Chapter 6: Ecology of the Everglades Protection Area

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SUMMARY

The studies and findings discussed in this chapter are presented within four main fields: (1) wildlife ecology, (2) plant ecology, (3) ecosystem ecology, and (4) landscape. 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 (EFA) [Section 373.4592, Florida Statutes (F.S.)] mandates, and the Comprehensive Everglades Restoration Plan. **Table 6-1** summarizes elements of the major Everglades research findings during Water Year 2008 (WY2008) (May 1, 2007–April 30, 2008) and highlights these findings in relation to the statutory mandates that drive the research and the WY2008 hydrologic pattern.

The hydrologic pattern is immediate and foremost an influence on the restoration of the Everglades wading bird populations, but is also critical to long-term ecological trends. This year, the amount of rainfall received was average, but the pattern of rainfall was far from normal. The onset of the wet season was delayed, water levels were low during the wet season, and the dry season was abnormally wet. As a result of these rainfall deviations, and in combination with WY2007's pattern, only an estimated 18,418 wading bird nests were initiated in WY2008. This was a 51 percent decline from WY2007 and a 74 percent decline from WY2002's banner nesting achievements. At the Loxahatchee Impoundment Landscape Assessment facility (LILA), where the hydrologic patterns were controlled to study the habitat selection process of wading birds, foraging was most active at sites with no or moderate levels of slough vegetation. In these LILA experiments, birds avoided deep sloughs with no emergent vegetation, and foraging success was mostly a function of prey densities. In addition to wading birds, a study of exotic fish was conducted at the U.S. Geological Survey (USGS) Florida Integrated Science Center, LILA, and Everglades National Park. Two trophic disrupters, jewelfish (*Hemichromis letourneuxi*) and Mayan cichlid (*Cichlasoma urophthalmus*), of the Everglades food web were found to have a minimum water temperature tolerance of only 10ºC. Thus, marsh specimens of these two exotic fish species were found to die when exposed to natural cold fronts, but canal specimens did not.

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Four of the five plant ecology studies in WY2008 focused on tree islands to begin illuminating the uncertainties associated with their biology and sustainability:

- Vegetation surveys in Water Conservation Area 3 continue to both monitor and control the spread of the invasive Old World climbing fern (*Lygodium microphyllum*) and other exotic species, such as Brazilian pepper (*Schinus terebinthifolius*), melaleuca (*Melaleuca quinquenervia*), Australian pine (*Casuarina equisetifolia*), and lobate lac scale (*Paratachardina pseudolobata*). In WY2008, it was apparent that this is a critical issue as *Lygodium* had spread to more than 60 percent of the tree islands in Water Conservation Area 3B. Spot spraying is expected to prevent further spreading.
- The sustainability of a tree island is dependent upon natural rates of re-seeding and recruitment, which is why seedling survivorship surveys are important for water management. This water year's study found high seedling densities for cocoplum (*Chrysobalanus icaco)* and white stopper (*Eugenia axillaris)*, especially in areas with short hydroperiods.
- New technologies being tested to measure ecophysiologic stress at the species level on tree islands may help to establish hydrologic restoration regimes (i.e., water potentials, isotopes, and sap-flow meters) and indicate that some short-term, rapid changes can have long-term impacts upon community structure.
- Seedling establishment on tree islands in LILA was evaluated to quantify long-term tree island sustainability and survival was found to be strongly inhibited by flooding, but growth rates were not.

The fifth study presents a new study on the composition of the polysaccharides secreted by Everglades's periphyton. This secretion is ubiquitous and is hypothesized to be an influential biological process associated with water quality, food webs, and the distribution of flocculent sedimentary particles.

At the ecosystem scale, the two large-scale experimental manipulations (Fire and CHIP) of the cattail (*Typha* spp.) impacted area of Water Conservation Area 2A that were discussed in the *2008 South Florida Environmental Report – Volume I* (Sklar et al., 2008), have made significant progress. At the time this report was written, it was reasonably clear that open plots have higher microbial activity, higher periphyton production, greater decomposition rates, and more wading birds than the surrounding cattails community. However, using fire to create and maintain these openings is a function of litter accumulation rates, and the timing and intensity of the fire. Related to these studies was a laboratory study of the response of sediment cores from the cattail impacted zone after the eradication of the cattail using herbicides. The result was a slow, continuous release of phosphorus from decomposing cattail tissue in the cores. Two new and related tree island ecosystem studies began in WY2008 and were associated with the hypothesis that groundwater and tree roots combine to create high pore-water nutrient fluxes and high total phosphorus soil accumulation rates. The groundwater study, conducted on LILA tree islands, found that water can up-well into islands. The nutrient flux study, on island 3AS3 in Water Conservation Area 3A, is currently indicating a movement of nutrients down into the soil on the head of the island, with the potential for these nutrients to move downstream towards the tail.

At the landscape level, remote sensing and photo interpretation continue to be significant efforts. This year, a mapping milestone occurred with the completion of the most complicated mapping product to date: Water Conservation Area 1 over a six-decade historical period. With an overall map accuracy of 93.3 percent, this vegetation map is expected to influence water management decisions for many years to come. Also of major consequence is the continued surveying of tree island elevations (both absolute and relative to the surrounding marsh).

Water Conservation Area 3B had the highest average marsh-to-tree-island elevation difference (0.85 meters). Similarly, ridge versus slough elevation differences continue to be captured by a detailed landscape analysis of historical images. These images are indicating the possibility of a landscape-level punctuated equilibrium in the Everglades where surface patterns appear unchanged for decades but then decompose rapidly once some accumulated threshold is reached. Finally, long-term studies in the mangrove transition zones of Everglades National Park are presented, and the results indicate that this zone is not keeping pace with current sea level rise.

Table 6-1. Summary of Water Year 2008 (WY2008) (May 1, 2007–April 30, 2008) Everglades research findings in relation to the following operational mandates: Regulation and Operational Schedules (ROS); Comprehensive Everglades Restoration Plan (CERP); Everglades Forever Act (EFA), Long-Term Plan (LTP); Minimum Flows and Levels (MFLs); Florida Everglades Improvement and Management (FEIM); and U.S. Environmental Protection Agency (USEPA).

Projects	Findings	Mandates
Hydrologic Patterns	Despite the second water year of official drought, total rainfall amounts and average stage readings across the Greater Everglades were not very different from historical averages. However, for WY2008, the onset of the wet season was delayed and its water levels were low; and the dry season was abnormally wet.	ROS, MFL
Wildlife Ecology		
Wading Bird Monitoring	Approximately 19,000 nests were initiated in WY2008, representing a 51 percent decline from last water year and a 74 percent decline from the banner nesting season of 2002. Poor reproductive effort and success can be attributed to a combination of dry conditions during preceding years and unfavorable hydrologic conditions during nesting.	ROS, CERP, MFL, FIEM
Factors Affecting Foraging Habitat Selection and Foraging Success of Wading Birds	Birds selected foraging sites with moderate levels or no amount of emergent vegetation at the LILA facility. Depth was the more important cue. Depth and emergent vegetation did not affect foraging success.	ROS, CERP, MFL, FIEM
Non-native Fish Minimum Temperature Tolerances	The minimum temperature tolerance of non-native jewelfish (*Hemichromis letourneuxi*) and Mayan cichlid (*Cichlasoma urophthalmus*) is approximately 10 °C. These species are susceptible to cold winter conditions in shallow Everglades marshes but deep canals function as thermal refugia.	CERP
Plant Ecology		
Lygodium Survey on Tree Islands in WCA-3A and 3B	Old World climbing fern (*Lygodium microphyllum*) has been expanded into WCA-3B where more than 60 percent of the tree islands are infested by this exotic climbing fern. However, the extent of the infestation on any particular island is small and can be treated with herbicide spot spraying.	ROS, CERP
Woody Plant Recruitment and Survivorship along a Hydrologic-Soil Nutrient Gradient on Two Tree Islands in WCA-3	Seedling density is higher on short hydroperiods tree island heads than on long hydroperiod near-tails. Similarly, seedlings of tree species that are less water tolerant, such as white stopper (*Eugenia axillaris*) and cocoplum (*Chrysobalanus icaco*), dominate areas of short hydroperiods and soil total phosphorus is relatively high.	ROS, CERP, EFA
Tree Island Ecophysiology as a Measure of Stress	Significant seasonal differences in water potential (Ψ) and $\delta^{18}O$ isotopes were observed between and within four study islands, suggesting that sap-flow measures are a sensitive tool for determining short-term plant responses to hydrologic conditions. An increase in hydroperiod may reduce the prevalence of lesser flood-tolerant species such as golden leatherfern (*Acrostichum aureum)* and swamp bay *(Persea palustris*).	ROS, CERP, EFA
Periphyton Polysaccharides	Content and composition of extracellular polymeric substances (EPS) — carbon-rich polysaccharides secreted by algae — were found to be regulated by the species composition of periphyton. Since EPS has several important ecological functions (e.g., controlling the cohesive properties of periphyton, providing a carbon-rich substrate for bacteria; and regulating the decomposition of periphyton), it is hypothesized that changes in EPS production can influence water quality, food-webs, and distribution of floc.	ROS, CERP, LTP,
Tree Survival and Growth at the LILA site	Two-year survival in several tree species planted at LILA was strongly inhibited by flooding, but growth was less sensitive to hydrology. The effects of planting density on growth and survival were negligible (year two).	CERP, ROS, MFL

Table 6-1. Continued.

Projects	Findings	Mandates
Ecosystem Ecology		
Cattail Habitat Improvement Project	Open plots experienced higher microbial biomass, greater microbial activity, higher periphyton productivity, more nutritional plants (i.e., algae), greater decomposition rates, reduced detritivore biomass and supported higher wading bird foraging than the surrounding cattail habitat. Wading bird foraging in enriched plots was of longer duration than that observed in reference sites. The sustainability of these trophic improvements is not yet known.	LTP, ROS
Accelerating Recovery of Impacted Areas	Fire characteristics such as timing, intensity, and frequency will significantly influence ecosystem responses. Cattail communities cannot sustain annual summer burning frequencies and litter needs to accumulate for at least two years to develop sufficient fuel loads.	LTP, EFA
Tree Island Hydrodynamics	Groundwater-surface water interactions on tree islands, i.e., the ability for water to percolate into the aquifer or up-well from the aquifer, was found to be dynamic due to variations in underlying geology and surface water levels. It is hypothesized that this can have a profound impact on tree island nutrient cycling.	CERP, EFA
Tree Island Nutrient Fluxes	The wet head lost total nitrogen and total phosphorus through infiltration, whereas the near-tail had a net accumulation of total nitrogen and total phosphorus. These findings suggest that there is a directionality of nutrient fluxes. If hydrologic connectivity between head and tail plant communities are altered, then nutrients could be lost from the head and exported to adjacent marshes.	ROSS, EFA
Evaluating Phosphorus Flux – The Supplemental Sediment Core Study	Sediment cores collected from the phosphorus-impacted area in WCA-2A exhibited a slow, continuous release of sediment phosphorus. Eradication of cattail with herbicide resulted in a high and prolonged release of phosphorus from decomposing plant tissues. $CaCO_3$-amended treatments lowered the outflow phosphorus concentrations while iron treatment exacerbated the release of soil phosphorus.	LTP
Landscape		
Landscape Pattern Change	Many landscape patterns in WCA-3 have changed since 1940. The nature of the patterning was quantified and trajectories plotted to describe how it has changed over six decades. Historical changes in 15 large plots show decline in some areas and no change in others, while some have actually improved from since 1940. Decadal responses to local conditions can be clearly identified.	ROS, EFA
Relative Marsh and Tree Island Elevation: Spatial Patterns in WCA-3A and WCA-3B	The average elevation difference between the maximum tree island elevation and the surrounding marsh-slough was 0.60, 0.75, and 0.85 meters at central WCA-3A, southern WCA-3A, and WCA-3B, respectively. Low elevated tree islands in southern WCA-3A are subjected to abnormally long hydroperiods.	CERP, ROS, EFA
Elevation Change and Soil Accretion in the Mangrove Salinity Transition Zone	Soil accretion is lower in long hydroperiod mangroves than in short hydroperiod mangroves. Similarly, elevation change was negative in long hydroperiod environments, indicating that most mangrove forests in the salinity transition zone are not keeping pace with current sea level rise.	MFL, ROS
CERP Vegetation Mapping	The WCA-1 vegetation map has been completed with a determined overall map accuracy of 93.2 percent. The map can be used to depict overall vegetation categorization for the area and specifically for cattail, tree islands, and the exotics Old World climbing fern and melaleuca (*Melaleuca quinquenervia*).	CERP, LTP, FEIM

HYDROLOGIC PATTERNS FOR WATER YEAR 2008

Fred Sklar

The amount of annual rain in the Everglades Protection Area (EPA) for Water Year 2008 (WY2008) (May 1, 2007–April 30, 2008) was greater than last water year by as much as 10.6 inches as in Water Conservation Area 1 (WCA-1), or by as little as 4.6 inches (in.) as in Water Conservation Area 3 (WCA-3). Most of this added rainfall fell during the dry season (November, 16, 2007–May 15, 2008), which is when wading birds nest, making wading bird foraging conditions unfavorable. The rainfall and associated stage readings for WY2008 are shown in **Table 6-2**. WCA-1 and Water Conservation Area 2 (WCA-2) together had a seven percent increase in rainfall compared to historical amounts and a 24 percent increase over WY2007. Conversely, even though there was increased rainfall in WCA-3, the amount was still a five percent decrease compared to historical periods, and was only 10 percent more than WY2007. Everglades National Park (ENP or Park) had a 10 percent increase compared to historical rainfall amounts and a 15 percent increase over WY2007. It is interesting to note that after a year of severe drought, the maximum stage for WCA-1 in WY2008 came close to the historical maximum stage. This hydrology may account for the resilience of the wading bird populations that were clustering in this region in WY2008.

Most of the rain fell during the wet season months of June and September in WY2008, and then again during the dry season months of February, March, and April. In the Park, for example, rainfall was 13.28 inches in June 2007, and 10.99 inches in September 2007. From March through April 2008, monthly rainfall in the Park averaged about 2.75 in. In the WCAs, rain in June was about 8.5 in. and in September was about 9.0 in. In the WCAs, there were only two months out of the water year that rainfall dropped below 1 inch. In the Park, rainfall was below 1 inch (per month) from November 2007 through January 2008. As shown in the hydrographs that follow, what might be expected from an above-average annual rainfall following a year of drought (i.e., a return to good foraging for wading birds) did not come to fruition in WY2008.

Table 6-2. Average, minimum, and maximum stage [feet National Geodetic Vertical Datum (ft NGVD)] and total annual rainfall (inches) for Water Year 2008 (WY2008) in comparison to historical stage and rainfall.[1] (Average depths calculated by subtracting elevation from stage.)

Area	WY2008 Rainfall	Historical Rainfall	WY2008 Stage Mean (min; max)	Historical Stage Mean (min; max)	Elevation (ft NGVD)
WCA-1	55.54	51.96	16.20 (13.57; 17.54)	15.60 (10.0; 18.16)	15.1
WCA-2	55.54	51.96	12.26 (10.29; 13.98)	12.55 (9.33; 15.64)	11.2
WCA-3	48.89	51.37	9.3 (5.89; 10.16)	9.53 (4.78; 12.79)	8.2
ENP	60.92	55.22	5.94 (5.39; 6.33)	5.98 (2.01; 8.08)	5.1

[1] See Chapter 2 of this volume for a more detailed description of the historic periods associated with rain, stage, inflows, and outflows for each area.

The following hydropattern figures (**Figures 6-1** through **6-7**) highlight the average stage changes in each of the WCAs for the last two years. The figures also show the relation to recent historical averages, flooding tolerances for tree islands, drought tolerances for wetland peat, and recession rates and depths that support both nesting initiation and foraging success by wading birds. These indices were used by the South Florida Water Management District (SFWMD or 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, 2003). **Figures 6-1** through **6-7** show the ground elevations in the WCAs as being essentially the same as the threshold for peat conservation. The wading bird nesting period is divided into three stoplight categories (red, yellow, and green) based upon foraging observations in the Everglades (Gawlik, 2002). A red label indicates poor conditions due to recession rates that are too fast (greater than 0.6 foot per week) or too slow (less than 0.04 foot for more than two weeks). A red label is also given when the average depth change for the observed week is positive rather than negative. A yellow label indicates fair conditions due to a slow recession rate of 0.04 foot for a week or a rapid recession between 0.17 and 0.6 foot per week. A green/good conditions label is assigned when water depth decreased between 0.05 and 0.16 foot per week. Although these labels are not indicative of an optimum 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 annual dry season (i.e., April and May).

WATER CONSERVATION AREA 1

WCA-1 started at very low water conditions in WY2008 after a nine-month period of below-average water levels. Water depths rose from a low in June 2007 of only a few inches to depths of 2.5 ft in three months and remained above average throughout the rest of the water year (**Figure 6-1**). The upper flooding tolerances for tree islands were reached very briefly in October 2007. Recession rates were poor for most of the 2008 dry season and stage trends were opposite from the steady declines observed during the previous dry season. Last calendar year (CY2007), water depths became optimum for foraging in central and southern WCA-1 during April and May. This water year, optimum depths were not reached until June 2007. However, June was probably an excellent foraging month because April and May had good recession rates, creating the perfect set-up for foraging when the right depths are reached. Unfortunately, by July 2007, the optimum depths were starting to be exceeded. Dry season foraging by wading birds in WCA-1 probably slowed significantly in mid-July. For the third year in a row, WCA-1 had the longest duration of good nesting and foraging periods of any region in the EPA.

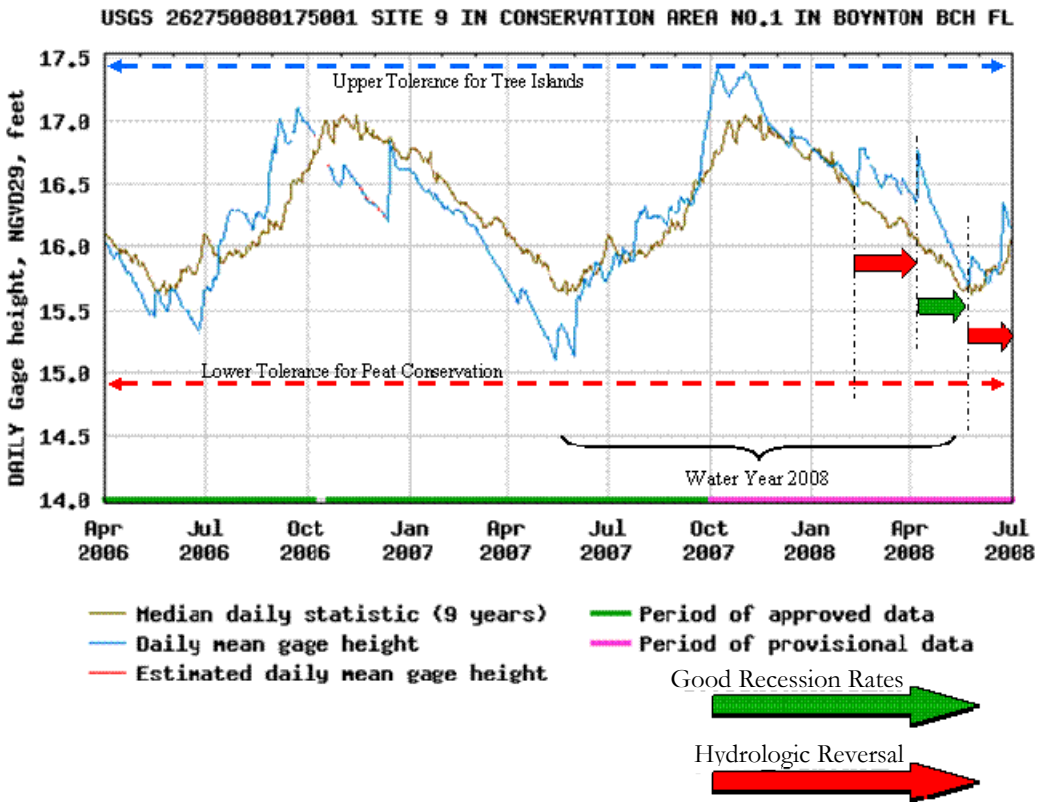

Figure 6-1. Hydrology in WCA-1 in relation to the nine-year median stage and indices for tree island flooding, peat conservation, and wading bird foraging.

WATER CONSERVATION AREAS 2A AND 2B

For the last three years (WY2006–WY2008) in WCA-2A, the stage levels during the wet season have exceeded the upper flood tolerance for tree islands for periods of one to two months, which is not enough to cause any tree island damage (Wu et al., 2002). The few islands that remain in this region are not likely to be impacted due to their northwest location within the WCA and their relative elevations. However, future efforts to restore WCA-2A islands will require a closer examination (i.e., frequency analysis) of these kinds of exceedances. In WCA-2A, the WY2006 and WY2007 dry seasons were very similar. Both dry seasons had very good recession rates, and both times the region completely dried out. However, in WY2006, WCA-2A exhibited excellent foraging conditions and many flocks of wading birds were observed. In WY2007, the hydroperiod was very short and stage was below average for most of the year — as a result, reports of large or multiple flocks were greatly reduced. In WY2008, there was some evidence of a large return of the WCA-2A prey base for wading birds because the hydroperiod was lengthened and foraging was limited to May 2007 due to poor recession rates for most of the dry season (**Figure 6-2**).

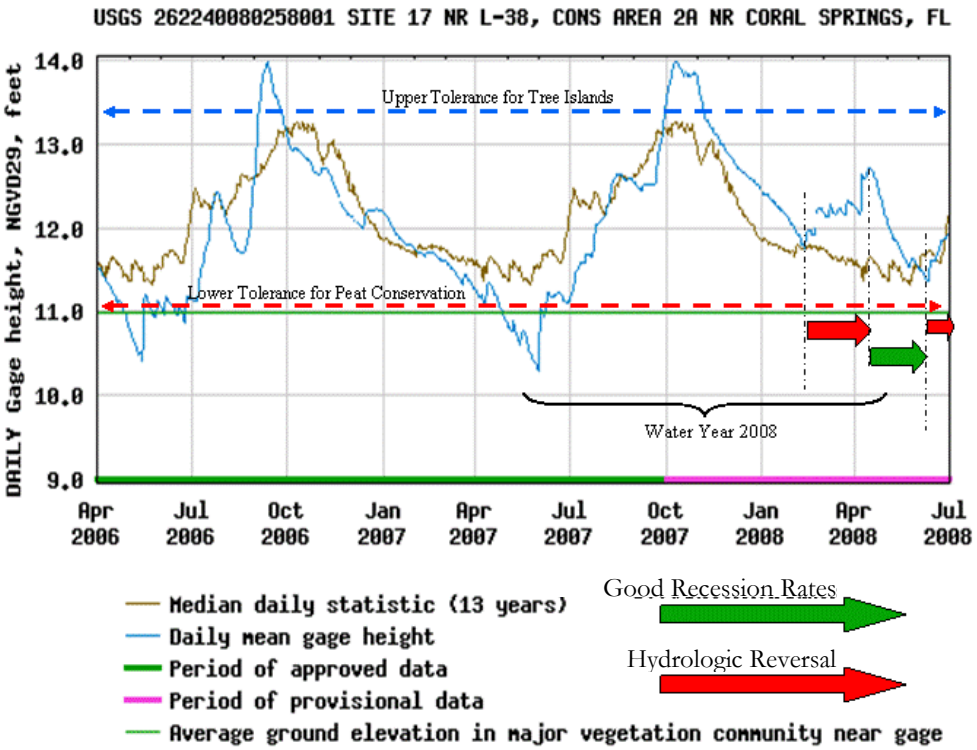

Figure 6-2. Hydrology in WCA-2A in relation to the recent 13-year average, and indices for tree islands, peat conservation, and wading bird foraging.

WCA-2B has always been utilized by wading birds during droughts because it tends to stay deeper for longer periods than the rest of the EPA. This was particularly true in WY2006 when dry season water levels went belowground in WCA-2A and the wading birds moved to WCA-2B. In WY2007, the drought was so severe that even WCA-2B became too dry to support any foraging from May to July (2006). The depth-drop to two feet below ground in this region was unique. This water year was a different. July rainfall caused water depths to increase rapidly in WCA-2B — a maximum depth of about 4 feet was reached in November. Just when wading birds needed good recession rates (March, April, and May), water levels increased and never dropped low enough to support foraging (**Figure 6-3**). Relief from foraging in WY2008 is expected to increase the prey base in this region and possibly support large nesting flocks in WY2009.

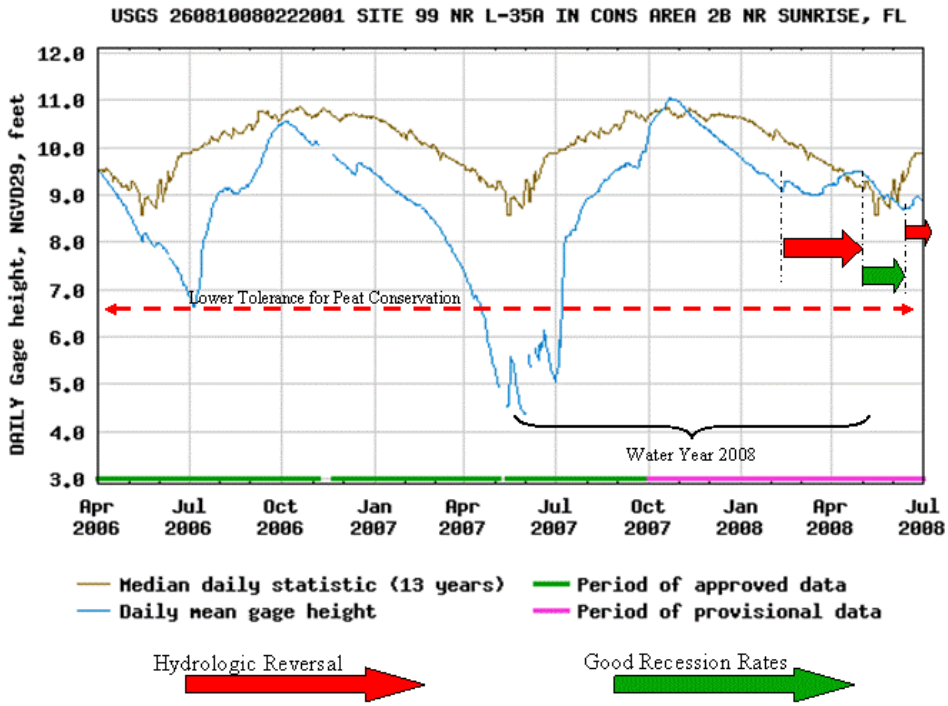

Figure 6-3. Hydrology in WCA-2B in relation to the recent 13-year average, indices for peat conservation, and wading bird foraging. Indices for tree islands in this region do not apply.

WATER CONSERVATION AREA 3A

The hydrology in the northeastern region of WCA-3A (gauge 63) in WY2008 was very different from that in WCA-1 and WCA-2A (**Figure 6-4**). In this part of the Everglades, the WY2007 drought extended well into WY2008. (Note: More than one foot below ground violates the guidance for MFLs.) It is very unlikely that such a reduced hydroperiod could be capable of rejuvenating the prey base for the large wading bird rookery (Alley North) where 20,000–30,000 nests have been historically observed. Water depths barely went over 1 foot for a few weeks. When nesting was expected to begin in March, water levels increased instead of declining characteristically to concentrate the prey base into sloughs and pools. This region dried out to a much greater degree than it did in WY2007. The combination of a late wet season and extended dry season created an inhospitable environment for wading birds, especially those that have historically frequented the popular Alley North Rookery; this rookery was unused in WY2008.

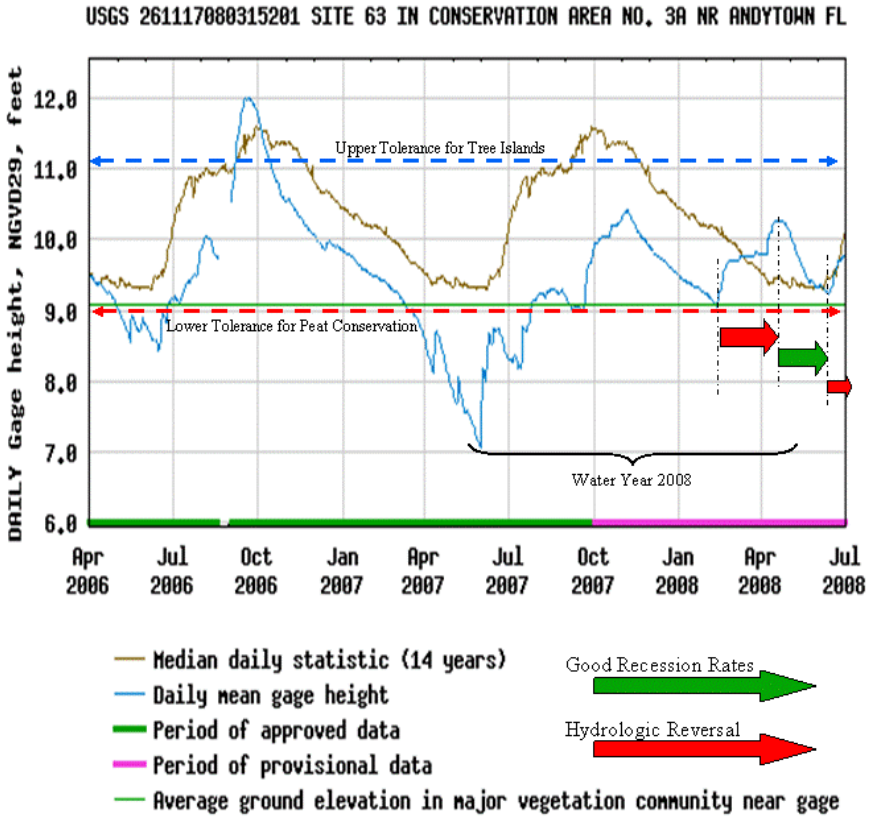

Figure 6-4. Hydrology in northeast WCA-3A (gauge 63) in relation to the recent 14-year average and indices for tree islands, peat conservation, and wading bird foraging.

The hydrologic pattern in central WCA-3A (gauge 64) in WY2008 did not suffer the drought as much as the northeast WCA-3A (**Figure 6-5**). Although there was no MFL departure, there was instead a greatly reduced wet-season stage. Water depths did not go above 1 foot until October and never went over 2 feet the entire water year. What should have been a great wading bird foraging environment starting in March was instead disrupted by increasing water levels rather than decreasing water levels for almost the entire nesting (dry) season. Last year the shallow depths and short duration of the wet season was probably sufficient to cause widespread depletion of wading bird prey species. In WY2008, the lack of foraging and the longer hydroperiod may well translate into a banner prey base for next year (WY2009).

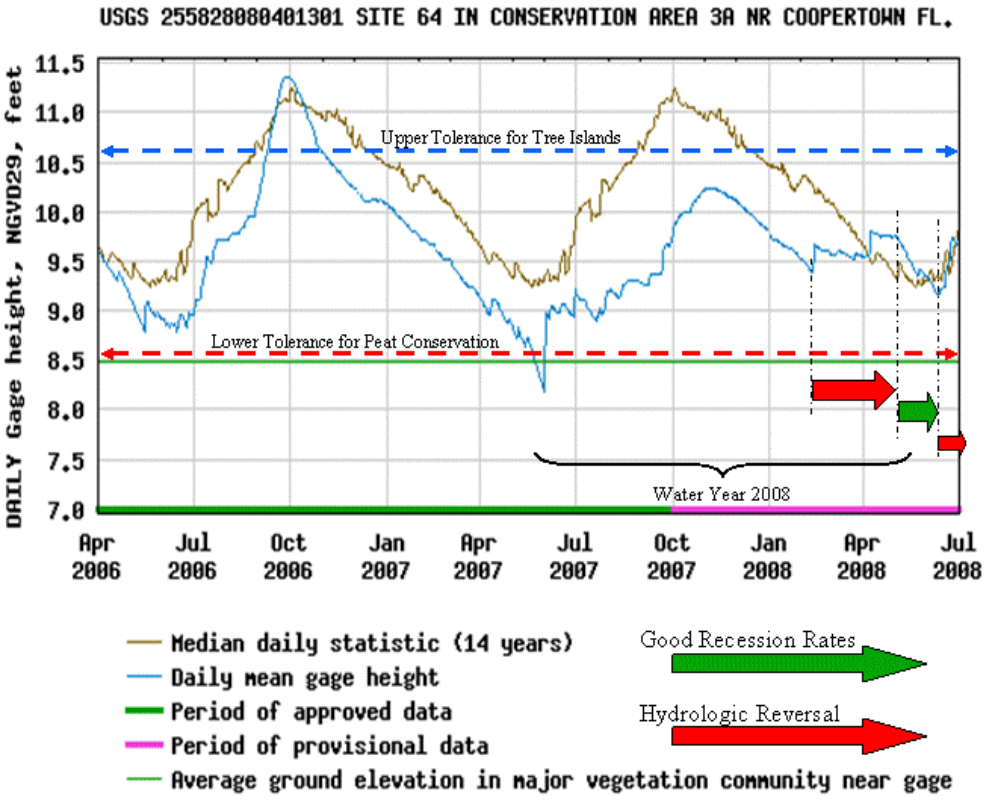

Figure 6-5. Hydrology in central WCA-3A (gauge 64) in relation to the recent 14-year average and indices for tree islands, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 3B

In WY2006, the water depths in WCA-3B did not go below 0.5 foot (optimum foraging depth) until May 2006, after most nesting behaviors had ceased. In WY2007, short but numerous reversals made this region marginal for foraging. WY2008 depths remained almost constant all year round, and recession rates were not long-lived enough (**Figure 6-6**) to function as a prey-concentrating mechanism (assuming that depths were adequate for prey recruitment). For three years in a row (WY2006–WY2008), this region's hydrology has not supported wading bird nesting or foraging.

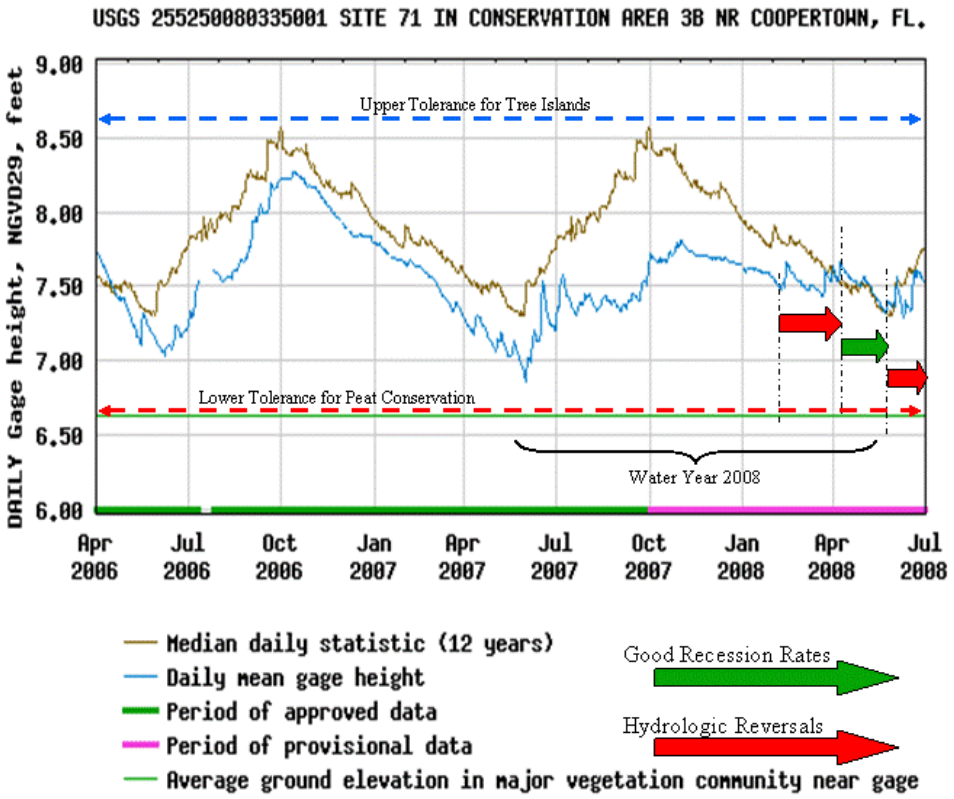

Figure 6-6. Hydrology in central WCA-3B (gauge 71) in relation to the recent 12-year average and indices for tree islands, peat conservation, and wading bird foraging.

NORTHEAST SHARK RIVER SLOUGH

The uniqueness of the hydrology and drought in the Everglades during WY2007 and WY2008 is captured by the Northeast Shark River Slough hydrograph (**Figure 6-7**). For three years in a row this region of Everglades National Park experienced significant departures from the MFL standard. These departures mostly occurred in WY2008. Water levels in this part of the system began dropping in December 2007, and never had any water to support wading birds during the nesting season. It is no surprise, looking at this hydrograph, that large areas of this region (i.e., the Mustang Corner) experienced vegetation and peat fires this past year. A prey base would be unlikely to recruit for next year and foraging is not expected to be good again in this region until at least WY2010.

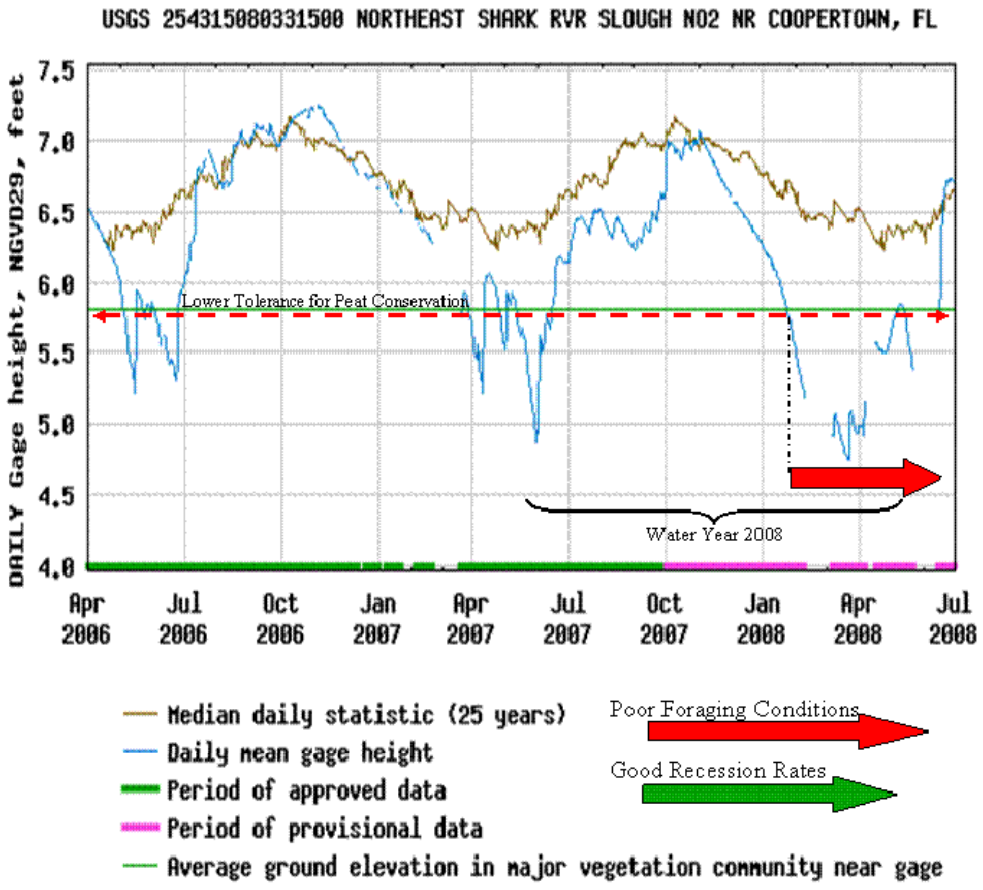

Figure 6-7. Hydrology in Northeast Shark River Slough in relation to the recent 25-year average and indices for tree islands, peat conservation, and wading bird foraging.

WILDLIFE ECOLOGY

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Previous research has shown that the distribution of wildlife in the Everglades is a function of hydrology, water quality, climate, and biotic interactions. Wildlife studies are conducted in the Everglades by the District, Everglades National Park (ENP or Park), U.S. Fish and Wildlife Service (USFWS), Florida Fish and Wildlife Conservation Commission (FWC), and Florida universities. The District focuses largely on the interactions between wading birds, aquatic prey species, and hydrology as part of a long-term goal to restore historical wildlife populations and a short-term goal to prevent further environmental degradation.

This section summarizes wading bird nesting effort and success during the 2008 breeding season (WY2008) and reports on year two of an experimental study at the Loxahatchee Impoundment Landscape Assessment research facility (LILA) examining how vegetation density and hydrology affect wading bird foraging success (a collaboration with Florida Atlantic University). This section also reports on an experimental examination of the physiological tolerances (temperature and salinity) of two non-native fish species [a collaboration with the U.S. Geological Survey (USGS)]. Elucidating the temperature tolerance of these tropical invaders is critical for predicting future dispersal patterns and providing management options for their control. Additional wildlife studies were conducted as part of the Cattail Habitat Improvement Project (CHIP) experiment and are reported in the *Landscape Processes* section of this chapter.

WADING BIRD MONITORING

Wading birds are excellent indicators of wetland ecosystem health and have a central role in the Comprehensive Everglades Restoration Plan (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*)

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[4] U.S. Geological Survey, Florida Integrated Science Center, Everglades National Park Field Station, Homestead, FL.

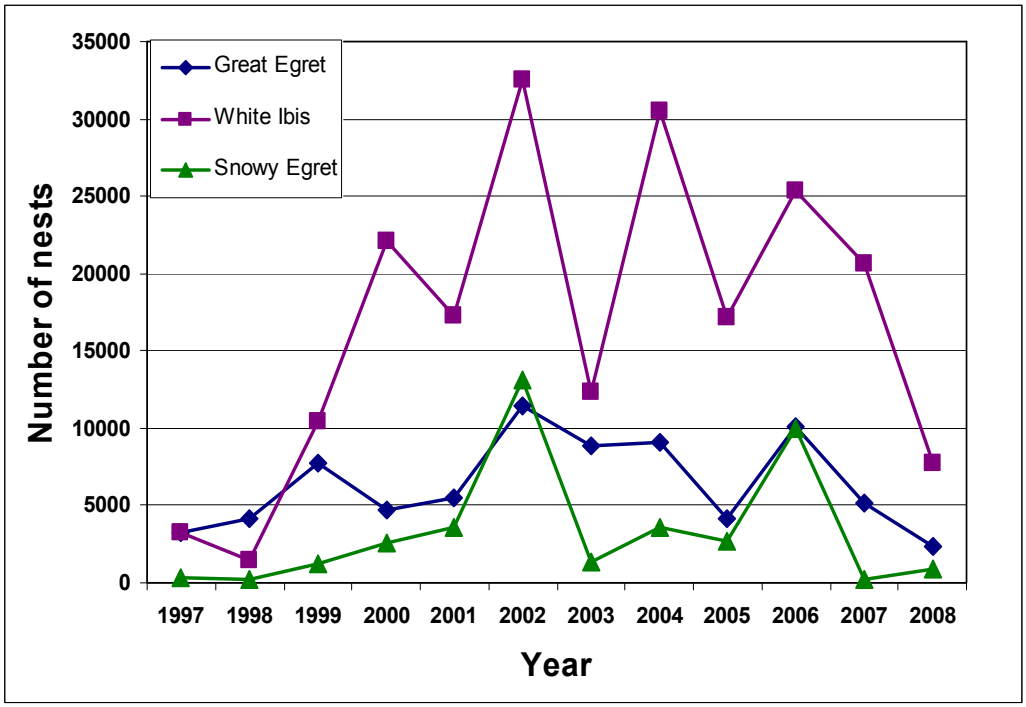
The timing of breeding, number of nests, and location of nesting colonies within the Everglades are used as CERP targets to evaluate the progress of the Everglades restoration effort. In addition to CERP, wading birds are of special interest to the public and play a prominent role in adaptive protocols,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

- 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 tricolor herons, 10,000–25,000 pairs of white ibises, and 1,500–3,000 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 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.
- Reestablishment of 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 Everglades basin.
- For wood storks, restore productivity for all colonies combined to greater than 1.5 chicks per nest.

The information reported in this section represents a compilation of data collected by a variety of institutions which includes Florida Atlantic University (FAU), University of Florida (UF), the ENP and the Audubon Society. The data counts include all wading bird species (except cattle egret, *Bubulcus ibis*) nesting throughout the South Florida region (for details on colony locations see Cook and Herring, in prep.) The period covered by this report is the nesting season from February through July 2008.

The estimated number of wading bird nests in South Florida in 2008 was approximately 18,418. This is a 51 percent decrease relative to last year's season and is 74 percent less than the 68,750 nests of 2002 (the best nesting year on record in South Florida since the 1940s), and 59 percent less than the average of the last eight seasons. All species of wading birds suffered significantly reduced nest numbers relative to the past 10 years (1999–2008) (**Figure 6-8**). Wood stork nesting was very much reduced and nesting was not initiated at the historical Corkscrew colony for the second consecutive year. White ibis nests were 61 percent of WY2007's and 64 percent of the past 10. Roseate spoonbill nest numbers were the lowest since records began. WY2008 had few wading bird nests relative to both the previous decade and pre-drainage years.



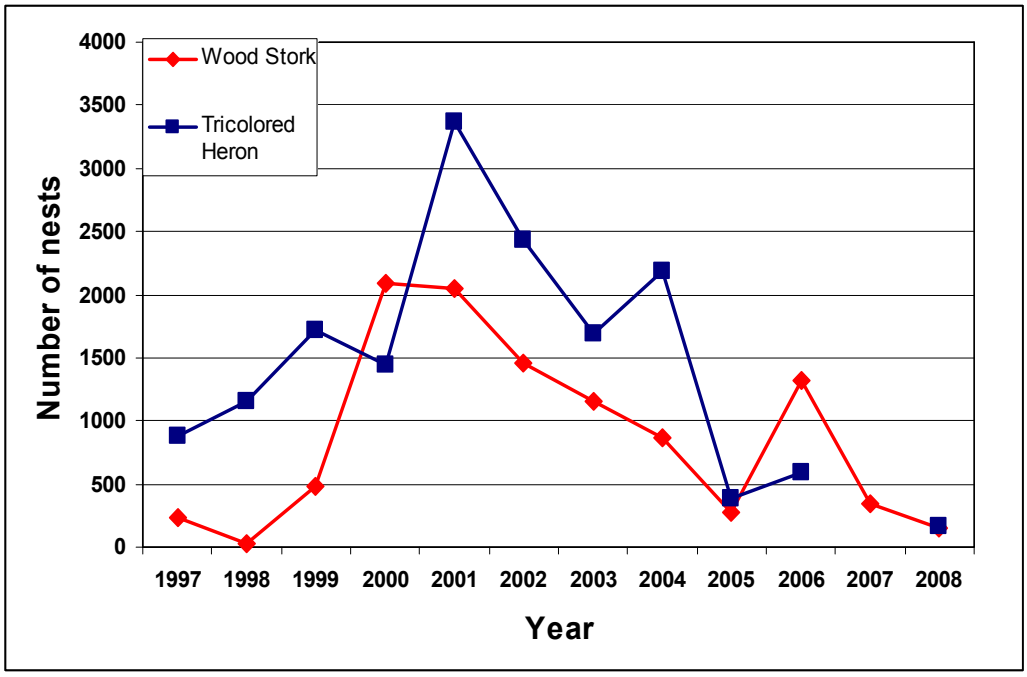


Figure 6-8. Historical wading bird nesting numbers in the Everglades for individual species since 1997.

Nesting effort in the Everglades is rarely distributed uniformly among regions. In 2008, WCA-1 supported the most nests (71 percent) followed by WCA-3 (23 percent), whereas the ENP supported the lowest number of nests (6 percent). This spatial distribution of nests continues the recent trend of an annual increase in the proportion of birds nesting in WCA-1 at the expense of nesting in WCA-3. The Park historically supported the largest number of nests in the system. CERP's goal is to restore hydrologic conditions to reestablish aquatic prey densities and concentrations across the landscape that, in turn, will support the return of large, successful wading bird nesting colonies to the Southern Everglades. Nesting effort in the estuaries has increased gradually over recent years (for example, by 20 percent in the 2006 season), but in WY2008 the estuaries supported only minimum nesting. Another pattern over the past 10 years has been for a large proportion of nests in South Florida to be concentrated in a single large colony (Alley North) located in northeast WCA-3A. For two consecutive breeding seasons, Alley North and the adjacent marsh dried prior to breeding and nesting was not initiated at the colony.

Generally, nesting was not successful for most species. Large abandonments occurred throughout the system after water level reversals in March and April 2008. In the few places that wood storks attempted to nest (Paurotis Pond and Cuthbert Lake), all nests failed immediately after these rain events. However, the presence of large numbers of mature white ibis chicks at Lox West colony in July 2008 suggests that later-nesting ibis in WCA-1 were reasonably successful.

The annual nesting response of wading birds improves the scientific understanding of how the Everglades ecosystem functions. WY2008's unsuccessful nesting season is probably a consequence of the direct effects of hydrology on foraging success and its indirect effects on prey production. Recession rates in WY2008 were largely classified as 'poor' and stages were generally too deep (WCAs) or too shallow (ENP) for effective wading bird foraging (see the *Hydrologic Patterns for WY2008* section of this chapter). Moreover, the annual monitoring of prey densities during the seasonal drydown reveals that WY2008 experienced significantly reduced aquatic prey production relative to WY2006 (Gawlik, personal communication), probably due to the extended dry conditions that have prevailed since WY2006. More stable water conditions in WCA-1 over the last two years and during the course of the 2008 season likely contributed to the dramatic difference in the number of nests and nest success of this region relative to WCA-3A and the ENP.

Two of four species groups (great egrets and white ibis) met the numeric nesting targets proposed by the South Florida Ecosystem Restoration Task Force (**Table 6-3**). Two other performance measures for Everglades restoration are (1) an increase in the number of nesting wading birds in the coastal Everglades and (2) a shift in the timing of wood stork nesting to earlier in the breeding season (Ogden, 1994). The 2008 nesting year showed no improvement in the timing of wood stork nesting or a general shift of colony locations.

Conclusion

Wading bird reproduction did not meet CERP performance targets and WY2008 can be considered an unsuccessful breeding season. The poor reproductive effort and low success were almost certainly due to two preceding years of drought and its affect on system-wide prey productivity. Low stages and short hydroperiods are not conducive to fish and crayfish production, and many areas in WY2007 and WY2008 were characterized by reduced dry-season prey densities (Dale Gawlik, personal communication) and nestling diets that contained high proportions of terrestrial prey (Mark Cook, personal observation). WY2008 did receive higher-than-average annual precipitation, but much of this rain fell too late to benefit aquatic

fauna. Instead, rain fell during the dry season causing widespread water-level reversals and the dispersal of an already limited prey base. This appeared to result in widespread nesting failure for those birds that did attempt nesting.

Table 6-3. Numbers of wading bird nests in the WCAs and the ENP compared to CERP targets and historical ranges. Target numbers are based on the known numbers of nests for each species during the pre-drainage period (1930–1940) that were summarized by Ogden (1994).

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

FACTORS AFFECTING FORAGING HABITAT SELECTION AND FORAGING SUCCESS OF WADING BIRDS IN THE EVERGLADES

Making quantitative predictions of wading bird population responses to hydrologic and habitat changes as a result of CERP will require a clearer understanding of wading bird responses to prey availability. Prey availability is a composite variable consisting of both prey density and the vulnerability of the prey to capture, which can be affected by characteristics of the predator, prey, and environment. The actual numbers of food, or prey, in an environment may not be as important to foragers as the effects of their habitat on how easily prey can be captured (Wiens, 1984; Sutherland, 1996; Gawlik, 2002). Water management and CERP are expected to produce major changes to wading bird habitat through effects on vegetation and hydrology. A key question is: How will habitat changes translate into effects on wading bird prey availability?

The Loxahatchee Impoundment Landscape Assessment (LILA) study experimentally investigates environmental factors effecting wading bird prey availability, focusing on the effects of vegetation density and water depth on wading bird foraging habitat selection and foraging success. The objectives of the experiments were to determine the effects of water depth and submerged aquatic vegetation (SAV) density (year one) or emergent vegetation density (year two) on wading bird foraging habitat selection and foraging success. It is hypothesized that wading birds will select foraging habitat with shallow water and lower densities of emergent vegetation because of increased prey availability under these conditions. Results from year two are reported here and compared to year one.

Methods

To quantify the effects of water depth and emergent vegetation on wading bird foraging, habitat selection, and foraging success, experiments were conducted in January 2008, and March 2008, at LILA. During the experiments, three 10 × 10 meter (m) nylon mesh enclosures each were established in both the deep and shallow sloughs of macrocosms one and four.

Two water depth treatments [10 centimeters (cm) and 25 cm] and three emergent vegetation densities [0 stems per 0.25 square meter (m^2); sparse densities of 11.5 ± 5.7 stems per 0.25 m^2; and moderate densities of 34.8 ± 8.2 stems per 0.25 m^2 of spike rush, *Eleocharis* sp.] were used to evaluate effects on wading bird foraging. Enclosures were stocked with 20 fish/m^2 mosquitofish (*Gambusia holbrooki*), a species that is native to the Everglades. Average fish size was 24.4 ± 0.3 millimeters (mm) standard length. Daily restocking within the enclosures ensured constant fish density throughout the experiments.

The number of fish restocked daily was determined using mark-recapture methods. Fish were marked in batches using Visible Implant Elastomer. Lincoln-Peterson estimates were used to estimate population size and additional fish were added maintain original stocking densities.

Every morning of the experiment, white plastic wading bird decoys were placed in each enclosure (Crozier and Gawlik, 2003). These decoys served to initially attract wading birds to the macrocosms to forage. Observations were conducted by vehicle from a nearby levee, or by individuals sitting on the levee.

The numerical response of wading birds was quantified in the field by documenting the presence of foraging wading birds in each enclosure throughout the entire observation period. Wading bird use of the enclosures was compared to availability to determine foraging habitat selection using Manly's standardized selection index.

Birds were videoed foraging in enclosures, and then converted to time-activity budgets using EthoLog 2.2 (Ottoni, 2000), from which capture rate and capture efficiency was calculated. Capture rate was defined as the number of prey captured per minute, and capture efficiency as the percent of successful strikes.

A habitat selection probability was established first (Manly et al., 1993; 2002) for wading birds using the formula:

$$Wi^* = Ui / (A+ \pi i)$$

where Ui = the number of used habitat units in treatment i (i.e., the number of times each habitat treatment was used by wading birds), and

A+ = the size of the total population of available habitat units (all habitat treatments), and πi = the proportion of available habitat units that are in treatment i (Manly, 2002). Then a standardized selection index for each habitat treatment was calculated using the following formula:

$$Bi = \hat{w}i / \left(\sum_{i=1}^{I} \hat{w}j\right)$$

where $\hat{w}i$ = habitat selection ratio for treatment I; and $\hat{w}j$ = sum of all habitat selection ratios.

Results and Discussion

Manly's standardized selection index showed that birds preferred sites with shallow water and sparse vegetation (**Table 6-4**). However, vegetation density had no apparent effect on foraging success, measured through both capture rate ($p = 0.19$) and efficiency ($p = 0.29$). Because of strong selection for shallow water (birds largely did not occur in the deep water treatment), differences in foraging success factors between water depths were not investigated. These results suggest that wading birds selected sites with shallow water and sparse levels of vegetation because they anticipated higher prey densities (in this case, though, prey density was controlled).

These results are in agreement with the findings from the SAV experiments discussed in Sklar et al. (2008). Birds showed strong selection for shallow water and vegetated habitat, but accrued little benefit in terms of foraging success. These patterns indicate that wading birds may forage equally successfully across a wide gradient of habitat conditions, including water depth (10-25 cm), SAV density, and emergent vegetation density, as long as prey densities are relatively high. If birds were allowed to deplete prey consistently throughout the experiment (if prey was not restocked daily), it is likely that birds would have abandoned the enclosures when prey densities reached species-specific giving-up densities (Gawlik, 2002). Thus, in determining ideal wading bird habitat as part of the Everglades restoration, suitable prey densities across various conditions may present suitable foraging habitat for wading birds. Focus on a hydrologic regime that provides a continual mosaic of areas with suitable water depths and prey availability throughout the dry season may be more important to wading bird conservation than specific parameters such as exact depths or plant densities.

Table 6-4. Manly's standardized selection index with 95 percent confidence limits for wading bird foraging habitat selection in relation to water depth and emergent vegetation density. Wading bird use was compared to availability across six enclosures in Loxahatchee Impoundment Landscape Assessment (LILA). A selection index greater than the population proportion indicates selection, and less than indicates avoidance.

Water Depth	Emergent Vegetation Density	Population Proportion	Selection Index	Confidence Limits	
				Lower	Upper
Shallow	None	0.167	0.302	0.285	0.319
Shallow	Sparse	0.167	0.404	0.386	0.422
Shallow	Moderate	0.167	0.208	0.193	0.223
Deep	None	0.167	0.037	0.030	0.044
Deep	Sparse	0.167	0.030	0.024	0.036
Deep	Moderate	0.167	0.019	0.014	0.024

NON-NATIVE FISH MINIMUM TEMPERATURE TOLERANCES

There are approximately 15 non-native fish species established in the Greater Everglades Region, and most of these are undesirable, illegal introductions (Loftus, 2000). The potential impact of these invasive species recently became a high priority for CERP planning, requiring research on the distribution, biology, and impacts of these species (RECOVER, 2006) and the development of performance measures (Ogden, 2004; Ferriter et al., 2008).

Most exotic fish species inhabiting the EPA are native to the tropics, and their capacity to invade temperate or subtropical systems is fundamentally linked to minimum winter water temperatures. Determining minimum-temperature mortality thresholds of key invasive species is critical for predicting species dispersal patterns across South Florida and for developing practical management options for their control.

The African jewelfish (*Hemichromis letourneuxi*) and Mayan cichlid (*Cichlasoma urophthalmus*) are non-native *Cichlidae* of tropical origin that are currently spreading throughout freshwater and estuarine habitats of South Florida. Little is known of their tolerances to low temperatures or how salinity modifies their low-temperature tolerance. This study used laboratory and field experiments to examine the temperature tolerance of these cichlid species.

The laboratory component was designed to determine the minimum-temperature tolerance of both species [two endpoints were examined: loss of equilibrium (LOE) and death]. The field component examined LOE and mortality of caged fishes in relation to temperatures of canals and marsh habitats in the ENP and LILA during a January 2008 cold front. The objectives were to (1) determine how a cold front affected the water temperature profiles in shallow (marsh) and deep (canal) aquatic habitats and (2) how that in turn affected the physiological response of the two focal species in those habitats. Endpoints were compared to a control group. The results of the field component are discussed in terms of the minimum temperature thresholds determined under controlled conditions from the laboratory study.

Note that the laboratory trials also examined the effect of acclimation salinity and temperature on low-temperature tolerance, and individuals of each species in this study were held at one of three salinities and two holding temperatures. These results are available at http://fl.biology.usgs.gov/projects/low_temperature_tolerance.html (as of November 2008).

Methods

The laboratory study was conducted at the USGS Florida Integrated Science Center, Gainesville, Florida. African jewelfish were collected from the ENP (N25°25.066, W80°38.605) in October 2007, and low-temperature trials were conducted in November 2007. Mayan cichlids were collected from WCA-2A (N26°21.223', W80°17.885') in December 2007, and trials were conducted in January 2008.

Prior to trials, fishes were held for between 13 and 32 days at two acclimation temperatures (28 and 24°C) at three salinities [0, 10, and 35 practical salinity units (psu)] that reflect typical salinities in freshwater (< 0.5), estuarine (0.5-17), and marine (32-37) systems.

Critical thermal methodology (CTM) was used to quantify temperature tolerances of the two species (Beitinger et al., 2000), which consists of subjecting fish to a continuous, linear decrease in temperature until an endpoint is reached. The study had two endpoints: LOE and death. LOE was the inability of a fish to right itself (i.e., lying on its side). Death was determined by lack of movement and subsequent examination in a hand net.

Experimental fishes (n = 67 African jewelfish, n = 53 Mayan cichlid) were removed from holding tanks, placed in individual observation tanks containing water from their holding tank, and subjected to a continuous one-degree-Celsius-per-hour decrease in temperature (based on the typical pattern of chilling during a cold front in the Everglades) until either an LOE or death endpoint was reached. Control fishes underwent the same procedure, except that temperatures were raised or lowered from acclimation temperatures to 25°C at one degree per Celsius per hour and then held constant. After all fishes had reached an endpoint, control and surviving LOE fishes were maintained at a constant 25°C for 14 days and their survival was monitored.

Fishes for the field experiment were collected as above and held in tanks at the ENP (African jewelfish) and LILA (Mayan cichlid) for approximately three weeks until a strong cold front arrived on January 1, 2008. Fishes were then held in cages from 4 p.m. January 1, 2008 to 8 a.m. January 3, 2008, in the marsh habitats at the ENP (n = 12 fish; 8-15 cm in length) and LILA (n = 24 fish; 35-115 cm); also in alligator holes at the ENP (n = 24 fish; 47-77 cm) and in the deepwater L-31 canal in the ENP (n = 2 fish; 214 cm). Fish were examined for LOE and death endpoints each morning at 8 a.m. Water temperature was recorded continuously in each trial site and in the L-40 canal adjacent to LILA. Control fishes were held in cages at each site in thermally-controlled tanks (n = 12 at each site) (**Figure 6-8**).

Figure 6-8. Thermally-controlled storage for fishes (photos by the U.S. Geological Survey).

Results and Discussion

Under controlled laboratory conditions, both cichlid species exhibited relatively similar low-temperature endpoints, approximately 10°C for death and 12°C for LOE (**Figure 6-9**). The relevance of these threshold temperatures is discussed below in relation to the field study results and in terms of the ecology and control of these species in the Everglades.

During the January 2008 cold front, the shallow marsh and deep canal habitats at both LILA and the ENP responded very differently to the sudden drop in air temperature. Most notably, at both sites temperatures dropped below the two species' LOE and death endpoints in the marsh habitats, but remained safely above these thresholds in the canals and control tanks (**Figure 6-10**). These temperature differences had important affects on fish mortality and LOE.

All fish caged in the marsh in the ENP survived the first night of the study when temperatures dropped to a low of 11.6°C. On the second night, temperatures in the marsh dipped to a low of 3.7°C (the coldest temperatures recorded in this study), resulting in the mortality of all caged fish by the following morning. All fish in the alligator holes survived the first night, when temperatures dropped to 14.6°C. By the second night, temperatures in the ponds ranged from 7.8 to 11.1°C. Of the 24 fish, seven (in the deepest, warmest pond) survived and did not exhibit LOE when examined the following morning. Six other fish were dead, and the remainder (11) had lost equilibrium when checked the following morning. At LILA, caged fish in the marsh also did not reach LOE or death endpoints until the second night when temperatures fell to 10.9°C; one fish died and all the rest (n = 23) experienced LOE. The canal in the ENP remained the warmest of all habitats throughout the cold snap. Water temperatures declined to lows of only 20.0°C at the surface and 20.4°C near the bottom. Neither of the two fish caged in the canal died nor exhibited LOE. Temperatures at the control site were relatively moderate and decreased only to 17.3°C (ENP) and 24.8°C (LILA) during the experiment. None of the control fishes died during the study.

These results suggest that cichlids are susceptible to cold winter conditions in the Everglades system and that the endpoints observed in the field closely match those determined in the laboratory. The findings also suggest that habitat has a critical role in the ability of these tropical species to survive and disperse in this subtropical system. Everglades marshes are shallow (< 1 m), open habitats and have the lowest water temperatures during cold fronts due to convective and radiative heat loss. Compared to the marsh habitats, many canals are thermally buffered by their morphology and contact with aquifer waters that remain at 22-24°C year-round. Canals can act as a thermal refuge for non-native fishes during winter.

The results of this work with African jewelfish and Mayan cichlid demonstrate the strong effect exerted by habitat on cold-temperature survival by introduced tropical fishes. Because management options for controlling such fish once they become established in the open Everglades are limited, it is important to consider ways to deny exotic fish access to thermal refuges provided by canals, culvert pools and pools near water-control structures. This research suggests that actions such as infilling canals and pools to water depths less than 1.5 meters (m) in winter, if done without affecting their water-management roles, may reduce exotic fish populations.

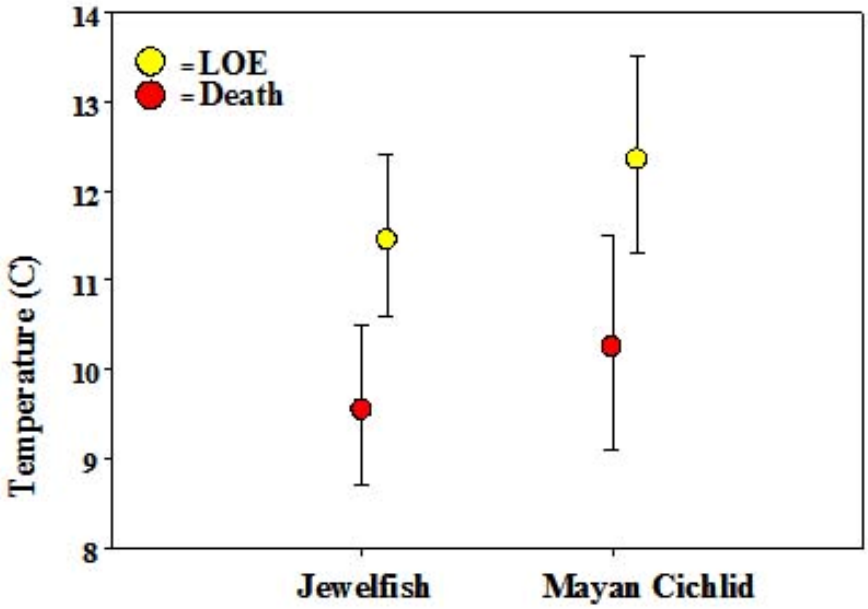


Figure 6-9. Mean ± S.D minimum temperature endpoints [loss of equilibrium (LOE) and death] for African jewelfish and Mayan cichlid.

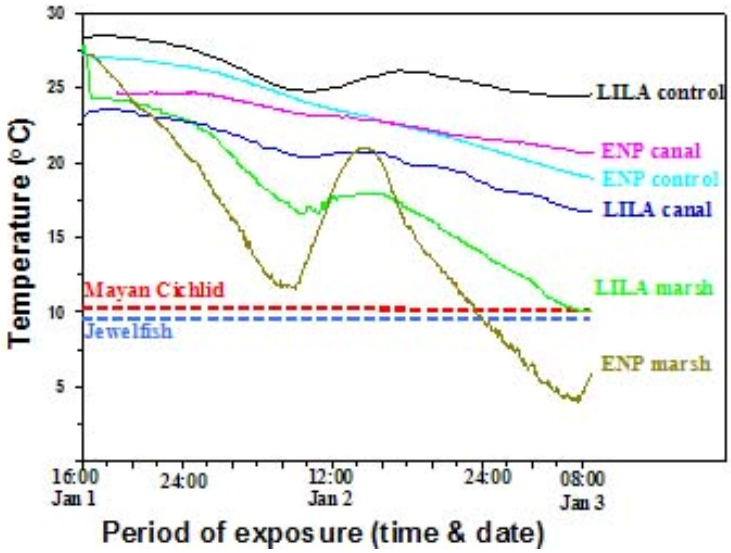


Figure 6-10. Canal and marsh temperatures during field exposure trials at LILA and the ENP in relation to mean LOE and death endpoints of African jewelfish and Mayan cichlid.

CONCLUSIONS

The LILA study experimentally investigates environmental factors affecting wading bird prey availability, focusing on the effects of vegetation density and water depth on wading bird foraging habitat selection and foraging success. The objectives of the current experiments were to determine the effects of water depth and submerged aquatic vegetation (SAV) density (year one) or emergent vegetation density (year two) on wading bird foraging habitat selection and foraging success. Wading birds selected foraging sites with shallow water and sparse vegetation, but the density of vegetation had little impact on foraging success. This suggests that changes in hydrology and vegetation affect the attractiveness of foraging sites to wading birds, but it is not clear how this selection behavior affects foraging and subsequent reproductive success. Previous studies have shown that habitat and hydrologic manipulations clearly produce strong patterns of habitat selection, but if these changes produce no benefit in terms of foraging success then more work is needed to understand how restoration and management will benefit wading birds.

The laboratory and field components of this study revealed that Mayan cichlids and African jewelfish lose equilibrium at approximately 12°C and die at approximately 10°C. Water temperatures during a January 2008 cold front dropped below these critical thresholds in Everglades marsh habitats resulting in cichlid mortality and LOE. However, during the same cold front, temperatures in deep water canals were stable and did not drop below critical end-point temperatures, thus, cichlids experienced no adverse effects. These results suggest that cichlid populations may be limited by low temperatures in the natural system, but deeper water canals operate as thermal refugia. Such refugia possibly act as a population source, allowing repeated invasion of natural marsh habitats. Reducing canal water depth is a potential control mechanism for non-native fish species.

PLANT ECOLOGY

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This section examines physiological, competitive, and population properties of plants for guiding water management and understanding potential risks associated with changes in regulation schedules or land use practices. Each different subsection addresses questions associated with the effect of hydroperiod at the species level and community level (periphyton study). The species-level subsections are studies conducted under control conditions (tree growth) and field conditions (seedling recruitment and ecophysiology). The rationale of these studies is to provide a better understanding of how plant species respond to changes in hydrology under control conditions so that results from field studies can be better interpreted. This requires that the biological processes that cause vegetation replacement, degradation, and premature death be examined in relation to environmental disturbances such as phosphorus enrichment, hydrology, water quality, fire, wind, or temperature change. Previous consolidated reports have focused on how phosphorus enrichment contributes to cattail expansion and the disappearance of ridge-and-slough communities. Updates for WY2007 (Sklar et al., 2008) were focused on hydrology, with discussions on tree seedling stress studies in a greenhouse experiment, marsh grass transplant plans, and tree root dynamics from tree islands with different hydrologic regimes. For WY2008, research was more synoptic and descriptive, continuing to focus on the population structure of the sloughs and tree islands to determine:

1. If patterns across hydrologic gradients indicate whether *Lygodium* is more frequently found on the higher elevation islands relative to the lower elevation islands,
2. Whether growth, survivorship, and recruitment rates on tree islands are a function of local hydrological conditions and soil properties,
3. How sap-flow meters on individual trees can be related to #1 and #2 above,
4. If periphyton polysaccharides are ubiquitous in the Everglades (with implications for water resource management and research), and

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5. If hydrology combined with tree species characteristics at the LILA facility give any indication that tree density can affect individual tree growth in terms of height, stem diameter, or crown size.

All five projects for WY2008 were designed to shed light on the underlying mechanisms that may account for the large-scale features seen at the ecosystem and landscape levels. Understanding these mechanisms may help explain why tree islands and sloughs continue to degrade in some regions but not others.

LYGODIUM SURVEY ON TREE ISLANDS IN WATER CONSERVATION AREAS 3A AND 3B

Over the past two decades, invasive non-native organisms have been recognized as one of the most serious ongoing causes of species declines and native habitat degradation (Vitousek et al., 1997; Wilcove et al., 1998). In South Florida, exotic species have become an increasingly significant management problem in parks and preserves and frequently complicate restoration projects. The greatest threat originates from those species which tend to form non-successional, monospecific canopies in the habitats that they invade. Examples of such invasive exotic plants include Old World climbing fern (*Lygodium microphyllum*), Brazilian pepper (*Schinus terebinthifolius*), melaleuca (*Melaleuca quinquenervia*), Australian pine (*Casuarina equisetifolia*), and lobate lac scale (*Paratachardina pseudolobata*). Invasive exotic plants have been documented to displace native species, reduce community diversity, and have been shown to alter ecosystem geomorphological, biochemical, and hydrological processes (Gordon, 1998).

The problems associated with exotic plant species in South Florida are documented extensively (Doren and Ferriter, 2001; FLEPPC, 2006; Ferriter et al., 2007). The SFWMD has joined efforts with the FWC to address knowledge gaps. As a part of this effort, a detailed ground-based tree island survey was designed to estimate the extent of exotic plant species in WCA-3. The objectives of this survey are to (1) develop and implement a statistically sound field protocol to determine the spatial extent of exotic plants on all islands and (2) identify the presence and stage of infestation of Old World climbing fern, Brazilian pepper, melaleuca, and Australian pine, along with the invasive insect, lobate lac scale.

Based on information on the presence of large populations of *Lygodium* in Big Cypress National Preserve (Big Cypress) (Volin et al., 2004), it was hypothesized that *Lygodium* is expected to be more commonly encountered in the western boundary relative to the other areas of WCA-3A because of a source population in Big Cypress. Secondarily, it was hypothesized that *Lygodium* would be more frequently found on the higher elevation tree islands relative to lower elevation tree islands.

Methods

A spatially stratified sampling method was used to survey the tree islands of WCA-3A; tree islands in this area were randomly selected from a group where elevations had been previously measured. All of the tree islands in WCA-3B were surveyed (Furedi and Volin, 2006). The locations and elevations of study islands were plotted and divided across four longitudinal zones in 0.05° increments (i.e. -80.850° to -80.800°W, -80.799° to -80.750°) across three elevation classes (i.e., 2.00-2.49 m, 2.50-2.99 m, and 3.00-3.49 m above sea level). Sampling was stratified across the zones (i.e., with respect to distance from Big Cypress). Five pairs of islands were selected per zone (n = 10), distributed from the north to the south of WCA-3A. Where possible,

each island pair was located at approximately the same longitude, in the similar size classification (i.e., < 4 hectare [ha], 4-8 ha, > 8 ha), but of differing elevations. To survey the extent of infestation by *Lygodium*, the same methodology followed by previous surveys carried out by Furedi and Volin (2006) and (2007) was used. Surveys focus on the tree island head, the transition area between head and tail, and the near-tail. The number of transects per island range from two to six transects for the small islands, 7 to 10 transects for the medium-sized islands, and 11 to 18 transects for the large islands.

Results

- At the writing of this report, a total of 152 tree islands had been surveyed (**Figure 6-11**); 136 in WCA-3A and 16 in WCA-3B.
- In WCA-3B, 43.7 percent (seven out of 16) of the tree islands had *Lygodium*; and in WCA-3A, 10 percent (14 out of 136) had *Lygodium* (**Figure 6-11**).
- Nine of the 21 infestations were small (i.e., seedlings, juveniles) and had not yet widely expanded into the canopy — although several plants had obvious signs of repeated growth and dieback, indicating that these individuals were most likely not new growth.
- *Lygodium* was mostly observed growing on elevated areas (either on dead stumps, or on the bases of native ferns and trees to reach the canopy). These stumps and bases not only provided structure for climbing, but also kept the fern base from deep flooding during the wet season.
- One of the islands (3BS12) where *Lygodium* was found had previously been treated by the SFWMD. The new *Lygodium* was small (< 3 m tall), indicating it was most likely a new recruit into this habitat.
- A second island (3BS18) treated by the SFWMD did not have any *Lygodium*.
- In general, most of the infestations of *Lygodium* were small and had not yet widely expanded into the canopy.

Management Implications

- The high density and continued expansion of *Lygodium* into WCA-3B is of significant ecological concern. Current management action includes a detailed survey of new populations of *Lygodium* and treatment of the exotic on each tree island where it has been found. This is a collaborative effort with the Vegetation Management Division who is responsible for treating infested tree islands.
- To date, herbicide applicators have covered 10,195 acres within WCA-3A and WCA-3B, resulting in the treatment of 2,037 acres of widely-scattered *Lygodium*. Due to the large management acreage in the WCAs and access difficulties, significant resources are required to implement an effective control program.
- Continued vigilance through on-ground surveys followed by treatment and re-surveying for recurrence will hopefully provide a measure of control against this invasive exotic fern.

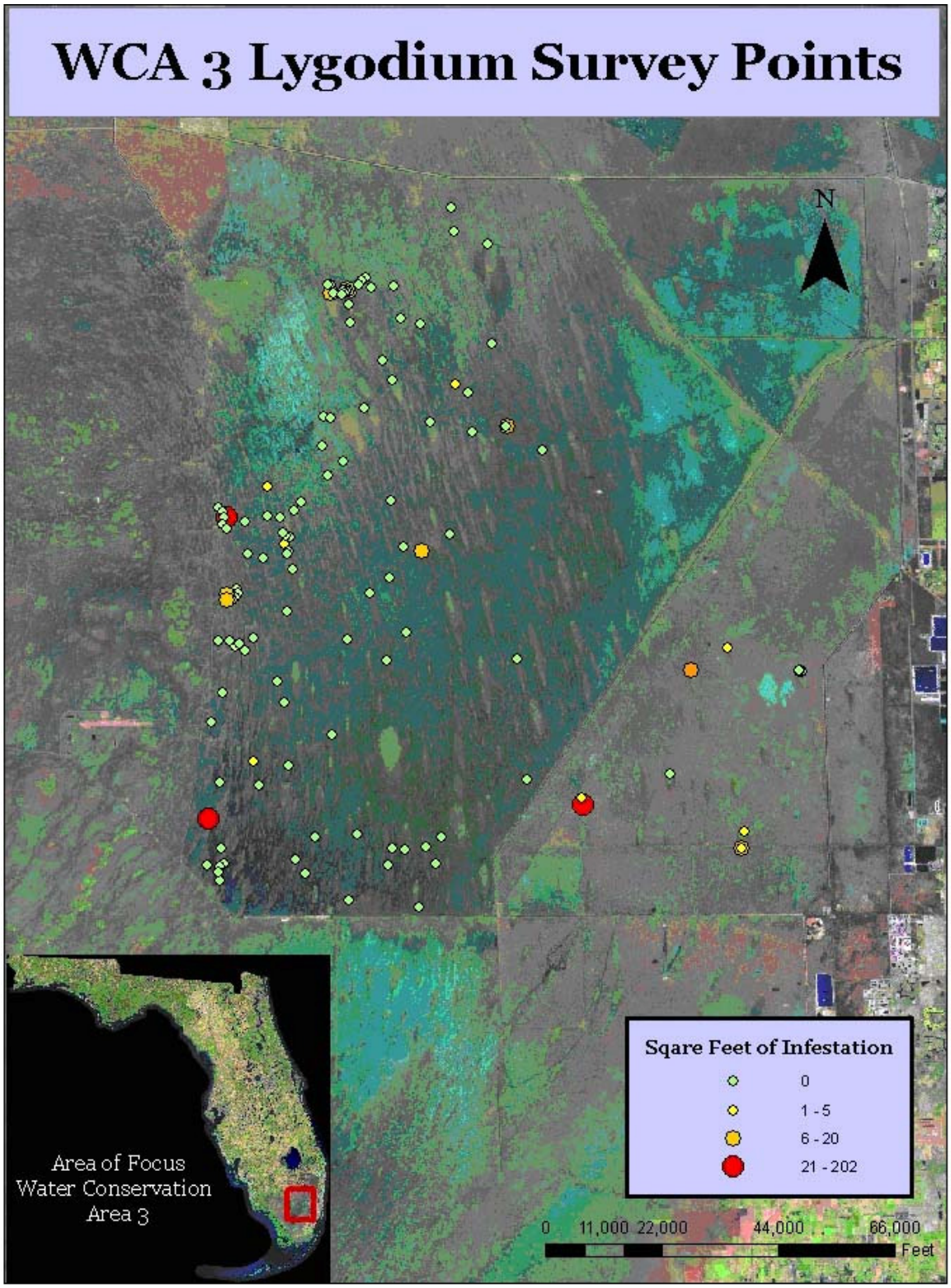

Figure 6-11. Tree islands surveyed for Old World climbing fern (*Lygodium microphyllum*) by the SFWMD and the Florida Fish and Wildlife Conservation Commission (FWC) during calendar years 2006, 2007, and 2008.

WOODY PLANT RECRUITMENT AND SURVIVORSHIP ALONG A HYDROLOGIC-SOIL NUTRIENT GRADIENT ON TWO TREE ISLANDS IN WATER CONSERVATION AREA 3

The woody plant communities on tree islands that have been subjected to extended periods of inundation are displaying signs of stress including slow growth rates, low primary production, reduced canopy coverage, and high mortality rates (Sklar et al., 1998). Signs of stress due to long hydroperiods affect the adult population of woody plant species performance (Jones et al., 2006) and ecological processes associated with seedling establishment, germination, and recruitment into the adult population (Kozlowski and Pallardy, 2002).

It is important to understand the effect that environmental factors, such as hydrology, light, and soil properties have on woody tree species germination, establishment, and recruitment processes to manage the ecosystem and promote the environmental conditions conducive to maintaining and restoring tree islands located in the Central Everglades. The main objectives of this study were (1) to examine the regenerative processes of woody species on tree islands and (2) to assess how local hydrological conditions and soil properties influence recruitment, growth, and survivorship. Woody species responses were assessed on two tree islands with contrasting flooding regimes (short versus long hydroperiod) and soil properties (nutrient-rich versus nutrient-poor). Due to long hydroperiods observed in the southern region of WCA-3A, it is hypothesized that the current hydropattern in this region is restricting the regeneration of woody species on tree islands. Long hydroperiods are likely adversely effecting seedling recruitment and survivorship by increasing mortality of species less tolerant to high water levels, and by hampering sexual reproduction in adult tree species that do not tolerate long hydroperiods.

Methods

Two tree islands located in WCA-3A were chosen for this assessment because they have contrasting hydroperiods (short or long) and either rich or poor soil properties. Tree island 3AS2, a tropical hammock island that experiences a short hydroperiod (about one month of inundation) with a defined elevated area at its northern end, is dominated by cocoplum (*Chrysobalanus icaco*) on the head and by sweetbay (*Magnolia virginiana*) on the near-tail and tail. In contrast, tree island 3AS5 is a flooded environment with an extended hydroperiod (> 6 months inundation) at both the head and near-tail and is dominated by adult individuals of willow (*Salix caroliniana*) throughout the entire tree island.

On both islands, two parallel north-to-south 100-meter-long transects were set up in March 2008. Along each transect four 5 x 5 m plots were laid out. Within each plot 10 randomly chosen 1 x 1 meter subplots were selected to measure seedling and sapling density. Additionally, on five of the 10 subplots, all seedlings and saplings were tagged to measure survival rates. Newly recruited seedlings within the five recruitment subplots were identified and tagged. Species composition and density of the adult population were measured within each 5 x 5 meter plot.

Results

Preliminarily results indicate that tree island 3AS2 is characterized by a high density of seedlings and saplings on the head plots where the elevation is relatively high and inundation rarely occurs (**Figure 6-12**). The species with the highest seedling densities on the head of 3AS2 were cocoplum and white stopper (*Eugenia axillaris*). However, seedling density sharply decreased on the near-tail plots, which were dominated by cocoplum, buttonbush (*Cephalanthus occidentalis*), and sweetbay. On tree island 3AS5, seedling density was relatively low and dominated by water-tolerant species, such as pond apple (*Annona glabra*), buttonbush, and swamp bay (*Persea palustris*) (**Figure 6-13**).

On 3AS2, there was also a sharp transition from seed-based recruitment on the head to asexual vegetative propagation on the near-tail and tail. Seed-based recruits were dominated by dahoon holly (*Ilex cassine*) and cocoplum. In contrast, asexual vegetative recruits were dominated by sweetbay and buttonbush. On 3AS5, there were a high number of seed-based recruits on the head with a gradual decrease towards the tail. Seed-based recruits were dominated by pond apple and swamp bay on the head and asexual vegetative recruits were dominated by sweetbay and buttonbush on the near-tail. In general, on 3AS2, seed-based recruits were more frequent (60 percent) than asexual vegetative recruits (40 percent). In contrast, on 3AS5, asexual vegetative and seed-based recruits were evenly distributed with 49 and 51 percent, respectively (**Table 6-5**).

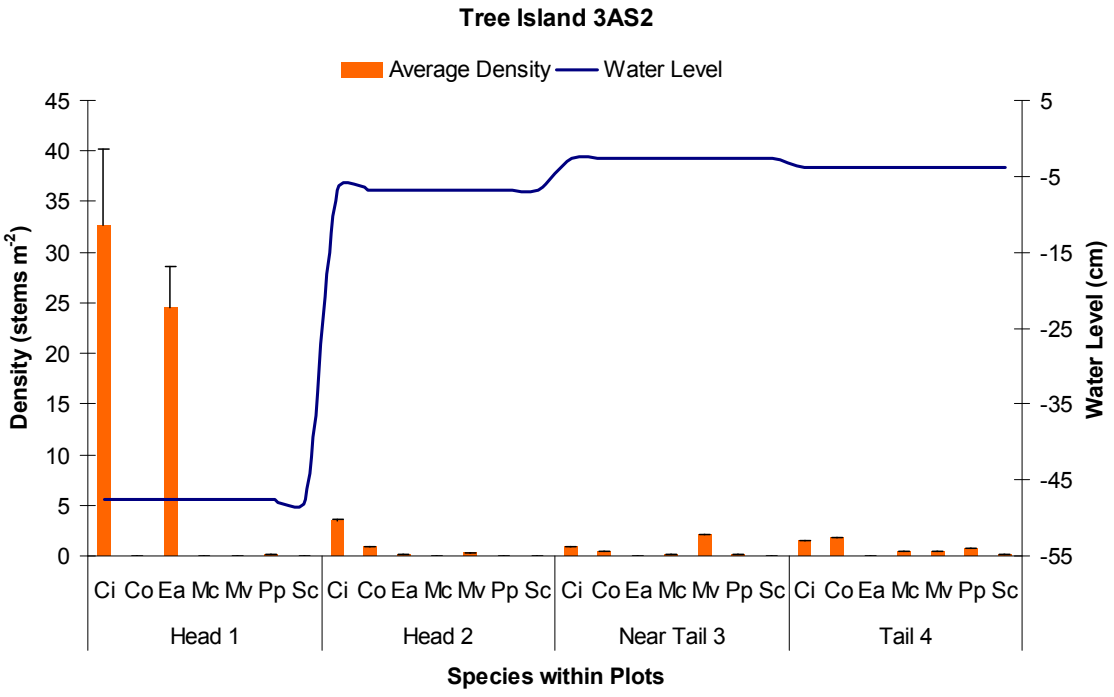

Figure 6-12. Species composition, seedling density (stems per square meter), and water level (cm) along a 100-meter (m) transect on tree island 3AS2, going from head to tail. Plots are located at 0 m (plot one), 25 m (plot two), 75 m (plot three), and 100 m (plot four).

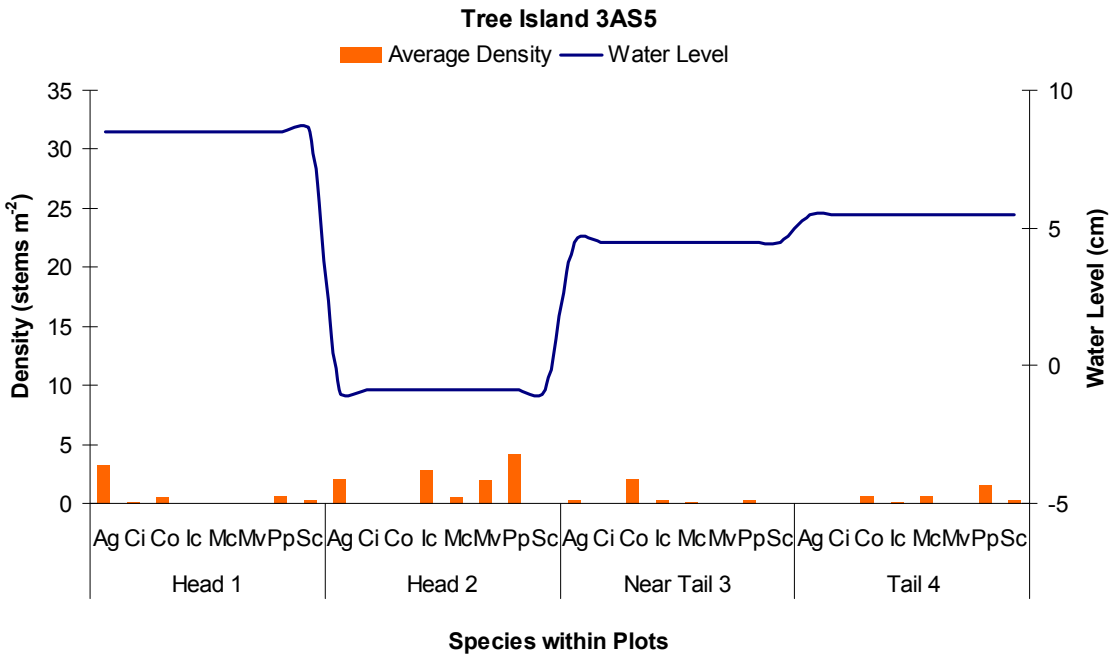

Figure 6-13. Species composition, seedling density (stems per square meter), and water level (cm) along a 100-meter (m) long transect on tree island 3AS5, going from head to tail. Plots are located at 0 m (plot one), 25 m (plot two), 75 m (plot three), and 100 m (plot four).

Figures 6-12 and **6-13**:

Ag	Pond apple (*Annona glabra*)
Ci	Cocoplum (*Chrysobalanus icaco*)
Co	Buttonbush (*Cephalanthus occidentalis*)
Ea	White stopper (*Eugenia axillaris*)
Ic	Dahoon holly (*Ilex cassine*)
Mc	Wax myrtle (*Morella cerifera*)
Mv	Sweetbay (*Magnolia virginiana*)
Pp	Swamp bay (*Persea palustris*)
Sc	Willow (*Salix caroliniana*)

Discussion

The high seedling density on elevated and relatively dry areas of tree islands under study indicates that woody species successfully colonize and become established on sites where the hydroperiod is short; however, even though woody species may colonize and establish on the near-tail where the hydroperiod is longer, their density is much lower there than on the head. It has been hypothesized that vegetative seedling recruits would be higher in response to high water levels and longer hydroperiods. This pattern was observed on 3AS2 where percent of seed-based recruits was higher on the head and lower on the near-tail, with vegetative recruits being more common on the near-tail than on the head. In contrast, on 3AS5, the seed-based recruits and asexual vegetative recruit distribution did not follow the pattern observed on 3AS2. For instance, seed-based recruits were dominated by less water-tolerant species, such as white stopper and cocoplum on 3AS2. In contrast, on the near-tail, asexual vegetative recruits were dominated by water-tolerant species, such as sweetbay and buttonbush on 3AS5. More data are required to better understand recruitment success on the tree islands (i.e., on a fern tussock, on a tree stump, and on the ground). Based on this preliminarily analysis it seems that variations in microtopography on the islands plays an important role in creating seedling niche-space allowing woody species with different biological traits to colonize and establish on specific microenvironments.

Table 6-5. Percent of seed-based recruits and asexual vegetative recruits at each plot along the 100-meter transect.

Tree Island	Seedling Source	Plot 1	Plot 2	Plot 3	Plot 4
3AS2	% Vegetative	9.80	46.84	78.57	45.49
	% Seed	90.19	53.15	21.43	52.65
	Water Level (cm)	-47.5	-6.75	-2.53	-3.87
3AS5	% Vegetative	24.3	63.9	57.57	60.6
	% Seed	75.6	36.0	42.4	39.3
	Water Level (cm)	8.56	-0.93	4.5	5.56

TREE ISLAND ECOPHYSIOLOGY AS A MEASURE OF STRESS

As part of the mandate to restore hydropatterns in the Everglades, the District embarked on an effort to understand the responses of vegetation to hydrologic management. The results of these studies are expected to define and determine the future trajectory and health of tree island habitats within the WCAs.

One approach to assessing tree island health is the use of ecophysiological techniques as a short-term metric to determine plant performance within the community. Ecophysiological measures provide insight into plant water use; these gas exchange patterns are critical for both short- and long-term assessments of tree island health. These instantaneous measurements contribute to understanding plant function in response to daily or weekly hydrologic fluxes and provide insight into long-term projections of plant community functioning.

The objective of this study is to compare landscape-level changes in plant responses with the ecophysiological responses, such as leaf instantaneous gas exchange and integrated CO_2 uptake patterns, stem predawn water potential, and plant sap-flow patterns, between the head and tail across a range of tree islands with contrasting hydrological regimes. The overall goal is to enhance our understanding of the responses of the plant community to hydrologic management. It is hypothesized that plants show significant physiological stress, such as low water potential, low gas exchange rates, and high carbon isotopic signature, on tree islands subjected to long hydroperiods.

Methods

Four islands of differing hydrology were selected for this study (**Figure 6-14**). In WCA-3A two tree islands were selected: 3AS3 which has contrasting ground elevations between the head and the near tail; and 3AS5 which does not have differing elevations between the head and near tail. In addition, 3AS3 has a shorter hydroperiod relative to 3AS5. In WCA-3B, an impounded area that receives no surface flows and is primarily rain-driven, the low elevated island 3BS2 remains flooded longer than the higher-elevated 3BS10. One head and near-tail site was selected on each island, resulting in a total of eight sites for physiological measurements. Sampling was designed to capture plant ecophysiological response during the highest water levels for the wet season and the lowest water levels during the dry season. Among the ecophysiological parameters measured at each tree island were:

- leaf instantaneous gas exchange (assimilation, stomatal conductance, and mesophyll conductance)
- leaf integrated CO_2 uptake patterns (stable isotopes of carbon, $\delta^{13}C$)
- stem predawn water potentials (Ψ) measured at 3 a.m.
- stable isotopes of water (δD) and oxygen ($\delta^{18}O$)
- plant sap-flow patterns

Physiological parameters were measured on nine native species (n = 5 individuals each) representing the dominant canopy on the tree islands. These species included: pond apple, dahoon holly, sweetbay, wax myrtle (*Morella cerifera*), willow, swamp bay, cocoplum, golden leatherfern (*Acrostichum aureum*), and swamp fern (*Blechnum serrulatum*).

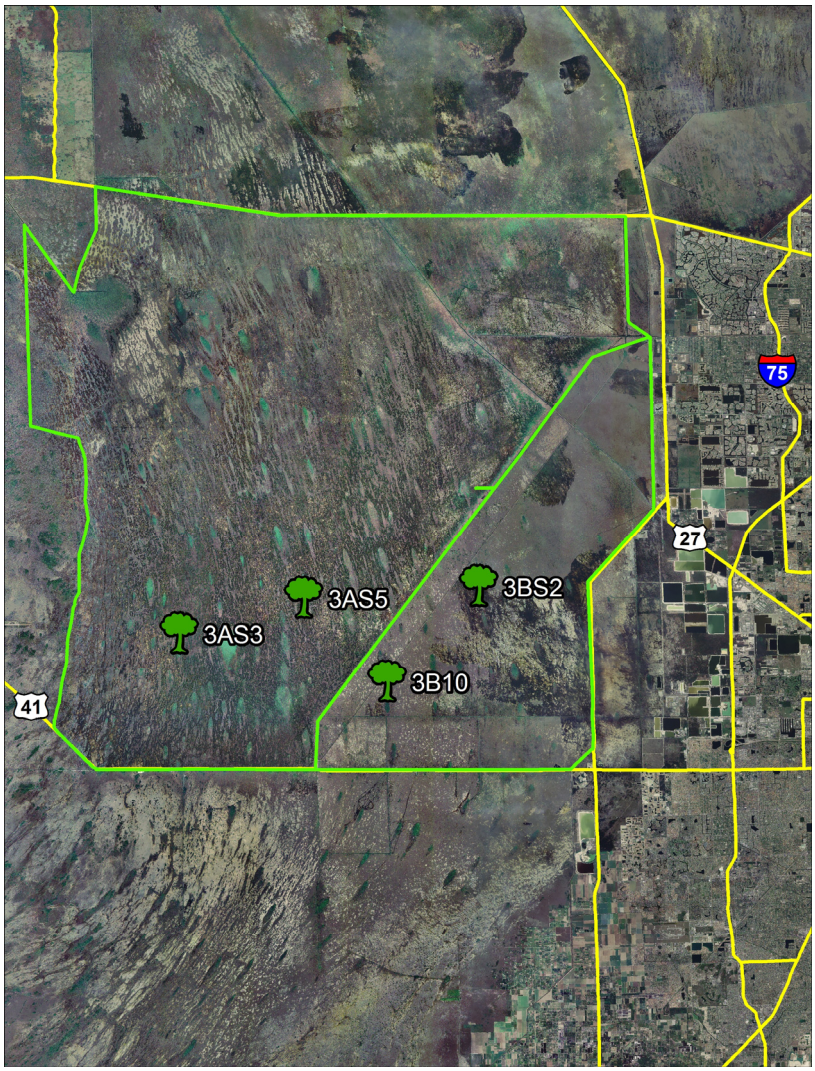

Figure 6-14. Map of locations of the study islands within WCA-3A and WCA-3B measuring plant instantaneous gas exchange.

Preliminarily Results and Discussion

The WY2008 wet season (May–November) was drier than WY2007's wet season due to below-normal levels of precipitation. This was followed by a wetter-than-normal spring dry season due to periodic rainfall. The muted seasonal wet-dry cycle of WY2008 resulted in lowered water level conditions compared to the previous water year. It was anticipated that the seasonal responses of the plants measured would be correspondingly muted as well. Nonetheless, key differences within and across seasons were observed for water potentials and water uptake sources. It is important to note that this a short-term study and it does not address long-term trends in the annual water cycle; however, to gain a better understanding of how plants will respond to long-term changes in the annual water cycles, these studies will be continued.

Plant Predawn Water Potentials

Predawn water potentials (Ψ) were measured from stems of plants at the head and near-tail of each tree island during the wet and dry seasons. **Figure 6-15** shows that Ψ of stems within islands were significantly lower in the wet season compared to the dry season ($F_{1,416}$ = 78.092, $p < 0.001$). This result suggests that the plants, regardless of where they were located on each island, overall were more water stressed during the wet season compared to the dry season.

Across the landscape, Ψ differences were also observed among islands ($F_{3,416}$ = 16.804, $p < 0.001$). Water potentials were lowest in WCA-3B (tree islands 3BS2 and 3BS10), followed by 3AS5 and 3AS3. These trends correspond to the hydroperiod encountered by plants within the islands — plants in the longer hydroperiod sites within each WCA (i.e., 3AS5 and 3BS10) had lower Ψ and greater seasonal change in Ψ relative to plants in 3AS3 and 3BS2 in the shorter hydroperiod sites.

When contrasting plants across the landscape, key differences were also observed between species ($F_{8,416}$ = 35.814, $p < 0.001$). Cocoplum, which was only found on 3AS3, the island with the high elevated head, had the highest Ψ among all the species compared. Swamp bay had the lowest Ψ among all the species in this experiment. This species occurs on both the heads and tails of 3BS10 and 3AS5, but only the tail of 3AS3. The consistently low Ψ in swamp bay relative to the other species (**Figure 6-16**) is most likely induced by high osmolyte content within the species. High osmolyte contents have been shown to be an adaptation to plant flooding for many wetland species (Kozlowski, 1997). These observations of Ψ in swamp bay are consistent with the findings of (Jones et al., 2006) that showed that this species to be the least flood-tolerant of all species compared in this study.

Plant Water Uptake Sources Using Stable Isotopes of Water

Significant differences were observed among the marsh water, open water, and soil water (shallow and deep) oxygen isotopic values ($\delta^{18}O$) at 3BS2, 3AS3, and 3AS5 ($p < 0.001$), but not at 3BS10. For these three islands, nearby marsh (marsh water) and open water (i.e., open puddles within the islands) sources were highly enriched relative to the shallow and deep soil water sources, indicating enrichment through evaporation of these water bodies. In contrast, shallow and deep soil water $\delta^{18}O$, which are composites of rainfall, marsh, and open water sources, were less enriched. For the three islands which exhibited differences between water sources (**Figure 6-15**), the water uptake patterns of each plant species was measured (**Table 6-6**). Using marsh water and the deep soil water of each location in a linear dual-end member equation (Ewe et al., 1999, 2002, 2003, and 2007), the percent groundwater use of each species at each site was measured.

Significant differences were observed in water use patterns among the islands ($F_{2,\ 160}$ = 11.731, $p < 0.001$), among the three islands compared (3BS2, 3AS3, and 3AS5). Plants in 3AS3 relied the least on groundwater (33.6 ± 3.9 percent) compared to plants in 3AS5 (55.2 ± 3.9 percent) or 3BS2 (52.2 ± 3.6 percent). This is consistent with the current understanding of the hydrology of these islands; tree islands of higher elevation tend to rely more on surface water sources relative to the deeper waters.

Despite large inter-site and inter-specific differences in water-use patterns, some significant differences were observed in water uptake patterns among the different species ($F_{8,\ 160}$ = 4.695, $p < 0.001$) across the islands (**Figure 6-15**; **Table 6-6**). On average, pond apple and wax myrtle had the highest fraction of groundwater usage among all species compared, while golden

leatherfern relied the least on groundwater. The findings related to the woody species are consistent with findings by Jones et al. (2006) who ranked pond apple and wax myrtle as the most flood-tolerant species in their greenhouse experiment.

Significant seasonal differences in Ψ and $\delta^{18}O$ isotopes were observed between and within the four study islands. These differences were observed despite the muted seasonality from a dry fall (i.e., wet) and wet spring (i.e., dry) season. These results suggest that plant physiologic measures are sensitive and robust tools for determining short-term plant responses to hydrologic conditions. Furthermore, these findings also suggest that an increase in hydroperiod of both WCAs will most likely induce a community composition shift, reducing the prevalence of lesser flood-tolerant species, but would most likely not affect the more flood-tolerant species.

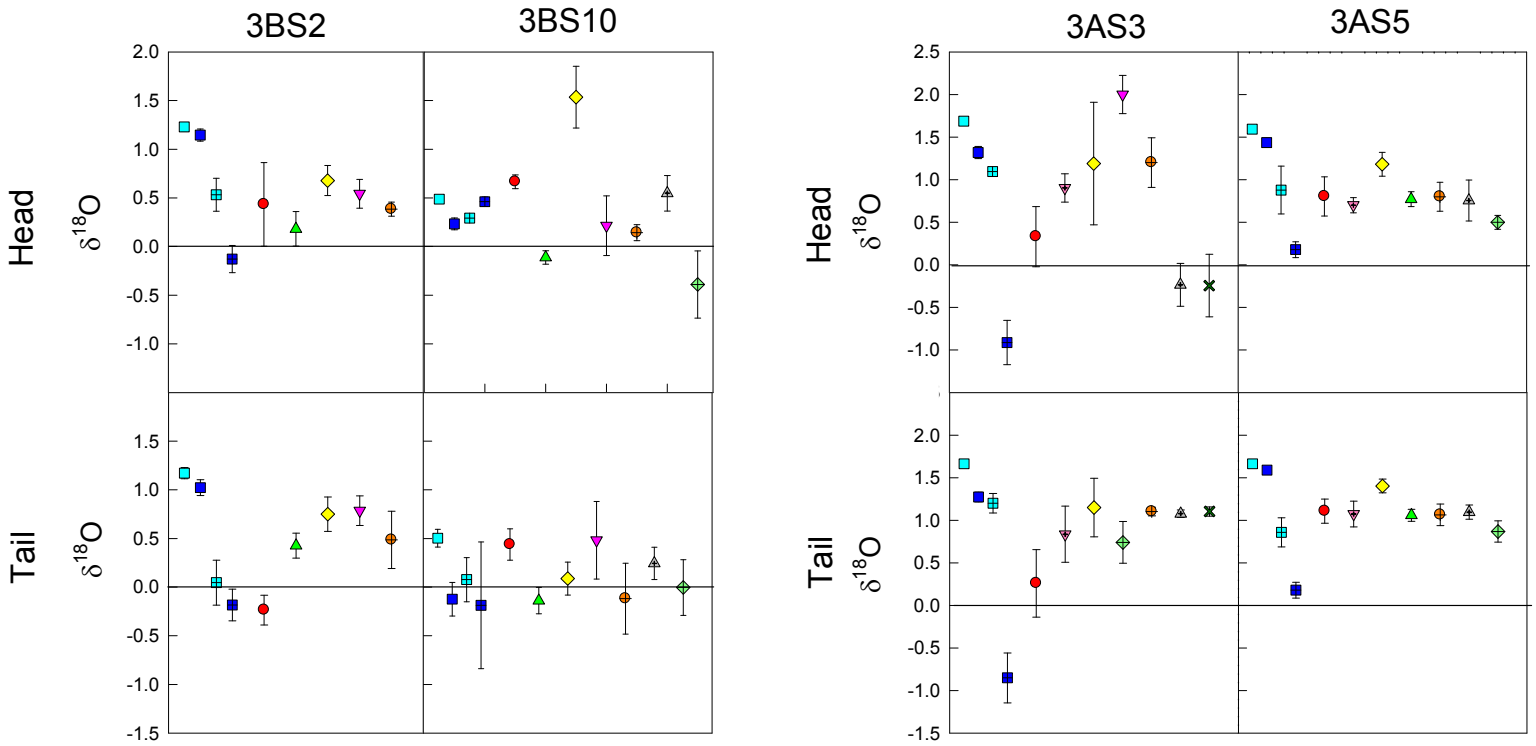

Figure 6-15. Average oxygen isotope signatures ($\delta^{18}O$) (± standard error of the mean) for plants and their water sources collected at the end of the wet season (November 2007). Both potential plant water uptake sources (marsh water, open water, shallow soil water, and deep soil water) dominant plant species within each island were sampled.

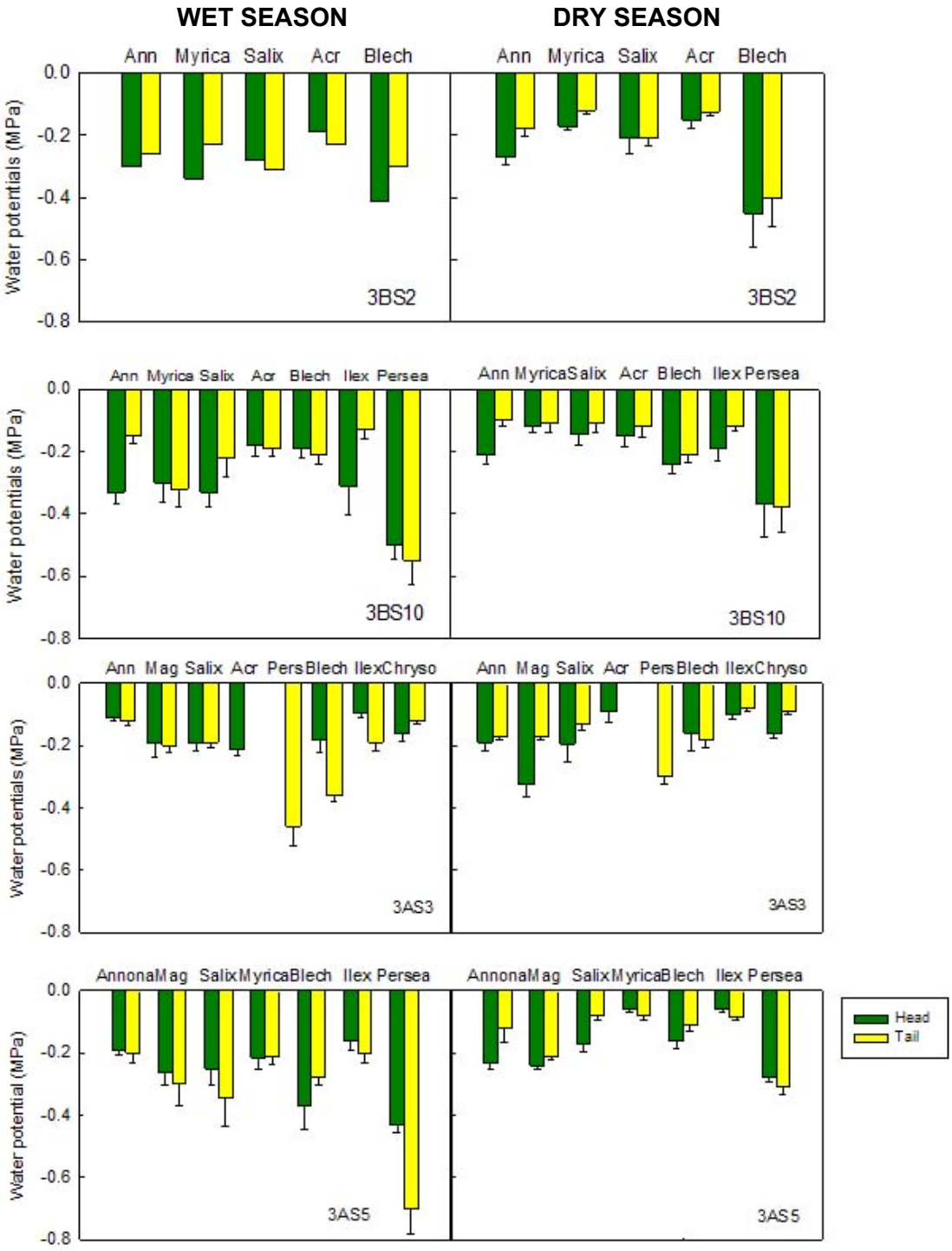

Figure 6-16. Average predawn water potentials (± standard error) for all species sampled at all sites in fall 2007 (wet season) and spring 2008 (dry season). See **Figure 6-13** for a species legend of common names.

Table 6-6. Average (± standard error) percent groundwater usage by each species within each site during the wet season. End members used are open marsh water and deep soil water for all the sites. The fraction of groundwater usage for 3BS10 was not calculated as the end members did not significantly differ. Superscripts indicate significant difference ($p < 0.05$) between species.

Species (Common Name)	3BS2		3AS3		3AS5	
	Head	Tail	Head	Tail	Head	Tail
Pond apple	59 ± 32	104 ± 11 [a]	52 ± 15 [a]	56 ± 16	66 ± 19	37 ± 10 [ab]
Wax myrtle	77 ± 13	55 ± 9 [ab]			69 ± 7	41 ± 5 [ab]
Willow	41 ± 11	31 ± 13 [b]	19 ± 28 [ab]	21 ± 14	35 ± 12	18 ± 5 [a]
Golden leatherfern	51 ± 11	28 ± 11 [a]	-12 ± 10 [b]			
Swamp fern	62 ± 5	51 ± 22 [bc]	19 ± 11 [ab]	22 ± 2	66 ± 14	40 ± 9 [ab]
Dahoon holly			74 ± 10 [a]	23 ± 2	70 ± 20	38 ± 6 [ab]
Swamp bay				37 ± 11	92 ± 2	54 ± 8 [b]
Cocoplum			74 ± 14 [a]	22 ± 2		
Sweetbay			30 ± 6 [ab]	33 ± 13	74 ± 10	40 ± 10 [ab]
Average:	59 ± 8	52 ± 8	38 ± 7	29 ± 4	67 ± 6	38 ± 3

PERIPHYTON POLYSACCHARIDES

In the Everglades, cohesive biofilms composed primarily of algae and bacteria dominate in slough environments. Extracellular polymers (EPS) produced by the algae and bacteria give the biofilm its structure and represent a significant proportion of the total mass (Decho, 1990; Hoagland et al., 1993; Decho, 2000). The term EPS describes the polymers that exist in a continuum from cell walls, sheaths, and cell capsules closely associated with the cell, to a loose glycocalyx/slime layer around the capsules. Some of the observed functions include adhesion, cohesion, and motility of the organisms that secrete EPS (Hoagland et al., 1993; Decho, 2000). In addition, EPS effectively binds nutrients, ions, and heavy metals (i.e., copper, lead, manganese, and mercury) (Decho, 1990; Freire-Nordi et al., 2005), and serves as a substrate for inorganic compounds such as detritus and calcium carbonate crystals (Decho, 1990; 2000). Cohesive periphyton mats can increase sediment stability (Paterson, 1989) and alter material and nutrient transport dynamics at the sediment/water interface. Upwards of 75 percent of the carbon fixed by algae may be exuded as EPS (Wolfstein et al., 2002). Isotopic enrichment studies of carbon cycling in Everglades periphyton identified a significant pulse of carbon within eight hours of phototrophic fixation to heterotrophic bacteria; EPS is hypothesized to be a significant carbon resource utilized by bacteria (Sklar et al., 2007).

Preliminary studies have suggested that the amount of EPS present within Everglades periphyton (10-20 milligrams per gram [mg/g], Bellinger and Hagerthey, unpublished data) exceeds that typically found in other environments (<1-10 mg/g common in estuarine mudflats, ~1 mg/g in freshwater lake sediments) (Underwood and Paterson, 1993; de Brouwer and Stal, 2001; Hirst et al., 2003). Since EPS can have important ecological functions, the EPS of Everglades periphyton indicative of the softwater and hardwater regions was quantified and characterized to gain insight into the potential roles in nutrient cycling, food web structure, and sediment stability.

Methods

Non-quantitative grab samples of periphyton mats were collected from a variety of the low nutrient interior marsh sites of WCA-1 (soft waters – pH ~ 6.5, conductivity typically < 150 microsiemens [μS] cm^{-1}) and WCA-2A (hard waters – pH ~ 7.4, conductivity ~ 950 μS cm^{-1}). Samples were frozen and lyophilized for EPS extraction using established methodologies from culture and field studies (Wustman et al., 1997; Kawaguchi and Decho, 2002; Stal, 2003; Decho et al., 2005). EPS that comprises the extracellular slime layer, or glycocalyx matrix was determined from the water-soluble fraction (WS). The periphyton were treated with deionized water (dH_20) at room temperature for one hour, centrifuged, the supernatant removed, and water extraction repeated. For EPS that comprises cell wall, sheath, or capsular material, remaining pellets were treated with 0.5M EDTA (ethylenediaminetetraacetic acid) for one hour at room temperature, centrifuged, the supernatant removed, and EDTA treatment repeated (EDTA fraction). Although these fractions are operationally defined, the sequential extraction protocol is effective in isolating distinct polymers. Colorimetric methods were used to determine total carbohydrate, uronic acid, protein, and sulfate content of each EPS fraction. Carbohydrates and proteins are the most common core constituents of algal polymers, and polysaccharides can be further modified by substituting anionic compounds (most common being carboxylic acids and sulfates) that will further increase the overall structural complexity of the polymers (Decho, 1990; Hoagland et al., 1993; Wustman et al., 1997). Because extracts were primarily polysaccharides, the relative proportion of constituent monosaccharides (glucose, galactose, mannose, xylose, arabinose, ribose, fucose, and rhamnose) was determined.

Results and Discussion

Periphyton from WCA-1 had prominent desmid (*Chlorophyta* spp.) and diatom (*Bacillariophyceae* spp.) components (> 50 percent of the algal assemblage) (**Figure 6-17**, panel A). The periphytic biofilms grew in close association with the macrophyte bladderwort (*Utricularia* spp.) and tended to have a very soft and loosely consolidated structure. Both the slime EPS (2.1-11.8 mg polysaccharide/g periphyton) and sheath/cell wall EPS (2.6-31.2 mg polysaccharide/g periphyton) were significant components of the biofilms from WCA-1. The loosely cell-associated slime EPS was comprised mostly of neutral six-carbon sugars (hexose) that are easily hydrolyzed and utilized by bacteria, whereas the sheath/cell wall EPS had greater amounts of five-carbon sugars (pentose), carboxylated and deoxy sugars that contribute to gel formation and increase structural complexity (Zhou et al., 1998) (**Table 6-7**). Carboxylated polysaccharides have a greater propensity for cross-linking cations, creating a more rigid structure and thus, making the sheath/cell wall component more resistant to hydrolytic enzymes then the slime EPS. The composition of EPS identified for the WCA-1 periphyton is consistent with results obtained from cultured desmids and diatoms (Hoagland et al., 1993; Domozych et al., 2005).

Periphyton from WCA-2A was dominated by cyanobacteria (*Cyanophyta*) and diatoms (> 90 percent of the algal assemblage). These biofilms were more rigid and cohesive then WCA-1 periphyton. Scanning electron microscopy revealed that calcium carbonate deposition was prevalent throughout the mats on the sheaths of filamentous cyanobacteria (**Figure 6-17**, panel B). As a result, very little EPS associated with the loose slime/glycocalyx was found (0.8-3.1 mg polysaccharide/g periphyton) compared to sheath/cell wall EPS (2.1-26.2 mg polysaccharide/g periphyton). Polysaccharides in the sheath/cell wall fraction were rich in pentoses, deoxy sugars, and acid residues which, when combined with the calcium carbonate deposited, will make these polymers very refractory and resistant to degradation and uptake by bacteria and other consumers (Decho, 2000). In contrast, slime EPS polysaccharides had a

significant glucose component, a very soluble, labile, easily hydrolyzed saccharide. However, the presence of more acidic sugar residues may increase the rigidity of the slime layer, suggesting that some portion of the layer is also resistant to decomposition. The compositions of EPS fractions analyzed here closely reflect previous culture and field studies of cyanobacteria (Bertocchi et al., 1990; Nicolaus et al., 1999).

Significance and Relevance to Water Management

While periphyton is a ubiquitous feature of the Everglades landscape, it has been known for sometime that periphyton structure (i.e., species composition) differs in association with nutrient and mineral enrichment. For example, there are desmid-rich assemblages in softwater WCA-1 and cyanobacteria-dominated calcitic mats in WCA-2A (see **Figure 6-17**). Water depth has also been shown to have an influence on periphyton structure; however, differences are primarily in species abundance rather than their presence versus absence as is the case with mineral enrichments (Gottlieb et al., 2006). These structural differences have been hypothesized to fundamentally alter the functional role of periphyton. One such function is the role of periphyton as the base of the Everglades food web. Results indicated that the quantity and quality of carbon fixed by periphyton differs between soft and hardwater regions characterized by low phosphorus. These differences control, in part, how periphyton maintains its structural integrity (cohesive or loosely bound), how readily available (labile) it is for consumption by bacteria and higher trophic levels, and how resistant to decomposition (refractory) the different algal components are (slime EPS and sheath/cell wall EPS). While the amount of water at a site will result in changes in constituent periphyton community relative abundance, overall the community will have the same basic make-up (cyanobacteria dominated, desmid-diatom mix). The more significant impacts of water management will be observed if mineral rich waters continue to intrude on the soft-water assemblages of WCA-1. Periphyton sits at the base of the food web and EPS represents a significant carbon resource for the microbial loop as well as influencing sediment properties (organic or inorganic via calcium carbonate binding). Studies of this type into the biochemical properties of the abundant periphyton mats will aid water managers by providing better insight and predictability into how water management activities will influence the Everglades food web and abiotic processes.

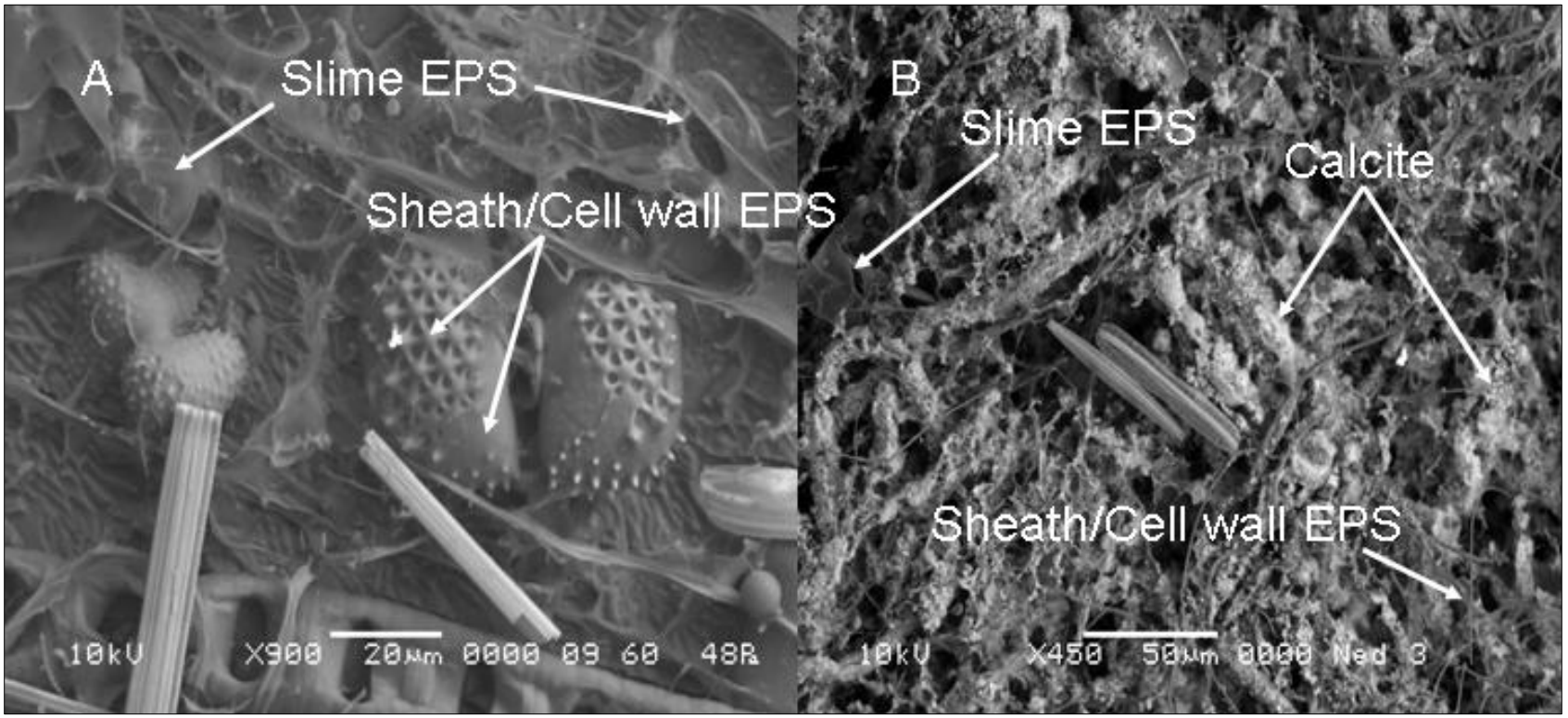

Figure 6-17. Scanning electron microscopy (SEM) pictures of periphyton mats from WCA-1 (panel A), WCA-2A and (panel B) (photos reprinted with permission of Dr. David Domozych, Skidmore College). Abundance of slime EPS evident in desmid/diatom mats (panel A). Less slime EPS present, and sheath/cell wall EPS less evident due to heavy encrustation by calcium carbonate (calcite) on cyanobacterial filaments (panel B).

Table 6-7. Compositional data for extracellular polymer (EPS) fractions (WS faction – slime EPS; EDTA fraction – cell wall/sheath EPS) isolated from periphyton mats. Monosaccharide data indicates relative abundance based on the total polysaccharide content of an extract. Data are averages for periphyton mats collected in WCA-2A from UC1, n = 5 and; WCA-1 from interior sites, n = 8.

						Monosaccharides (%)							
Site	ID	Sample type	EPS fraction	Polysaccharide (mg/g periphyton)	Uronic Acid (% w/w)	Glc	Gal	Man	Xyl	Ara	Rib	Fuc	Rha
WCA-2A	UC1	Periphyton	WS	2.1	9.8	64.0	10.6	8.1	4.4	2.5	0.0	4.9	5.6
			EDTA	9.7	13.5	37.3	12.3	8.1	17.5	1.6	0.1	16.6	6.6
WCA-1	Interior	Periphyton	WS	5.8	8.0	40.8	13.0	7.3	8.4	5.8	0.0	18.2	6.5
			EDTA	12.9	16.8	31.2	15.5	10.8	15.3	5.1	0.2	11.1	10.9

Note:

Glc-glucose

Gal-galactose

Man-mannose

Xyl-xylose

Ara-arabinose

Rib-ribose

Fuc-fucose

Rha-rhamnose

TREE SURVIVAL AND GROWTH AT THE LILA SITE

Tree islands are among the most distinctive features of the Florida Everglades, and have drawn the attention of authors writing for both lay and scientific audiences for over a century. In relation to the Everglades size, tree islands cover a small proportion but perform disproportionately important ecosystem and cultural functions, especially nutrient cycling, provision of habitat for wildlife, and as religious/archaeological sites for humans (van der Valk and Sklar, 2002). Recent declines in tree island density and area have been reported, mostly in the WCAs (Sklar and van der Valk, 2002). The loss of tree islands is mainly attributed to prolonged periods of high water, but depressed water tables can also lead to tree island loss when associated with very intense fires. Within the context of CERP, maintenance and/or restoration of tree islands requires a better understanding than currently exists of the flood tolerances of resident tree species, and those capable of expanding to tree islands of differing hydroperiods in the future.

The LILA site, because of its controlled hydrologic framework, provides an excellent opportunity to investigate species responses to flooding during tree island development. An experiment was designed to test hydrologic effects on seedling growth and survivorship and the effects of tree spacing on individual tree and stand growth. Understanding these so-called "neighbor" effects and their interactions with hydrology will become important in the event that CERP-related activities expand to include the creation or active restoration of tree islands in portions of the Everglades where they have been lost.

A mixture of eight indigenous tree species was planted on two tree islands per macrocosm in March 2006 (M1 and M4) and 2007 (M2 and M3). Each island was divided into quarters that were randomly assigned a density treatment in which trees were planted on centers spaced 1, 1.7, 2.3, and 3 m apart (**Figure 6-18**). The four densities were chosen to provide the ranges characteristic of newly developing forest communities in nature. At 10,000 stems per hectare, the densest planting treatment represents numbers likely in young, post-disturbance forests where recruitment has been prolific and rapid. Conversely, the most open treatment represents early successional stages where recruitment is slow and dependent on distant seed sources. Because each island was graded from a high plateau area through side slopes that reached to the water's edge, the hydrology affecting each tree could easily be determined by combining detailed topographic surveys with stage records from recorders in the adjacent slough.

The planned duration of the study was predicated on two issues: (1) survival assessment should be continued as long as density-dependent mortality exceeds background levels, as it does now; and (2) monitoring of individual and stand growth should continue long enough to assess differences among density treatments once crown closure has been achieved. In the high-density treatment, crown closure began to take place within two years of planting, but the process has been much slower in the wider spacings. This update shows results from the cohort planted in 2006, whose development has now been tracked for two full years. Hydrologic relationships with survival and growth are inferred from raw elevations, i.e., high elevation equates to shallow water and short flooding duration, while low elevation equates to deep water and prolonged flooding.

Cumulative average two-year survival for all species was 63 percent. Gumbo limbo (*Bursera simaruba*), strangler fig (*Ficus aurea*), and swamp bay survival increased sharply with elevation, from virtually nil near the edges of the islands to nearly 100 percent at the highest elevations (**Figure 6-19**). Dahoon holly and red maple (*Acer rubrum*) also had better survival at high elevation than low, but the difference was not as dramatic as in the previous group. Finally,

survival rates of a third group of species, i.e., pond apple, cocoplum, and wax myrtle, were statistically unaffected by hydrologic condition as inferred from elevation.

Height growth of several species reflected an effect of hydrology. When statistically significant, growth was always higher on drier sites. Effects on survival in these early years of stand development were stronger and more consistent than effects on growth. Growth analyses, however, did indicate an important element — the concentration of vegetative growth in the pronounced South Florida wet season. Growth plateaus during dry periods (September–March), followed by growth spurts in the wet season (March–September), are evident in successive years for all eight tree species.

Through two years of development, the analyses give no indication that density has begun to affect individual tree growth in height, stem diameter, or crown size. This is not unexpected, as crown closure is only now beginning to take place in the high-density treatments. The relevance of LILA tree island research depends on its capacity to reflect processes taking place in Everglades tree islands, but under controlled conditions and with a known developmental history. Excellent first year survival among the 2007 planting cohort (82 percent, equaling survival of the 2006 cohort at a similar stage) promises that responses in eight well-stocked islands will be available to base conclusions about the effects of species, hydrology, and stem density on tree island development in the future.

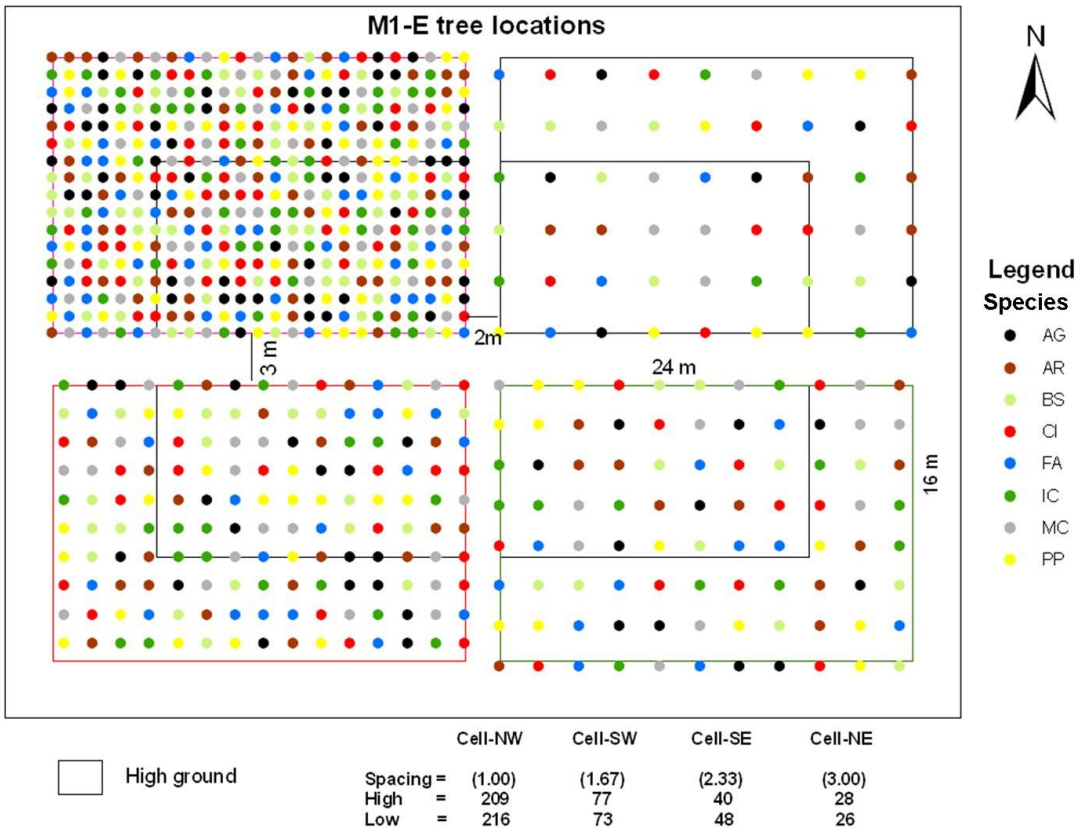

Figure 6-18. Planting scheme for one of the tree islands (M1-E). pond apple, red maple, gumbo limbo, cocoplum, strangler fig, dahoon holly, wax myrtle, and swamp bay.

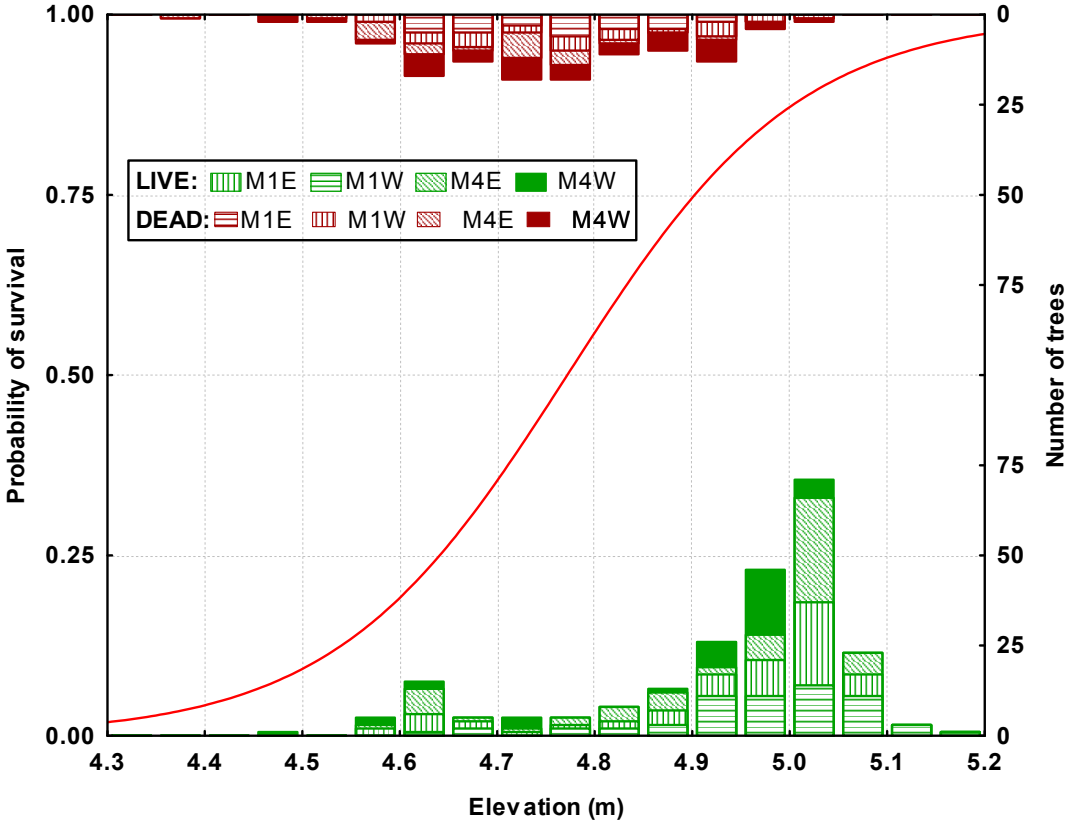

Figure 6-19. Logistic regression functions of representative species survival with respect to elevation in four islands. Stacked bar graphs originating from the bottom and top of the figures represent the raw density distributions of live and dead individuals, respectively, on which the regression functions are based.

ECOSYSTEM ECOLOGY

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Contributors: Damon Rondeau[6], Steve Krupa and Gregg Lozada[6]

Ecosystem research continues to focus on areas of the Everglades severely impacted by nutrient enrichment. In WY2007, the focus was on periphyton (the base of the food chain in many areas of the Everglades), phosphorus dynamics, and the impacts of fire on cattail (*Typha domingensis*) and sawgrass (*Cladium jamaicense*) populations. The WY2008 focus began a more detailed investigation of the microbial communities (including periphyton), fish communities, and wading bird foraging in artificially opened areas versus densely vegetated areas to see if and how habitat improvement of a cattail zone is possible. The District also investigated the impacts of a controlled burn on cattail growth recovery rates, the chemistry of cattail and sawgrass ash, and soil reduction-oxidation reactions (redox) to see if fire can be an effective management tool for nutrient-impacted marsh. Finally, a study of the movement of groundwater within tree islands was initiated to better understand the hydrologic function of these islands, and the cycling of phosphorus in nutrient-enriched areas of the Everglades was studied to evaluate the extent of phosphorus reflux from the impacted soils with restoration.

CATTAIL HABITAT IMPROVEMENT PROJECT

The Cattail Habitat Improvement Project (CHIP) is being conducted in WCA-2A. WCA-2A is a large impoundment impacted by agricultural runoff for over 30 years. The net result is the development of a well-established nutrient gradient and a monotypic stand of cattail [> 11,000 hectacres (ha)]. The two primary objectives of CHIP are to assess whether creating openings in dense cattail areas will sufficiently alter trophic dynamics such that wildlife diversity and abundance is increased, and to determine to what extent these created open areas' functions compare to the natural Everglades. The experiment consists of creating replicated (n = 3) 6.25 ha openings in the landscape in a region dominated by cattail and a transitional region containing a

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50:50 mix of cattail and sawgrass. The former region is highly enriched, with average surface water total phosphorus (TP) > 50 micrograms per liter (µg L^{-1}) and sediment (floc) TP > 1,500 milligrams per kilogram (mg kg^{-1}), whereas the latter region is moderately enriched, with average surface water TP > 15 µg L^{-1} and sediment (floc) TP > 900 mg kg^{-1}. Control plots were also established in unenriched areas (reference sites). Reference sites are more natural nutrient-poor sites with average surface water TP ≤ 10 µg L^{-1} and floc concentrations < 400 mg kg^{-1}. Using a combination of herbicides and fire, open areas were created in enriched and moderately enriched areas of WCA-2A in July 2006. Specifically, glyphosate was applied in May 2006, and the plots were burned from July 20 through 21, 2006. The hypotheses, experimental design, and rationale behind this research project were described in Sklar et al. (2007), while the detailed project description and methodologies can be found at www.sfwmd.gov, under the *Watershed Management, Everglades/Florida Bay* links. This report focuses on samples collected during an intensive sampling event that occurred in from September through October 2007, just over one year since treatment was initiated. However, in some cases data were not available for this time period, so the closest sampling event information is presented to help provide a more complete data interpretation. The first of the two objectives are emphasized then reference-site information presented as appropriate. For all results, sites are delineated based on their location; enriched (E), transitional (T), reference (UC) and whether burned, open (O), or unburned controls (C). Differences in composition among the plots were examined and then focus shifted to the associated functional changes. Specific hypotheses examined in the current report are shown in **Table 6-8**.

Table 6-8. Specific hypotheses evaluated for the Cattail Habitat Improvement Project.

PARAMETER	HYPOTHESIS
Structural Changes	
Microbial Community	There will be a change in microbial community composition in the open treatments compared to the emergent macrophyte controls due to differences in the quality of carbon, more SAV/periphyton in the open treatments versus more cellulose/lignin in the controls.
Periphyton Community	Increased abundance of periphyton in open versus control plots as dense vegetation is removed and light limitation is eliminated.
Fish Community	Prey species richness and diversity will be highest at the moderately enriched treatment and lower at both the highly enriched treatment and reference area.
Functional Changes	
Periphyton	Periphyton productivity will increase in open plots in response to increased light availability. Increased periphyton productivity will result in elevated dissolved oxygen levels in the water column, resulting in increased ecosystem metabolism.
Decomposition	Open plots will have increased microbial respiration resulting in more rapid decomposition of plant material.
Prey Biomass	Herbivorous species (fish) will increase in open plots compared to controls, while detritivorous species (crayfish) will be reduced in open plots. The biomass of prey species will be greater with increasing nutrient enrichment.
Wading Bird Foraging	Wading bird foraging will increase in open plots in response to accessibility to prey species. Foraging will be positively related to nutrient enrichment.
Secretive Bird Usage	The loss of the vegetative cover and a decrease in nutrient enrichment would result in a decrease in the use of the habitat by secretive bird species (rails, bitterns, etc.).

Results and Discussion

Community Composition

Microbial Community Composition. The microbial consortium inhabiting floc, sediment, and periphyton strongly regulates many key ecosystem functions (e.g., material and energy fluxes and decomposition). Measuring changes in microbial community composition is difficult (Bobbie and White, 1980); however, phospholipid fatty acid (PLFAs) biomarkers can be a powerful tool for broadly quantifying and characterizing the microbial composition (Vestal and White, 1989; Findlay, 2007). PLFAs are ubiquitous components of all cell membranes but differ among organisms such that they can be used as biomarkers (Vestal and White, 1989; Zelles, 1997). Periphyton (collected via composite grab sampling at multiple locations from the plot), floc, and sediment (the latter two collected via 10 cm ID cores, composited from three locations in each plot), if present, were collected from each plot (15 total samples) from September 10 through 20, 2007. Samples were freeze-dried and shipped to Microbial Insights (Rockford, TN) for total lipid extraction using the methods of Bligh and Dyer (1959) and modified by White et al. (1979). Phospholipids were isolated using silica chromatography and individual fatty acids identified and quantified by gas chromatography (GC) and GC/MS (mass spectrometry), respectively. Classification of microbial groups using diagnostic fatty acids were based on well-established culture studies of bacteria, fungi, plants, and algae (Vestal and White, 1989; Ahlgren et al., 1992; Zelles, 1997; Findlay, 2007).

The analysis of PLFA results indicates clear treatment effects, with an overall greater biomass of microorganisms present within open treatments [EO = 2.2 million and TO = 1.3 million pica moles PLFA per gram of sediment (pmols PLFA/g)] relative to the dense emergent macrophyte controls (EC = 1 million and TC = 1.2 million pmols PLFA/g sediment). For the E and T sites, floc had the greatest microbial biomass of all measured substrates, confirming the high metabolic activity of Everglades floc. Metabolic status ratios are a reflection of available substrate for growth. Higher ratios reflect increased production of cyclopropyl fatty acids in place of the normal fatty acid (for example proportion of cy19:0 relative to 18:1ω7), indicating slower growth rates due to reduced or poor quality food available (Guckert et al., 1986 and references therein). The detrital quality also indicated that floc is a better food source in the open treatments because the metabolic status ratio of 0.08 indicated rapid growth and no substrate limitation. Proportionally, eukaryotes were more prevalent within the open treatments relative to controls, with prokaryote:eukaryote ratios of 19.8, 26.5, 49.8, and 41.6, for enriched open, transitional open, enriched control, and transitional control, respectively. Relative abundance of Gram positive bacteria was lower for the open treatment, indicating more aerobic conditions. This causality was confirmed by an increased proportion of Gram negative bacteria since proportions of Gram negative bacteria tend to increase under aerobic conditions (Bossio and Scow, 1998). Actinobacteria were more abundant at the controls reflecting the greater abundance of complex plant material to degrade. As with the sediment layer, microbial biomass was lowest at the oligotrophic reference site (0.4 million pmols PLFA/g sediment).

Periphyton was not present at all sites. For those with periphyton, PLFA analysis revealed differences in the microbial and algal composition among sites. The low-nutrient reference site (UC) periphyton had greater biomass compared to the other sites, with the exception of EO which was equivalent. Chlorophytes (green algae) were generally a greater proportion of the algal assemblage for the eutrophic EO and TO sites, whereas diatom relative abundance was greater for the oligotrophic reference site (UC). In the aerobic mats, the abundance of Gram positive bacteria was lower while Gram negative bacteria were abundant.

Algal Community Composition. Algal composition continues to be a key indicator of nutrient status and treatment response. Algal taxonomic analysis was performed for epiphyton (attached to plants), epipelon (attached to sediment), and metaphyton (floating) samples collected, if present, from each subplot within a plot between July 23 and July 30, 2007. Taxonomic analysis, expressed as relative abundance, for the 50 samples collected was performed by the Florida Department of Environmental Protection's Biological Laboratory. Compositional comparisons were made using non-metric dimensional scaling (NMDS) followed by multiple response permutation procedures (MRPP). Algal divisions (*Cyanophyta*, *Chlorophyta*, and *Bacillariophyta*) comparisons were made using analysis of variance (ANOVA) and post-hoc multiple comparisons.

Periphyton was not present in the densely vegetated control plots; thus, comparisons were only made among areas of enrichment, specifically EO, TO, and UC sites. A total of 153 taxa were identified. The total number of taxa per site was 54 for the EO, 65 for the TO, and 45 for low-nutrient reference (UC). Algal composition did not differ greatly among algal types (epiphyton, epipelon, or metaphyton). The relative abundances of algal groups were basically similar, although slight differences were statistically significant. Generally considered to be a poor resource for higher tropic levels (some taxa are known to produce toxins that actually inhibit consumption) (Dow and Swoboda, 2000), cyanobacteria dominated algal composition but was significantly greater for the enriched (95 ± 3 percent) than the transitional (92 ± 4 percent) or reference (92 ± 4 percent) sites (ANOVA $F = 3.32$; $p = 0.032$). Diatom relative abundances were significantly greater for the transitional (6 ± 4 percent) and reference (7 ± 3 percent) sites than the enriched (3 ± 2 percent) sites (ANOVA $F = 6.67$; $p < 0.001$). Chlorophyte relative abundances for the enriched (2 ± 1 percent) and transitional (2 ± 1 percent) sites were significantly greater than the reference (0.5 ± 0.4 percent) sites (ANOVA $F = 16.85$; $p < 0.001$). Algal composition differed significantly among sites (NMDS Stress = 10.99; MRPP $A = 0.129$; $p < 0.001$; all pair-wise comparisons had $p < 0.001$).

Fish and Crayfish Composition. During October 2007, a total of 401 individuals across 11 species were collected in the following order of abundance: mosquitofish, slough crayfish (*Procambarus fallax*), sailfin molly (*Poecilia latipinna*), Florida flagfish (*Jordanella floridae*), freshwater shrimp (*Palaemonetes paludosus*), least killifish (*Heterandria formosa*), golden topminnow (*Fundulus chrysotus*), marsh killifish (*Fundulus confluentus*), bluefin killifish (*Lucania goodei),* Mayan cichlid and redear sunfish (*Lepomis microlophus*). Mosquitofish and crayfish accounted for approximately two-thirds of all recorded aquatic prey.

Diversity scores were calculated and tested for community differences using multivariate techniques in PC-ORD™. Matching study predictions, mean richness (S), and diversity (H) were highest at moderately enriched treatments ($S = 6.3$, $H = 1.5$), with fewer species found at greater enrichment ($S = 4.7$, $H = 0.9$) or lesser enrichment ($S = 3.7$, $H = 1.2$). To detect compositional differences, prey data were plotted using NMS ordination, followed by a nonparametric test of group differences (MRPP). Finally, an indicator species analysis (ISA) identified which species belonged to each group. Ordination results indicated that control treatments were generally distinct from open treatments and reference areas. Using MRPP, only the comparison between EC and EO indicated significant differences in composition (MRPP, A 0.10, $p = 0.02$). The ISA analysis determined that EC supported crayfish and larger-body fish, while EO supported shrimp and smaller-body fish.

Functional Changes

Periphyton Productivity. The fixation of inorganic carbon, which can drive the food web, and oxygenation of the water column are two important functions that periphyton perform in the Everglades ecosystem. Periphyton primary productivity was measured to determine (1) periphyton's contribution to the overall primary productivity within a plot, and (2) if periphyton primary productivity differs between treatments and among regions.

Periphyton productivity, expressed as grams of carbon per square meter per day (g C/m^2/day), was measured for epipelon, epiphyton, and metaphyton by combining an approximation for biomass [grams of Ash Free Dry Matter per square meter (g $AFDM/m^2$)] with biomass-specific primary productivity values (mg C/g AFDM/mole photon/m^2) obtained using the light-dark bottle method (Wetzel and Likens, 1991). Measurements were made from October 1 through 3, 2007. Between treatments, gross primary productivity (GPP), net primary productivity (NPP), and respiration for all periphyton types were significantly greater in the open plots (EO and TO) compared to the control plots (EC and TC) since the dense emergent macrophyte biomass in the control plots inhibited the growth of periphyton (**Table 6-9**).

Comparing among regions, mean NPP for the enriched region was two and three times greater than that of the reference and transitional regions, respectively (**Table 6-9**). Overall, the high mean NPP measured for metaphyton raised the mean value; however, the coefficient of variation (CV percent) was similarly high (116 percent). The spatial variability in metaphyton biomass (range 0 to 87 g AFDM/ m^2) and biomass-specific productivity (range 0.25 to 2.71 mg C/g AFDM /mole photon/ m^2) likely caused the high CV percent. Plots with high metaphyton biomass also had high biomass-specific productivity. These results indicate that the removal of large stands of emergent macrophytes increases periphyton NPP. This has the potential to significantly affect the food web within the created opening since carbon fixation is shifted from the more recalcitrant emergent macrophytes to more labile algae and submerged aquatic vegetation (SAV).

Table 6-9. Net primary productivity, gross primary productivity, and respiration (mean ± sd) for the different periphyton types between treatments (open versus control) and among regions (unenriched reference, transitional, or enriched).

PeriphytonType	Treatment				
	UC	TO	TC	EO	EC
Net Primary Productivity (g C/m^2/d)					
Epipelon	0.40±0.18	np	np	0.12±0.25	np
Epiphyton*	0.47±0.18^{a}	0.50±0.48^{a}	np	0.04±0.10^{b}	np
Metaphyton*	0.32±0.33^{a}	0.11±0.25^{a}	np	2.31±3.39^{b}	np
Gross Primary Productivity (g C/m^2/d)					
Epipelon	0.46±0.21	np	np	0.16±0.34	np
Epiphyton*	0.94±0.35^{a}	0.53±0.51^{b}	np	0.05±0.13^{c}	np
Metaphyton*	0.39±0.41^{a}	0.13±0.29^{a}	np	2.38±3.49^{b}	np
Respiration (g C/m^2/d)					
Epipelon	0.06±0.03	np	np	0.04±0.09	np
Epiphyton*	0.47±0.17^{a}	0.03±0.03^{a}	np	0.01±0.03^{b}	np
Metaphyton	0.07±0.08	0.02±0.04	np	0.07±0.10	np

O = open
C = control
UC = unenriched reference
T = transitional
E = enriched
NP indicates periphyton not present.
N = 9
*Indicates significant (ANOVA, $p \leq 0.05$) difference among regions.
Values with the same letter (a/b) are not significantly different (Tukey HSD test).

Dissolved Oxygen. Water column dissolved oxygen (DO) was used to assess if ecosystem function differed between treatments and among regions since oxygen strongly influences biogeochemical reactions and the distribution of organisms. HydroLab sondes were used to measure DO in milligrams per litre (or parts per million) (mg/L) in each of the 15 plots at 30 minute intervals from August 13 through 17, 2007. DO profiles differed between the open and control plots with dense emergent macrophytes (**Figure 6-20**). Both the EO and TO treatments had strong diel patterns with daytime maximums exceeding 6 mg/L and nighttime minimums dropping below 1 mg/L. In contrast, DO rarely exceeded 1.5 mg/L and no diel patterns were evident for EC or TC controls. Among regions, daily DO varied more for the enriched and transitional sites (EO and TO) than the reference sites (UC). DO for the reference sites ranged from a daytime maximum of approximately 7 mg/L to a nighttime low greater than 2 mg/L. These results indicate that the removal of dense macrophyte stands can significantly alter ecosystem function. The elevated DO concentrations and strong diel patterns observed in the open sites (EO and TO) suggests primary production has shifted from an emergent macrophyte dominated system to a periphyton/SAV system. The greater DO concentrations further suggest that other important ecological processes (e.g., decomposition and fish distributions) are likely to be effected.

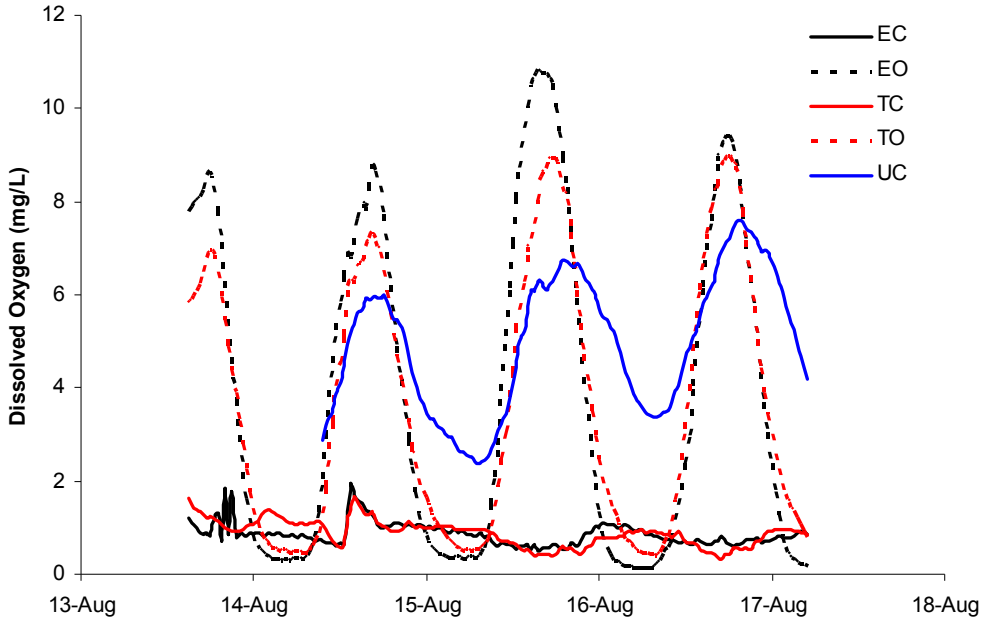


Figure 6-20. Mean dissolved oxygen (DO) diel profiles for the created openings (EO and TO), paired emergent macrophyte controls (EC and TC), and reference plots (UC) with n=3 for each treatment.

Decomposition. Decomposition is a primary controller of nutrient availability in study-subject peatland. Cattail litter was collected within the vicinity of each plot pair and approximately 15 g were placed in litter bags made of 1.6 mm fiberglass mesh screening, a similar approach to that of Newman et al., 2001. These litter bags were deployed within each plot and data collected from the six- and 12-month retrievals are presented (N = 3 per treatment/time combination). After six months, samples from most plots were similar, having approximately 60 percent of their initial mass remaining, with the exception of reference (UC) sites where 85 percent of the initial mass remained ($p < 0.001$). After 12 months, continued rapid decay was observed. The most rapid decomposition was observed in treatment EO, which had a significantly lower mass remaining (17 percent compared to either EC or TO sites in which 29 and 28 percent mass remained) ($p < 0.001$). In contrast, decay was significantly slower in the TC and UC plots, which had similar remaining masses of 54 and 67 percent, after 12 months.

Enzymatically mediated processes are key rate-limiting steps in decomposition. Using fluorescent analogs, key processes controlling carbon (C), nitrogen (N), and phosphorus cycling were examined by measuring the activity of ß-glucosidase (for carbon), leucine aminopeptidase (for nitrogen), and phosphomonodiesterase and phosphodiesterase (for phosphorus) in the surficial floc material. In September 2007, ß-glucosidase activity ranged from a high of 0.59 micromoles per hour per gram of Ash Free Dry Matter (µmoles/h/g AFDM) in floc from EO sites compared to a low of 0.04 µmoles/h/g AFDM at UC sites (**Figure 6-21**). Sites with the highest glucosidase activity had the lowest carbon concentration. Specifically, total carbon concentrations were lower in EO floc (402 g/kg) compared to floc from EC (464 g/kg), TC (451 g/kg), and TO (g/kg) sites. In addition to more rapid carbon turnover, this may indicate a more labile pool of carbon being cycled in the EO sites.

Similarly, nitrogen cycling, as indicated by leucine aminopeptidase activity, was highest in open plots, with the greatest value occurring in EO (**Figure 6-21**), with reduced activity in the control plots. Unlike that observed for carbon, the nitrogen concentrations in the floc were similar at all sites, ranging from 26-28 g/kg, with the exception of UC sites, where nitrogen concentrations averaged 14 g/kg. However, while no differences in nitrogen concentrations were observed in the floc itself, dead cattail and sawgrass, major contributors to the floc material at E and T sites, had significantly elevated nitrogen concentrations in open versus control sites, which in turn may explain the differences in nitrogen cycling. For example, the concentration of nitrogen in dead cattail averaged 16, 11, 5.6, and 5.6 g/kg for sites EO, TO, EC, and TC, respectively.

As expected, the highest phosphatase activity was observed in UC floc, the most phosphorus-limited sites. Similar activities were observed for both phosphomonodiesterase and phosphodiesterase (**Figure 6-21**). Nuclear magnetic resonance spectroscopy, a means to look at molecular structure, of the floc has previously shown the significant contribution of diesters, in addition to monoesters, to the organic phosphorus pool (Turner and Newman, 2005). These new results show that despite elevated phosphorus concentrations, microbial biomass and activity are high, such that the phosphorus pool is continuing to be hydrolyzed by enzymes to support carbon turnover and this activity not inhibited by high phosphorus concentrations.

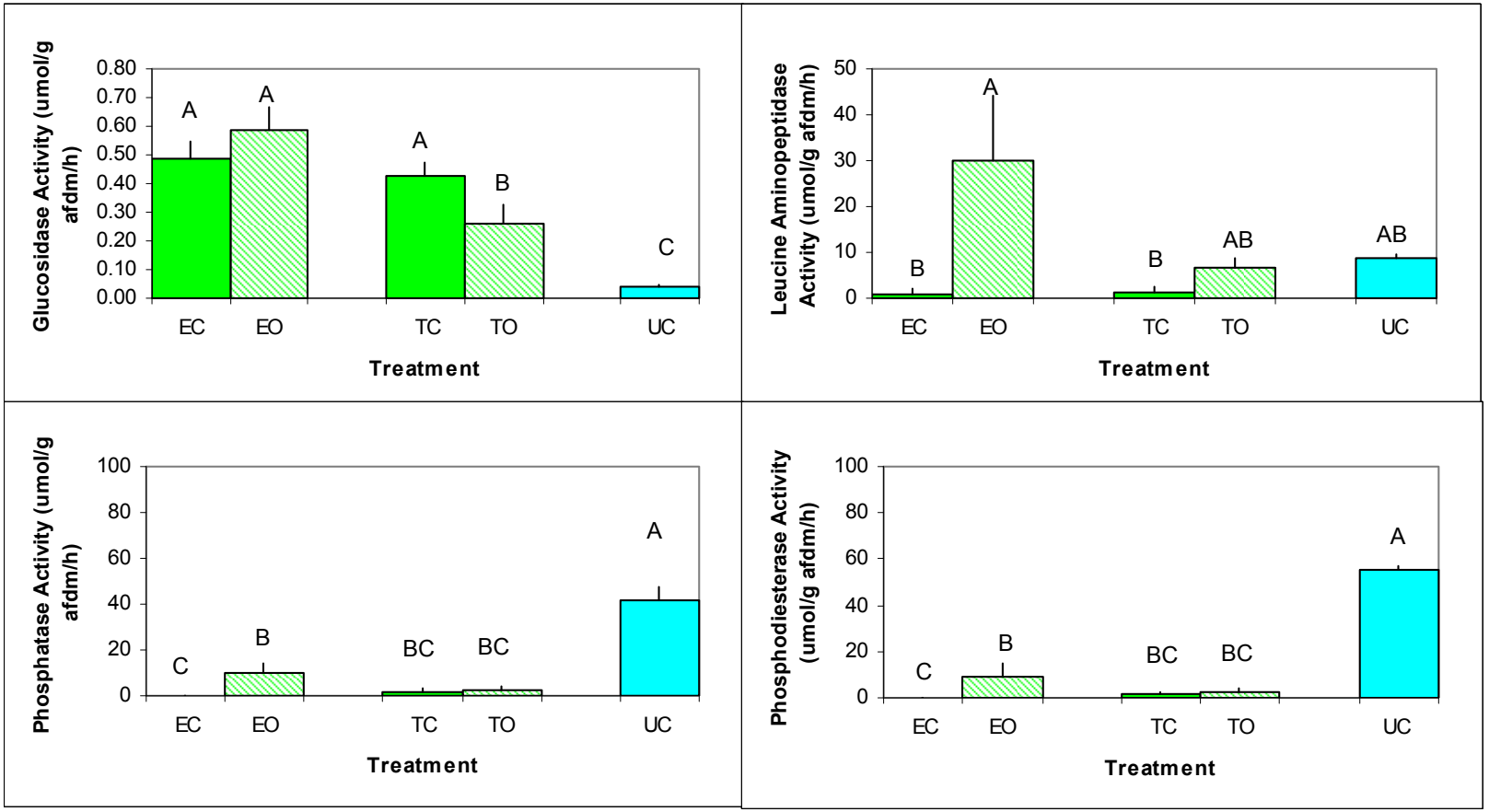


Figure 6-21. Mean enzyme activity for created openings (EO and TO), paired emergent macrophyte controls (EC and TC), and reference plots (UC) in floc samples collected in September 2007. The potentials for nutrient cycling are represented by ß-glucosidase (for carbon), leucine aminopeptidase (for nitrogen), and phosphatase and phosphodiesterase (for phosphorus) activities. Bars with different letters are significantly different from each other, at $p < 0.05$.

Both phospholipid fatty acid (PFLA) biomarkers and bacterial cell counts using 5-cyano-2,3-ditolyl tetrazolium chloride (CTC) staining (data not shown), show highest microbial numbers at EO compared to other sites, thus providing support for greater potential carbon and associated processing at those sites. However, in areas with extensive macrophyte biomass, fungi were also expected to play a role. Other data suggest, in contrast, that fungal activity is greater in control sites compared to open sites. Ergosterol, a chemical found in fungal cell membranes, was significantly higher in EC compared to EO sites, 43 versus 14 mg ergosterol/kg, respectively; and almost twofold greater in TC compared to TO sites, 15 versus 9 mg ergosterol/kg, thus indicating the importance of fungi in macrophyte carbon processing in the study wetland. Fungi are one of the groups that can break down both cellulose and lignin, thus increased abundance of fungi will have significant effects on decomposition of plant material — increased rates occurring in areas where there is increased fungal biomass.

Prey Biomass. Because traditional methods of sampling aquatic animals in the Everglades are ineffective in dense vegetation, a $1m^2$ bottomless pull trap was developed to provide comparative density estimates of small fish and macroinvertebrates in both open water and densely vegetated habitats. Sampling was conducted during October 2007. It was predicted that the biomass of herbivores (fish) would be greater in open treatments than in control treatments, the opposite being evident for detritivores (crayfish), and that the biomass of both trophic groups would be greater with increasing nutrient enrichment.

Prey responses were examined using one-way ANOVA models with biomass of fish or crayfish as the response variable against site (EO, EC, TO, TC, and UC) as the predictor variable. Detritivore (crayfish) biomass varied by area and treatment ($F_{4,10}$ = 5.41, p = 0.01), showed a general tendency to be greatest in control treatments and enriched areas (**Figure 6-22**), but only EC and U differed significantly from each other and all other area and treatments (Tukey's post-hoc tests: $p < .05$). Thus, during this sampling, all treatments had similar quantities of crayfish except the area that was most enriched and had a cattail monoculture, indicating the importance of dense vegetation and nutrients in crayfish growth, and/or protection from predation. Herbivore (fish) biomass did not differ significantly ($F_{4,10}$ = 0.72, p = 0.60).

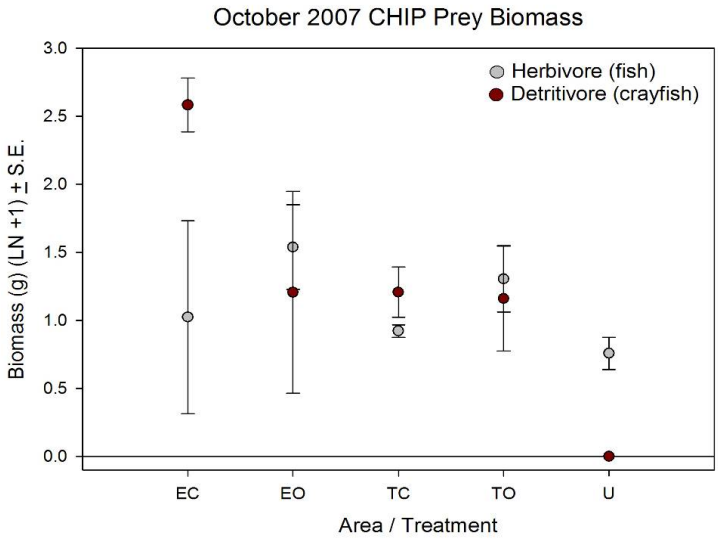


Figure 6-22. Prey biomass collected from created openings (EO and TO), paired emergent macrophyte controls (EC and TC), and reference plots (UC) in October 2007.

Wading Bird Foraging. Wading birds were surveyed weekly by helicopter from October 5, 2007 through May 1, 2008. A total of 6,271 individuals of 11 species in the following decreasing order of abundance were counted: white ibis, glossy ibis (*Plegadis falcinellus*), snowy egret, great egret, tricolored heron, little blue heron (*Egretta caerulea*), great blue heron (*Ardea herodias*), roseate spoonbill (*Ajaja ajaja*), black-crowned night-heron (*Nycticorax nycticorax*), wood stork, and limpkin (*Aramus guarauna*). White ibis accounted for approximately half the observed birds.

Water depths were suitable for wading bird foraging (5-25 cm) in E and T plots from December 2007 to early February 2008. During this period, more birds were observed in open plots than in control plots (all species combined), and average densities in the open conditions were very high, often over 100 birds per plot (**Figure 6-23**). Those few birds observed in the control plots were restricted to small open areas within the vegetation matrix. These results mirror closely those from the WY2007 nesting season, and agree with the predictions that created openings would attract greater wading bird foraging.

Observations also provided some support for predictions that foraging would be positively related to nutrient enrichment. During both the WY2007 and WY2008 seasons, more birds were observed in T and E plots than in UC plots, but differences were not evident between E and T plots. This suggests that foraging is positively related to nutrient enrichment at a relatively broad scale, i.e., between enriched and unenriched areas, but that some threshold value of enrichment is reached at the transitional zone where further enrichment does not elicit more foraging. The significance of this pattern is unclear at this point, particularly given that prey biomass tends to increase from T to E plots.

The total period that birds spent foraging in open plots decreased from 22 weeks in WY2007 to 12 weeks in WY2008, largely due to longer periods of deeper water in WY2008. Despite this decline, the temporal availability of foraging in the open plots appears to be considerably longer than that in the natural system where large foraging flocks at any one place rarely remain for more than a week.

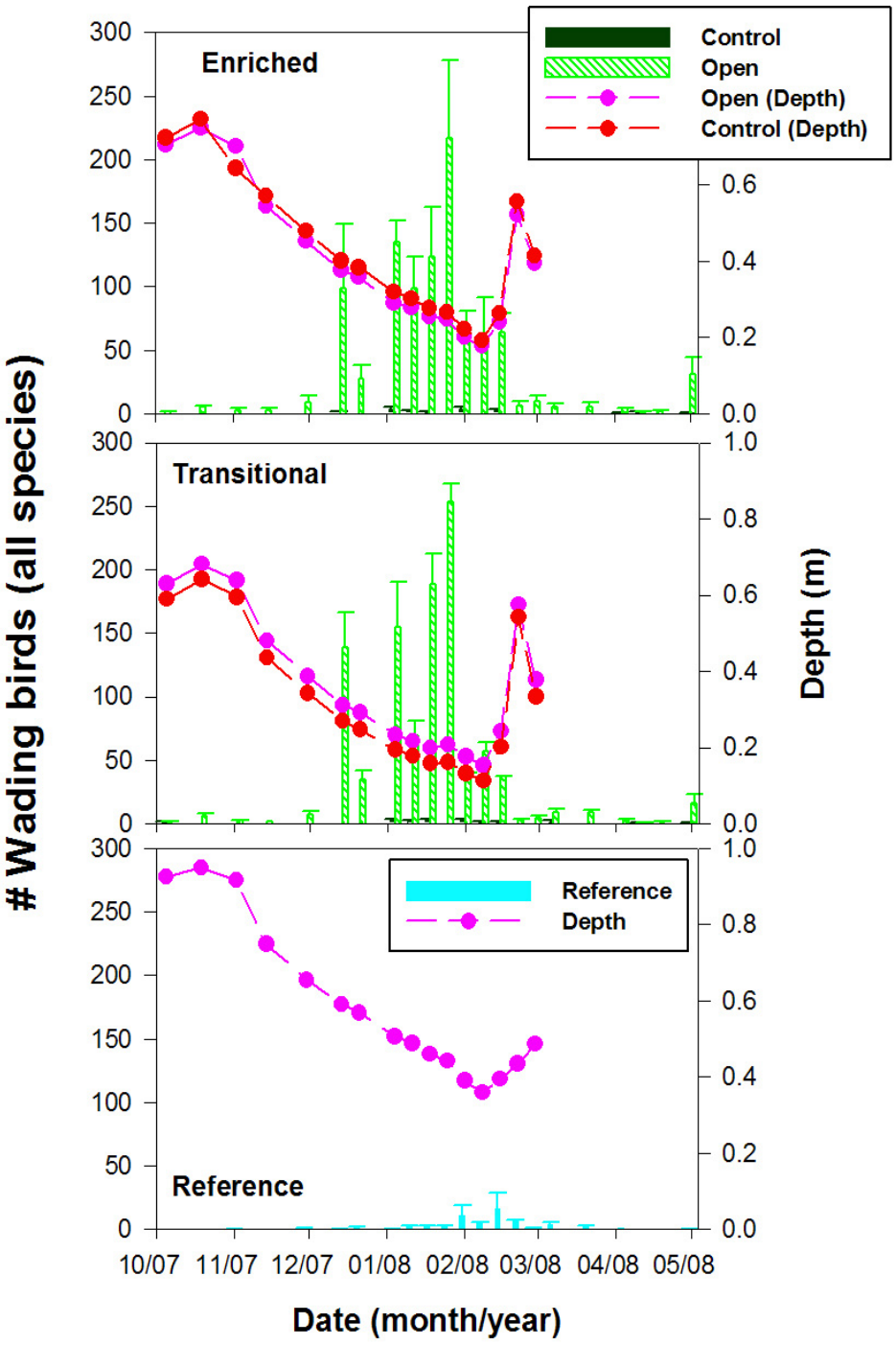


Figure 6-23. Wading bird numbers and water depth in Cattail Habitat Improvement Project (CHIP) plots from October 2007 through May 2008 (mean ±1 SE).

Secretive Birds. Numbers of secretive birds were estimated using call-broadcast point-count surveys during the early (November 2007), mid (January 2008), and late (March 2007) wintering periods. Six species of secretive marsh birds were detected: king rail (*Rallus elegans*), sora rail (*Porzana carolina***)**, American bittern (*Botaurus lentiginosus*) (bird of Conservation Concern, U.S. Fish and Wildlife Service), least bittern (*Ixobrychus exilis*) (Florida Species of Special Concern), pied-billed grebe (*Podilymbus podiceps*), and purple gallinule (*Porphyrula martinica*).

The relatively common American coot (*Fulica americana*) and common moorhen (*Gallinula chloropus*) were not surveyed. The king rail was the most common species detected followed by the least bittern, but interspecies differences in detectability may be partly responsible for the observed differences. The American bittern, for example, rarely calls during winter and detection of this species was based solely on visual sightings, which is potential for considerable underestimate.

Secretive bird use of plots were examined with a three-way ANOVA for number of birds (all species combined, natural-log transformed) as the response variable, and treatment (open and control), site (E and T) and stage of wintering season (early, mid, and late) as the predictor variables. As expected, significantly more secretive birds were found in control plots than in open plots ($F_{1,35}$ = 24.86, p = < .0001), and more inhabited E plots than T plots ($F_{1,35}$ = 9.52, p = 0.0043). Stage of the wintering season was not significant ($F_{2,35}$ = 2.05, p = < .1455). Interactions were not significant and were removed from the final model.

Conclusions

Intensive sampling shows that within one year of creating the openings within densely vegetative areas there are successful changes, i.e., habitat improvement, to the structure and function of these areas. Specifically, phospholipid fatty acid analyses indicated significant changes to the microbial community structure, with greater overall biomass of microorganisms, especially eukaryotic organisms, in the open plots.

The effects of eutrophication were evident as the oligotrophic reference (UC) had reduced microbial biomass in the sediment and floc. Periphyton mats had tremendous microbial biomass at the reference site (UC), significant components of which were diatoms and cyanobacteria. Green algae, indicators of more eutrophic conditions, were more prevalent at the other CHIP plots. Compared across sites, significant differences in species composition were observed; however, all periphyton assemblages were dominated by cyanobacteria (> 90 percent). Cyanobacteria are generally considered to be a poor resource for higher tropic levels and some taxa are known to produce toxins that inhibit consumption.

- The changes in microbial communities and metabolism in the created open areas increased the oxygenation of the plots and fostered a return to diel O_2 cycles, driven by high net primary productivity. This in turn resulted in increased processing of organic matter, as evidenced by increased decomposition rates and greater enzyme activity associated with carbon, nitrogen, and phosphorus acquisition.
- Compared to open plots, control plots had significantly greater living and dead macrophyte biomass. Therefore, these sites were dominated by functions geared towards processing detrital tissue. Specifically, higher fungal activity and higher detritivore biomass were found in the controls when compared to the open plots.

- Wading bird foraging was higher in open plots compared to controls and was of longer duration than that observed in the natural system.

The changes observed in open versus control plots point toward improved habitat quality and enhanced ecological function in these nutrient-enriched areas. Continued analysis of data collected over the remaining year will provide further evidence of the temporal trends and sustainability of these responses. Additionally, nutrient budgets to examine carbon cycling still need to be developed.

ACCELERATED RECOVERY OF IMPACTED AREAS

As a research component of the Long-Term Plan (Burns and McDonnell, 2003), the District is conducting a large-scale experiment (the Fire Project) designed to evaluate the use of fire as a management tool to accelerate the recovery of the phosphorus-impacted areas of WCA-2A. Fire was chosen as a possible option for accelerating recovery because of its role in shaping the historic Everglades landscape. (See Chapter 8 of this volume for details on the Long-Term Plan).

Since very little is known about fire ecology in the Everglades, two main objectives emerged for the Fire Project:

- To understand fundamental impacts of fire on soil, water, and vegetation processes in the Everglades wetlands
- To assess whether repeated prescribed fires will accelerate ecosystem recovery from nutrient enrichment and lead to a species shift from cattail-dominated communities to macrophyte communities with more indicative species of the historic Everglades

The Fire Project is designed to address three overall hypotheses:

- Fire will stress cattail, although the degree of stress will largely depend on timing and physical environmental conditions.
- Frequent multiple fires will provide a repeated disturbance that will accelerate the decline of cattail communities and enhance recovery of native species adapted to fire, such as sawgrass.
- Multiple fires will decrease soil phosphorus availability by burying the high-phosphorus content peat with low-phosphorus content detritus.

Project Milestones

The Fire Project was initiated in 2005 and consists of about 15 sub-studies related to major wetland ecosystem processes including water, soil, periphyton, and vegetation dynamics (Miao et al., in press). Two fires were initiated in 2006, a winter fire at the moderately enriched plot and a summer fire at the highly enriched plot. These fires represent the first set of fires in our multiple fire experimental design. Preliminary analyses were conducted focusing on short-term ecosystem recovery for some of the sub-studies. Several documents were created based on these current findings including: a book chapter focused on design and scale issues for large-scale, nonreplicated experiments (Miao et al., in press). Using the Fire Project as an example, the chapter addresses some dilemmas and solutions for large-scale and long-term ecosystem and landscape studies. Two manuscripts based on the results of the first fires were accepted for publication. One focused on fire effects on dissolved inorganic carbon dynamics (Gu et al., 2008),

and found that surface water dissolved inorganic carbon did not increase dramatically after fire as would be expected. This result was due to an increase in surface water pH in the short-term and increased periphyton biomass and photosynthesis in the longer-term. Another manuscript examined ash nutrient forms and availability (Qian et al., in press) and is described in greater detail below.

Ash Nutrient Forms and Fire Intensity

Cattail and sawgrass ash nutrient forms and concentrations were examined to determine possible effects of fire on nutrient balance and cycling (Qian et al., in press). This is one of the first studies to investigate plant ash phosphorus fractionation. Factors that affect ash nutrients include fire intensity, plant species, habitat nutrient availability, and life stage of the leaf. Laboratory simulations were used to determine the effect of temperature on ash nutrient composition, especially phosphorus fractions, in live and dead sawgrass and cattail leaves derived from the highly enriched, moderately enriched, and reference plots. The results were compared to ash collected from the prescribed fire at the highly enriched plot.

Two main conclusions resulted from this study. The first was that temperature determined the volatilization of carbon and nitrogen. Near-complete organic matter combustion occurred around 450°C. Although there was no temperature gradient effect on phosphorus concentrations during burning using a muffle furnace, phosphorus fractionations changed in response to fire intensity. The water-soluble phosphorus fraction was greater when leaves were exposed to lower temperature fires. Secondly, significant differences in ash phosphorus forms and availability were found between sawgrass and cattail, which has important implication for fire impacts in Everglades wetlands. Sawgrass ash had a larger ammonium chloride (NH_4Cl)-extractable fraction than cattail ash, which could result in a greater release of phosphorus after a fire in sawgrass-dominated areas.

Laboratory-produced ash phosphorus from both species was primarily composed of water soluble phosphorus and calcium-magnesium (Ca/Mg) bound phosphorus (HCl-extractable phosphorus) and/or residual phosphorus (non-extractable phosphorus) (**Figure 6-24**). Significantly greater amounts of labile inorganic phosphorus (mainly NH_4Cl-extractable phosphorus with an average of 56 percent) remain in the sawgrass ash versus the cattail ash. Approximately 81 percent of total phosphorus (TP) in cattail was converted to Ca/Mg bound phosphorus (67 percent) or residual phosphorus (14 percent) in the laboratory and over 95 percent of field ash was Ca/Mg bound phosphorus or residual phosphorus. These compounds are relatively stable at pH values above seven and are thus unavailable to plants, which may have important management implications when considering fire as a tool for reducing plant phosphorus availability.

Cattail ash had higher phosphorus content than sawgrass ash, and TP concentration generally increased with increased soil phosphorus concentration. Burned live leaves had higher phosphorus content than burned dead leaves. However, in the field, mostly dead leaves were burned, while live leaves were scorched but not converted to ash. Field ash had more remaining nitrogen and carbon, but 40 percent less phosphorus than laboratory ash. The Ca/Mg bound phosphorus fractions were similar, but the NH_4Cl-extractable fraction was different between the field and laboratory ash.

Differences between field and laboratory ash could result from several factors. These include variable temperatures during the field burn when compared to the uniform temperatures in the muffle furnace, and a mixture of live and dead leaves from several species found in the field, compared to only dead cattail leaves in the laboratory. However, the results from the laboratory simulations were important for understanding how fire intensity may affect the nutrient balance and biogeochemical response to fire, which directly affects vegetation recovery dynamics.

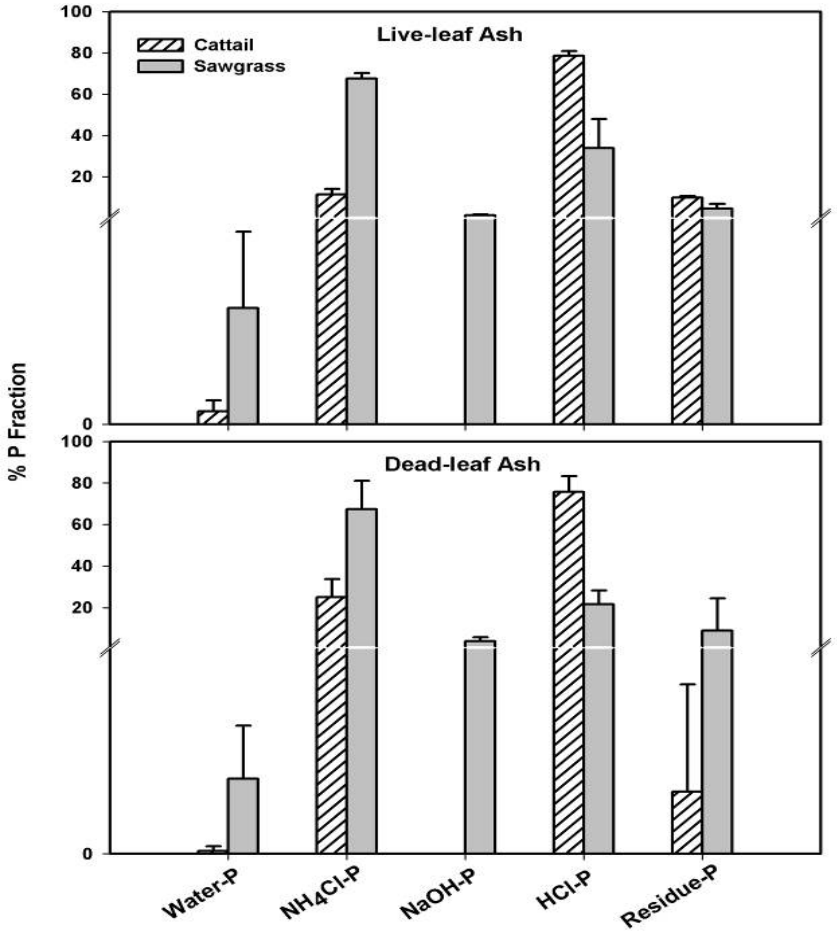


Figure 6-24. Inorganic phosphorus fractionation in ash from live and dead cattail and sawgrass leaves.

Seasonal Variations of Seed Bank Germination and Response to Fire

To assess the effectiveness of prescribed fire in controlling cattail and to predict post-fire vegetation dynamics in WCA-2A, it is pivotal to have knowledge of the seasonal variation of seed bank germination and its interplay with nutrient enrichment and fire.

The objectives of this sub-study were to investigate:

- species richness and density of the soil seed bank along the nutrient gradient
- temporal (seasonal) germination dynamics
- germination response to fire (Miao and Zou, in review)

Soil samples were collected from each plot along the nutrient gradient during different seasons and pre- and post-fire and placed in germinating pots. Seeds were allowed to germinate, and the number and species of each plant were recorded. Both species richness (number of species per soil sample) and total seed bank density were significantly higher at nutrient-enriched sites. At each nutrient level, the seed bank density of most species varied with seasons. The seed bank density of cattail was higher in summer and the largest seed bank of sawgrass was in fall. Moreover, the temporal dynamics in germination varied greatly among species. Cattail had a very short incubation period and germinated as quickly as two to three days after an assay was initiated. Peak germinations appeared during the first, fourth, and sixth week in summer, fall, and winter, respectively. The onset of sawgrass germination did not vary greatly between seasons and would generally start during the fourth week after initiation. Water lily (*Nymphaea odorata*) and bulltongue arrowhead (*Sagittaria lancifolia*) had relatively low seed densities and germinated more sporadically. Southern amaranth (*Amaranthus australis*) and the remaining other species generally germinated predominantly within the first eight weeks.

The seasonal timing of the fire also made a difference in seed germination. Results indicate that a winter fire could significantly reduce the cattail seed bank and result in a soil seed bank dominated by sawgrass at the moderately enriched site. The summer fire effectively reduced the seed bank density of cattail, but cattail seeds still comprised more than 60 percent of the total seed bank. Germination and establishment of cattail would likely overwhelm other species post-fire. However, whether fire will change species dominance of the in situ seed bank and whether the change at the seed bank level will eventually translate into dominance in the recovered vegetation, or benefit native vegetation recovery at landscape scale, need to be examined further.

Cattail Recovery Dynamics Following Fire

The cattail community was monitored before and after the fires (**Figure 6-25**) at the highly enriched and moderately enriched plots to assess the underlying mechanisms controlling vegetation recovery patterns and dynamics. Fire increased cattail ramet (shoots from a single plant or clones) emergence within six months after the fire compared to the unburned areas – but at the same time there was also an increase in ramet mortality (**Table 6-10**). Ramets that survived the fire grew faster than newly emerging ramets, indicating the parental ramets had preferential access to internal nutrient reserves (**Table 6-11**). There was a decrease in the shoot-base to leaf-biomass ratios after the fire, which indicated that resources for the initial regrowth of cattail following fire came from their internal belowground storage components. While community level vegetation biomass had almost recovered to pre-fire levels by the end of the first year, individual

cattail ramet biomass was still significantly less than pre-fire while density was greater, which suggests a trade-off between ramet density and biomass during the recovery period (**Figure 6-26**).

Several community structure parameters such as leaf litter mass had not returned to pre-fire conditions after one year. The timing of the fires also impacted cattail recovery. The summer fire caused greater stress on cattail plants than the winter fire due to differences in seasonal plant phenology and also because of differences in post-fire hydrology. Water levels were very low following the winter fire and high following the summer fire. Water depth differences effected soil redox potential and also leveled out the differences in surface water phosphorus concentrations that might otherwise be expected between enrichment areas. (See the *Soil Redox Temporal and Spatial Patterns in Water Conservation Area 2A* section of this chapter.) All of these factors together created more favorable environmental conditions for cattail recovery.

Preliminary findings indicate that fire characteristics such as the timing of the fire, the intensity, and frequency of the burn, all play important roles in ecosystem responses. The timing of the fire seemed critical for vegetation recovery speed and patterns. The recommendation is that the interval between two burns in cattail-dominated habitats be at least two years, dependent on fuel load. All the findings discussed here should be considered as management factors when implementing prescribed fires.

Based on results from the first set of fires, multiple fires at frequent intervals might possibly weaken cattail populations enough to allow the re-establishment of other, more fire-tolerant species native to the area. However, this will depend on the time required for adequate accumulation of leaf litter to fuel the next fire. These results suggest that these cattail communities cannot sustain annual summer burning frequencies since dead leaf litter accumulation was too slow. Thus, the answer to whether repeated prescribed fires could successfully control cattail in enriched areas of South Florida seems to depend largely on the potential to re-burn an area before the cattail has completely recovered. After two years, the litter layer may have accumulated enough to sustain a second fire, but the question is whether the cattail will have recovered enough to not be more negatively effected than after the first fire.

Figure 6-25. Cattail regrowth within one week (left) and four months (right) after fire (photos by the SFWMD).

Table 6-10. Cohort (same age) dynamics of individual cattail ramets (per square meter) in the highly enriched area. Cohorts 1 and 2 were ramets which emerged pre-fire and cohorts 3 and 4 emerged post-fire. Mortality calculations are cumulative with time and were made 6, 12, and 18 months post-fire for all cohorts.

		Burned	Unburned	Difference (%)
Cohort 1	Initial ramets (Feb 2006)	11.0	13.0	-15.4
	Mortality 6 months post-fire	10.7	10.7	0.0
	Mortality 12 mo. post-fire	11.0	13.0	-15.4
Cohort 2	Emerged ramets (Feb - Jul 2006)	7.3	6.3	15.8
	Mortality 6 mo. post-fire	4.7	3.0	55.6
	Mortality 12 mo. post-fire	6.7	5.7	17.6
	Mortality 18 mo. post-fire	7.3	6.0	22.2
Cohort 3	Emerged ramets (July 2006 - Feb 2007)	21.7	13.3	62.5
	Mortality 6 mo. post-fire	3.7	0.7	450.0
	Mortality 12 mo. post-fire	12.3	6.3	94.7
	Mortality 18 mo. post-fire	20.3	11.0	84.8
Cohort 4	Emerged ramets (Feb - July 2007)	8.7	10.0	-13.3
	Mortality 18 mo. post-fire	4.7	4.7	0.0

Table 6-11. Growth rates of surviving and new ramets (centimeters per day plus or minus standard error) following the prescribed fire in the highly enriched area.

	Surviving Ramet		New Ramet	
Weeks post-fire	cm day $^{-1}$	s.e.	cm day^{-1}	s.e.
1 wk.	6.48	± 0.24	4.96	± 0.69
2 wk.	6.94	± 0.96	4.23	± 0.55
3 wk.	6.12	± 1.29	4.01	± 0.74
4 wk.	2.97	± 0.35	2.13	± 0.32
12 wk.	0.60	± 0.12	1.13	± 0.15

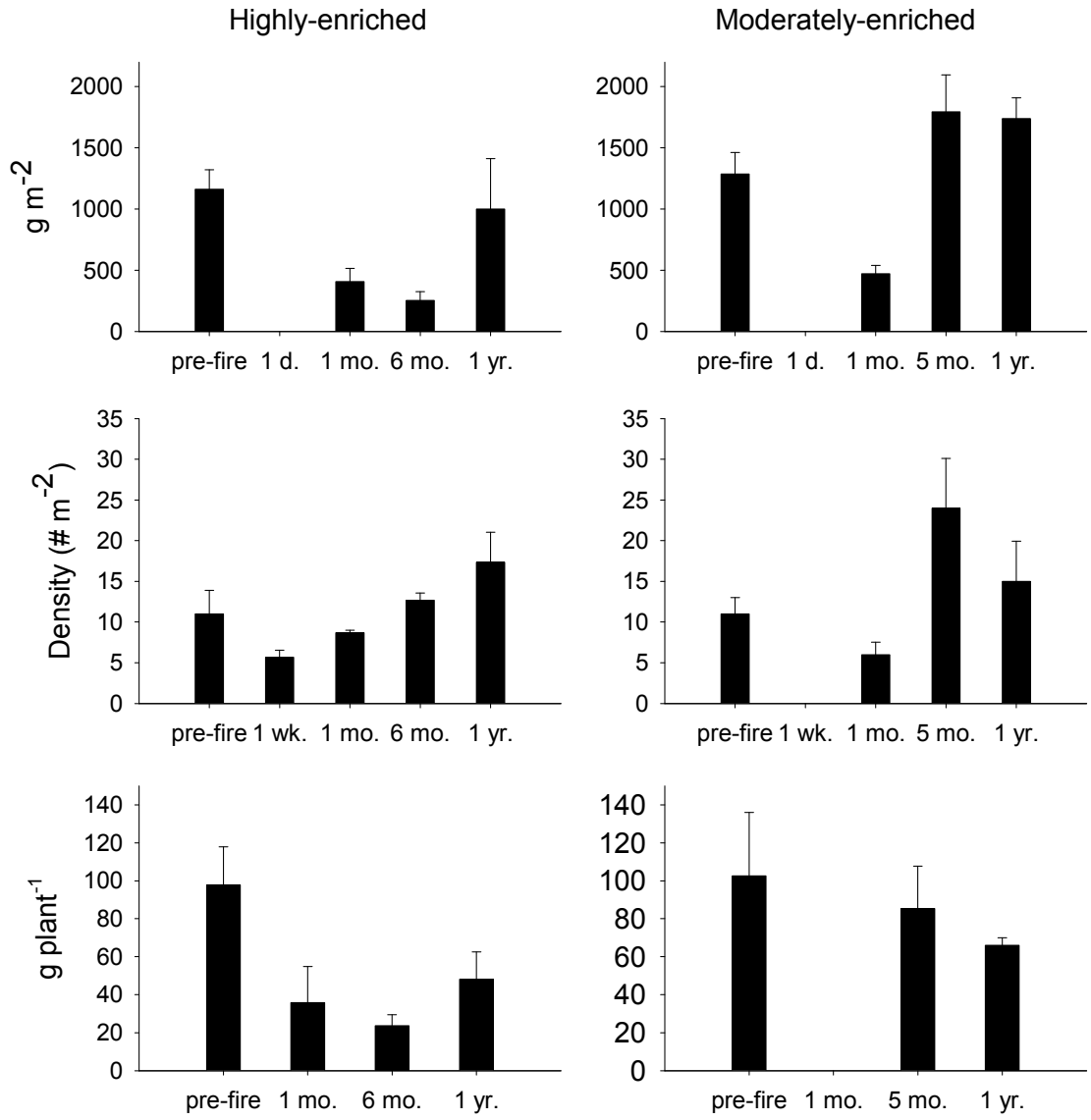


Figure 6-26. Changes in cattail population biomass, ramet density, and individual ramet biomass at specific time intervals (as noted) following fire in the highly and moderately enriched area. Pre-fire values are means of at least three sampling locations.

Soil Redox Temporal and Spatial Patterns in Water Conservation Area 2A

The reduction-oxidation (redox) potential of soil is an indicator of physically and/or biologically driven chemical reactions such as oxygen demand, decomposition, geochemical equilibria, and potential plant stress. Temporal and spatial redox dynamics, in turn, effect wetland ecosystem functions and processes. Cattail and sawgrass have different adaptive strategies to survive in low-oxygen soil conditions that result in competitive advantages for cattail growing in flooded conditions where soil redox is low. The objectives of this study were to determine the patterns and variability of soil redox in relation to water depth, dominant vegetation community, and soil phosphorus concentration. Redox potential was measured at several depths 2, 5, 10, and 20 cm using platinum-tipped copper probes to determine the temporal and spatial patterns. Probes were permanently installed starting in March 2007, and measured monthly. Probes were allowed a one-month period to equilibrate with the soil before first measurements were taken.

Soil redox was directly related to water level changes, which vary seasonally. Redox responded exponentially to increases in water depth; redox changed very little once water levels reached 0.1 m above the marsh surface but increased rapidly as water levels fell below 0.1 m (**Figure 6-27**). During high water conditions, soil redox in the root zone was approximately -200 millivolts (mV), but when the water table dropped below the marsh surface, soil redox reached as high as +600 mV, especially for the soil depths closest to the marsh surface. Low water conditions generally occur in spring, while the marsh is generally flooded the remainder of the year. At the small spatial scale, there was no difference in redox between the different soil depths within the root zone during high water conditions.

The redox for each soil depth was approximately -200 mV when water depths were greater than 0.1 m above the marsh surface. However, when water level was at the marsh surface, a redox gradient became apparent in the soil profile such that at 2 cm, soil depth redox averaged +102 mV; at 5 cm, soil depth averaged +61 mV; at 10 cm, soil depth averaged +31 mV; and at 20 cm, soil depth averaged -117 mV. Small-scale spatial variability was dependent on the location of the water table.

At the large spatial scale, no patterns in redox were found for soil where different vegetation communities dominated. Soil redox conditions where cattail dominated were similar to mixed communities and sawgrass-dominated communities. Soil redox conditions also were neither affected by the soil phosphorus concentration gradient present in WCA-2A nor by the concentrations of different inorganic phosphorus fractions such as phosphate, iron-bound phosphorus, or calcium-bound phosphorus. Large-scale differences in redox may be apparent in the floc or soil-water interface, but redox was not measured at these discrete depths in this study.

Water levels alone were the major predictor of soil redox variability at the temporal and spatial scales considered. Post-fire water levels may have important management implications for vegetation recovery as cattail is better adapted to low redox conditions than sawgrass.

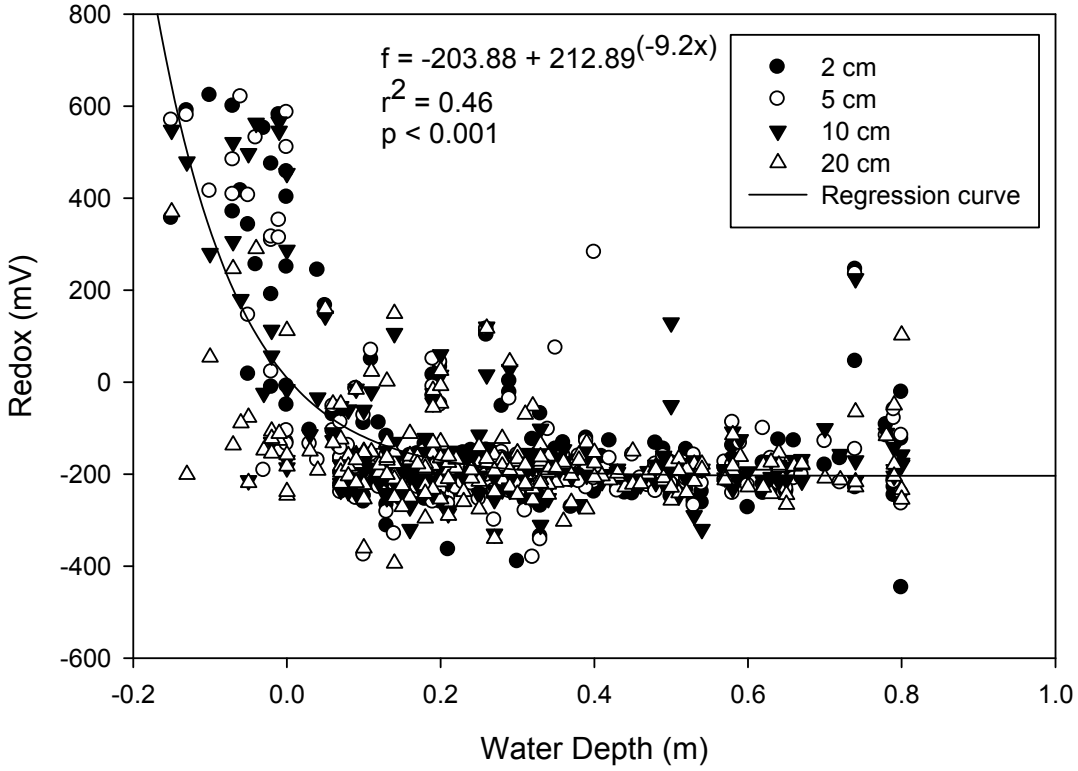


Figure 6-27. Redox at different soil depths with changing water levels.

TREE ISLAND HYDRODYNAMICS

Identifying groundwater-surface water interactions on tree islands is necessary to gain a better understanding of the effects of managed surface water levels on tree island formation and restoration. Over the last century, the construction of canals, dikes, and levees across the Everglades has led to drastic hydrologic changes, which have been linked to the 60 percent reduction in tree island cover in WCA-3 and the 90 percent reduction in WCA-2 (Sklar and van der Valk, 2002). This loss of topography is due, in part, to periods of extended high surface water levels that have drowned trees and caused the accumulation of peat in sloughs. Though the overall topographic variation of tree islands is similar across the Southern Everglades, their shape and underlying geologic material differs from higher latitudes to lower latitudes. These differences have the potential to alter the rate of exchange between groundwater and surface water of tree islands. In the north, round peat core tree islands dominate WCA-1 and WCA-2A, while to the south, in WCA-3 and the ENP, tree islands are predominantly teardrop in shape with limestone cores (Ross and Jones, 2004). As was discussed in the *Plant Ecology* section of this chapter, percent groundwater usage differs by species and by island. In this section, the direct physical interactions of surface water and ground water are discussed to understand the ecophysiology and nutrient cycling of these habitats.

The major hypothesis for this LILA research program asks the question: Is the rate of exchange between surface water and ground water related to inundation, flow, the underlying geologic material of the island, and the tree island vegetation?

Field Methods

To determine groundwater-surface water interactions, nine wells were drilled or augured into eight tree islands at LILA with an average depth of 1.34 ± 0.15 m and an average bottom elevation of 3.49 ± 0.08 m. Each well has a diameter of 3.8 cm and a 0.6 m screen interval at the bottom. Surface water and groundwater levels and temperature were recorded at a 15-minute sampling rate with 26 in situ 500-Troller™ pressure transducers. Seven of these pressure transducers are permanently installed in the center well of each of the islands, while the other 21 have been moved around to accommodate varying experimental designs. Additional stage level recorders managed by the SFWMD for LILA were used to supplement data collection of surface water levels in header canals, macrocosms, and the tail canal. Precipitation data from a District weather station in close proximity to LILA was used to correlate large changes in groundwater levels and rain events (site: LOX WST). (Note: The LILA design relevant to this particular experiment, presented in previous SFER reports, is composed of a total of four 15-acre macrocosms, and a total of two man-made 0.75-acre tree islands within each macrocosm. One of these two islands has a core of limestone rock, while the other island has a core of peat.)

Results and Discussion

The total amount of rainfall at LILA for 2007 was 125 cm. The average daily rainfall during the dry season (January through May and November through December) was 0.1 cm, while during the wet season (June through October) the daily average rainfall was 0.7 cm. Throughout the dry season, limestone-core tree islands typically had groundwater levels lower than the surface water, which suggests that the surface water was recharging the groundwater (**Figure 6-28**). Only during rain events in the dry season did the water levels in the limestone-core tree islands exceed the surface water level, indicating that the groundwater from limestone-core tree islands was discharging into the surface water at that time.

Conversely, groundwater levels in the peat core tree islands were highly correlated to surface water levels, although the groundwater levels were always higher than the surface water (**Figure 6-28**), which suggests that the groundwater was discharging to the surface water. Mid-May through July, the groundwater levels in both types of tree islands were higher than the surface water level and appeared to be highly correlated to rain events. The actual change in groundwater levels might be less than detected due to the Lisse effect, which occurs when intense rain seals the surface soil layer to airflow, trapping and compressing air in the unsaturated zone, causing an increase in pressure which is realized in high groundwater levels, though the water table has not changed (Larsen, 1932; as referenced in Weeks, 2002). The data still suggests that from June through July the groundwater levels in the islands were higher than the surface water. As surface water levels rose to a maximum in mid-November, groundwater levels in the limestone-core tree islands equated with those of the surface water while the peat core islands maintained groundwater levels slightly higher than that of the surface water. This may indicate a small amount of capillary rise.

Diurnal groundwater signals were detected year-round in the wells located in the center of the islands while from mid-March to mid-May the diurnal groundwater signal was detected in all wells in the peat and limestone core tree islands. These diurnal signals appear to be correlated with the evapotranspiration signals detected by Ross et al. (2006) and other tree island studies. This data suggests the trees on the islands are relying on groundwater more when the surface water levels are low (mid-March to mid-May).

Though the groundwater levels in the peat core tree islands appear to be more correlated to the surface water levels, the temperature data supports water level results indicating that the limestone core tree islands were recharged by the surface water (**Figure 6-29**). Throughout the dry season, when the limestone core tree islands were recharged by surface water, the groundwater temperature on those tree islands was similar to those of the surface water. A higher hydraulic conductivity of limestone as compared to peat may explain the greater groundwater-surface water exchange in the limestone versus the peat core tree islands.

Conclusion

Tree islands are dynamic within the Everglades. It is important to take into consideration that managed surface water levels will effect the groundwater-surface water interactions differently on peat- versus limestone-core tree islands. In addition, these groundwater-surface water interactions indicate that tree island vegetation needs to be studied in relation to groundwater movements.

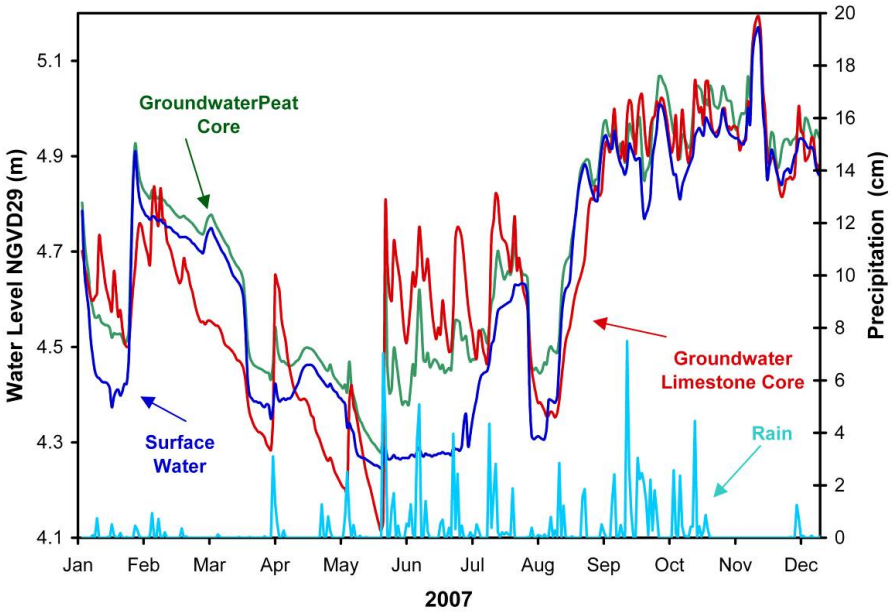


Figure 6-28. Water level elevations (m) measured in the surface water and center well of a peat and a limestone core tree island from January through December 2007. Daily rainfall values (cm) are shown on the second y-axis.

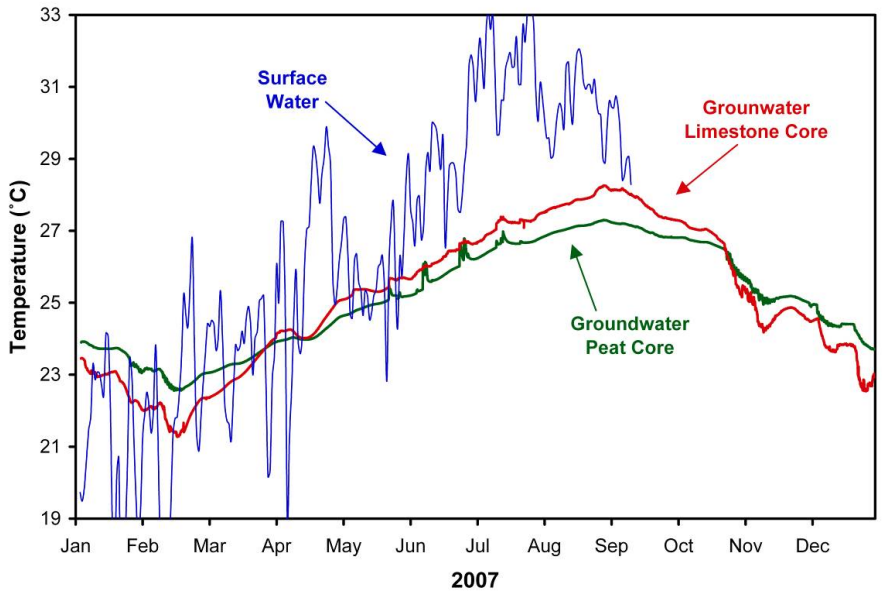


Figure 6-29. Temperature (˚C) signals from surface water and groundwater in a peat and a limestone core tree island from January to December 2007.

TREE ISLAND NUTRIENT FLUXES

Tree islands appear to concentrate large quantities of phosphorus as shown by high soil phosphorus concentrations (Orem et al., 2002) and may have an important function in landscape sequestration of inorganic nitrogen (Troxler-Gann, 2005). Thus, with hydrologic restoration of freshwater marshes the nutrient function of tree islands has the potential to change. However, this function is not clearly defined either past or present. The long-term research goals are to investigate and describe the ecological significance of tree islands by quantifying the contribution of tree islands to the nutrient balance of the Everglades landscape. As part of the long-term research effort, the current study's goal was to determine the nutrient budget on tree islands. Phosphorus sequestration may occur via atmospheric deposition, biotic uptake, decomposition/soil accumulation, surface water loading, and groundwater upwelling. Nitrogen sequestration may occur via biotic uptake, microbial immobilization, coupled nitrification-denitrification, surface water loading, and decomposition/soil accumulation. Long-term results from this study will aid in our understanding of the role of tree islands in landscape nutrient budgets and provide a comprehensive metric with which to assess tree island ecosystem responses to hydrologic change and to address a critical science need by quantifying the phosphorus and net inorganic nitrogen standing stocks and sequestration capacity of a characteristic tree island of WCA-3A.

The hypothesis is that tree islands are open ecosystems and, thus, have the capacity to sequester nutrients (especially phosphorus) from the surrounding environment.

Methods

Net nitrogen flux in the study site was determined using results from nitrogen (N) transformation studies (Troxler-Gann, 2005) in conjunction with surface water and tree island-island edge groundwater fluxes and biomass nitrogen pools and fluxes. Following methodology proposed by Troxler-Gann (2005), Craft and Richardson (1993), and Fetter (1994), in which the tree island-marsh interface is considered as the boundary, the N budget followed the form:

$[(N_{dep} + N_{accretion} + N_{min} + N_{nit} + N_{sw} + N_{ssw(IM)} - N_{demand}] - N_{NH4imm} - N_{NO3imm} - N_{ssw(EX)}$ = net ecosystem N flux (Fetter, 1994).

where N_{dep} is nitrogen as atmospheric deposition, $N_{accretion}$ is soil accretion, N_{min} is gross mineralization, N_{nit} is gross nitrification, N_{sw} is surface water of dissolved inorganic nitrogen (DIN), $N_{ssw(IM)}$ is subsurface water inputs of DIN, N_{demand} is plant nitrogen required by external nitrogen sources (hydrologic imports) to meet the minimum requirement of sustaining canopy leaf standing crop, N_{NH4imm} is ammonium (N_{H4}) consumption, N_{NO3imm} is nitrate (N_{O3}) consumption, and $N_{ssw(EX)}$ is subsurface water export of total nitrogen (TN). In this estimate, denitrification and N fixation were considered negligible. The rationale for assuming that denitrification and N fixation rates are negligible is that our previous studies on bayhead islands have shown that both rates are very small (Troxler and Childers, in review). All units are in grams per square meter per year (g m^{-2} yr^{-1}).

Net phosphorus flux in tree island 3AS3 was determined by utilizing results from the described surface water and tree island-marsh edge groundwater fluxes (Troxler-Gann, 2005) and biomass phosphorus (P) pools and fluxes. With the tree island-marsh interface as the boundary, the P budget followed the form:

$[(P_{dep} + P_{accretion} + P_{sw} + P_{ssw(IM)}) - P_{demand}] - P_{ssw(EX)}$ = net ecosystem P flux (Fetter, 1994).

where P_{dep} is P as atmospheric deposition, $P_{accretion}$ is soil accretion, P_{sw} is surface water inputs/outputs of soluble reactive phosphorus (SRP), $P_{ssw(IM)}$ is subsurface water import of total phosphorus (TP), P_{demand} is plant P required by external P sources (hydrologic imports) to meet minimum requirements to sustain canopy leaf standing crop, and $P_{ssw(EX)}$ is subsurface water export of TP. All units are g m^{-2} yr^{-1}.

Results and Discussion

Results from this field study have generated preliminary data analyses on major nitrogen and phosphorus pool and fluxes for two plant community types, the wet head and near-tail of tree island 3AS3. A wet head is a relatively high wetland with a long hydroperiod due to surrounding hydrology; the near-tail is a low-elevation region just downstream of the wet head. It was found that the wet head had a net ecosystem DIN loss of 8.42 g nitrogen m^{-2} yr^{-1} and a net ecosystem accumulation of DIN in the near-tail of 26.8 g m^{-2} yr^{-1} (**Table 6-12**). Results also show that the wet head had a net ecosystem P loss of 3.25 g m^{-2} yr^{-1} and the near-tail had a net ecosystem accumulation of P of 1.81 g m^{-2} yr^{-1} (**Table 6-12**). These results indicate that the wet head loses a large proportion of its nitrogen and phosphorus budgets through infiltration, whereas the near-tail loses considerably less and, in fact, has net accumulations of nitrogen and phosphorus. These results suggest that direction of nutrient fluxes, especially surface water, are likely very important in maintaining the tree island ecosystems. If this hydrologic connection between wet head and near-tail plant communities was severed due to changes in flow or flow direction, then the nutrients lost in the wet head communities may be exported to adjacent marshes. This preliminary analysis suggests a strong nutrient function on tree islands and hints at a possible larger-scale impact of tree islands related to the ridge-and-slough landscape of the Everglades.

Future plans are to assess the nutrient budget for three contrasting plant communities along a phosphorus gradient that goes from a dry head to the near-tail. To accomplish this assessment, a more intense nutrient sampling regime along this gradient will be included. Finally, the relevance of this study to the Everglades restoration goals is that the District is developing baseline datasets in anticipation of major hydrologic modifications in the WCAs. These datasets will allow assessment how tree islands may be impacted by these hydrologic changes.

Table 6-12. Tree island 3AS3 net ecosystem nutrient fluxes.

Nitrogen Fluxes		
	Wet Head	**Near-Tail**
Sediment Accretion	10.640	8.260
Plant Demand	4.443	4.206
Microbial Assimilation	2.780	7.210
Surface Water Load	7.558	11.330
Subsurface		
Import	16.371	50.13
Export	36.445	33.04
Throughfall	0.67	1.58
Net Ecosystem Nitrogen Flux	-8.429	26.84
Phosphorus Fluxes		
	Wet Head	**Near-Tail**
Sediment Accretion	2.935	2.100
Plant Demand	0.623	0.222
Surface Water Load	0.521	0.781
Subsurface		
Import	1.164	1.753
Export	7.277	2.844
Throughfall	0.03	0.24
Net Ecosystem Phosphorus Flux	-3.25	1.81

EVALUATING PHOSPHORUS FLUX – THE SUPPLEMENTAL SEDIMENT CORE STUDY

Reflux refers to the movement of TP out of sediments of high TP content into an overlying water column containing very low TP concentrations. The likelihood and extent of reflux in impeding the reclamation of the impacted areas of WCA-2A are unknown. If reflux is a significant biogeochemical process, then the cattail-dominated plant community may remain unchanged, and downstream habitats continue to be degraded (Reddy et al., 1999a, b; Fisher and Reddy, 2001). The Reflux Study (also known as the Enhancing Sediment Phosphorus Storage in Impacted Regions of the Everglades Protection Area Project) is a four-year project that will be completed in 2009. The principal objectives of the Reflux Study are to:

- Quantify in situ sediment phosphorus flux rates to the water column in an impacted area of WCA-2A
- Use field enclosures and sediment cores to evaluate management practices that may immobilize phosphorus in the sediment
- Model sediment phosphorus flux under different scenarios

There are two hypotheses for this study:

- Low TP concentrations in the water column leads to the release of legacy phosphorus from nutrient-enriched Everglades sediments.
- Chemical amendments or surface soil removal mitigate the legacy phosphorus flux from the impacted Everglades wetlands.

These objectives are related to the Long-Term Plan mandate for improving wetland regions considered impacted by excess phosphorus.

Site Locations and Descriptions

The Reflux Study is located within the northern cattail region of WCA-2A, which is a large (42,706 ha), shallow, diked impoundment characterized by marsh, slough, and tree island landscape features. The phosphorus-impacted area of WCA-2A occupies about 8,100 ha of northeast WCA-2A (Davis and Ogden, 1994) and is dominated by cattail. For a second water year, the Supplemental Sediment Core Study was conducted and consisted of 34 sediment cores (19-inch diameter) collected in WCA-2A near the highly impacted site F1 (Reflux cores) and from near the moderately impacted F3 site. Seventeen cores were retrieved from each site and transported to the South Advanced Technology Treatment Site (SATTS) of Stormwater Treatment Area (STA-1W) (**Figure 6-30**). All 34 cores initially contained intact cattail plants.

Supplemental Sediment Core Study Design

Three cores from each site were assigned to the following treatments (**Figure 6-31**):

- Herbicide (glyphosate) application to the cattail
- Herbicide application followed by layering calcium carbonate ($CaCO_3$) at 1 cm thickness on top of the sediment surface (without overlying water and after cattail mortality)
- Herbicide application followed by spraying liquid iron chloride ($FeCl_3$) to the top of the sediment surface (100 g Fe/m^2) and then layering sand at a 1 cm depth (without overlying water and after cattail mortality)
- Removal of the top (surficial) 40 cm of sediment from 80 cm deep cores (the scraped condition)

In addition to the experimental treatments, three cores from each site did not receive herbicide. These served as the control group. Cores were then reflooded with SATTS pre-treated low-phosphorus water with a hydraulic retention time of seven days.

Figure 6-30. Set-up of the flow-through Supplemental Sediment Core Study conducted at the South Advanced Technology Treatment Site of STA-1W (photo by DB Environmental, Inc., under contract to the SFWMD).

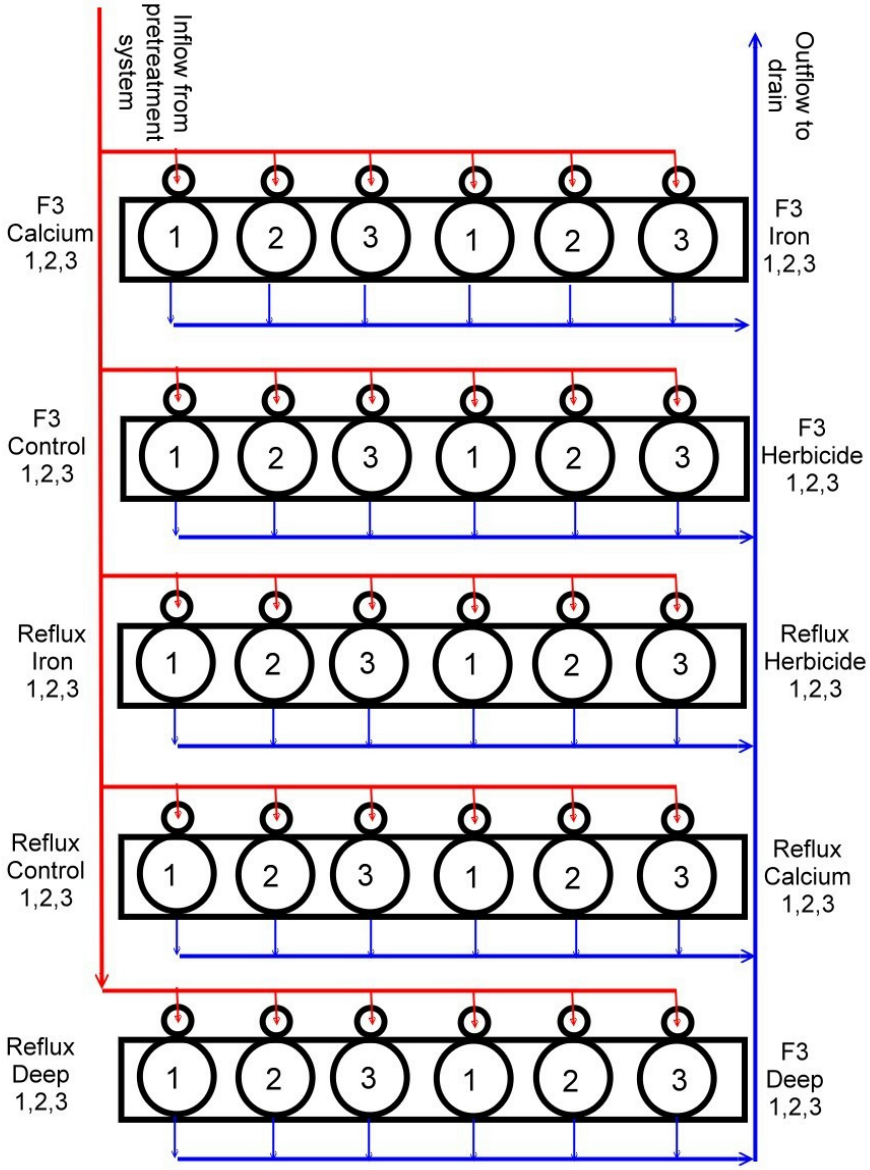


Figure 6-31. Schematic of the experimental design of the Supplemental Sediment Core Study.

Significant Results

A slow, continuous flux of sediment phosphorus to the water column was observed for the intact cores containing cattails. Control sediment cores containing cattail, retrieved from the Reflux Study and F3 sites released comparable amounts of phosphorus, increasing mean inflow water TP levels from 27 to 43 µg/L. Although there was a negligible difference between the two sediment types for phosphorus released from the control cores containing intact cattails, the remaining cores retrieved from the Reflux site had higher mean surface water TP concentrations than those from F3 (**Figure 6-32**). After an initial flush of high-phosphorus water, the calcium carbonate-amended sediments consistently yielded outflow waters containing phosphorus concentrations that were less than the herbicide-only control, but slightly higher than the outflow from the control (intact) cattail cores (**Figure 6-32**).

Cores amended with iron after herbicide treatment along with non-amended herbicide cores from both sites typically had higher phosphorus concentrations than the other treatments, although concentrations have generally decreased over time in the iron-amended cores. Among treatments, only the scraped cores maintained average phosphorus concentrations below the mean inflow phosphorus concentrations, while remaining treatments tended to export phosphorus relative to the low-phosphorus inflow water (**Figure 6-32**).

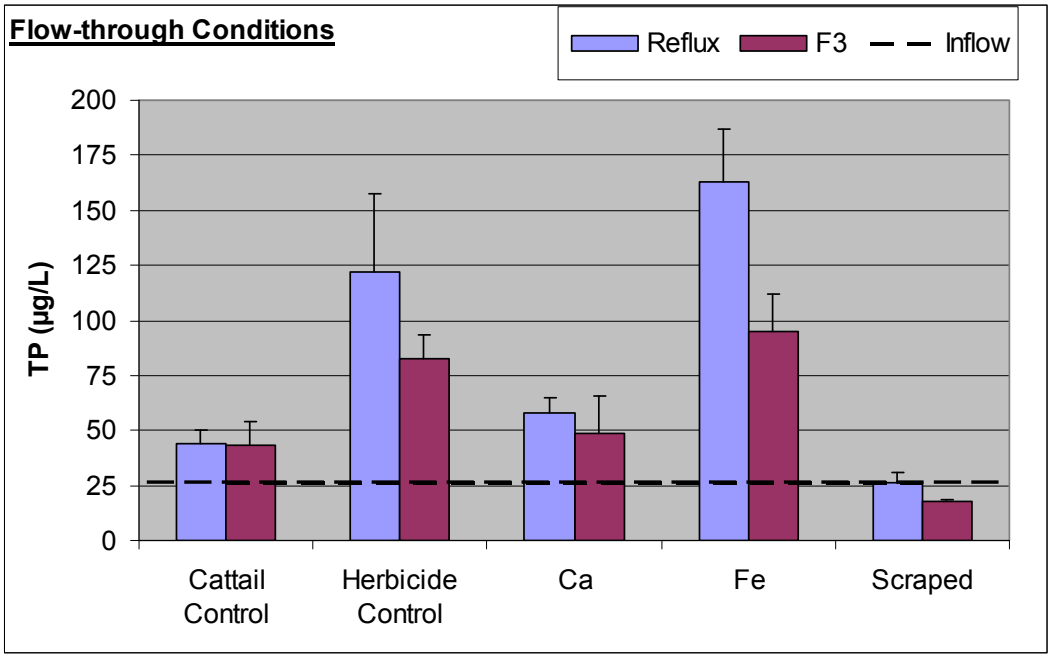


Figure 6-32. Mean inflow and outflow total phosphorus (TP) concentrations for the barrel cores containing sediment from the Reflux and F3 field sites. Each histogram represents the mean of bi-weekly sampling during the flow-through period (April 3, 2007 to March 13, 2008). Error bars represent +1 standard error (S.E.); the +1 S.E. for the inflows was 0.7 mg/L.

Discussion

Removing the cattail-dominant community in the impacted region of WCA-2A has been considered a potentially useful approach for both encouraging the re-growth of sawgrass and as a pre-treatment condition for chemically amending the sediment to sequester phosphorus. Applying the herbicide glyphosate to the cattails without any treatment follow-through resulted in an initial flush of TP that gradually declined, but then subsequently increased to remain one of the higher-phosphorus exporting treatments for both Reflux and F3 sediments (**Figure 6-32**). Based on these results, herbicide-induced mortality of cattail will likely result in the release of biomass phosphorus for extended periods (months).

Sediment scraping (of the top 40 cm) was the only treatment that totally curtailed sediment phosphorus export. However, this is unlikely to be a cost-effective management approach.

As opposed to the calcium carbonate-amended sediments, the TP outflow concentrations from the iron-treated barrels have continued to remain high, which is contrary to the expected outcome. The iron was applied as a measure to sequester sediment phosphorus, rather than as a mobilizer. The two most likely geochemical explanations for the release of phosphorus in the iron-treated barrels are:

- an initial phosphorus hydrolysis of the sediment organic phosphorus and dissolved calcium-phosphorus pools by the acidic (pH < 2) stock $FeCl_3$ solution
- the subsequent high pH (> 7.5) of the overlying water, which exceeded the pH for the minimum solubility of iron-phosphate compounds

Conclusions

The data indicates that intact, vegetated (cattail) sediment cores collected from two phosphorus-impacted locations in WCA-2A exhibited a slow, continuous release of phosphorus. Eradication of cattail by herbicide treatment resulted in a high and prolonged release of phosphorus from decomposing plant tissues. Of the two sediment chemical amendments, the calcium carbonate-amended treatments lowered the outflow phosphorus concentrations at both sites relative to the herbicide control (with no follow-up amendments). For what appears to be geochemical reasons, the iron chloride treatment exacerbated the release of sediment phosphorus at both sites. The outflow TP concentration from the intact cattail control cores was lower than any treatment outflows except for the scraped treatment, but cost considerations likely will not justify the use of surficial sediment removal as a management practice.

LANDSCAPE

Ken Rutchey, Ted Schall, Carlos Coronado, Martha Nungesser, John Volin[13], Dianne Owen[2] and Fred Sklar

Contributors: Jennifer Mellein[7] and Jennifer Allen[2]

Structure observed at the population level and processes studied at the ecosystem level are manifested in the goals and objectives associated with the District's landscape investigations in the Everglades. In WY2008, landscape studies continued to examine the large-scale features of the ridge, slough, and tree island patterns seen via aerial photos, elevation transects, and accretion measurements. Significant insights were obtained in association with four major landscape projects including: (1) a multi-decade time series of digitized maps designed to analyze area-specific ridge-and-slough patterns, (2) the most comprehensive field survey ever conducted of tree island elevation in WCA-3 relative surrounding marsh elevations, (3) a comprehensive field measurement of coastal mangrove accretion rates in Florida Bay, and (4) the completion of the first comprehensive and highly accurate vegetation map of WCA-1 (whose boundaries are nearly synonymous with the Arthur R. Marshall Loxahatchee National Wildlife Refuge).

LANDSCAPE PATTERN CHANGE

Patterns of the ridge-and-slough landscape are defined by long, linear sawgrass ridges, regularly spaced across the marsh, separated by interconnected wet sloughs and scattered tree islands (SCT, 2003; Sklar et al., 2008). As the hydrologic environment changed over time with the construction of canals to drain the Everglades and subsequent compartmentalization, the landscape scale patterns often changed (Sklar et al., 2008). Research on the pattern changes in WCA-3 indicates that major pattern changes in the ridge-and-slough landscape have occurred in less than a decade.

Maps were created manually from digitized aerial photography for the years 1940, 1953, 1972, 1984, and 2004, using methods described in the 2008 SFER – Volume I (Sklar et al, 2008). These maps were drawn from boundaries defined by the edges of emergent vegetation separating ridges from sloughs. Ridge and tree island measurements for each of 15 study plots (4 km x 6 km) during each of the five years (1940, 1953, 1972, 1984, and 2004) provided both temporal and spatial data on patterns at fixed sites over time (**Figure 6-33**). Each study plot data summary included mean length, width, perimeter, area, and orientation of the large ridges and tree islands. The quality of patterning in the landscape has been shown previously to be differentiated by mean length/width ratios, total number of longer ridges and tree islands, and variability of the ridges' orientation within a plot (Nungesser et al., unpublished).

[13] University of Connecticut

Using these three variables, multivariate analyses indicated that pattern quality has changed in a relatively dynamic fashion over the last six decades in many of the plots. Hierarchical agglomerative cluster analysis produced six distinct pattern classes for the 15 study plots for all five years (75 plots). Nonmetric multidimensional scaling, an ordination methodology that captures structure in data, revealed that these six classes were clearly distinct from each other with no overlapping members. High values define the strongest ridge-and-slough patterning and low values indicate an undifferentiated marsh. The study sites displayed a wide range of pattern changes ranging from degradation to improvement over time. **Figure 6-34** presents examples of dramatic changes that have occurred over the observational study period.

These classes provide a quantitative measure of pattern changes in each study plot over time. Several plots changed little over time. Some varied over time, such as N5 (**Figure 6-34**), which both improved and degraded. Plot G3 improved dramatically from poor in 1940 to strong in 2004. Other areas degraded over the 60 years, particularly I1. While the overall trend for any one plot was up or down, variability from decade to decade appears in many of the plots.

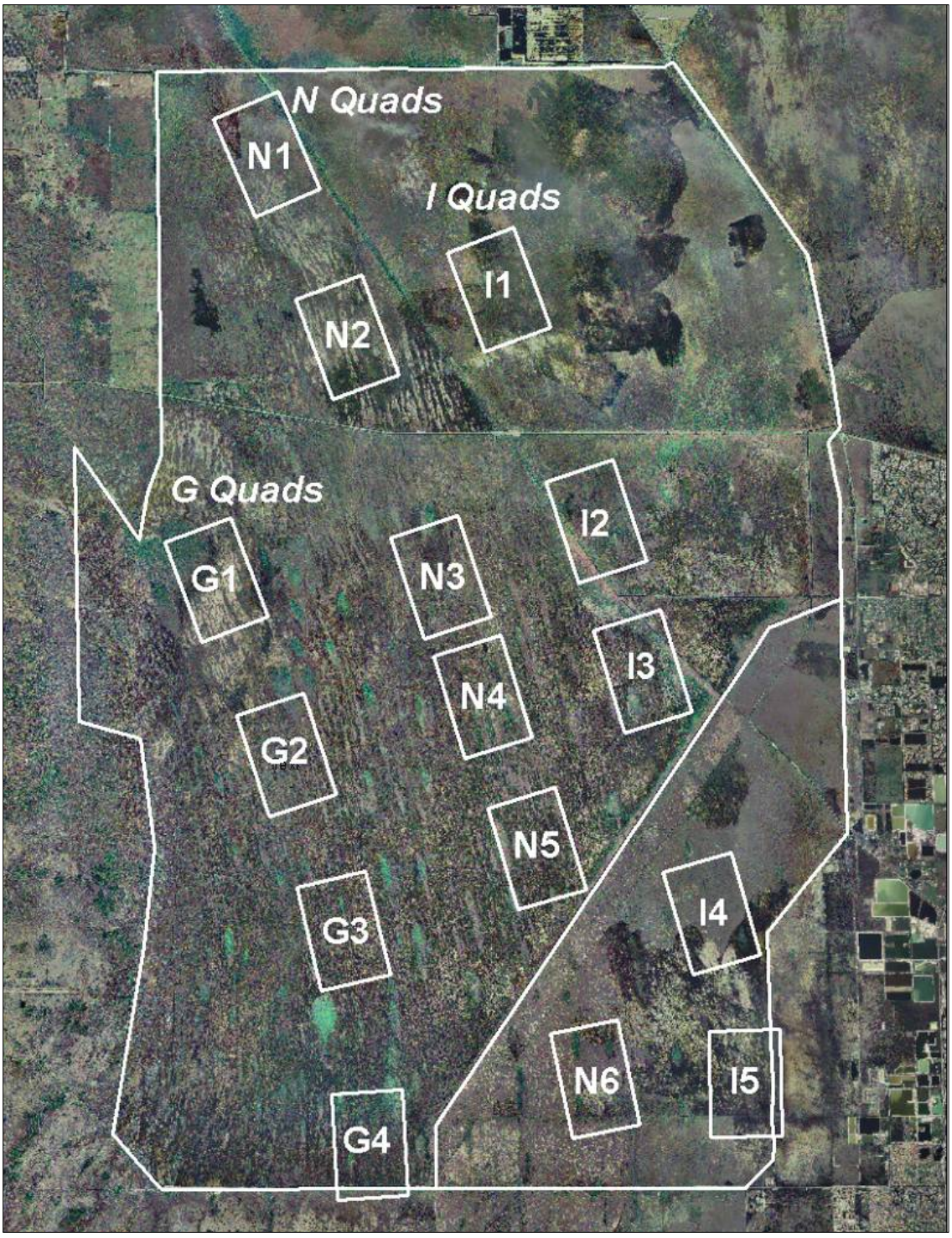


Figure 6-33. Locations of study plots for historical pattern changes in WCA-3.

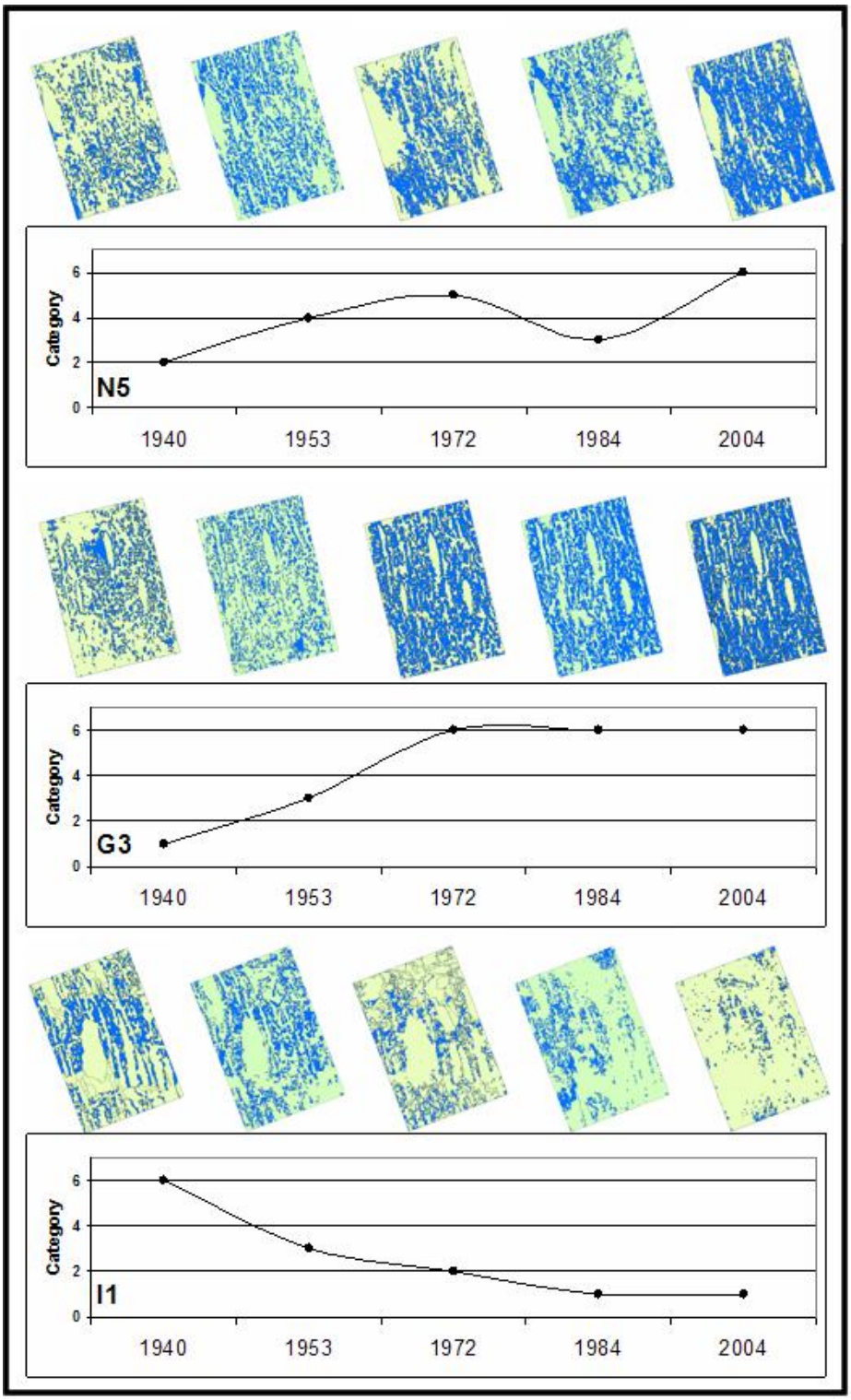


Figure 6-34. The historical changes in ridge-and-slough patterning are displayed for the years 1940, 1953, 1972, 1984, and 2004 for three study plots. The highest value (6) represents strong patterns. Plot labels correspond to the locations on **Figure 6-33**.

While the causes of pattern changes are not certain, the individual uniqueness of the pattern changes spatially among plots indicates that local factors rather than regional factors are responsible. Plots G3 and N5 near levees in the southern end of WCA-3 may have improved patterns because of post-compartmentalization water depths. In contrast, plot I1's location in the northern portion of WCA-3 probably lost elevation and peat microtopography because of repeated drying. This kind of altered hydrology tends to result in the accumulation and expansion of sawgrass into the sloughs. These changes suggest that local water depths and flows control vegetation patterns, although the mechanisms are not yet known.

Pattern improvements as significant as those in G3 probably depend on long-term retention of the ridge-and-slough microtopography (which is still approximately 20 cm in G3; McVoy et al., in prep). Microtopography in other study plots, such as I1, has disappeared and may not recover for many decades. Peatlands microtopography builds over long periods of time (multi-decadal to centuries) (Willard, 1997; Willard et al., 2001). Hypotheses related to the changes in patterning may be tested with analyses of peat cores from these study plots to discern changes in peat accumulation rates (Sklar et al., 2008) as well as peatland microtopography models (Nungesser, 2003).

The pattern classifications described here are somewhat surprising because they reveal that the ridge-and-slough patterns can respond relatively quickly to changes in hydrology, particularly depths and flow, presumably if the surface retains its underlying microtopography. Further research into the processes that create and degrade the microtopography is needed to expand upon these findings.

RELATIVE MARSH AND TREE ISLAND ELEVATION: SPATIAL PATTERNS IN WATER CONSERVATION AREA 3A AND 3B

Restoration of degraded tree islands and protection of intact tree islands are among the goals for restoring the Everglades ridge-and-slough ecosystem (Sklar et al., 2005). Current restoration plans predict dramatic changes in water depth patterns over portions of the ridge-and-slough ecosystem, including a large number of tree islands (Sklar and van der Valk, 2002). Information about topographic differences across a broad spectrum of the ecosystem is needed to estimate the effects of proposed hydrologic changes on tree island species composition, hydroperiod, and size. Predicting the effects of changes in water depth and hydroperiod on tree islands, or managing water to restore degraded tree islands, cannot be accomplished until the spatial height distribution of tree islands and their elevation relative to the surrounding marsh is better known. Thus, knowing the relationship between the height of tree islands and their surrounding sloughs is critical for determining the differences in their hydrology and for planning hydrological restoration within the tree island ridge-and-slough landscape of the central Everglades.

The main objective of this ongoing study is to measure water depth in and around tree islands in order to calculate the ground-surface height in sloughs relative to a current network of benchmarks established by a collaborative effort between the FDEP and the District in WCAs 3A and 3B. It is hypothesized that the plant communities on highly elevated tree islands, relative to low-elevation tree islands, are more diverse and more biologically complex. These data will be used to determine tree island elevation relative to the surrounding marsh/slough environment and determine water depths and hydroperiods for tree islands located in WCAs 3A and 3B under current hydrological conditions. To date, hydrological data have been collected for 258 tree islands; data was also gathered from a representative set of sloughs adjacent to the measured tree islands. This project supports the Greater Everglades Wetland module of the CERP Monitoring

and Assessment Plan (CERP MAP) and the EFA. Finally, it is directly linked to a ridge-and-slough landscape sustainability monitoring and research component (Sklar et al., 2008).

Methods

Water depth measurements were recorded in marshes/sloughs adjacent to tree islands for which hydrographs had previously been calculated as part of a contract with FAU (Furedi and Volin, 2006). Water depth was measured in the marsh/slough at stratified, random locations that varied in distance from around the head of the tree island being assessed, ranging from immediately adjacent to approximately 200 meters away. All measurements were at least 10 meters apart. Three measurements were taken due north of each island and nine measurements were taken on both the east and west side of each island. The measurements were performed using a graduated metric steel rod with a flared base. The measuring rod was allowed to rest on top of the sediment surface. The location of each point was recorded using a Garmin® Global Positioning System (GPS) unit.

Results and Discussion

Slough water depth measurements were collected for 258 tree islands in WCA-3A and WCA-3B from June 2007 to February 2008 (**Figure 6-35**). To obtain a better understanding of the relationship between the tree islands and surrounding sloughs, the difference between the maximum tree island elevation and minimum slough ground surface elevation for the north, east, and west were compared. To examine the regional trends in the difference in height between the tree islands and adjacent sloughs, each island was assigned to a specific geographic region based on its associated benchmarks that were established in WY2005 (see 2006 SFER – Volume I, Chapter 6). Thus, tree islands associated with benchmarks 3, 4, 6, 8, 9, 10, 11, and 12 were grouped as central WCA-3A. Islands associated with benchmarks 14, 16, 17, 19, 20, 22, 23, 26, 27, 28, and 29 were grouped as southern WCA-3A, and islands associated with benchmarks 13, 15, 18, 21, 24, 25, 30, and 31 were grouped as WCA-3B (**Figure 6-35**). The average marsh-slough elevation within each region was 2.24 m, 1.81 m, and 1.38 m at central WCA-3A, southern WCA-3A, and WCA-3B, respectively. Similarly, the elevation difference between the maximum tree island elevation and the surrounding marsh-slough ranged from 0.18 m to 1.59 m; based on the regional grouping, the difference in elevation between tree islands and the surrounding marsh-slough environments was less pronounced on the north-western region of WCA-3A and more pronounced in the southeast region of WCA-3A and in WCA-3B (**Figure 6-36**). A consistent relationship was found between the elevation difference and maximum tree island elevation within all three regions (**Figure 6-36**). The slopes of the resulting regression equations (r^2 =0.6146 and r^2 = 0.7892 in central and southern WCA-3A, r^2 = 0.9376 in WCA-2B) suggest that tree islands in WCA-3B are steeper than tree islands in WCA-3A. However, it is important to mention that sloughs, with intervening expanses of sawgrass, were commonly located further from the tree islands in WCA-3B, so the greater elevational differences were not directly associated with steeper ground-surface slopes from tree island to slough, but may have been a function of greater distance. Nonetheless, knowing the elevation difference between tree islands and their surrounding marsh-slough environment is important information that can aid in understanding better how water management decisions affect the ecological integrity of the ridge-and-slough and tree island ecosystem.

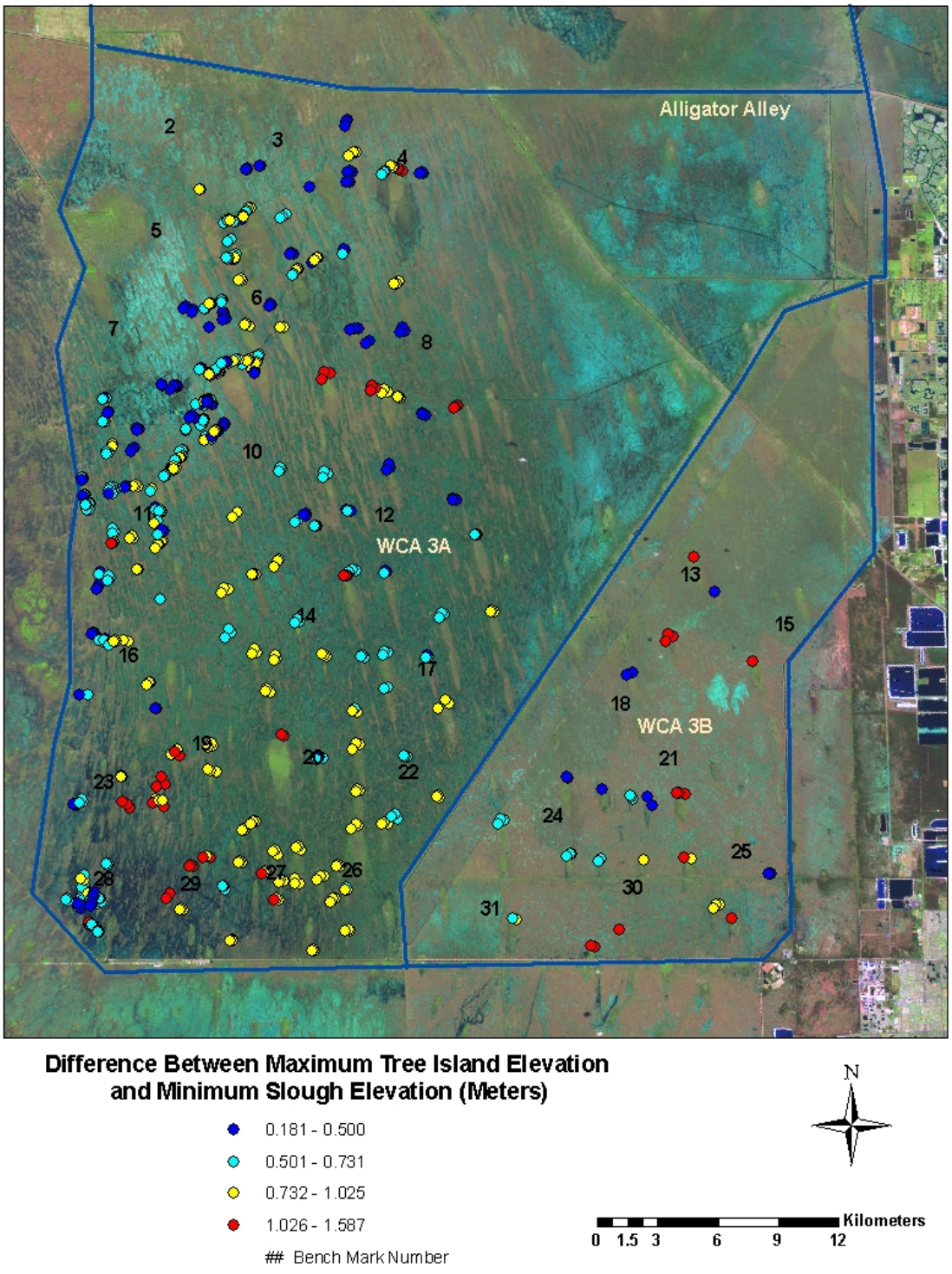


Figure 6-35. Elevation difference between maximum tree island elevation and minimum slough elevation located in WCA-3A and WCA-3B in feet North American Vertical Datum 1998 (ft NAVD88). The 31 benchmarks used to estimate tree island and slough elevations are labeled as numbers.

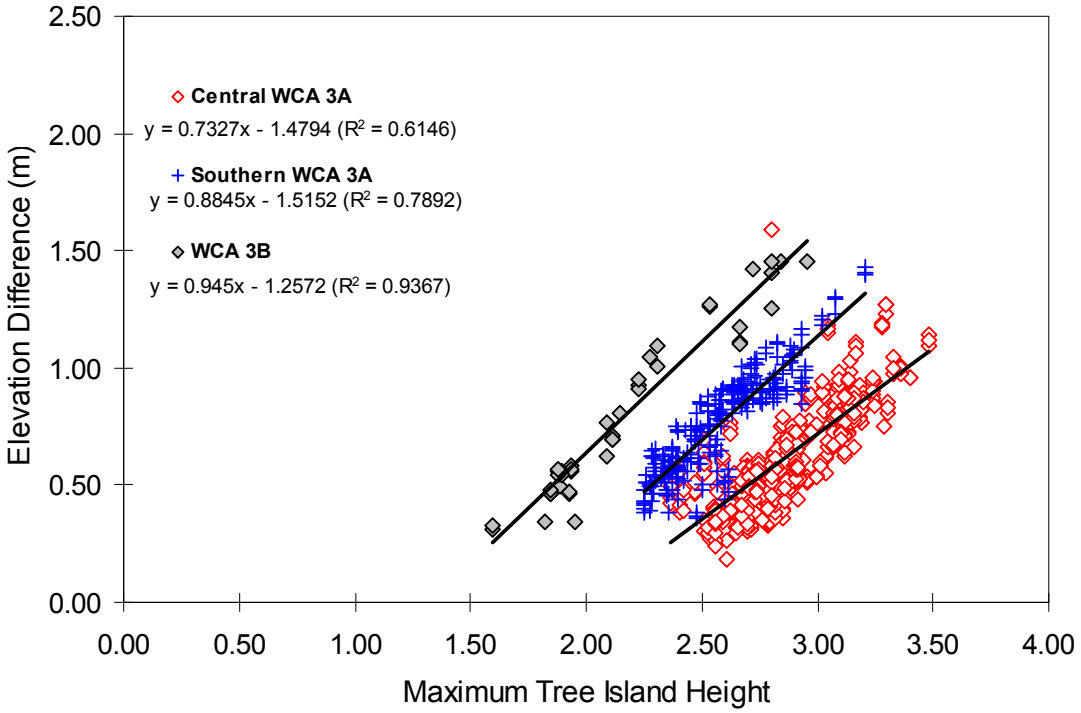


Figure 6-36. Relationship between the maximum tree island elevation (ft NAVD88) and the elevation difference (average tree island elevation minus slough elevation) in the central WCA-3A, southern WCA-3A, and WCA-3B.

ELEVATION CHANGE AND SOIL ACCRETION IN THE MANGROVE SALINITY TRANSITION ZONE

Mangrove wetlands, like other coastal wetlands, are considered highly vulnerable to submergence under a rising sea level (Gornitz, 1991). The eustatic global mean sea level has risen approximately 1-2 millimeters per year during the past 100 years (Gornitz, 1995). Additionally, sea level is enhanced on a local scale relative to the land surface by subsidence. Thus, relative sea level rise (RSLR) is referred to as the combined effect of eustatic sea level rise and land subsidence.

Accretion, the buildup of material on the forest floor, is affected by changes in hydrologic and geomorphologic (e.g., erosion) conditions that result in an apparent rise in sea level. The rate at which accretion occurs is a function of the combination of the inputs of both inorganic and organic material to the soil. Organic material is mostly derived from the growth of plant roots, which provide a matrix to which other soil material can adhere and contribute to soil formation directly upon their death. Thus, the continued existence of mangrove wetlands depends on the maintenance of vertical accretion such that the rate of elevation gain is greater than or equal to the rise in sea level. In terrigenous coastal environments, rivers play an important role as sediment sources, depositing sediment along the coast line as they outflow. Conversely, in carbonate environments where there is little mineral sediment input, such as South Florida, above- and belowground production of mangrove peat is considered the primarily soil-building mechanism (Middleton and McKee, 2001). Mangrove wetlands are considered excellent land builders because mangrove roots have a high soil-binding capacity (Augustinus, 1995) and cause soil formation through belowground production. It is hypothesized that elevation change and soil accretion patterns are controlled by the spatial and temporal variability of above- and belowground processes that, in turn, are controlled by environmental factors including sediment input, hydroperiod, salinity, and soil fertility. The objective of this study is to evaluate how water management practices, sea level rise, and regional ecology influence long-term soil elevation changes in the mangrove salinity transition zone (MSTZ) of Florida Bay.

Study Site

The Everglades mangrove wetlands are located at the southeastern tip of the Florida peninsula within the MSTZ. The wetland borders Florida Bay, which is a large, shallow, subtropical embayment limited on the south and east by the Florida Keys (**Figure 6-37**). Study sites are located at McCormick Creek, Taylor River, Trout Creek, and Highway Creek which drain into several shallow ponds and into extensive dwarf mangrove forest before reaching Florida Bay. Spatially, the MSTZ can be divided into upper, middle, and lower zones. The upper zone is dominated by freshwater marsh species, such as sawgrass and spike rush (*Eleocharis cellulosa*). The middle zone is dominated by dwarf red mangrove (*Rhizophora mangle*) and buttonbush (*Cephalanthus occidentalis*). In the lower zone, the freshwater vegetation is completely replaced by mangrove forests.

Field Methods and Analysis

Sedimentation elevation stations were established at two sites within the fringe and basin zones of each study site. The sites are located along two transects. At each site the sediment elevation measurements were made using a Surface Elevation Table (SET) (**Figure 6-38**). The SET is attached to a benchmark pipe driven into the soil surface 3-4 meters deep and is assumed

to be a stable datum over the period of study (Cahoon et al., 1995). Vertical accretion was measured as the rate of accumulation above feldspar marker horizons laid on the soil surface in 1998. Three feldspar marker horizons were laid around each SET platform in the fringe and basin zones of each study site. Elevation change and vertical accretion have been measured every year since 1998.

Based on water depth and duration of inundation data, sites were grouped into three hydrological environments: non-flooded, seasonally flooded, and permanently flooded. The spatial sampling design described above is compatible with several different ANOVA models; we used a nested repeated measure design two-way ANOVA to separate temporal effects from the within-level variance among sites.

Results

The average vertical accretion rate was 0.08 ± 0.02, 0.56 ± 0.21, and 0.55 ± 0.11 cm yr^{-1} at the non-flooded, seasonally flooded, and permanently flooded environments, respectively (**Figure 6-39**, panels A-C). These rates are similar to those reported by Cahoon and Lynch (1997). The vertical accretion rate observed at the non-flooded environment was significantly lower relative to the accretion rates observed at the seasonally flooded and permanently flooded environments ($p < 0.05$).

Elevation change rates at the study sites have been very small. For instance, at the non-flooded environment, elevation change rate was 0.15 ± 0.05 cm yr^{-1}. The small elevation change suggests that erosion processes, particularly during strong storms or hurricane events, may play an important role in controlling changes in elevation in this environment (**Figure 6-39**, panel A). However, due to the great variability in the data, there were not significant differences in changes of elevation among the three environmental settings ($p > 0.05$). Elevation changes in seasonally flooded and permanently flooded environments were 0.03 ± 0.03 and -0.1 ± 0.01 cm yr^{-1}, respectively. Those values suggest that shrink-swell and root production and decomposition processes may control elevation changes in these environments (**Figure 6-39**, panels B and C, respectively). Shallow subsidence was -0.07 ± 0.04, 0.52 ± 0.27, and 0.63 ± 0.15 cm yr^{-1} at the non-flooded, seasonally flooded, and permanently flooded environments, respectively.

Discussion

Erosion and oxidation dominate the biogeochemical processes of soil formation in the non-flooded environment. It is hypothesized that pulsing events, such as hurricanes and thunderstorms, play an important role in nourishing this environment with inorganic matter imported from Florida Bay.

All three environments had high shallow subsidence and very low change in elevation. Biogeochemical processes, such as organic matter decomposition, and physical processes such as shrink-swell of the soil, seem to dominate the mechanisms that control soil formation below and above the marker horizon. Data analyses indicate that these environments are not keeping pace with the current sea level rise rate. Previous studies show that mangrove forests are migrating into freshwater environments. This migration has been attributed to a decrease in freshwater input at the salinity transition zone of Taylor Slough and probably in response to an increase in sea level rise (Ross et al., 2000).

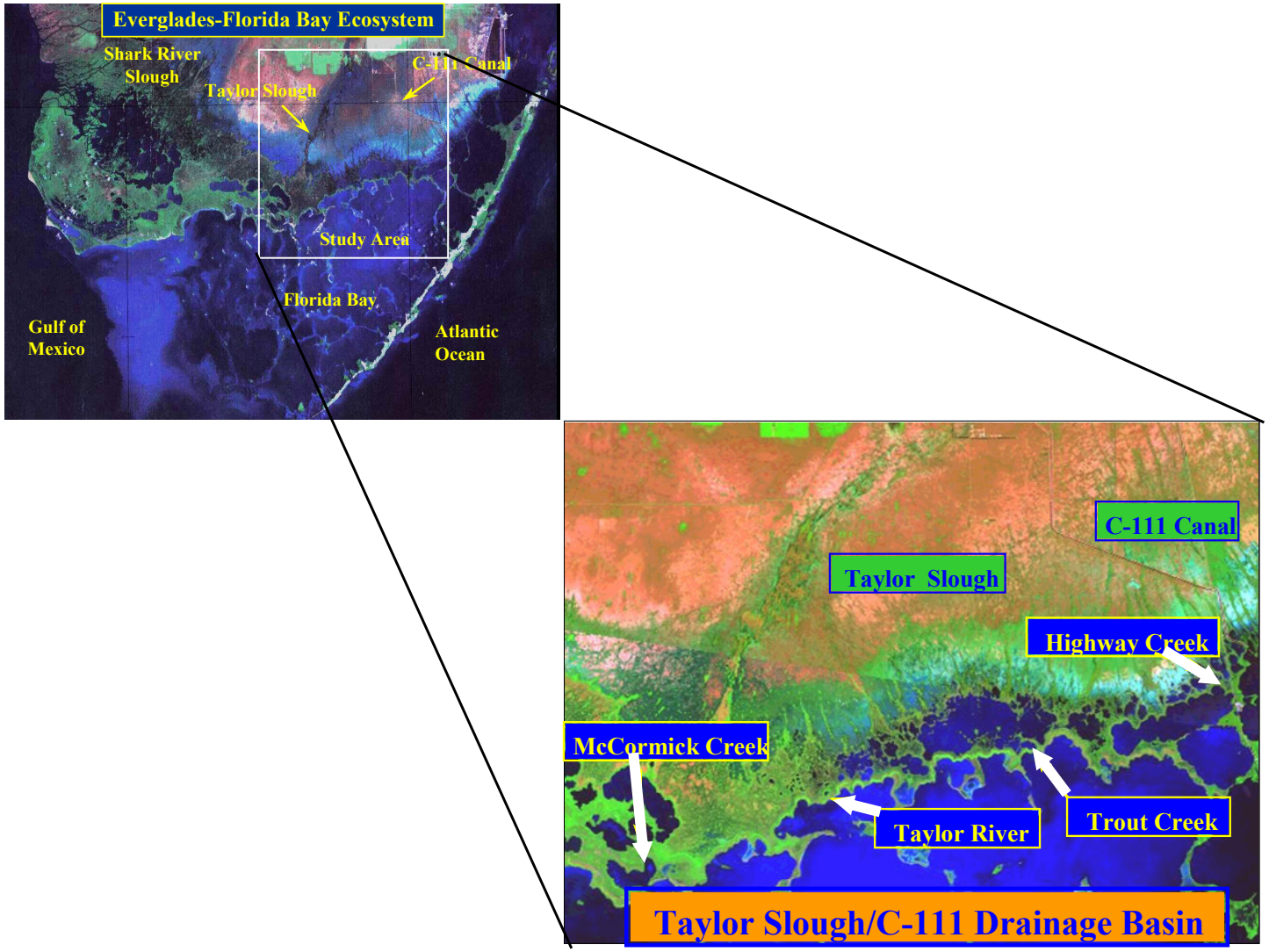


Figure 6-37. Study sites along the Northeastern Florida Bay. Twenty Surface Elevation Table sites are located at McCormick Creek, Taylor River, Trout Creek, and Highway Creek.

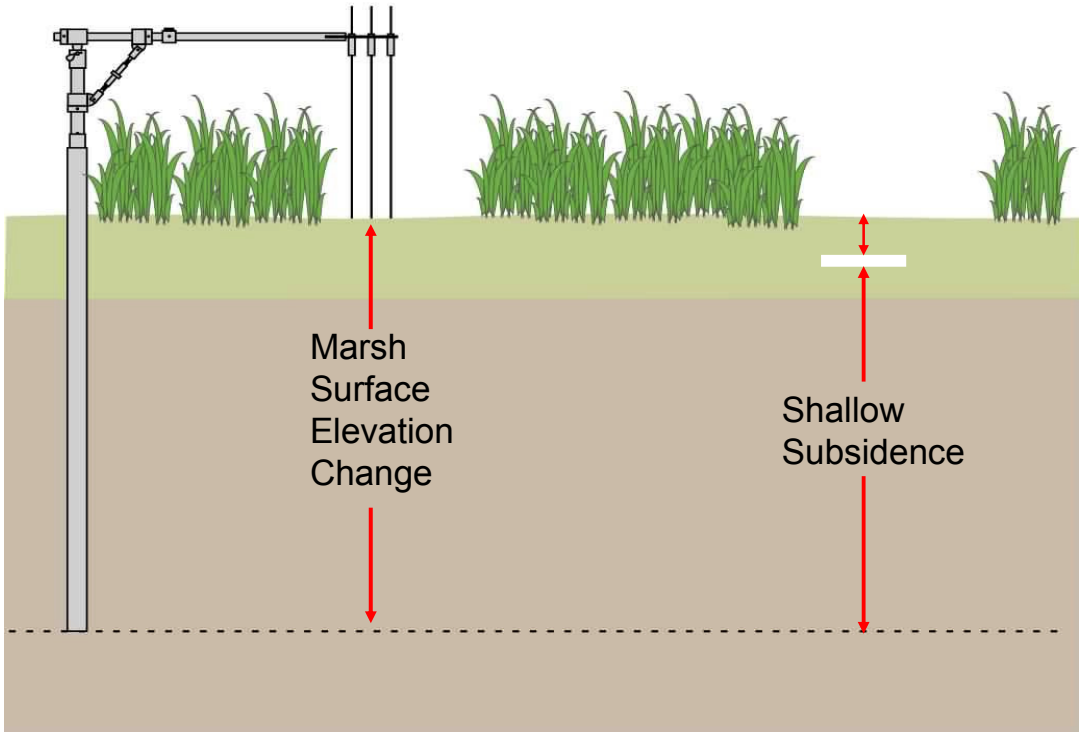
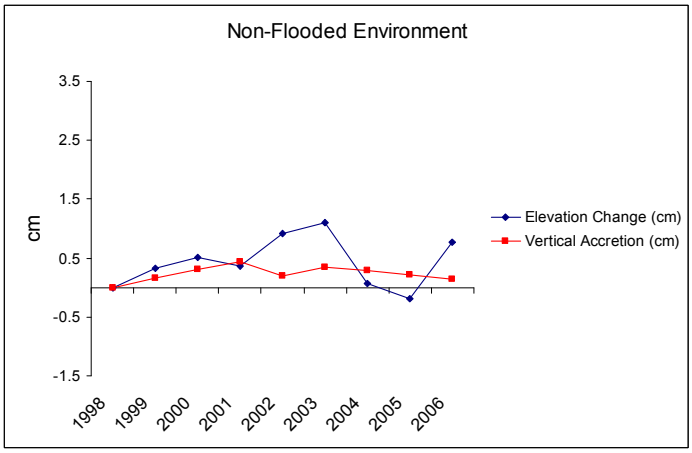
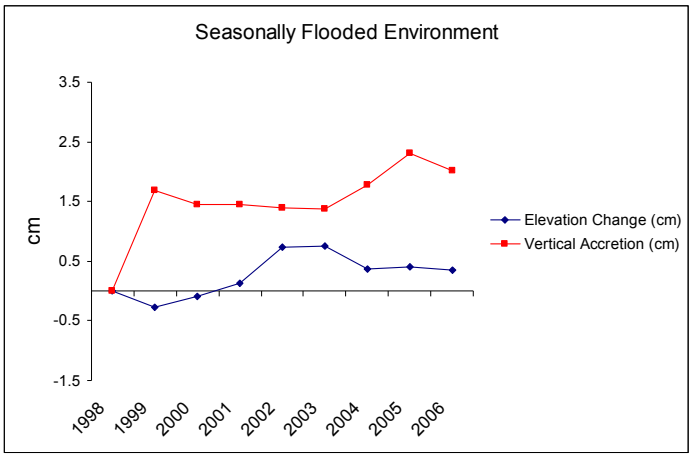


Figure 6-38. Surface Elevation Table and Marker Horizon (Feldspar).

Panel A



Panel B



Panel C

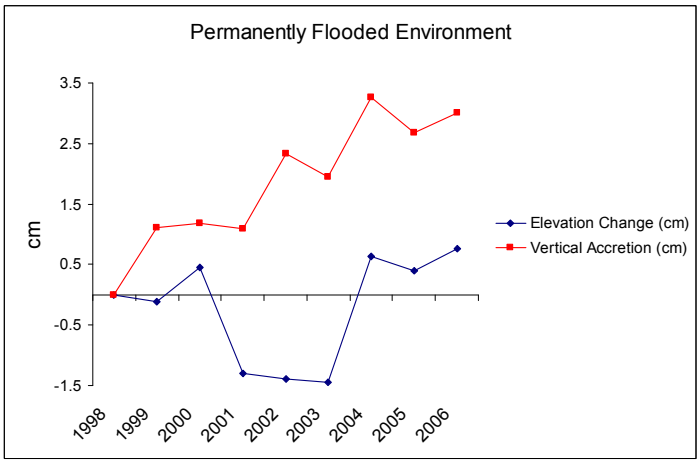


Figure 6-39. Elevation change and vertical accretion at (panel A) non-flooded, (panel B) seasonally flooded, and (panel C) permanently flooded environments.

CERP VEGETATION MAPPING

The MAP is designed to document how well CERP is performing (RECOVER 2004a, b). One component of the monitoring plan involves vegetation. Vegetation maps will document any changes in the spatial extent, pattern, and composition of plant communities within the landscape. The MAP vegetation mapping effort began in 2004 with the collection of approximately 1,400 color-infrared aerial photographs at 1:24,000-scale. The second step in the mapping process involved geo-referencing aerial photographs. During WY2008, the last remaining aerial photographs were geo-referenced.

The final step in the vegetation mapping process requires photointerpretation of each quarter hectare (50 x 50 m) grid cell located within the boundaries of the mapping project, totaling approximately 4.4 million grid cells. The grid system more accurately depicts the overall heterogeneity of Everglades vegetation than a vector approach would (Rutchey et al., in press; Rutchey and Godin, in review). This grid network was superimposed over the color-infrared aerial photographs at 1:24,000-scale. 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). In addition, the classification allows for exotic species 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)

Cells that contain herbicide-treated exotics were identified. Cattail, although not an exotic, was mapped using the same density class criteria. The sparse category for exotics was originally set with a lower limit of 10 percent because detection below this is not always possible. However, if exotics are detected at less than 10 percent then they are also classified as sparse. The presence of a tree island within a portion of the grid cell is noted in the classification.

In WY2008, the WCA-1 vegetation map was completed. The WCA-1 map contains 227,429 individual 50 x 50 m grid cells. Photointerpretation of each ¼ ha grid cell was performed using a Leica SD2000 analytical stereo-plotter by superimposing the two-dimensional grid over the three-dimensional stereo imagery. Grids were labeled using PRO600 and Microstation software as part of the SD2000 stereo mapping system. All classification data were then migrated to the District's new DAT/EM softcopy workstations where quality assurance/quality control evaluations were performed and the final map accuracy assessments were completed.

To correlate the spectral signature of vegetation types on the photos with field conditions, a total of 775 ground-truth sites were interactively selected from the photography during initial and subsequent photointerpretation. Horizontal coordinates for the sites were obtained from the geo-referenced aerial photography. Ground-truthing sites were located by helicopter, airboat, or by truck using real-time GPS receivers with a horizontal accuracy within one meter. Experience and information gained from the ground-truthing investigations were crucial to the labeling of the vegetation types within grid cells. Field verification data were used to finish labeling the grids where the vegetation signatures were previously in question or unknown. All final data resides in ArcGIS geodatabase format.

The WCA-1 map represents the most difficult area mapped so far. The difficultly was due to the area being so ecologically complex (not in the ability to identify vegetation categories). This complexity was largely from the presence of small, pop-up tree islands found throughout the impoundment. Tree islands were challenging to map due to the large numbers of islands and the degradation that appears to have occurred on many of the larger strand islands, both from hydrology and the invasion of exotic species. Some islands in the southern part of the impoundment appear to have succumbed to flooding. The northern drier sections of the impoundment exhibit a proliferation of brush species and exotics. These factors made it extremely difficult, in many cases, to identify whether a feature was a tree island or some other grouping of trees and shrubs. Other factors that complicated the mapping process were the extensive coverage of the exotics *Lygodium* and melaleuca that were found throughout the impoundment. Even with these difficulties, the final overall map accuracy was determined to be 93.2 percent, which meets the established standard for the vegetation mapping project. **Figures 6-40** and **6-41** are provided for an overall map categorization of cattail, tree islands, and the exotics *Lygodium* and melaleuca.

The creation of the WCA-1 map completes the set of baseline vegetation maps for the WCAs. This set of maps will allow the detection of changes in vegetation patterns as the areas are remapped on a six-year cycle, in parallel with the expected completion of CERP projects. This next phase of mapping will include WCA-3, whose comparison map has a projected completion date of late calendar year 2009. The new map will then be compared to a pre-1995 WCA-3 base vegetation map for change detection.

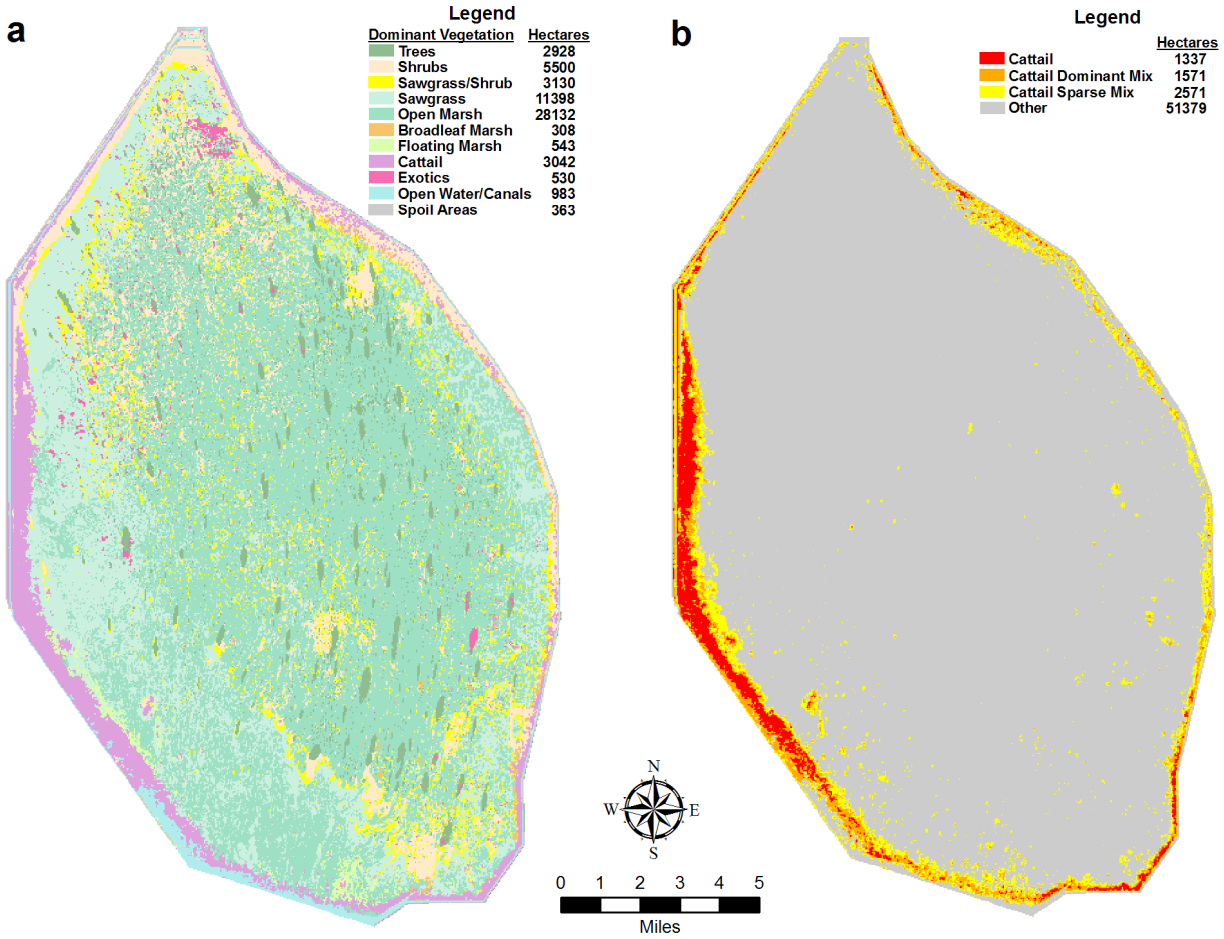


Figure 6-40. Depiction of WCA-1 vegetation showing overall vegetation (panel a) and cattail distribution (panel b).

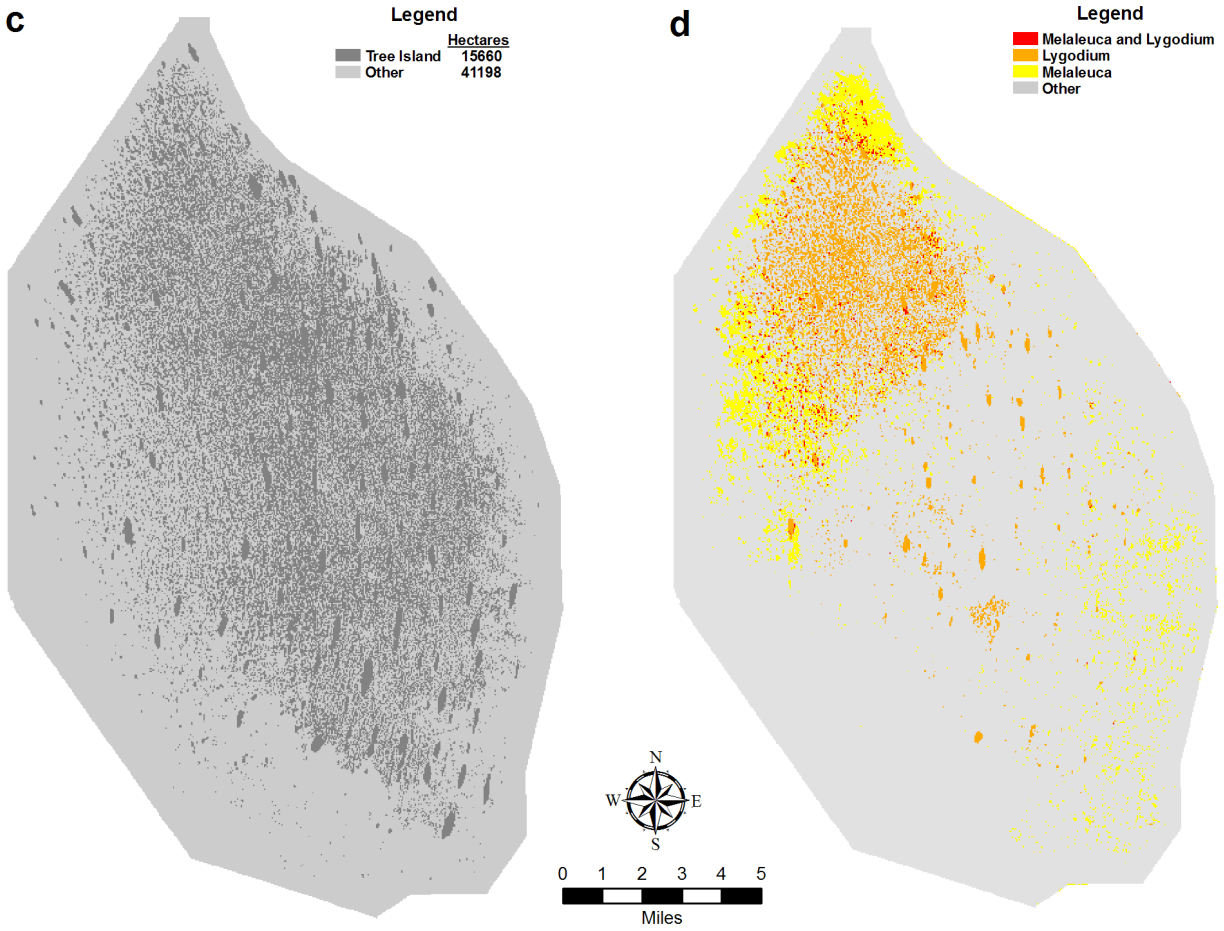


Figure 6-41. Depiction of WCA-1 vegetation showing tree island (panel c) and exotic vegetation distributions (panel d).

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