
- Dominant mix (50–89 percent)
- Sparse mix (10–49 percent)

A grid cell could be labeled with a majority category and have a secondary classification indicating the presence of exotics, treated exotics, or cattail. Any grid cell where more than two categories are noted could end up being labeled as a sparse mix. The classification system sets the lower limit for the identification of exotics at 10 percent areal coverage; however, exotics were identified within grid cells wherever they could be identified.

The photointerpretation was conducted using customized DAT/EM Summit Evolution digital photogrammetric workstations, which provided sufficient magnification capability to accurately identify and delineate the vegetation within a virtual three-dimensional (3-D) rendered landscape.

WCA-3 was divided into six nearly equal sections to make certain that the requirements of overall map accuracy of 90 percent or better was being met as the project was progressing. Two-hundred-and-twenty random sampling points were selected for each section and used to calculate an overall map accuracy assessment. Binomial probability formulas require the use of a minimum of 204 points to check for an 85 percent accuracy level with an error of ±5 percent (Snedecor and Cochran, 1978). Two photointerpreters stereoscopically reviewed the photography and classified the 220 random points independently. All the locations that were classified the same by the two independent photointerpreters and that matched the final map output were denoted as correct. All the points that were classified differently were further assessed using field ground-truthing methods. Ultimately, the field ground-truth data were compared to the map data for the purpose of assessing the accuracy of those areas that were classified differently by the panel of photointerpreters. Results of overall accuracy were computed by dividing the number of correctly labeled points by the total of the 220 randomly selected points and multiplied by 100. Final overall map accuracy was calculated for all the sections with the same methodology that was utilized for each section.

The complete 2004 gridded vegetation map was then compared to a previously completed map representing conditions in 1995. The 1995 WCA-3 data were derived from Rutchey et al., (2005) work that was based on a vector approach for mapping vegetation within the conservation area. These data were converted to the same 50 x 50 meter grid format used for creating the 2004 vegetation map. No significant changes were noted in this conversion when going from the vector to the grid format. The original 1995 data have an overall map accuracy of 89.7 percent.

Results / Discussion

The 2004 WCA-3 vegetation map resulted in 939,415 photointerpreted 50 x 50 meter grid cells or 234,854 ha of land surface mapped. Overall individual map accuracies ranged from 85.9–95.5 percent for the six sections (**Figure 6-35**). These accuracies reflect the relative difficulties of mapping the various sections. The average for the six sections was 90.8 percent, which compared favorably to the overall map accuracy of 90.9 calculated for the entire project area.

Mapping results indicate that sawgrass/shrub areas increased approximately 48 percent, from 3,871 ha to 5,738 ha from 1995–2004 (**Figure 6-36** and **Table 6-14**). Broadleaf marsh increased 30 percent (1,123 ha to 1,454 ha), while floating marsh decreased by 37 percent (3,621 to 2,279 ha) during the same period. Exotic species were again a small (38 ha) overall component of the conservation areas. Most significant may be the change in cattail cover. Analyzing each grid cell for any amount of cattail showed a 63 percent increase of 19,871 to 32,349 ha from 1995–2004, respectively (**Figure 6-37**). An increase in cattail represents a state change from historic ridge-and-slough patterns.

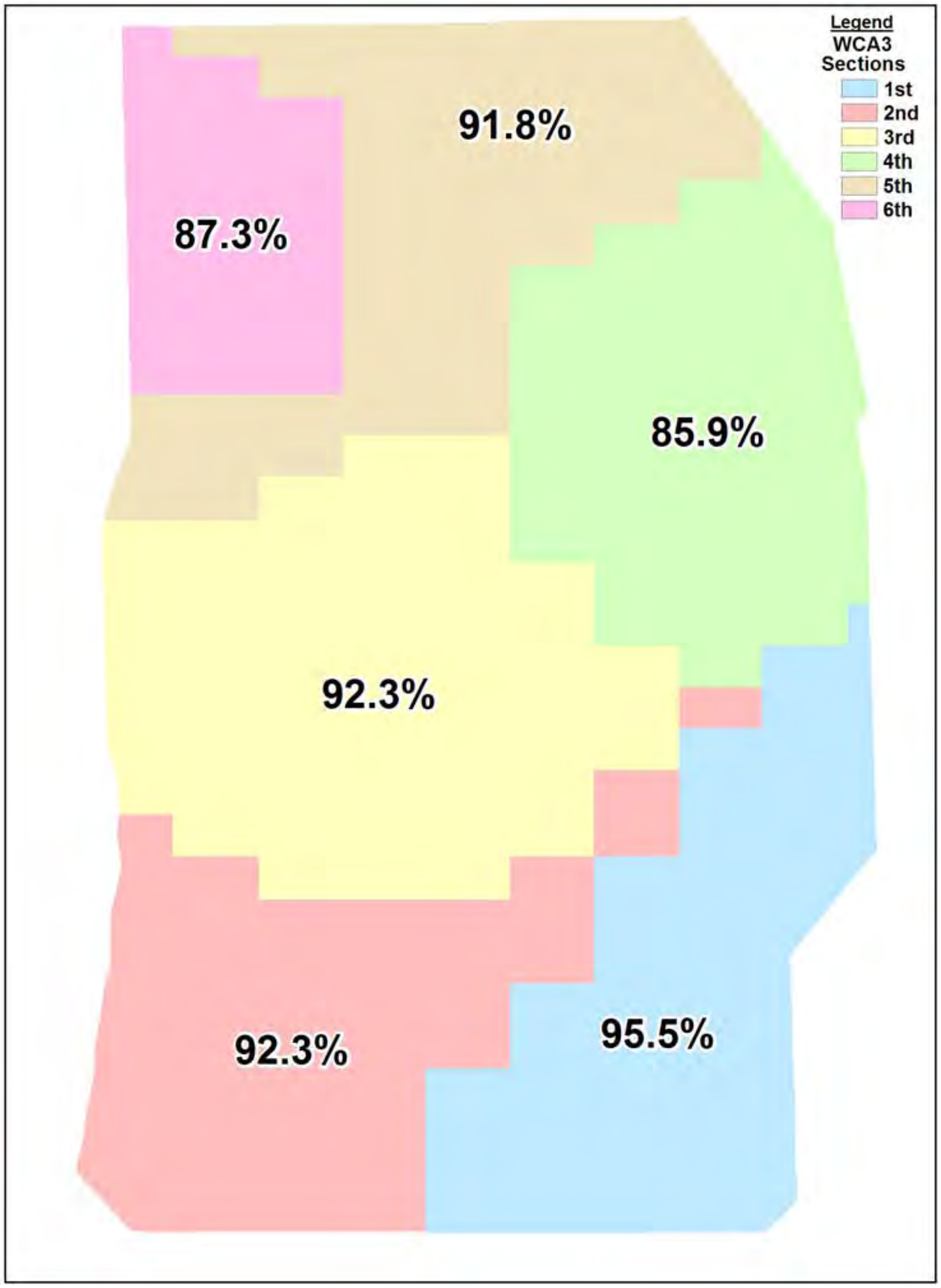


Figure 6-35. The 2004 WCA-3 vegetation map accuracies depicted for the six sections.

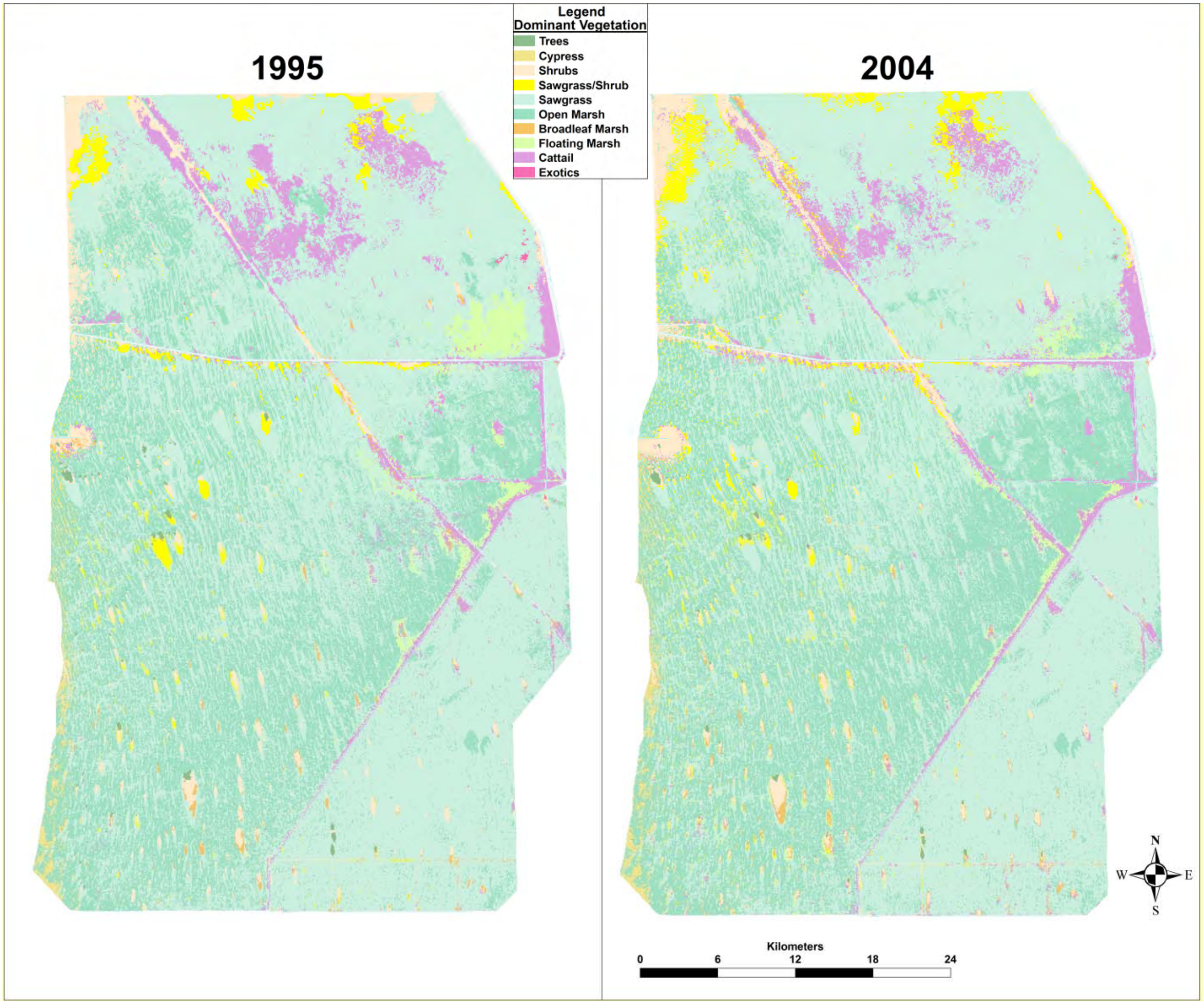
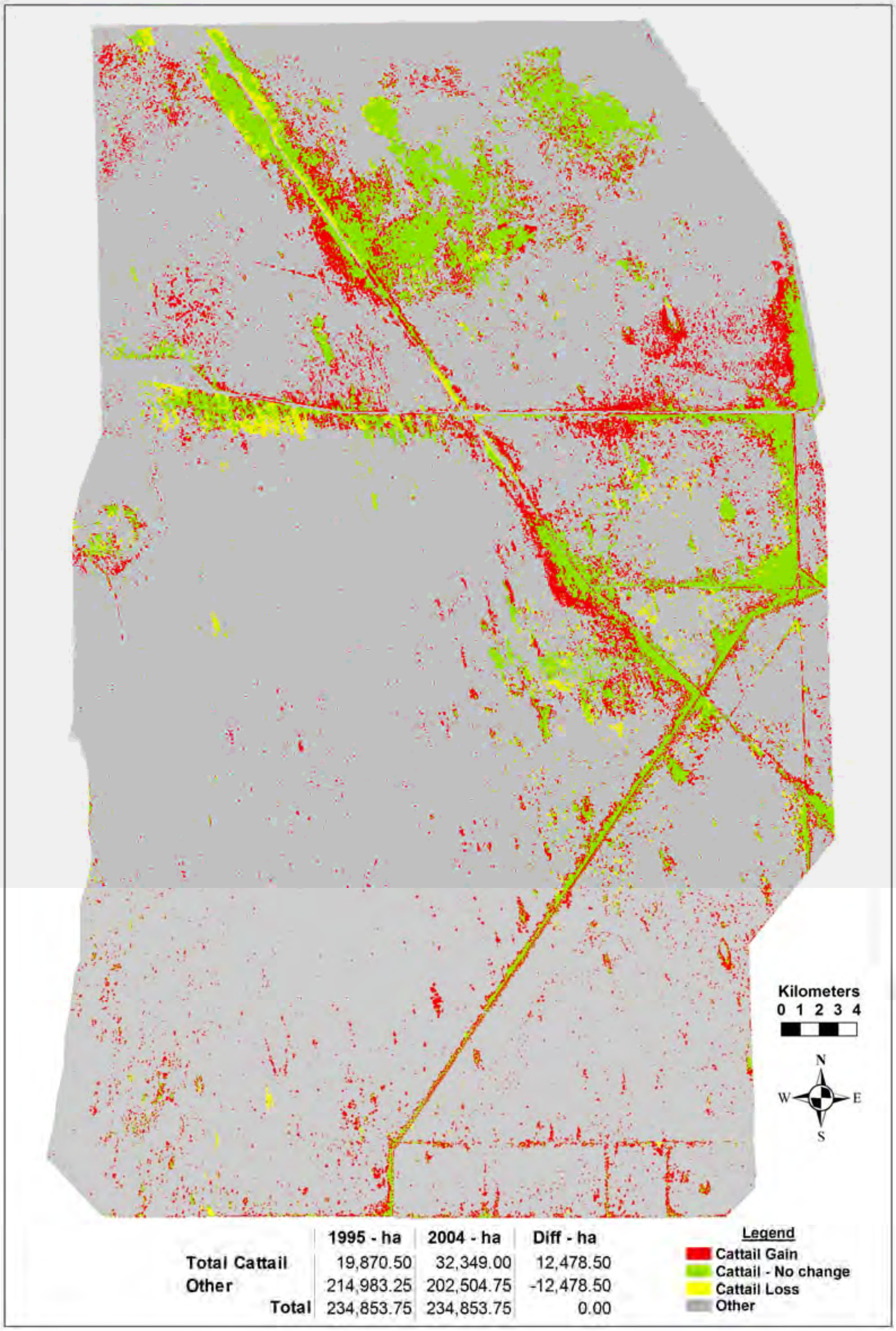


Figure 6-36. Dominant vegetation types found in 1995 and 2004 WCA-3 vegetation maps.

Table 6-14. Dominant vegetation hectares found in 1995 and 2004 WCA-3 maps.

Vegetation Category	1995 hectares	2004 hectares	Difference hectares
Trees	509	409	-100
Cypress	1,413	1,567	154
Shrubs	7,080	6,750	-330
Sawgrass/shrubs	3,871	5,738	1,867
Sawgrass	138,788	134,901	-3,897
Open marsh	64,109	68,122	-4,013
Broadleaf marsh	1,123	1,454	331
Floating marsh	3,621	2,279	-1,342
Exotics	88	38	-50



	1995 - ha	2004 - ha	Diff - ha
Total Cattail	19,870.50	32,349.00	12,478.50
Other	214,983.25	202,504.75	-12,478.50
Total	234,853.75	234,853.75	0.00

Figure 6-37. Cattail (*Typha* spp.) difference map depicting gain, loss, and no change in WCA-3.

Conclusions

These data establish a trend from which future vegetation mapping products can be compared and to help to ascertain if the implementation of restoration efforts are successful in preserving and restoring predrainage landscape features. The most significant finding during this nine-year period of change was the rapid cattail expansion of nearly 12,500 ha. The encroachment of cattail due to its ability to out-compete other native vegetation under high nutrient conditions has been well documented (Davis, 1991; Newman et al., 1996; Doren et al., 1997; Miao and DeBusk, 1999; Rutchey and Vilchek, 1999) and is probably the most visible sign of an Everglades in decline. Altered hydrology (e.g., water depth, hydroperiod, flow) has also caused dramatic changes in the composition and structure of plant communities within the Everglades (Alexander and Crook, 1975; Davis et al., 1994). Natural stochastic variations within this system were most likely necessary for its continued health and survival, but have been difficult to mimic within the limits of the currently constructed system of levees, canals, and pumps. These hydrologic alterations in combination with large inflows of phosphorus may have altered the Everglades for many decades to come.

Relevance to Water Management

Excessive nutrients, hydrologic alterations, and fire have been shown to have an influence on the successful establishment of cattails in the Everglades. The relative importance of these factors in establishing the cattail populations shown in this map of WCA-3 has not, however, been determined. Nevertheless, these findings provide insight into the degrading trends that need to be reversed for ecosystem restoration and the successful implementation of DECOMP.

QUANTIFYING REGION-WIDE NONINDIGENOUS PLANT INFESTATIONS USING DIGITAL AERIAL SKETCH MAPPING

The availability of geospatial data on invasive species plant infestations is an essential component of land management and ecosystem restoration programs. To be operationally useful for invasive species management efforts, the information should have high positional accuracy, high species detection accuracy (particularly for low-density infestations), rapid turnaround time, relatively low cost, and the ability to quantify the degree of infestation (Lachowski et al., 2007). To address the need for more detailed geospatial information on priority invasive plants and to meet (Section 373.4592, Florida Statutes) requirements to prepare biennial surveys of exotic species within the EPA, the District and the National Park Service (NPS) are now utilizing digital aerial sketch mapping (DASM) for regional invasive plant surveys. Sketch mapping is a remote sensing technique of observing ground conditions from low-flying aircraft and manually documenting observations on paper maps. In the 1990s, the U.S. Forest Service began integrating computing and global positioning system (GPS) technologies with manual sketch mapping techniques in order to automate forest pest outbreak monitoring (Schraeder-Patton, 2003). The resulting DASM system utilizes touch-screen computers, GPS receivers, specialized software, and high resolution imagery, allowing trained observers to digitize spatial and attribute observations in real time. With over one million hectares of conservation lands within the EPA, invasive species scientists recognized DASM as a potentially cost-effective and valuable invasive plant survey tool. This section documents results of invasive plant mapping DASM conducted by District and NPS biologists within the EPA during 2009 and 2010. Specifically, the spatial extent and dominance of four priority invasive plant species — Australian pine, Brazilian pepper, melaleuca, and Old World climbing fern were examined.

Methods

DASM was used to quantify invasive plant infestations in the Greater Everglades region during March 2009 and March–April 2010 (northern half and southern half, respectively). All management areas within the Everglades Cooperative Invasive Species Management Area (Everglades CISMA) were included in the survey. These include Holey Land, Rotenberger, and Southern Glades wildlife management areas, Big Cypress Seminole Indian Reservation, WCAs 1, 2, and 3, the Miccosukee Reservation, Big Cypress National Preserve, the ENP, East Coast Buffer lands, South Dade Wetlands, and other areas. Two biologists were flown in a helicopter along east-west transects gridded on 1-km intervals, allowing observers to map 500-m strips on each side of the aircraft for a complete census. Each biologist had at least 100 hours of previous aerial invasive plant mapping experience in the Everglades. The aircraft flew at an altitude of 150 m at variable speeds, depending on abundance of target species. By using a helicopter, observers could direct the pilot to hover at low altitude when species identification was uncertain.

The DASM system comprised two networked touch-screen laptops connected to a GPS receiver, GeoLink® sketch mapping software, preloaded boundary and flight transect shape files, and 1-meter pixel true color digital imagery. Observers digitally sketched polygons of infestations for each invasive species. The percent vegetation cover was estimated for each species using a modified Braun-Blanquet cover abundance scale (Mueller-Dombois and Ellenberg, 1974): 1–5 percent, 6–25 percent, 26–75 percent, and > 75 percent. During post-flight data processing, shapefiles from both observers were combined and overlapping polygons with similar attributes were rectified. After completing geographic information system (GIS) quality assurance/quality control (QA/QC), gross infestation area (GIA) and net infestation area (NIA) were calculated. GIA is the summed area of all polygons for a given species. NIA is a percent cover-adjusted calculation for each species using the mid-point of each cover class [$\text{NIA} = \sum(.875)H_{\text{dense}} + \sum(.50)H_{\text{medium}} + \sum(.15)H_{\text{low}} + \sum(.025)H_{\text{sparse}}$, where H is area, in hectares, for a polygon in a given cover class]. To determine mapping accuracy, a stratified random sample of polygon centroids was collected from the dataset for each species at each cover class. A random sample of coordinates was also collected from areas where no invasive plants were mapped. A total of 181 sites were visited via helicopter, allowing for low altitude hovering and carefully observation of each site. The large number of sites in remote and impenetrable locations prevented ground-based validation of polygons. At each location, the presence or absence of target invasive species was determined by carefully scanning the site at low altitude (< 100 feet).

Results and Discussion

Australian Pine

- Australian pine is the least abundant of the targeted species with a total GIA of 2,338 ha within the survey area (**Table 6-15**). Regionally, this species is now at maintenance control levels, meaning that continuous low intensity management will keep this species at the lowest feasible level.
- The large majority of Australian pine (87 percent) occurs on District and Miami-Dade County lands in the South Dade Wetlands and Model Lands Basin (**Figure 6-38**) where it forms dense stands to widely scattered patches in remote mangrove swamps and sawgrass marsh.
- Australian pine continues to occur in widely scattered patches in sawgrass marshes in the northeastern ENP.

Brazilian Pepper

- Brazilian pepper is widely distributed throughout the survey area (**Figure 6-38**) with an estimated GIA of 27,282 ha (**Table 6-15**). This broad distribution is consistent with previous estimates using the Systematic Reconnaissance Flight methodology (see the *2008 SFER – Volume I, Chapter 9*).
- Brazilian pepper is a dominant component of buttonwood (*Conocarpus erectus*) swamps and graminoid (grass) marshes along the fringes of southwestern mangrove swamps of the ENP. The most severe infestations extend from the Ten Thousand Islands Area to Cape Sable, representing roughly 60 percent of the total GIA within the survey area.
- Dense infestations of Brazilian pepper also occur throughout the Big Cypress Seminole Indian Reservation, primarily on improved pastures and along the fringes of cypress swamps.
- Brazilian pepper was detected on small tree islands throughout the central Everglades region. In many cases, this species is dominant or co-dominant in the canopy. Ground-based observations of tree islands infested with Brazilian pepper revealed that little to no understory native vegetation remains beneath the canopy. Other widely scattered but dense infestations occur in the western Everglades hardwood hammocks within Big Cypress National Preserve. Brazilian pepper is rarely observed growing on the tree islands of WCA-1.

Melaleuca

- Melaleuca occupies an estimated 41,938 ha within the survey area (**Table 6-15**). However, NIA (5,689 ha) is less than that calculated for Brazilian pepper (7,600 ha). This is partly due to the large melaleuca polygons mapped in WCA-1 (**Figure 6-39**). In this management unit, melaleuca is evenly distributed at relatively low densities in sawgrass marsh, wet prairie, and cypress strands. Given this relatively even distribution, the mapping of several large polygons with low percent cover classification for melaleuca was conducted to allow more mapping focus on the spatially complex infestations of Old World climbing fern.
- Significant infestations of melaleuca also occur within the Big Cypress Seminole Indian Reservation, where it invades pine flatwoods, wet prairie, and cypress swamps.
- Melaleuca occurs in widely scattered small stands in sawgrass marsh and cypress swamps in Big Cypress National Preserve and the eastern ENP. The exotic is at maintenance control levels in WCAs 2 and 3.

Old World Climbing Fern

- Old World climbing fern is estimated to occupy 2,338 ha (GIA) within the survey area (**Table 6-15**). The large majority of Old World climbing fern (92 percent) mapped in this survey occurs within the WCA-1, where it aggressively forms dense mats over tree island canopies (**Figure 6-39**). The 2009 estimate for WCA-1 (2,151 ha GIA) closely aligns with a predicted 2012 infestation area by Wu et al. (2006).
- An estimated 1,988 ha of graminoid/prairie marsh in the southwestern sections of the ENP are infested with Old World climbing fern. At the time of the survey (March 2010), *Lygodium* cover was substantially reduced by frost damage in the

region. It is expected that current estimates substantially underestimate infestation levels for both percent cover and areal extent.

- Old World climbing fern was not detected in WCA-3 using DASM. Ground-based observations of understory infestations in WCA-3 confirm that DASM is ineffective for early detection of *Lygodium* in sub-canopy strata of tree islands (see the *Tree Island Lygodium Habitat Suitability Analysis* section of this chapter). This result emphasizes the importance of continued ground-based surveys in helping to contain the spread of this aggressive Everglades invader.

DASM Method Assessment

- Ground truthing (based on observations from low-flying helicopters) indicates a high degree of accuracy for identified invasive plant occurrences. Mapped polygons for Old World climbing fern, melaleuca, and Brazilian pepper were confirmed 98 percent, 91 percent, and 92 percent of the time, respectively. [Note: Australian pine was not included in the accuracy analysis due to the low number of occurrences in the dataset.]
- Mapping accuracy was lower for areas identified as having none of the target invasive plants. At least one of the target species was observed at 35 percent of randomly selected null sites. In all cases, the missed plants — typically Old World climbing fern and melaleuca — were small and at very low densities. This result is not unexpected given the inherent difficulty in detecting small plants from low-flying aircraft.

Table 6-15. 2009–2010 gross and net infestation areas of four priority invasive plant species in the Everglades Protection Area.

COVER CLASS	SPECIES AREA (ha)			
	Australian pine	Brazilian pepper	Melaleuca	Old World climbing fern
Sparse (<5%)	1,582	5,105	8,616	732
Low (5-25%)	505	12,495	32,110	1,439
Medium (26-75%)	228	7,662	1,073	620
Dense (>75%)	24	2,020	139	50
TOTAL GROSS INFESTED AREA (GIA)	**2,338**	**27,282**	**41,938**	**2,840**
NET INFESTED AREA (NIA)*	**250**	**7,600**	**5,689**	**588**

*NIA = total hectares of target species cover, calculated by adjusting polygon area with the midpoint of each cover class = $\sum(.875)H_{dense} + \sum(.50)H_{medium} + \sum(.15)H_{low} + \sum(.025)H_{sparse}$, where H is area (hectares) of a polygon in a given cover class.

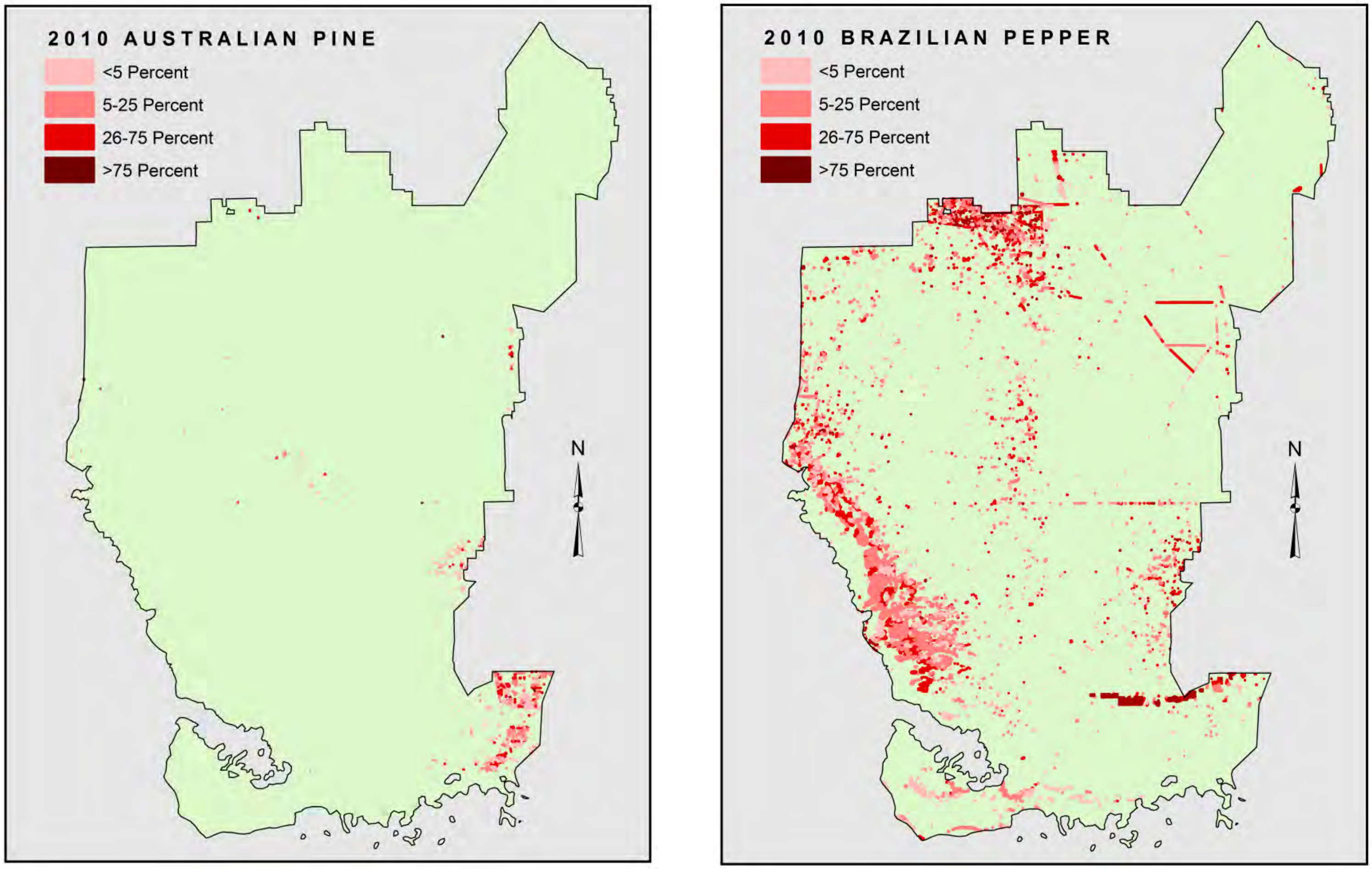


Figure 6-38. Distributions of Australian pine (*Casuarina* spp.) (right) and Brazilian pepper (*Schinus terebinthifolius*) (left) in the Everglades Protection Area during the study period.

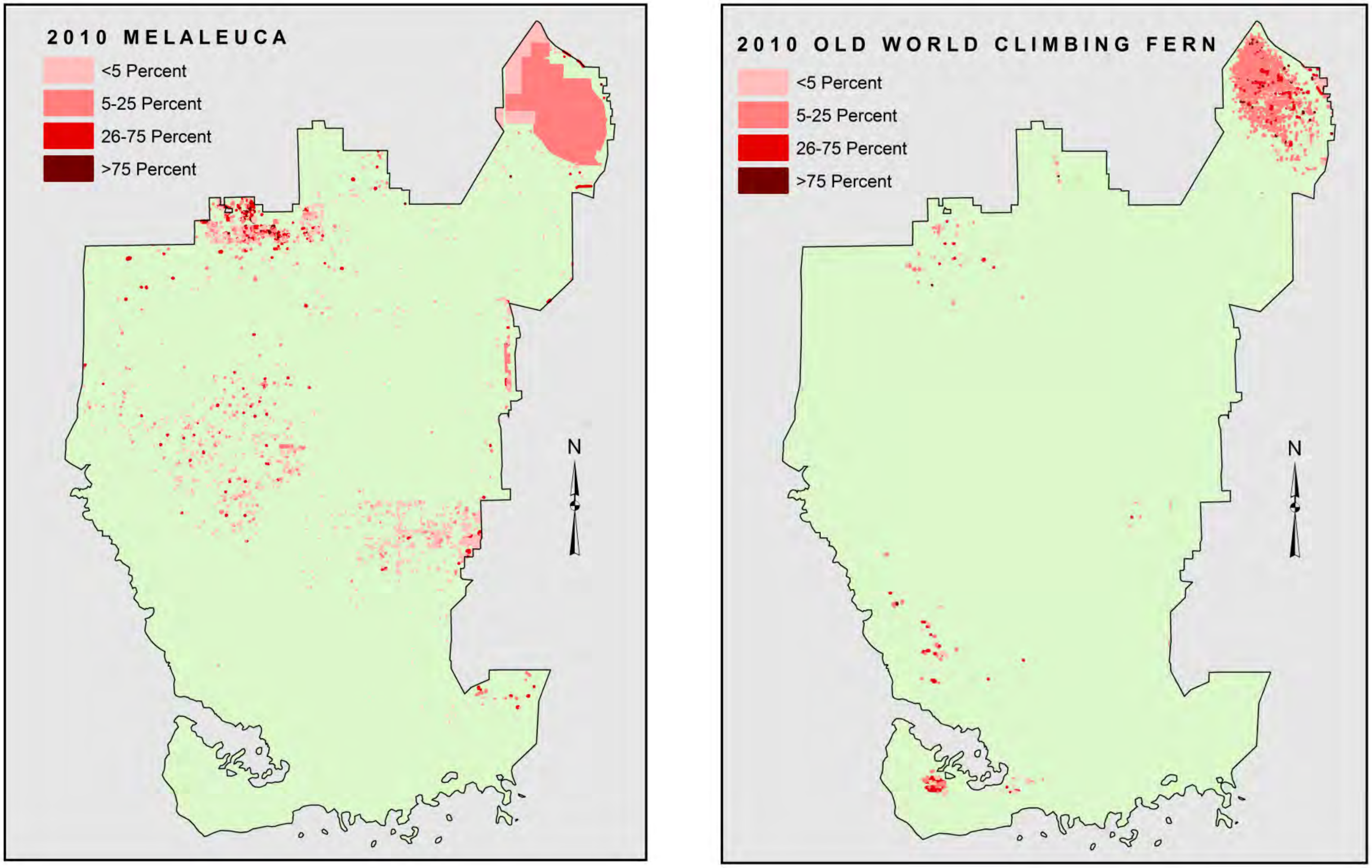


Figure 3-39. Distributions of melaleuca (*Melaleuca quinquenervia*) (right) and Old World climbing fern (left) in the Everglades Protection Area during the study period.

Conclusions

Results of this region-wide mapping effort document the spatial extent and dominance patterns of four priority invasive plant species within the EPA. Given its relatively low-cost, low turnaround time, and acceptable mapping accuracy (0.89), DASM has great potential for numerous invasive plant mapping applications across the vast Everglades landscape. These include early detection in open-canopied plant communities, invasive plant management planning, short-term change detection (e.g., tracking rapid spread of new invaders), and support for regional biological control monitoring efforts. The flexibility in timing data collection allows surveyors to take advantage of phenological events, which can facilitate target species detection (e.g., flowering, leaf drop), with the caveat that the low detection rate of small infestations in closed-canopied plant communities is a significant limitation of this survey method. Ground-based assessments of sub-canopy infestations must be coupled with DASM to provide a complete picture of invasive plant infestations across the landscape.

Relevance to Water Management

The benefits of Everglades restoration efforts will be greatly reduced without successful control of invasive plant species. A comprehensive understanding of the extent and intensity of these species is critical to planning and assessing management and restoration efforts. DASM appears to provide a cost-effective component of these planning and assessment needs.

CONCLUSIONS

Fred Sklar

Data, findings, and in some cases, recommendations from 14 projects were presented in this chapter. Results were presented across trophic scales spanning from population- to landscape-level, highlighting the broad requirements of water management decision making. Multi-scale data such as these are critical because all Everglades water management decisions have uncertainties and environmental risks that can effect ecological “imbalance,” which can lead to an evaluation of potential environmental trade-offs. As the Everglades system continues to evolve due to a legacy of drainage, storage, agriculture, development, hurricanes, and exotic species, restoring the region to historical reference points becomes a highly dynamic and complex process. Scientific research provides the basis and methods needed to achieve long-term restoration goals while balancing the day-to-day water management needs of agriculture, residents, and the environment.

The wading bird response in the 2010 nesting season was a testament to the resilience of wading birds to persist despite large, inter-annual hydrologic deviations; the data also point to the significance of multi-year processes and cumulative impacts. A highly productive recruitment of new wading birds in one year does not translate into a highly productive nesting event the next year particularly if (1) recession rates are poor, (2) winter and spring temperatures are unseasonably cold, or (3) prey populations are low due to extended dry conditions during the dry season of the previous water year. As each of these influences were manifested in WY2010, it was not surprising to observe a 45 percent and 68 percent decline in nesting (in relation to the 10-year average and last year, respectively). Indeed, during the 2009 nesting season, 76,791 nests were observed, making that year the best on record in South Florida since the 1940s. The post-nesting 2009 influences, combined with 20 years of wading bird science in the Everglades, suggest that to continue the restoration momentum demonstrated by the wading bird nesting season of 2009, the roles of crayfish, exotic fish, and habitat loss in relation to water management need further study.

Large scientific uncertainties and questions still remain in association with the restoration and preservation of tree islands. However, some important relationships were discovered and reported, including the findings that (1) the spread of *Lygodium* on tree islands in WCA-3 was not a function of the distance from an infested island, but rather the hydrologic regime during the previous two years; (2) the faunal contributions of phosphorus in the form of guano may account, in part, for the enriched nutrient status of tree island soils; (3) sap flow is a physiological indicator of stress because even the most acclimated, old, and flood-tolerant tree species responded to the seasonality and extent of flooding; (4) where tree islands have downstream nutrient-hydrology gradients, woody species successfully colonize, become established, and survive on sites where hydroperiods are short and soil nutrients are high; and (5) a landscape change analysis for WCA-3 for the 1995–2004 period showed a continuation of the conversion of 15.2 percent of strand tree islands into marsh. Although these data provide useful information for water management, a more comprehensive understanding and an adaptive management approach are needed to preserve and restore tree islands.

Two critical and innovative ecosystem-scale manipulations of the cattail-impacted zones of WCA-2A are nearing completion. The FIRE manipulation resulted in the development of a simulation model which demonstrated the need for repeated fires in the cattail areas to suppress the accumulation of cattails and decrease soil TP concentrations. The CHIP manipulations continued to provide evidence of a sustainable state change (DO, floc, species composition, and nutrient cycling) and evidence for an accelerated ecological rehabilitation toward an open, SAV-dominated habitat that can support high fish biomass and good foraging for wading birds.

Two new and related projects have been initiated to examine regional, large-scale climate drivers in the Everglades. A study using plant fossil seeds to determine historic hydrologic regimes adds to a growing body of literature linking Everglades vegetation to regional climatic drivers, especially to the very dry periods associated with southward shifts of the ITCZ and the increasing dry-season rainfall pattern over the past 5,000 years, in association with a steadily strengthening El Niño cycle. These climatic trends support the fossil seed data that indicate a general trend toward wetter conditions over the last 2,000 years in Northeast Shark River Slough. However, this wetter trend is not found everywhere, and does not appear in Fakahatchee Strand data. This difference may be due to greater temperature and precipitation spatial heterogeneity across the Everglades than was previously believed. The discussion of climate gradients in this chapter related temperature and rainfall patterns to ENSO teleconnections. The finding that ENSO more strongly and significantly influences dry season rainfall in the west (nearer Fakahatchee), but not to the east (i.e., EPA) of South Florida may reconcile these two lines of paleoecological evidence.

At the landscape scale, the tree island update was already mentioned. However, two other mapping efforts have lead to conclusions not previously discussed: (1) new mapping techniques associated with DASM were found to be a cost-effective means of rapidly obtaining and recording spatial and temporal information on invasive plant distributions; (2) a new vegetation map, based on 2004 imagery, was completed for WCA-3 and compared with a vegetation map from 1995. The change analyses found significant and disturbing increases in cattail, especially along canals and in the northern reaches of WCA-3. Analyzing each 50 x 50 m grid cell for any amount of cattail showed a 63 percent increase and a change from 19,870 ha in 1995 to 32,349 ha in 2004. Cattail represents a degradation and state change away from the historic ridge-and-slough patterns in the Everglades.

Invasive species monitoring and control continue to be a challenge in South Florida. Invasive species compete with native species for space and resources, often destroying regional native populations. A natural control of exotic invasive species is lacking due to the absence of their native predators, parasites and diseases that control the populations within their native habitats. Tools such as DASM aid in locating and documenting exotic invasive species for targeted control.

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