Chapter 6: Ecology of the Everglades Protection Area

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SUMMARY

The studies and findings discussed in this chapter of the *2008 South Florida Environmental Report – Volume I* are presented within four main fields: (1) wildlife ecology, (2) plant ecology, (3) ecosystem ecology, and (4) landscape ecology. Programs of study were based on the short-term operational needs and long-term Everglades 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, Everglades Forever Act mandates, and the Comprehensive Everglades Restoration Plan. **Table 6-1** summarizes elements of major Everglades research findings during Water Year 2007 (WY2007) (May 1, 2006–April 30, 2007) and highlights these findings in relation to the statutory mandates that drive the research.

The District's continued focus on wading birds has revealed a 31 percent decline in total nests from last year and a 46 percent decline from WY2002 (the best nesting year on record). The total number of wading bird nests in the Greater Everglades was 37,623. Nest failures were attributed to (a) dry conditions, which led to poor foraging, and (b) rain-driven reversals in March and April 2007, which also led to poor foraging. A more detailed experimental feeding program was found to further validate this notion that hydrology impacts food supplies for wading birds. Foraging experiments at the Loxahatchee Impoundment Landscape Assessment (LILA) Research Facility did not support the notion that open-water, non-vegetated sloughs are better foraging habitats than vegetated sloughs.

The plant ecology studies in calendar year 2007 were designed to provide new spatial and physiological information to better track changes over time and guide natural resource management. New information included: (1) vegetation mapping products for Water Conservation Area (WCA) 2A and Rotenberger Wildlife Management Area; (2) results from a greenhouse study indicating that two important tree island species, swamp maple and pond apple, had lower growth than expected under extremely flooded treatments; and (3) the finding that woody plant communities growing on low-nutrient, long-hydroperiod islands in WCA-3 had low root production rates, suggesting that flooding may lead to poor soil formation, which can then cause an island to have a longer hydroperiod and less root production (a negative feedback loop).

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Two new large-scale experimental manipulations of the cattail impacted area of WCA-2A were introduced in calendar year 2006. This year, preliminary findings of the FIRE and CHIP Studies highlighted some significant ecological mechanisms, including: (1) The significant increase in phosphorus concentrations in the water and pore-water after a cattail fire; and (2) the ability for open plots to grow more nutritional plants (i.e., algae) and support a higher wading bird foraging than the surrounding cattail habitat. Continued sampling and analysis over the next few years will assess whether sawgrass can replace cattail and whether open plots can function as natural sloughs.

In calendar year 2007, the landscape perspective on Everglades ecology was supplemented with two paleoecological assessments indicating that; (1) the original ridge and slough patterns were stable over decades and perhaps centuries, and although this patterning can appear relatively unchanged for several decades despite apparent changes in hydrology and other environmental conditions, they disappear rapidly once some (yet-to-be-identified) threshold is exceeded; and (2) down-core profiles of macrofossils (mainly seeds) from modern sawgrass communities in Shark River Slough are all suggestive of wetter conditions prior to 1940 and drier conditions afterward. Remote sensing and photo interpretation continues to be a significant landscape effort. This year, vegetation mapping products have been completed for WCA-2A and the Rotenberger Wildlife Management Area. At the time of this report, Loxahatchee National Wildlife Refuge was approximately 75 percent complete and projected to be completed in the last quarter of 2007. Mapping is also underway for a 67,900-hectare area of Everglades National Park (~11 percent).

This year, due to possible impacts associated with the drought, the District choose to illustrate hydrologic patterns in the Everglades relative to last year. These hydrologic patterns indicated that even with the drought there were no peat fires and, thus, ecological suitability for wading birds and peat conservation was maintained for most of WY2007. The negative effects of shortened hydroperiods and hydrologic reversals were either not enough to dehydrate the organic soil matrix, or they tended to be more local/regional and lacked overall landscape significance.

Table 6-1. Summary of Water Year 2007 (WY2007) Everglades research findings in relation to the following operational mandates: Regulation and Operational Schedules (ROS); Comprehensive Everglades Restoration Plan (CERP); 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 drought, there were no peat fires and ecological suitability was high for most of WY2007. Negative effects were: shortened hydroperiods throughout the Everglades and hydrologic reversals in the dry season in the southern Everglades.	ROS, MFL
Wildlife Ecology		
Wading Bird Nesting Patterns	The number of wading bird nests present was about 37,623; a 31-percent decline from last year and a 46-percent decline from the best nesting year on record. Nest failures were attributed to a combination of dry conditions and rain-driven reversals in March and April 2007.	ROS, CERP, MFL,FEIM
Food Limitation on Wading Bird Reproductive Success	The 2007 data supports the notion that white ibis nesting success was limited by food supply and that this supply may have been limited by the hydrology.	ROS, CERP, MFL,FEIM
Factors Affecting Wading Bird Foraging	The density of submerged aquatic vegetation (SAV) and water depth can affect foraging patch choice in wading birds. Depth is the more significant foraging cue. Neither depth nor SAV affected foraging success.	ROS, CERP MFL, FEIM
Macroinvertebrates for Rapid Assessment	More analysis is needed to refine the nine metrics that were used to detect impaired subtropical wetlands.	CERP, FEIM, MFL
Plant Ecology		
Ridge and Slough Plant Interactions	It is possible to transplant sawgrass, spikerush, and water lily across a range of depth and flow regimes to test the hypothesis that species morphology alone can create ridge, slough and wet prairie topographies through effects on sedimentation, but that the water depth-flow rate interactions determines a species' ability to grow.	CERP, MFL USEPA
Tree Seedling Stress	Five hydrologic treatments captured a range of hydrologic regimes. Gumbo limbo, the least flood-tolerant species, had the lowest growth under the two most flooded treatments. Swamp maple and pond apple, moderate and high flood tolerant species, respectively, also had the lowest growth under the two most flooded treatments.	ROS, CERP, MFL
Tree Island Root Processes	Woody plant communities growing on poor-nutrient and long hydroperiod islands have low root production rates and low root turnover rates, but have a relatively high standing stock of total root biomass. This may feedback to less soil formation, which leads to longer hydroperiods.	CERP, FEIM, MFL

Ecosystem Ecology		
Periphyton Pigment for Rapid Assessment	Six regression trees were developed to predict water quality from phylogenetic groups of algae on periphytometers. Chemotaxonomy provides a rapid, less expensive means to assess biological conditions within the Everglades.	FEIM, CERP
Phosphorus Reflux	Low nutrient SAV-treated water from a STA, added to field enclosures in the WCA-2A impacted region, may have caused porewater phosphorus to be released into the water column thereby increasing the outflow of phosphorus relative to a control enclosure.	LTP
Accelerated Recovery of Impacted Wetlands	Phosphorus concentrations in the water and porewater increase after a cattail fire. Fire will affect vegetative and biogeochemical processes in the short-term, but may have longer-term implications. With additional application of fire treatments, the use of fire as a management tool to accelerate recovery of nutrient-enriched areas of the Everglades will become clearer.	LTP
Cattail Habitat Improvement Project (CHIP)	Open plots experienced greater nutrient fluxes, grew more nutritional plants (i.e., algae) and supported higher wading bird foraging than the surrounding cattail habitat. Floc and sediment phosphorus speciation suggests that phosphorus cycling is being modified in these open plots. Continued sampling and analysis over the next two years will allow a better assessment to whether there is a sustained change in trophic dynamics and whether open plots cans function as natural sloughs.	LTP, ROS
Landscape Ecology		
Vegetation Mapping	Vegetation mapping products have been completed for Water Conservation Area 2A and Rotenberger Wildlife Management Area. Loxahatchee National Wildlife Refuge is approximately 75 percent complete and is projected to be completed by October 2007. Mapping is also underway for a 67,900 hectare area (approximately 11 percent) of Everglades National Park.	CERP, FEIM, ROS
Historic Everglades	A form of “forensic ecology” was used to reconstruct the pre-drainage Everglades.	CERP, EFA MFL, ROS
Soil Profiles of Macrofossils	Increased sawgrass abundance over the 20th-Century has occurred in Shark Slough of the Everglades National Park. Downcore profiles of macrofossils (mainly seeds) from modern sawgrass communities are all suggestive of wetter conditions prior to 1940 and drier conditions afterward.	MFL, CERP, FEIM
Change in the Ridge and Slough Pattern	The original landscape patterns were stable over decades and perhaps centuries. Surface patterning can appear relatively unchanged for several decades despite following severe changes in hydrology and other environmental conditions, but then fail rapidly once some threshold is exceeded.	CERP, FEIM, MFL
Drought Risk Assessment	The index to monitor this year’s drought used peat hydration and wading bird nesting requirements to provide continuous, updated assessments throughout the drought period, and evaluate how various water management alternatives might exacerbate or alleviate ecological stress during this time.	ROS, MFL, FEIM

HYDROLOGIC PATTERNS OF WATER YEAR 2007

The hydrology of the Everglades is a key frame of reference for studies that examine intra-annual variations within the ecosystem or that compare one ecological component's season to another. These hydrograph descriptions should be kept in mind when reading this chapter's updates on wading birds nesting patterns, wading bird foraging, the cattail (*Typha* spp.) burning schedule associated with Acceler8's Fire Project, and drought risk assessment. Although the current hydrology plays a minor role when discussing greenhouse experiments, macrocosm manipulations, rapid assessment techniques, or vegetation mapping, current hydrologic trends are suggestive of a future drought that may have broad ecological significance that will be reported in the *2009 SFER – Volume I.*

The amount of rain in the Everglades Protection Area (EPA) for Water Year 2007 (WY2007) (May 1, 2006–April 30, 2007) was only 4 to 5 inches less overall than the previous water year, WY2006. However, this difference was enough to maintain water levels below regulation for all of the Water Conservation Areas (WCAs) for most of WY2007. The rainfall and associated stage readings for WY2007 are shown on **Table 6-2**. WCA-1, WCA-2, and WCA-3 all showed a 14 percent reduction in historical rainfall amounts. However, Everglades National Park (Park or ENP) showed only a 5 percent reduction in historical rainfall amounts.

Table 6-2. For the Everglades Protection Area (EPA), average, minimum, and maximum stage [feet National Geodetic Vertical Datum (ft NGVD)] and total annual rainfall (inches) for Water Year 2007 (WY2007) in comparison to historical stage and rainfall.[1] (Average depths calculated by subtracting elevation from stage.)

Area	WY2007 Rainfall	Historical Rainfall	WY2007 Stage Mean (min; max)	Historical Stage Mean (min; max)	Elevation
WCA-1	44.94	51.96	15.99 (14.07; 17.08)	15.58 (10.0;18.38)	15.1
WCA-2	44.94	51.96	11.91 (10.42; 13.97)	12.55 (9.33;15.64)	11.2
WCA-3	44.26	51.37	9.61 (8.4; 11.26)	9.54 (4.78;12.79)	8.2
ENP	52.76	55.22	6.15 (5.45; 6.67)	5.98 (2.01;8.08)	5.1

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

In WY2007, most of the rain fell during July and August 2006. July totals ranged between 8.1 inches (in WCA-1) and 11.5 inches (in the ENP). August totals ranged between 7.7 inches (in the ENP) and 8.7 inches (in WCA-1). For the rest of the water year, rainfall patterns were rather consistently lower than average and the dry season seemed to come a month or two early. October and November rainfall totaled a mere 1.8 inches across WCA-3A. As shown in the hydrographs in this section (see **Figures 6-1** through **6-7**), and as might be expected from a below-average rainfall water year, the 2006 hydrologic stage conditions in WY2007 were also below average throughout most of the system.

As depicted in previous SFER's the hydropattern graphs highlight the average stage changes in each of the WCAs in 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 (**Figures 6-1** through **6-7)**. 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 to be 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 was divided into three simple categories (red, yellow, and green) based upon foraging observations in the Everglades (Gawlik, 2002). A red label indicates poor conditions due to recession rates that are too fast (greater than 0.6 foot per week) or too slow (less than 0.04 foot for more than two weeks), or that the average depth change for the week was positive rather than negative. A yellow label indicates fair conditions due to a slow recession rate of 0.04 foot per week or a rapid recession between 0.17 foot and 0.6 foot per week. A green label indicating good conditions was assigned when water depth decreased between 0.05 foot and 0.16 foot per week. Although these labels are not indicative of an appropriate depth for foraging, they have been useful during high water conditions to highlight recession rates that can lead to good foraging depths toward the end of the dry season (i.e., April and May).

WATER CONSERVATION AREA 1

During WY2007, Water Conservation Area 1 (WCA-1) started at a relatively low water condition, but then quickly rose to above-average conditions and remained above average through September 2006 (**Figure 6-1**). After September, rainfall rates declined significantly and stages quickly went below average and stayed below average for the rest of the water year. This was not necessarily bad for WCA-1 because the upper flooding tolerances for tree islands were never reached and recession rates were excellent for most of the dry season. During the previous water year (WY2006), there were a number of large-scale reversals in WCA-1 during March and April (**Figure 6-1**), whereas in WY2007, recession rates during the critical wading bird nesting season (January to June) were steady with only a minor reversal observed in April. Water depths became optimum for foraging in central and southern WCA-1 during April and May. Dry season foraging by wading birds in WCA-1 probably slowed significantly in mid-June when water levels increased by 0.5 ft. Like WY2006, WCA-1 had the longest duration of good nesting and foraging periods of any region in the EPA during WY2007. Similarly, water levels in WCA-1 were below regulation most of the time, upper tolerance levels were never reached, and recession rates were steady.

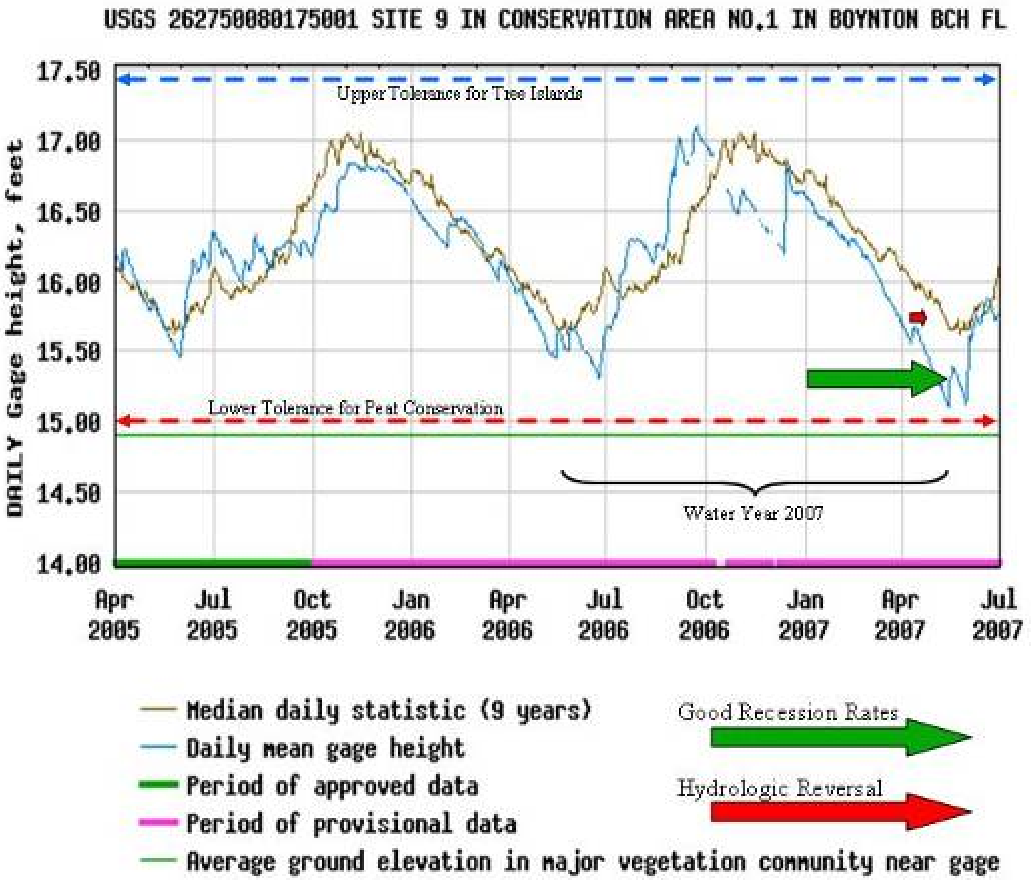


Figure 6-1. Hydrology in Water Conservation Area 1 (WCA-1) in relation to the 9-year median stage and indices for tree island flooding, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 2A AND 2B

In Water Conservation Area 2A (WCA-2A), the differences between WY2006 and WY2007 were most obvious during the wet seasons (**Figure 6-2**). In June 2005, the wet season began abruptly and was so intensive that it caused this region to exceed the upper flood tolerance for tree islands. In June 2006, WCA-2A was dry and wet season water depths were less than or equal to only 1 foot for most of July and August. For WY2007, only September stage heights were above average, the other 11 months were either average or some one ft below average. [Note: The short period of 30 days when the upper tree island tolerance was exceeded in WCA-2A was not enough to cause any tree island damage (Wu et al., 2002)].

In WCA-2A, the WY2006 and WY2007 dry seasons were very similar. Both dry seasons had very good recession rates, both had minor recessions, and both times the region completely dried out. The difference is that the area dried out almost a month earlier in WY2007 than in WY2006. The other difference is that WCA-2A exhibited excellent foraging conditions and many flocks of wading birds were observed in WY2006. In WY2007, although foraging conditions should have been about the same, reports of large or multiple flocks were greatly reduced.

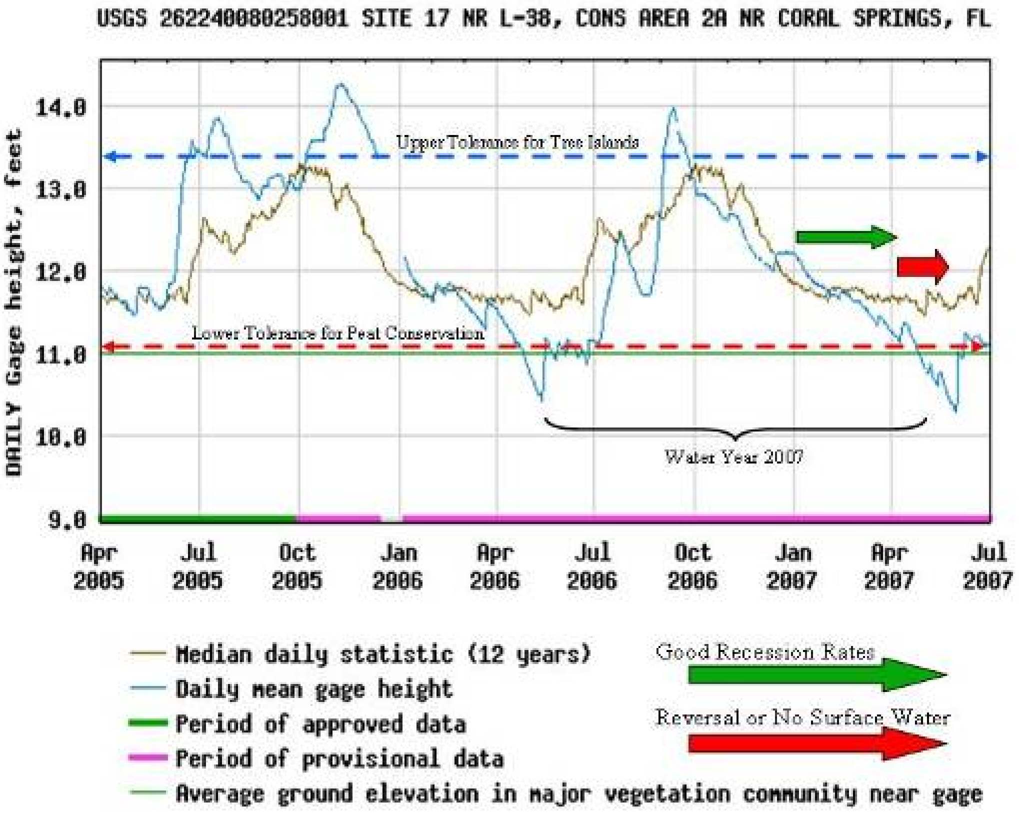


Figure 6-2. Hydrology in Water Conservation Area 2A (WCA-2A) in relation to the recent 12-year average, and indices for tree islands, peat conservation, and wading bird foraging.

In Water Conservation Area 2B (WCA-2B), there was no hydrologic similarity between WY2006 and WY2007 (**Figure 6-3**). Most of WY2006 was slightly above average, while all of WY2007 was significantly below average. In WY2006, when dry season water levels went below ground in WCA-2A, the wading birds moved to WCA-2B because rainfall patterns and recession rates in WCA-2B created a suitable foraging habitat for the displaced wading birds in WCA-2A. In WY2007, WCA-2B and WCA-2A dry season hydroperiods were much more synchronous, and both regions became too dry to support any foraging from May to July. WCA-2B has a history of being the wettest of the WCAs and it was unique to see depths drop about 2 foot below ground in this region. [Note: More than 1 foot below ground violates the guidance for Minimum Flows and Levels, per Subsection 373.042(1), Florida Statutes (F.S.).]

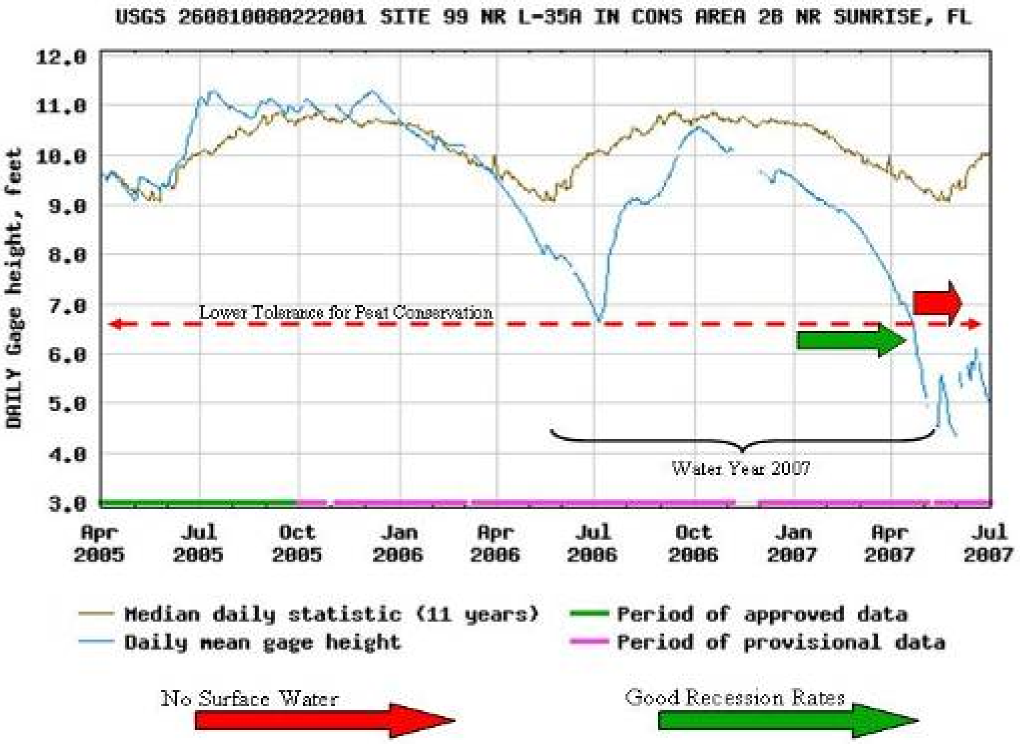


Figure 6-3. Hydrology in Water Conservation Area 2B (WCA-2B) in relation to the recent 11-year average, and indices for peat conservation, and wading bird foraging. Indices for tree islands in this region do not apply.

WATER CONSERVATION AREA 3A

The hydrology in the northeastern region of Water Conservation Area 3A (WCA-3A) (gauge 63) in WY2007 was very similar to that in WCA-2A **(Figure 6-4)**. They both had very much below-average stage readings for most of the water year; they had the same abrupt September peak, same late beginning of the wet season, good recession rates during the dry season, and an extended dry period when water levels were below ground. (Note: More than 1 foot below ground violates the guidance for Minimum Flows and Levels, per Subsection 373.042(1), F.S.) However, this region dried out to a much greater degree than the previous water year (WY2006), and the combination of a late wet season and extended dry season created an inhospitable environment for wading birds, especially those that frequent the popular Alley North Rookery. During WY2007, this region had good recession rates for the entire nesting season and better foraging conditions (in terms of hydrology) than in WY2006. In WY2007, wading birds were fortunate that their rookery did not burn.

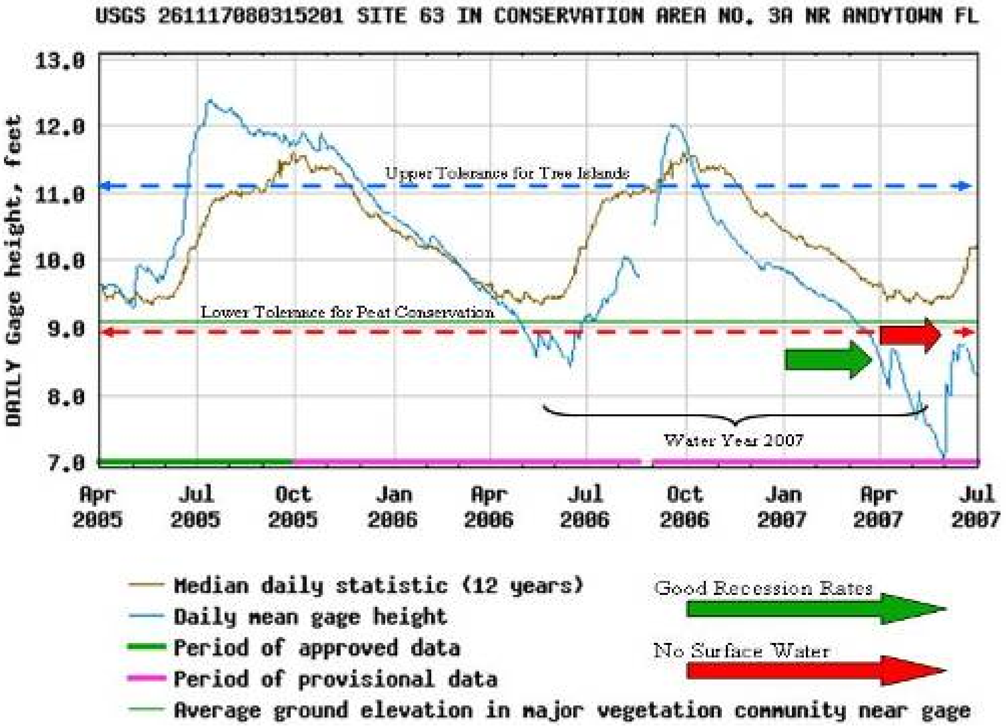


Figure 6-4. Hydrology in northeast Water Conservation Area 3A (WCA-3A) (gauge 63) in relation to the recent 12-year average and indices for tree islands, peat conservation, and wading bird foraging.

The hydrologic pattern in central WCA-3A (gauge 64) in WY2007 (**Figure 6-5**) was almost identical to that shown for the northeast WCA-3A **(Figure 6-4)**. However, the hydrograph is shown in **Figure 6-5** to illustrate the one most significant difference – good foraging hydrology and no violation of the MFL during the dry season. This does not mean, of course, that foraging was indeed good in this area. It is very possible that the shallow depths and short duration of the wet season was sufficient to cause widespread depletion of wading bird prey species.

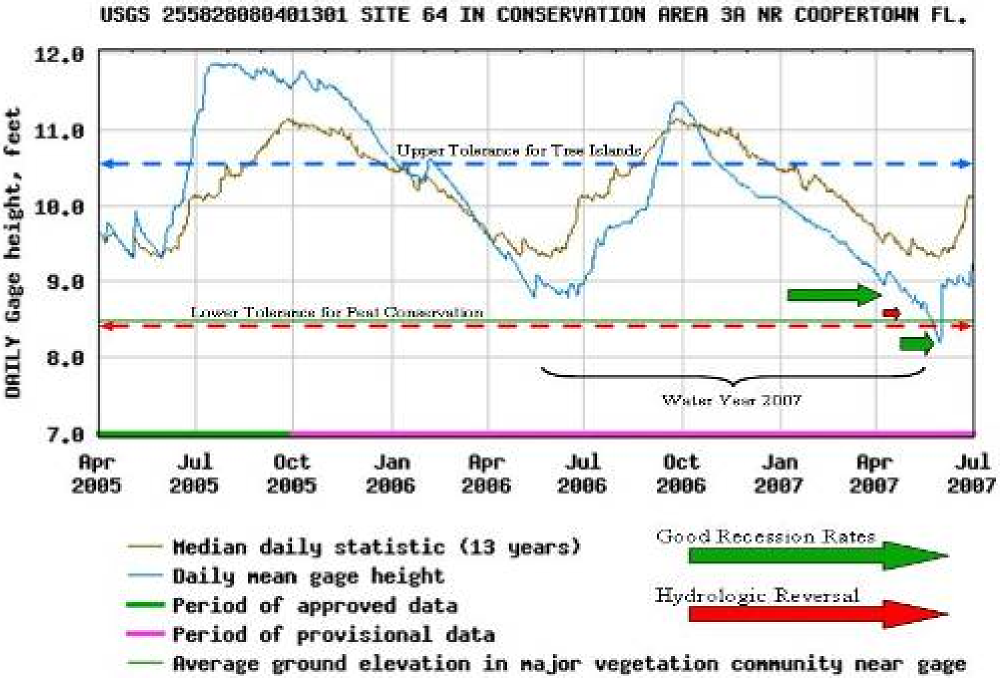


Figure 6-5. Hydrology in central WCA-3A (gauge 64) in relation to the recent 13-year average and indices for tree islands, peat conservation, and wading bird foraging.

During WY2006, despite good recession rates during the entire nesting season, 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, reversals occurred in March, April, May, and June, making this region marginal for foraging visits by wading birds. The reason stated for these conditions at WCA-3A may also be true here, and it is possible that the shallow depths and short duration of the wet season was sufficient to cause widespread depletion of wading bird prey species (see **Figure 6-6**).

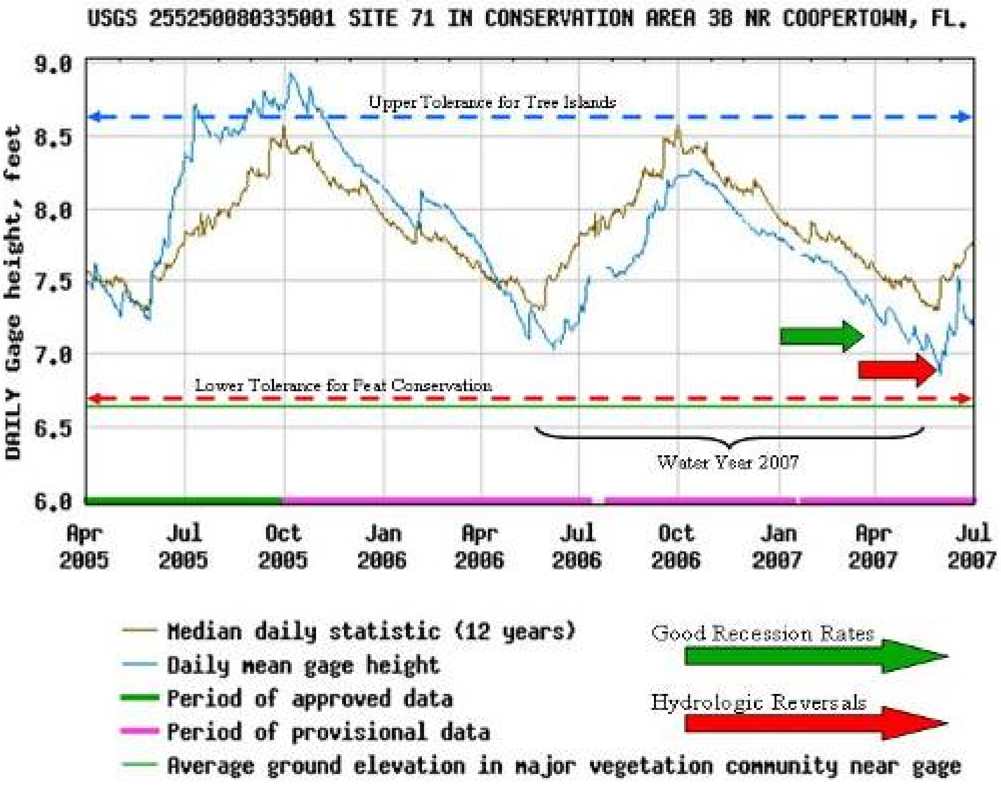


Figure 6-6. Hydrology in central Water Conservation Area 3B (WCA-3B) (gauge 71) in relation to the recent 12-year average and indices for tree islands, peat conservation, and wading bird foraging.

NORTHEAST SHARK RIVER SLOUGH

The uniqueness of the hydrology and drought in the Everglades during WY2007 is captured by the Northeast Shark River Slough hydrograph (**Figure 6-7**). Everglades National Park, like most of southeast Florida, did not experience below-average rainfall for most of the year. Dry season recession rates were good, for the most part, until April when depths became too low and a series of large reversals caused foraging, if there was any, to probably cease. This trend was similar to that from last year. Likely, it was made worse by the short duration of the WY2007 wet season.

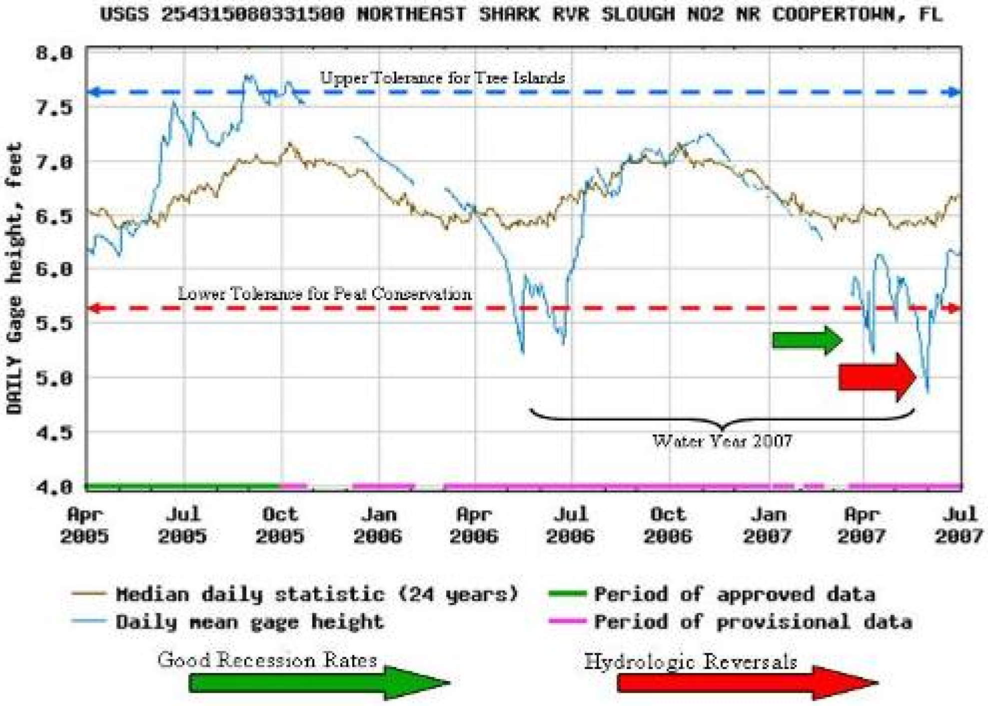


Figure 6-7. Hydrology in Northeast Shark River Slough in relation to the recent 24-year average and indices for tree islands, peat conservation, and wading bird foraging.

WILDLIFE ECOLOGY

Previous research has shown that the distribution of wildlife in the Everglades is a function of hydrology, water quality, climate, and biotic interactions. Most wildlife studies in the Everglades have been conducted by the District, Everglades National Park (ENP or Park), U.S. Fish & Wildlife (USFWS), Florida Fish and Wildlife Conservation Commission (FWC), and state universities. The District focuses 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.

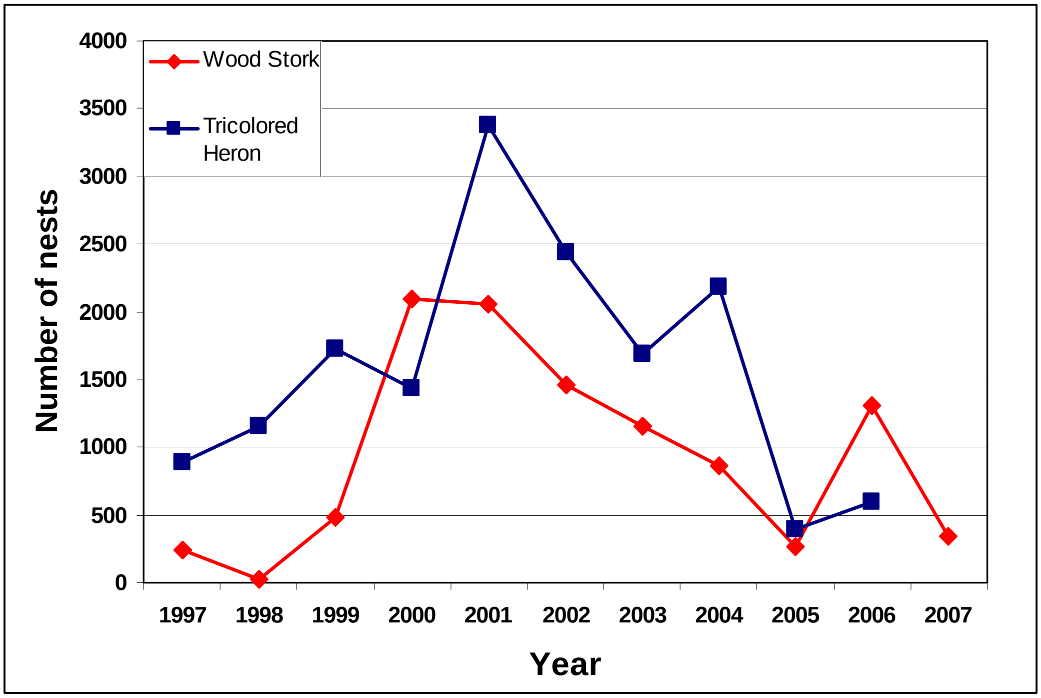
The format of this year's *Wildlife Ecology* section of the chapter is similar to the *2007 South Florida Environmental Report (SFER) – Volume I, Chapter 6* (Sklar et al., 2007). This year's chapter reports on wading bird nesting effort and success during the 2007 breeding season and results from year two of the three-year white ibis (*Eudocimus albus*) supplementary feeding experiment. This experiment is examining the causal relationship between food availability, hydrologic conditions, and white ibis nesting success (see the *2007 SFER – Volume I, Chapter 6*, for details and results of year one of this study). This chapter also reports on the first year of a two-year experimental study conducted in the Loxahatchee Impoundment Landscape Assessment (LILA) that examines the environmental factors affecting prey availability and foraging success of wading birds (a collaboration with Florida Atlantic University) and on the development of an assessment of environmental conditions using macro-invertebrates.

WADING BIRD MONITORING

Because wading birds are excellent indicators of wetland ecosystem health, they have a central role in the Comprehensive Everglades Restoration Plan (CERP). Nesting figures for CERP performance measures are restricted to five species – great egret (*Casmerodius albus*), snowy egret (*Egretta thula*), tricolored heron (*Egretta tricolor*), white ibis (*Eudocimus albus*), and wood stork (*Mycteria americana*) – from nesting colonies in the Greater Everglades region, i.e., the WCAs and the ENP. 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 restoration effort. In addition to CERP, wading birds are of special interest to the public and play a prominent role in adaptive protocols, Minimum Flows and Levels (MFLs), and day-to-day operations of the District.

Recovery of pre-drainage wading bird nesting patterns are measured using four parameters: (1) number of nesting pairs for the five species, as shown by three-year running averages of nest numbers, (2) a recovery of nesting in the traditional 'rookeries' in the southern, mainland estuaries downstream from Shark Slough, (3) a return to early (December-to-January) dry season nesting by wood storks, and (4) an increase in the frequency of supra-normal nesting events. The information reported in this section represents a compilation of data collected by a variety of institutions which includes Florida Atlantic University (FAU), Florida International University (FIU), University of Florida (UF), USWFS, U.S. Geological Survey (USGS), and the National Academy of Sciences (NAS). 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, 2007). The period covered in this report is the nesting season from February through June 2007.

The estimated number of wading bird nests in South Florida in 2007 was approximately 37,623. This is a 31 percent decrease relative to last year's successful season, 46 percent less than the 68,750 nests of WY2002, which was the best nesting year in South Florida on record since the 1940s, and 24 percent less than the average of the last six years (**Figure 6-8**). All species of wading birds experienced reduced nesting effort relative to WY2006, but the most extreme declines were for wood storks (79 percent), tricolored herons (69 percent), and snowy egrets (96 percent). The number of white ibis nests was 21 percent lower than WY2006 but was similar to the average of the past 10 years. WY2007 was a poor nesting season for wading birds compared to the past 10 years and to pre-drainage years, but nest numbers were relatively high relative to the period from 1960 through 1998.



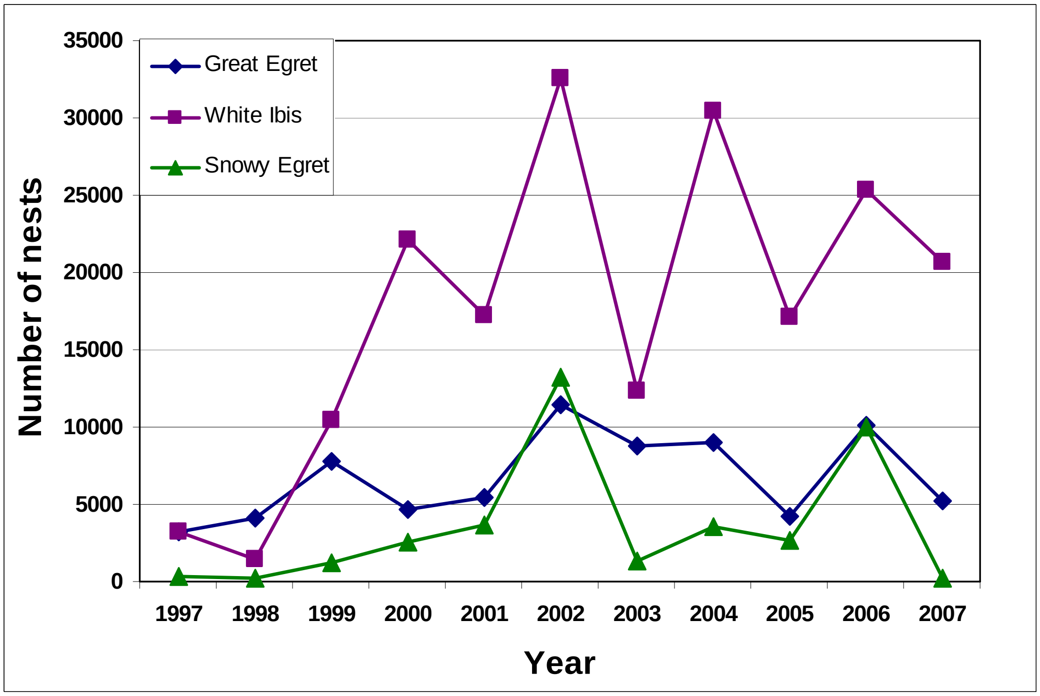


Figure 6-8. Historical wading bird nesting numbers in the Everglades for individual species since 1997. The count for tricolored herons in 2007 is omitted because surveys could not be completed for this species in this year due to the dry conditions. Birds with white plumage were counted by aerial survey.

As usual for recent years, nesting effort in the Everglades was not uniformly distributed among regions. WCA-3 and WCA-1 supported the most nests (47 and 44 percent respectively), whereas the ENP supported the lowest number of nests (9 percent). This spatial distribution of nests represents a change from that of recent years in that a greater proportion of nesting occurred in WCA-1 at the expense of nesting in WCA-3. The ENP historically supported the largest number of nests in the system, and a goal of CERP is to increase the proportion of birds nesting in the traditional estuarine "rookeries" downstream of Shark Slough. Nesting effort in the estuaries has increased over recent years but in WY2007 they supported only minimum nesting. Another pattern in recent 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. In WY2007, Alley North and the adjacent marsh dried prior to breeding and nesting was not initiated at the colony. The loss of this important colony appeared to be partly offset by increased nesting activity in WCA-1 and by the expansion of two extant colonies proximate to Alley North.

Generally, nesting was not successful for most species in that the total numbers of surviving chicks were below replacement rates. Some of the nest failure can be attributed to the dry conditions which led to poor foraging and possibly to increased mammalian predation when colonies dried completely. Despite the dry conditions, rain-driven reversal events in March and April induced moderate nest failure particularly for nests containing eggs or very young chicks. Wood stork nesting success was particularly poor in WY2007. At Paurotis Pond, all nests had failed by late May and at Tamiami West, only about 40 of 90 pairs appeared to fledge young. Counts of young per nest suggest that approximately 1.37 chicks were brought to a large fledgling stage per successful nest, which would translate into approximately 0.57 young per nest start. Both figures are far below the suggested replacement rates (Frederick and Simon, 2007) for this species. However, successful nesting was evident at large colonies of both great egrets (e.g. Vacation, Cypress City), and white ibises (6th Bridge, Lox 73, New Colony 4).

Despite the reduced nesting effort and success, Systematic Reconnaissance Flight (SRF) surveys show that very large numbers of birds foraged in the Everglades in 2007: the system-wide total abundance was 26 percent higher than last year and 48 percent higher than the average of the past five years. Extreme low stages on the Kissimmee floodplain and other wetlands precluded foraging for much of the 2007 dry season and birds from these systems were forced to migrate to longer hydroperiod marshes. This exodus may explain the marked increase in the Everglades population.

The annual nesting response of wading birds helps provide a better understanding of how the Everglades ecosystem functions. Recession rates in WY2007 were generally classified as 'good' (see the *Hydrologic Patterns of Water Year 2007* section), but stages were generally below average and provided unsuitable foraging conditions over large areas of the system for much of the breeding season. The magnitude of the 2006–2007 drought (see Chapter 2 of this volume) and its effect on wading bird reproduction varied considerably by region. Nesting effort and success was greatest in areas where water levels were relatively high at the start of the breeding season, where it declined at appropriate rates, and where it did not dry completely during chick rearing. Little or no nesting occurred in areas that were too shallow prior to nesting season. The poor nesting effort and reproductive success in WCA-3 and the switch in nesting effort to WCA-1 were almost certainly due to differences in hydrologic patterns. However, the dry conditions do not fully explain WY2007 observed reproductive patterns. Water depths in WCA-2 and WCA-3 were optimal for foraging early in the breeding season, but compared to recent years these important pre-breeding foraging areas supported only limited wading bird foraging.

This disconnect between wading bird foraging and hydrology may be related to aquatic prey production. The annual monitoring of aquatic prey during the seasonal dry-down reveals that prey densities were relatively low in WCAs 2 and 3 in 2007, and adults that foraged in these areas had low body-condition scores. Prey production in WCAs 2 and 3 may have been reduced by the extended 2006 dry season during which surface waters fell below ground level for an extended period, potentially killing much of the prey stock for the 2007 breeding season. By contrast, water levels in WCA-1 in 2006 remained above ground and subsequent prey densities and wading bird reproductive output were relatively high. Thus, wading bird reproduction is likely tied not only to appropriate dry-season hydrologic conditions which increases prey vulnerability (a strong recession and appropriate water depths), but also to the hydrologic conditions of the preceding wet season which affects prey production. This is supported by the strong link between very successful breeding seasons (i.e., 2002, 2004, and 2006) and appropriate long-term hydrologic conditions: i.e., high stages during the preceding wet season followed by appropriate dry season recession rates/water depths. Breeding seasons without this continuum of conditions have had much reduced nesting effort.

WY2007 was noteworthy in that the large numbers of foraging birds did not translate into a comparable nesting effort. This suggests that the factors attracting birds to the Everglades are not always identical to those determining it suitability for breeding. For example, the increased foraging response may have been a consequence of unsuitable foraging conditions elsewhere in South Florida such that many birds had little choice but to feed in the Everglades. The relatively low prey densities in the system may have then precluded nesting for many birds.

Two of four species-groups met the numeric nesting targets proposed by the South Florida Ecosystem Restoration Task Force (**Table 6-3**). Two other targets 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 2007 nesting year showed no improvement in the timing of wood stork nesting or a general shift of colony locations.

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

Species	Base low/ high	1998-2000	1999-2001	2000-2002	2001-2003	2002-2004	2003-2005	2004-2006	2005-2007	Target
Great Egret	1,163/ 3,843	5,544	5,996	7,276	8,535	9,656	7,267	7797	6987	4,000
Snowy Egret/ Tricolored Heron	903/ 2,939	2,788	4,269	8,614	8,089	8,079	3,783	6478	4559*	10,000-20,000
White Ibis	2,107/ 8,020	11,270	16,555	23,983	20,725	24,947	19,896	24,242	21,660	10,000-25,000
Wood Stork	130/294	863	1,538	1,868	1,554	1,191	762	807	636	1,500-2,500

*Tri-colored Herons are excluded from this total due to incomplete surveys for this species in 2007.

FOOD LIMITATION ON WADING BIRD REPRODUCTIVE SUCCESS: YEAR TWO

The number of wading bird nests in the Everglades has decreased by approximately 70 percent since the 1930s (Crozier and Gawlik, 2003) and those individuals that do nest often experience reduced reproductive output. A reduction in prey availability brought about by water management activities is considered the most important factor responsible for these declines. This view is supported by studies showing correlations between hydrologic variables and wading bird reproductive effort and success (Kushlan et al., 1975; Frederick and Collopy, 1989). The term “nesting success” as used in this chapter refers to the survival of a chick up to the time it leaves the natal nest. An observational approach, however, does not verify a causal relationship between hydrology, food supply and breeding success, and understanding the specific mechanisms and pathways responsible for the population declines remain limited. Empirical studies that manipulate food supplies and control for naturally correlated variables that also affect nesting success are needed.

Results from the first two years of a three-year study examining the effects of food limitation on white ibis nestling growth and survival are presented in this section. In *2007 SFER – Volume I, Chapter 6*, results from year one (2006) of this study were reported. In the current chapter, preliminary results from the second field season (2007) are presented with a discussion of their relevance to 2006’s results. The primary objectives of the study are to determine experimentally (1) whether food supply limits white ibis (*Eudocimus albus*) nesting success, and (2) whether food limitation is a function of hydrologic conditions. The study uses a supplementary feeding experiment in which a group of ibis nestlings are fed with locally collected aquatic prey. The effects of food supplementation on nestling fitness (growth, survival and physiological responses), nestling behavior, and parental provisioning responses are being quantified and compared to a control group. White ibis nestlings leave the natal nest and form crèches at approximately 25 days post-hatching (25d) but remain reliant on parental provisioning until attaining independence at approximately 40 to 60d when they depart the colony. For the study, food was supplemented only during the nestling stage but its effects on offspring fitness and behavior were measured from the early nestling stage, through the crèche period, and into the initial natal dispersal period (i.e., from 5d through 60–80d). The study will be repeated in three consecutive breeding seasons to examine the effects of hydrologic conditions on food limitation. The hypotheses are that (1) the success of chicks from food-supplemented nests should be greater than those of control nests and (2) the magnitude of the difference between treatments should be greatest during breeding seasons when hydrologic conditions are poor.

Methods

Nesting season 2007’s study was conducted at a tree island colony (New Colony 4; 26º 32’ N, 80º 16’ W) of approximately 8,000 breeding white ibis in the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge) between April and June 2007. This colony was situated approximately 1 mile east of last year’s study colony. Nestling behavior and parental food provisioning in experimental and control groups were recorded directly from two raised observation blinds using spotting scopes. Data were collected from 46 randomly selected nests situated approximately 50 meters from the blinds. Every nest was numbered and visible from at least one blind. Nests with chicks of similar age were matched (to control for possible differences in breeding performance of adults related to hatching date) and assigned to either a supplementary feeding group or control group (24 control and 22 supplemented nests). Chicks in the supplemented group were hand fed every 1.4 days with 10 grams (g) of fresh, locally caught fish. This quantity was determined through a trial study and provided sufficient energy to have a potential affect on growth/survival but not so much that the parents would lose their provisioning response. Supplementary feeding began when chicks were six days old and continued until nest departure at about 22d. Growth of all chicks was measured every 3 to 4 days from age 5d (one day prior to supplementation) until they could no longer be captured (15–25d). On each occasion, body mass, bill length, right tarsus length, and right wing length was measured, and the survival status of each chick was recorded. The District collaborated with FAU to measure physiological parameters (such as triglycerides, glycerol, and corticosterone) from blood and fecal samples taken at ages 10d and 20d. These provided a measure of nestling physiological condition. Feather samples were also taken at these ages to measure mercury loads. As many nestlings as possible were banded with a BBL aluminum band and a combination of unique color bands to identify individuals after nest departure. At 20d, each chick was captured and fitted with a radio transmitter and tracked daily by helicopter until departure from the Refuge and adjacent areas.

Hydrologic variables and prey density were measured once per week at ten randomly positioned sloughs within a 5-kilometer radius of the colony. Prey density was quantified using standard methods (1-m^2 throw trap). To determine chick diet during the study, bolus samples were taken weekly from a group of surrogate nestlings on an adjacent tree island to the experimental nestlings and analyzed in the lab. Prey species were identified to the taxonomic family level or higher.

Growth and survival data were analyzed in relation to treatment (supplemented and control) and hatching order (A-chick and B-chick). A-chicks and B-chicks were labeled according to typical studies in scientific literature, which classifies those birds hatching first in a nest as A-chicks, and those hatching after that as B-chicks. The District used a mixed model repeated measures analysis of variance (ANOVA) (PROC MIXED) to compare mass growth of nestlings and a logistic regression model was used to examine chick survival to age 25d. Non-parametric Kruskal-Wallis tests were used for all other analyses.

Results and Discussion

Data collection from the second season of this experiment only recently finished. As such, only provisional analyses of the survival and the mass growth data have been completed.

The provision of extra food had a significant effect on nestling mass growth. At 7d of age (day two of food supplementation), no differences existed between body masses of food-supplemented and control nestlings (**Figure 6-9**). However, beyond 7d of age the growth of chicks in the two groups diverged, such that chicks in supplemented nests grew larger than those in control nests (**Figure 6-9** and **Table 6-4**). In general, A-chicks were larger at the study's conclusion than B-chicks, but the non-significant interaction between treatment and hatching order suggests that the relative increase in mass from supplementation was similar for both A- and B-chicks (**Table 6-4**). Food supplements also increased nestling survival: the proportion of nestlings that survived to 25d in supplemented nests (82 percent) was significantly greater (X12 = 10.59, p = 0.001) than in control nests (48 percent). This increase in survival was a function of hatching order (X12 = 13.51, p = 0.001): that is, there was a large difference between treatments in the survival of B-chicks (supplemented: 64 percent survival; controls: 20 percent survival) but little difference between A-chicks (supplemented: 100 percent; controls: 82 percent). Mortality tended to occur at a young age (mean age 7.2d ± 0.66 SE, min.: 1d; max.: 16d) but age of mortality was not effected by treatment or hatching order ($p > 0.05$). Probability of survival increased once birds reached 20–25d (the crèche period) and the proportion of birds that survived from 25d to dispersal from the colony was extremely high for both treatments (88 percent of 32 radio-tracked birds fledged). Mean age of dispersal (60.3 ± 1.3 SE old; range: 49 to 74 days) was not affected by treatment or hatching order (both $p > 0.05$). The pattern of fledgling dispersal was similar to that in 2006: after leaving the colony fledglings immediately flew out of the Refuge and, in most cases, were not relocated thereafter.

These preliminary analyses of the 2007 data support the notion that white ibis nesting success was limited by food supply. When considered in the context of local stage data the results suggest that water levels became too low to sustain optimal foraging throughout the nesting period, as noted elsewhere in this chapter (see *Hydrologic Patterns for Water Year 2007* and *Wading Bird Monitoring* sections). However, further analyses are needed to allow a more precise characterization of the role of hydrology and food limitation on nesting success in 2007. Prey densities appeared to be relatively high early in the nesting season (unpublished data) which suggests that prey production per se was not limiting. Needed is a better understanding of how the dry conditions and a rain-induced reversal event affected nesting success.

A major objective of this multi-year study was to compare years with different hydrologic conditions in order to define good and poor breeding conditions in terms of hydroperiod, recession rate, and water depths. Breeding season 2007's results during a relatively dry breeding season contrast sharply with those of the 2006 breeding season when growth and survival rates were exceptional and hydrologic conditions appeared to be optimal for reproduction. Further examination of these two breeding seasons will help fine tune wading bird hydrologic requirements during the nesting period. Defining these requirements is essential to supporting regulation schedules and setting CERP hydrologic targets. An additional season of study during a wet year will further increase our understanding of the role of hydrology on nesting success.

Table 6-4. Repeated measures ANOVA table for the effects of treatment (supplemented or control), hatching order (A-chick or B-chick) and chick age (categories 7, 10, 13, and 16d) on growth of nestling body mass.

Source	*F*	d.f.	*P*
Treatment	19.07	1, 59	<0.0001
Hatching order	5.96	1, 59	<0.0177
Age	139.0	3, 98	<0.0001
Age x hatching order	3.65	3, 98	0.0152
Treatment x hatching order	1.30	1, 59	0.2581
Treatment x age	4.30	3, 98	0.0068
Treatment x age x hatching order	4.36	3, 98	0.0063

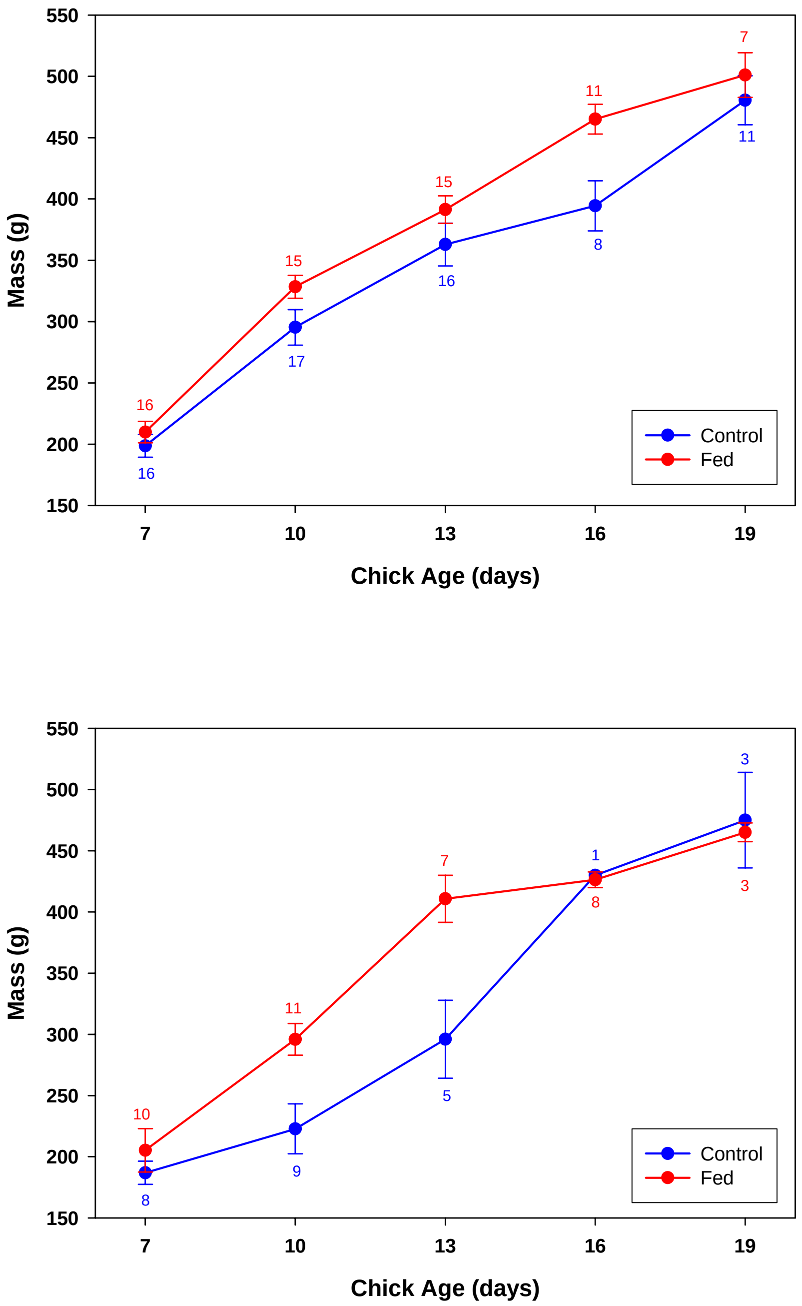


Figure 6-9. Mean nestling mass (±1 SE) at age categories 7, 10, 13, 16, and 19d post-hatch for A-chick (top) and B-chicks (bottom) in food-supplemented and control nests. Sample sizes are above and below error bars.

FACTORS AFFECTING PREY AVAILABILITY AND FORAGING SUCCESS OF WADING BIRDS IN THE EVERGLADES: YEAR ONE

Prey availability within a habitat is important in determining foraging site selection by wading birds (Gawlik, 2002; Safran et al., 2000; Frederick and Spalding, 1994), and is the major factor limiting reproductive success in wading birds (Powell and Powell, 1986). However, factors affecting prey availability are poorly understood (Frederick and Spalding, 1994).

A reasonable hypothesis based on previous studies is that open-water, non-vegetated sloughs are better foraging habitats than vegetated sloughs. Results from the first year of a two-year study examining water depth and SAV density on wading bird prey availability and foraging success are presented in this section. The specific objectives of this two-year study are to determine the effects of submerged aquatic vegetation (SAV) and water depth (year one) and the effects of emergent vegetation and water depth on wading bird prey availability (year two). Because it is difficult to measure prey availability directly, the response variables for each leg of the study will be (1) foraging site selection and (2) foraging success. For the 2007 effort, it was predicted that foraging site selection and foraging success would be higher in enclosures with lower SAV densities and shallow water.

Methods

To quantify the effects of submerged aquatic vegetation and water depth on wading bird foraging site selection and foraging success, experiments were conducted in January and April 2007 at the Loxahatchee Impoundment Landscape Assessment (LILA) Facility (see LILA Work Plan for details of this experimental facility). During each experiment, 10 x 10 m nylon mesh enclosures were established in a macrocosm at LILA. Three enclosures each were established in both the deep and shallow sloughs of the macrocosm. Macrocosm I was used in January 2007, and Macrocosm IV was used in April 2007.

Two water depth treatments,10 centimeter (cm) and 25 cm, and three SAV densities: 0 litres per square meter (L/m^2), 2 L/m^2, or 5 L/m^2 of bladderwort (*Utricularia* sp.) were used to evaluate effects on wading bird foraging. Previous observational and experimental studies have suggested that the optimal foraging depth for wading birds is about 10 cm and the maximum depth is about 30 cm. The two experimental depths cover this range. Bladderwort was chosen because it is native to the Florida Everglades, is structurally complex, and is one of the most common submerged plants in slough areas of the interior marshes. Sampling in the Everglades as part of a CERP Monitoring and Assement Plan study showed that it is common to find densities of 5 L/m^2 of this species (Gawlik, unpub. data). The bladderwort was collected from within the surrounding LILA compartments and was evenly distributed throughout each enclosure to avoid patchiness.

Enclosures were stocked with 20 fish/m^2 of mosquitofish (*Gambusia holbrooki*), the most common small-fish species in the Everglades. Fish were of a known size, density, and caloric content, based on formulas in Kushlan et al. (1986). Sizes were > 2 cm in length, the minimum size preferred by most wading birds. Past studies have shown that a high stocking density will attract the largest variety of wading bird species, and the density of 20 fish/m^2 is similar to that of the mean fish density found in wading bird foraging habitats of the Everglades.

Mark-recapture methods were used in order to restock the enclosures. Fish were marked in batches using Visible Implant Elastomer. Lincoln-Peterson estimates were used to assess the populations, and additional fish were added to maintain original stocking densities. This restocking and a relatively short observation period ensured that fish densities remained relatively constant throughout the experiments.

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. Enclosures were observed for a continuous three-hour period on each observation day from a vehicle parked on a nearby levee, or by individuals sitting on the levee.

The number of foraging wading birds in each enclosure was counted at 15-minute intervals throughout each entire three-hour observation period. Wading bird use of the enclosures was compared to availability to determine foraging site selection using Manly's standardized selection index.

Individual observations of foraging birds were obtained by videotaping the enclosures. Foraging success was later quantified in the laboratory by analyzing videotapes of foraging birds and constructing time-activity budgets using EthoLog 2.2 (Ottoni, 2000). Capture rate was defined as the number of prey captured per minute.

Results and Discussion

Most species of wading birds found in the Everglades foraged in the experimental enclosures. Wading bird use at any given time ranged from 0–31 birds per enclosure and from 0–78 birds summed throughout the enclosures. The duration spent in the enclosures was highly variable, ranging from less than a minute to three hours (the entire observation period). Most birds arrived at dawn and fed primarily in the enclosures. Time activity budgets ranged from 1–15 minutes.

Numerical response data, analyzed using Manly's standardized selection index, suggests that birds preferred shallow water for foraging. In the first experiment, birds used all treatment combinations, selecting shallow over deep treatments, whereas in the second experiment, site selection was limited to shallow treatment enclosures. A two-way analysis of variance (ANOVA) showed that water depth significantly affected site selection ($p < 0.01$, both experiments). SAV density had a significant effect in the first experiment but not in the second experiment ($p = 0.024$, $p = 0.267$, respectively). Neither capture rate (number of captures per min) nor capture efficiency (number of captures per total number strikes) was affected by depth ($p = 0.998$, $p = 0.359$, respectively) or SAV density ($p = 0.870$, $p = 0.581$ and $p = 0.897$, $p = 0.278$, capture rate and efficiency, respectively) in either experiment. Although SAV density and water depth did not significantly affect foraging success, foraging site selection by wading birds suggests that these factors may be environmental cues to foraging birds. Further analyses and data from next year's (WY2008) study on the effects of emergent vegetation on wading bird prey availability may elucidate a better understanding on environmental cues to foraging wading birds.

RAPID ASSESSMENT OF ENVIRONMENTAL CONDITIONS USING MACRO-INVERTEBRATES

The United States Fish and Wildlife Service (USFWS) has the responsibility of issuing permits for activities that affect wildlife, plants and their habitat. Of these habitats, the subtropical wetlands of South Florida are in danger of impacts from land use changes, development and other anthropogenic impacts. To assist in the permitting processes, and preserve/conserve these sensitive wetlands, the USFWS has assembled "Habitat Evaluation Teams" (HET) to develop assessment tools for detecting impact status within wetlands of South Florida. A Macroinvertebrate Working Group has been assembled to establish a macroinvertebrate rapid assessment tool in which environmental conditions of a wetland can be determined on site within a short (hours) time period. The metrics will be based on field identifiable taxa and all assessments will be made at the site. The group, which consists of scientists from the District, Florida Gulf Coast University's Water and Air Research, and the Florida Department of Environmental Protection (FDEP), has conducted several workshops to select a series of taxonomy-based metrics capable of discriminating between impaired and unimpaired wetland conditions. The District understands that much more work is needed to complete the development of this tool. This report presents SFWMD's contribution as the process continues.

There are a number of biomonitoring procedures designed to identify environmental impacts (e.g., Index of Biotic Integrity (IBI), Wetland Rapid Assessment Procedure (WRAP), Uniform Mitigation Assessment Method (UMAM), Lake Condition Index, Stream Index, etc.). Many of these apply to temperate lakes and streams and few are applicable to subtropical lakes. Assessment procedures for subtropical wetlands are lacking and may be valuable as restoration plans are put into effect. Unlike rapid assessments, most biotic assessments are quantitative, thus they require extensive field sampling and costly laboratory processing (see **Table 6-5**). Assessments based on soil, hydrology, and chemical conditions are often important for the initial characterization of wetlands. Unfortunately, using abiotic metrics alone greatly limits the ability to document crucial ecological changes. In addition, assessments based solely on vegetation type may be ideal in wetlands flooded by a degraded water source; however, episodic events such as short-term nutrient pulses may go undetected. Macroinvertebrates vary in their life history, habitat use and trophic function. These small animals can enhance our ability to distinguish between episodic events and/or long-term impacts; understanding these differences is necessary in determining ecosystem stability and sustainability.

Table 6-5. General differences between biotic indices (bio-assessments) and rapid assessments.

Bio-Monitoring Requirements	Rapid Assessment Requirements
Quantitative sampling	Qualitative sampling
Extensive lab processing *(ID all taxa to the lowest possible level)*	Field identification of taxa only
Density-dependent data	Requires presence/absence data

Methods

A list of nine taxonomy-based metrics has been generated based on ecological function or the personal experience of members of the Macroinvertebrate Working Group. Field identifiable taxa were assessed based on their presence or absence using nine taxonomy-based metrics. They were nominally classified as **Present** (1–3 per area sampled), **Common** (4–10), **Abundant** (11–100) and/or **Dominant** (> 100). The metrics used in determining environmental impact are listed below.

Taxonomy-Based Metrics

- Number of total taxa
- Percent ETO (*Ephemeroptera*, *Trichoptera* and *Odonata*)
- Percent CHO (*Coleoptera*, *Hemiptera* and *Odonata*)
- Percent *Ephemeroptera*
- Percent *Crustacea*
- Percent mollusks
- Percent air breathers
- Percent long-lived taxa
- Percent predators

During August 2007, three teams collected samples from two locations in WCA-2A using a Time Limited Qualitative sampling procedure to determine if the taxonomy-based metrics resulted in similar outcomes despite the variability associated with the patchiness of the invertebrate community and/or human error. The sampling procedure required an individual to collect and process a sample within a predetermined time period. Collections were restricted to field identifiable taxa and wetland areas that could be sampled by wading so that all habitat types could be sampled within the allotted time.

These metrics were also applied to 2004 (wet season) and 2005 (dry season) macroinvertebrate datasets to assess inter-annual variability associated with this region.

Results

Both the impaired and reference marshes yielded similar orders of taxa, although the number of species within each Order varied (**Figure 6-10**). *Coleoptera* (beetle), *Gastropoda* (mollusk), *Hemiptera* (true bugs), *Diptera* (fly), *Crustacea* (amphipod, shrimp, crayfish), *Odonata* (damselfly and dragonfly), and *Ephemeroptera* (mayfly) were common in both reference and impaired marshes. *Acariformes* (water mite) were an important component of the reference marsh assemblage. Total numbers of taxa was generally greater in the impaired marsh (**Figure 6-11**). Despite sampling variability, percent CHO (beetle index), percent ETO (mayfly index), percent *Ephemeroptera,* and percent long-lived taxa were consistently lower in the reference marsh (**Figure 6-12**). The percent predators, percent air breathers (*Apneustic* taxa), percent mollusks and percent *Crustacea* varied but also showed a similar deficit in the reference marsh.

During the wet and dry season sampling events, percent CHO, percent air breathers and percent predators were lower in the reference marsh (**Figure 6-13**). By contrast, percent ETO, percent *Ephemeroptera,* and percent *Crustacea* were all greater in the reference marsh. The percentage of mollusks was lower in the reference marsh than the impaired marsh during the wet season sampling, and reversed this trend for the dry season sampling event. The percent of long-lived taxa were only found in the impaired marsh during the wet season sampling.

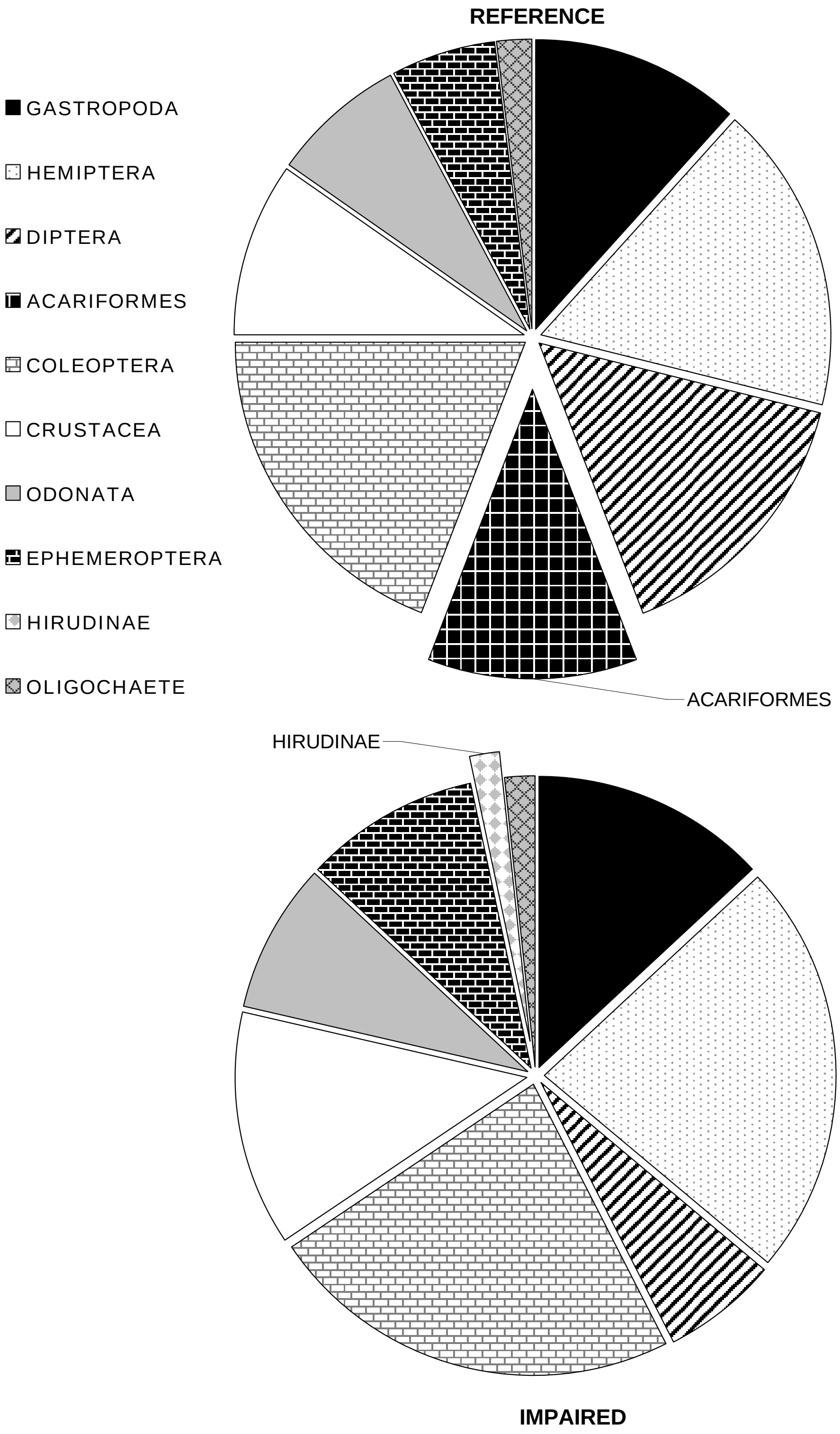


Figure 6-10. Macroinvertebrate taxonomic compositions of the reference (top) and impaired (bottom) marshes.

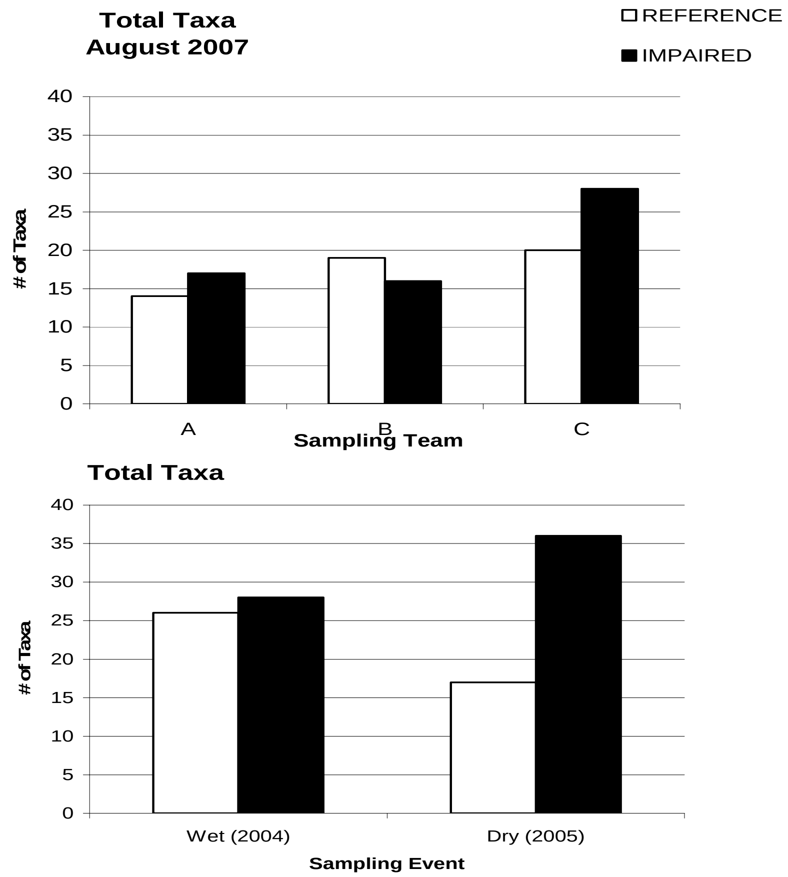


Figure 6-11. Total number of taxa in the reference and impaired marshes. Sampling teams (i.e., A, B, and C) consisted of two individuals (one member of the invertebrate working group and one person to log information onto data sheet). Samples were collected August 2007, August 2004 (wet season) and January 2005 (dry season).

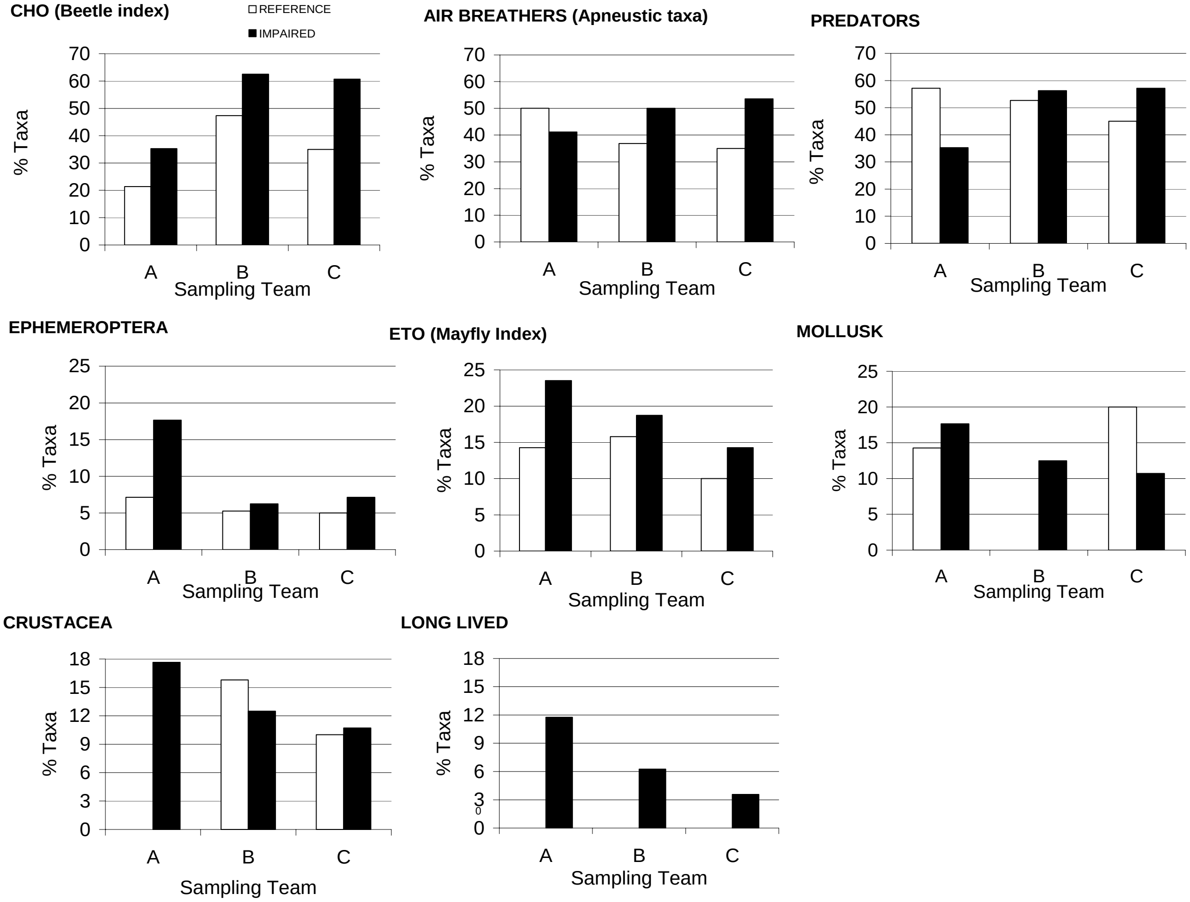


Figure 6-12. Invertebrate metrics for the rapid assessment procedure. Sampling teams (i.e., A, B, and C) consisted of two individuals (one member of the invertebrate working group and one individual to log information onto data sheet). Samples collected August 2007.

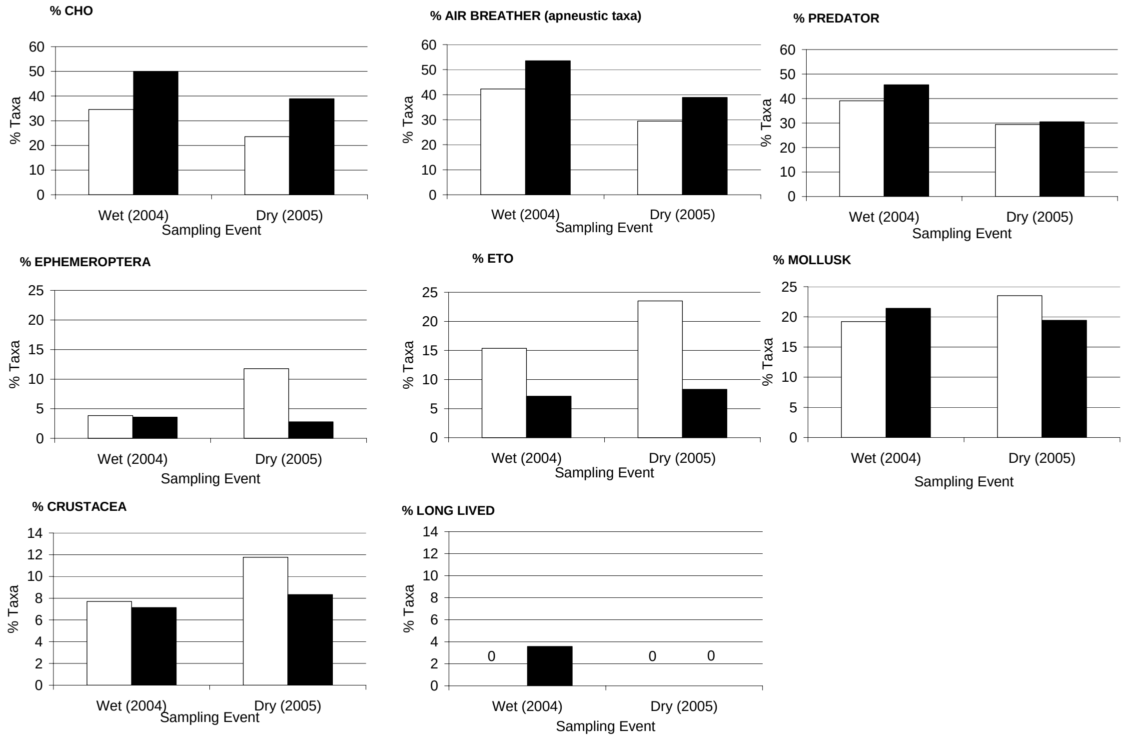


Figure 6-13. Invertebrate metrics for the rapid assessment procedure. Samples were collected during 2004 (wet season) and 2005 (dry season).

Discussion

Of the nine metrics, six expressed similar results between impaired and reference sites regardless of season. Percent ETO, percent *Ephemeroptera*, and percent *Crustacea* all expressed higher percentages in reference (or unimpaired) conditions. *Odonata*, *Trichoptera*, and *Crustacea* (particularly *Amphipoda*) have been shown to be common inhabitants of reference conditions within the WCA-2A marshes (McCormick et al., 2004). By contrast, percent CHO, percent air breathers, and percent predators exhibited greater percentages in the impaired marshes. *Coleoptera* taxa comprises a large percentage of the overall taxa composition in enriched marshes and is responsible for comprising a majority of the air breathers in this region. These factors may explain the increased influence on taxa in enriched marshes.

Total taxa and percent long-lived taxa exhibited opposite trends between seasons. Greater numbers of these metrics occurred in the impacted marsh during dry season as the water levels declined. This is not an unusual trend, as greater animal diversity generally occurs in disturbed areas. The percentage of mollusk taxa also showed opposing trends among seasons. The number of mollusk taxa decreased greatly in the impaired marsh during the dry season. This difference in taxa is likely a result of fewer taxa adaptability to withstand desiccation during rapidly falling water levels.

Generally, trends suggest that the selected metrics may be useful in clearly distinguishing impaired and reference (unimpaired) wetlands based on the presence (and number) of certain taxa. This tool is designed to identify impacted conditions in subtropical wetlands of South Florida, while its use in other subtropical wetlands requires further study.

PLANT ECOLOGY

Plant ecology studies are being conducted to understand why dominant plant species or algal communities are either disappearing or invading various Everglades habitats. This section examines the physiological, competitive, and population properties of plants for guiding water management and to understand potential risks associated with changes in regulation schedules or land-use practices. 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/slough communities. For example, processes of root oxygenation during extreme hydrologic events have been found to favor cattail growth when phosphorus concentrations in the soil and water are high. Last year's updates in the *2007 SFER – Volume I, Chapter 6*, were more focused on hydrology, with discussions on tree stress studies at the LILA Facility and tree growth dynamics in WCA-3. For WY2008, research continues to focus on hydrology, including the beginnings of a new slough competition study at LILA, preliminary tree growth results from a complex greenhouse hydrologic manipulation, and tree root dynamics from tree islands with different hydrology.

RIDGE AND SLOUGH TRANSPLANT EXPERIMENTS IN LILA

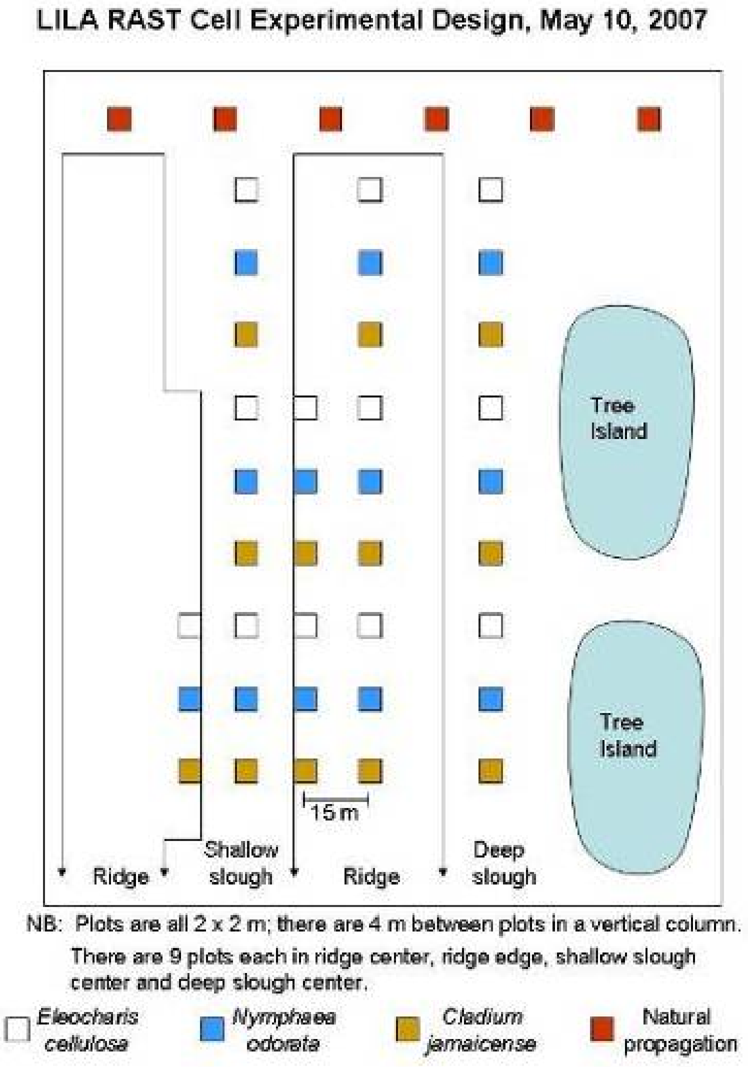
The low-relief Everglades landscape has been shaped by interactions among vegetation, hydrology, and nutrients. Plants alter rates and patterns of flow, leading to asymmetric deposition of sediments, which can affect nutrient regimes and, thus, plant growth in positive or negative feedback loops (Tooth and Nanson, 2000; Bouma et al., 2005).

The central portion of the historical Everglades was a flow-way characterized by a corrugated ridge-and-slough landscape, where ridges of sawgrass (*Cladium jamaicense*) alternated with deeper-water sloughs dominated by water lily (*Nymphea odorata*), purple bladderwort (*Utricularia purpurea*), and species of spikerush (*Eleocharis elongata* and *E. cellulosa*) (Davis and Ogden, 1994; SCT, 2003). These ridges and sloughs were elongated parallel to the direction of flow. Anthropogenic modification of this landscape, such as digging canals and building levees, has significantly modified water levels, hydroperiod, and flow with subsequent changes in landscape vegetation patterns.

Although the loss of spatial patterning has been attributed to reduced flow, experimental evidence that separates the effects of flow from those of water depth and hydroperiod are lacking, as is an understanding of how the interaction between flow and nutrients affects these processes. Thus, the experimental basis to predict whether increased flow will lead to Everglades restoration is lacking. One reason for this is that in existing field experiments it is difficult to vary flows in a way that reflects both the natural conditions and the enormous scale at which landscape-level processes occur. The experimental flow-through macrocosms established at the LILA facility provide a large-scale setting in which to perform experiments that examine these hydrological effects. Initiated in May 2007, this is a new collaborative project between the District, USEPA, and FIU. This project will analyze how flow rate and water depth interact with plant structures to build ridge-and-slough habitat.

Methodological Approach

In order to compare the effects of water depth and flow rate and to examine sedimentation, soil-building and nutrient dynamics, strips of vegetation composed of blocks of three keystone Everglades wetland species have been planted in 2 x 2 m patches (**Figure 6-14)**. These strips were planted at two depths and two flow rates in the sloughs of each cell, as well as on the interior and edge of a ridge in each cell. In each cell, an upstream portion of one ridge is built out into the adjacent shallow slough to constrict flow and thus increase water velocity in this area of the shallow slough, while the constructed tree islands constrict flow in the deep slough. This built-in variation in flow will be utilized to provide a within-cell flow velocity treatment. Additionally, two of the cells will have slow flow, while two will have higher flow, giving a between-cell difference in flow rate.


LILA RAST Cell Experimental Design, May 10, 2007

NB: Plots are all 2 x 2 m; there are 4 m between plots in a vertical column. There are 9 plots each in ridge center, ridge edge, shallow slough center and deep slough center.

☐ *Eleocharis cellulosa* 🟦 *Nymphaea odorata* 🟨 *Cladium jamaicense* 🟥 Natural propagation

Figure 6-14. Plan view of a single cell with plantings of sawgrass (*Cladium jamaicense*), spikerush (*Eleocharis cellulosa*), and water lily (*Nymphaea odorata*). P = plots for monitoring natural propagation. Species are planted in 2 x 2 m blocks of a single species, separated by 3 m.

As depicted on **Figure 6-14**, the three species planted are sawgrass (*Cladium jamaicense*), spikerush (*Eleocharis cellulosa*), and water lily (*Nymphaea odorata*). These three species have very different growth forms that could affect local flow rates and sedimentation very differently. Intermixing plantings of sawgrass, spikerush, and water lily under different flow rates and water depths, then monitoring sedimentation and soil accretion, as well as growth of each species, will help the team to understand how these species affect the landscape (i.e., function as "ecosystem engineers"). This intermixing will also determine whether the morphology of each of the different species results in local differences in flow rate and soil-building processes. The hypothesis is that species morphology alone can create ridge, slough, and wet prairie topographies through effects on sedimentation, given sufficient flow, but that the water depth-flow rate interaction determines a species' ability to grow. Additionally, comparison of direction of expansion of the plantings on the edge of the ridges to plants in the interior, as well as rates and direction of expansion around blocks of plants in the sloughs, allows us to examine species expansion versus contraction under different flow rates within a cell.

This planting configuration will allow monitoring of growth and sedimentation in a hydrologic environment that is already channelized and where each species grows in an isolated patch. Each species was just recently planted at initial densities of 1 plant/0.25 m^2. Growth will be monitored by counting the number of stems in six permanent 0.25 m^2 quadrats in each block, one on each of the four edges and two in the interior. Leaf length and number of leaves per plant will be determined for each of these quadrats. There will be no leaves in these edge quadrats initially, but these are expected to fill in over time. This design allows the team to determine whether the growth into these areas is related to direction of flow, water depth, and/or flow rate. Sediment traps will be set out upstream, downstream, and inside vegetation blocks to document rates of sedimentation. Local velocity measurements around each block will be collected in conjunction with sediment trap collections. The data will be analyzed for the effects of flow rate, water depth, and their interaction on growth and productivity of each species and results will be compared among species.

This project will utilize monitoring that is part of other ongoing research taking place at LILA, including both water-level and velocity data. Other collected data will include sediment transport and deposition; elevation change using sedimentation and erosion tables (SET) and feldspar markers; tissue, soil and water nutrient chemistry; and below- and above-ground biomass production.

Expected Results and Benefits

Hydrologic parameters are the most important—but least understood and quantified components—of wetland ecosystems. This is because of the inherent difficulty in studying and producing cause-and-effect relationships in an open system where it is hard to test a single variable at a time. The LILA facility provides the only effective tool for this type of landscape-scale testing. Therefore, results will produce some of the best guidelines for creation, restoration and management methodologies needed by water and resource managers. Expected results include:

- Plant water depth and flow tolerances and optimal hydrologic conditions for growth.
- The effects of current velocity on above- and below-ground productivity, decomposition, accretion rate (peat formation), deposition patterns and habitat mosaic.

TREE SEEDLING STRESS EXPERIMENT

The pattern and frequency of the fundamental forces driving the hydrological fluctuations that maintain the structural and functional integrity of the Everglades are being disrupted by natural events (such as hurricanes, storms, etc.), direct human intervention (management policy), and indirect human activities (agricultural runoff). District staff want to determine how much of this integrity change is due to policy and management practices, and how much of the natural integrity is likely to return if these policies and practices were to change. This is especially needed for the slough, ridge, and tree island mosaic that has been rapidly disappearing, as highlighted in previous SFERs. The experimental focus described in this section of the chapter is the influence of the frequency and intensity of hydrologic extremes on the recruitment of tree seedlings on tree islands.

Extreme hydrological fluctuations involve two extreme living conditions of contrasting nature – flooding and droughts. With intensifying El Niño-Southern Oscillation, the sequence of extreme weather events, such as severe droughts followed by prolonged flooding, or flooding followed by extreme drought, are predicted to increase and create unprecedented growing environments for plant communities in coastal wetlands. Similarly, with extensive economic growth and development, the needs for rapid flood control and water supply can make surrounding natural systems more vulnerable to hydrologic extremes.

Methods

Although ecosystem responses to extreme events should be better evaluated at multiple spatial and temporal scales using multiple attributes ranging from individual, community, and ecosystem levels (Jentsch et al., 2007), as a starting point, District staff evaluated how extreme hydrological events and their sequences will result in species-level responses, which has important implications to the structure, function, and services of the ecosystems. The responses of three co-occurring, dominant tree species with perceived differences in hydrological tolerance in a controlled greenhouse experiment were investigated. Specifically, the following questions were addressed: (1) How do species differ in their responses to constant hydrological regimes (including normal and extreme situations)? (2) Can the sequential order of drought and flood result in significant differences in species responses? Finally, (3) can a period of normal, non-extreme conditions mitigate the effects of extreme events sequence?

Three tree species – gumbo limbo (*Bursera simaruba)*, the least flood tolerant species; red maple (*Acer rubrum*), the intermediate flood tolerant species; and pond apple (*Annona glabra*), the most flood tolerant species – were selected for this study based on their tolerance to a hydrological gradient. Seeds of *A. rubrum* and *A. glabra* were collected from tree islands in the Everglades in 2003 and subsequently germinated, while the *B. simaruba* seedlings were gathered from various locations in the Everglades. All seedlings were then transplanted to 15 cm diameter by about 20 cm deep pots filled with soil collected from a disturbed tree island, because most roots of field tree island seedlings and samplings were about 10-20 cm in depth. After acclimation to the pots for several months, 156 vigorously growing, healthy seedlings of similar heights of each species (9.09 ± 1.69 cm, 18.6 ± 3.88 cm and 24.94 ± 3.21 cm for *B. simaruba*, *A. rubrum*, and *A. glabra*, respectively), a total of 468 potted seedlings, were placed into 12 plastic, 2 m × 2 m tanks (**Figure 6-15**). A closed-loop irrigation system was used to circulate water between each of the twelve tanks and the filtration reservoir. Water in the reservoir was maintained from experimental ponds having a phosphorus concentration similar to that found in the field (i.e., 10 parts per billion, or ppb).

Figure 6-15. Experimental plants of three tree species before final harvest after about one year grown in different hydrological regimes.

Five constant hydrologic treatments were achieved by manipulating the in-tank water level. The watering scheme was such that the severe flooding treatment was implemented as a prolonged water-logging situation with the soil surface of the pots constant at 10 cm under the water surface and the moderate flooding treatment had a constant water saturated condition with the water surface at the soil surface. For the optimal and two drought treatments, the retreat of flooding was simulated by raising the pots above the water surface with the extreme and moderate drought treatments receiving 30 and 60 percent of the water of the optimal water requirement, respectively. Two types of extreme disturbance sequences were created which included (1) an abrupt switching sequence of flood-to-drought versus drought-to-flood (approximate duration of four months at each phase without a transitional period between) (n = 36), and (2) a gradual switching sequence of flooding-to-optimal to drought-versus-drought to optimal-to-flooding treatment (approximate duration of four months at each disturbance phase) (n = 12) (**Figure 6-16**).

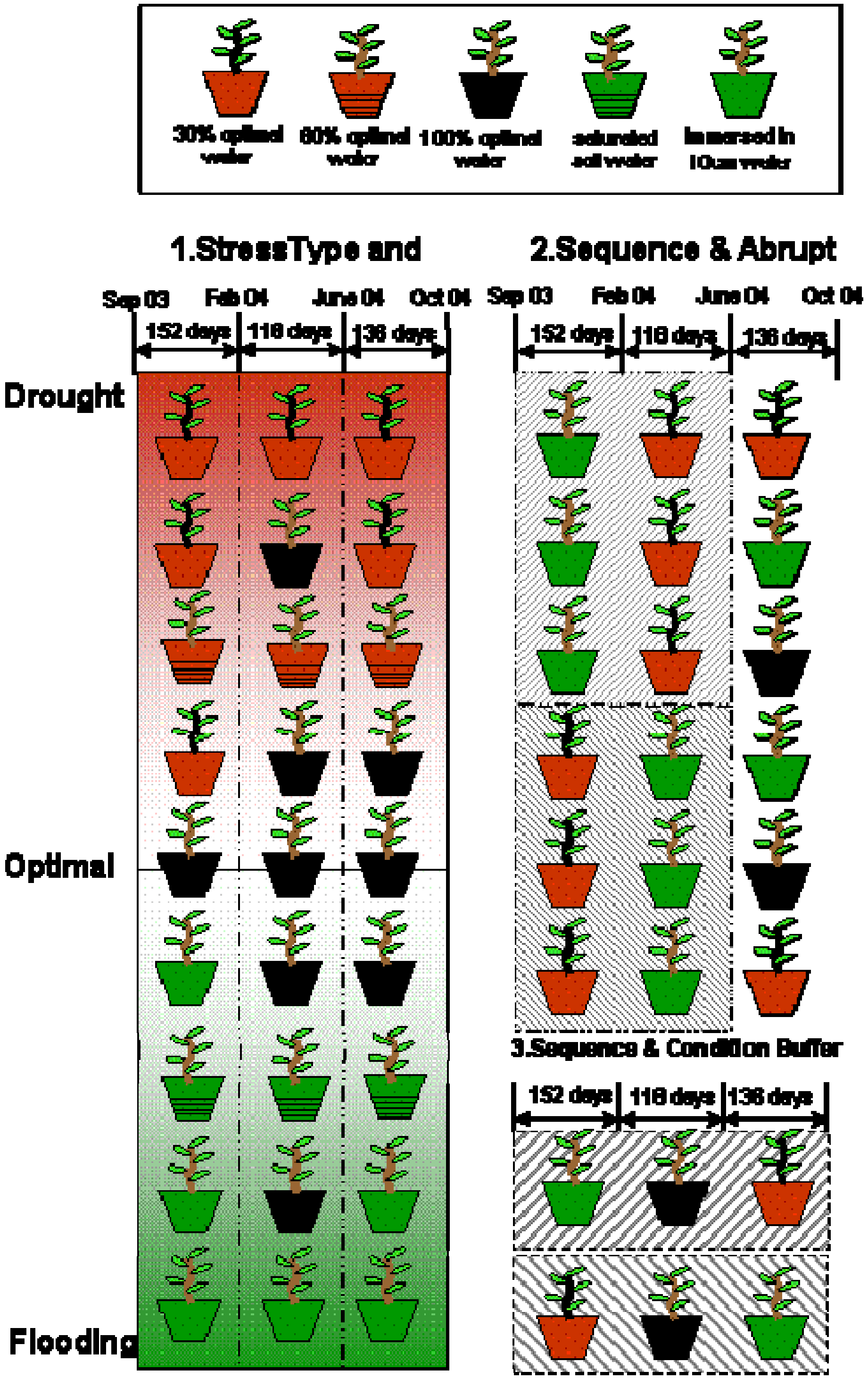


Figure 6-16. Experimental design of the effects of hydrological regimes on three tree species, including a water depth gradient from extreme drought to flooding and abrupt and smooth switches between the two extreme regimes (30 percent optimal water and immersed in 10 cm water).

Preliminary Results and Discussion

Under constant hydrological treatments, *B. simaruba*, the least flood tolerant species, had only a 42 percent survivorship under the extreme flood treatment, while it demonstrated 100 percent survivorship for other treatments (**Figure 6-17, Panel C**). The opposite was true for *A. rubrum* and *A. glabra*, the intermediate and most flood tolerant species, which showed high survivorship (75 and 100 percent, respectively) under optimal and flooding condition; however, survivorship decreased with increased drought intensity (**Figure 6-17, Panel C**). Relative height and biomass (ratios of treatment to constant optimal condition) of all three species exhibited asymmetrical bell-shaped curves with the highest growth under optimal conditions (**Figures 6-17, Panel A** and **Panel B**), declining significantly under both extreme drought and flood conditions. As expected, *B simaruba* had the lowest growth under the two flooding treatments; but surprisingly, *A. rubrum* and *A. glabra* also showed the lowest growth under the two flooding treatments.

Although further data analyses are ongoing, our preliminary results also demonstrated that the pulsed hydrological events resulted in differential responses at the species level. The final results are expected to have significant implications for ecosystem management at both regional and continental scales.

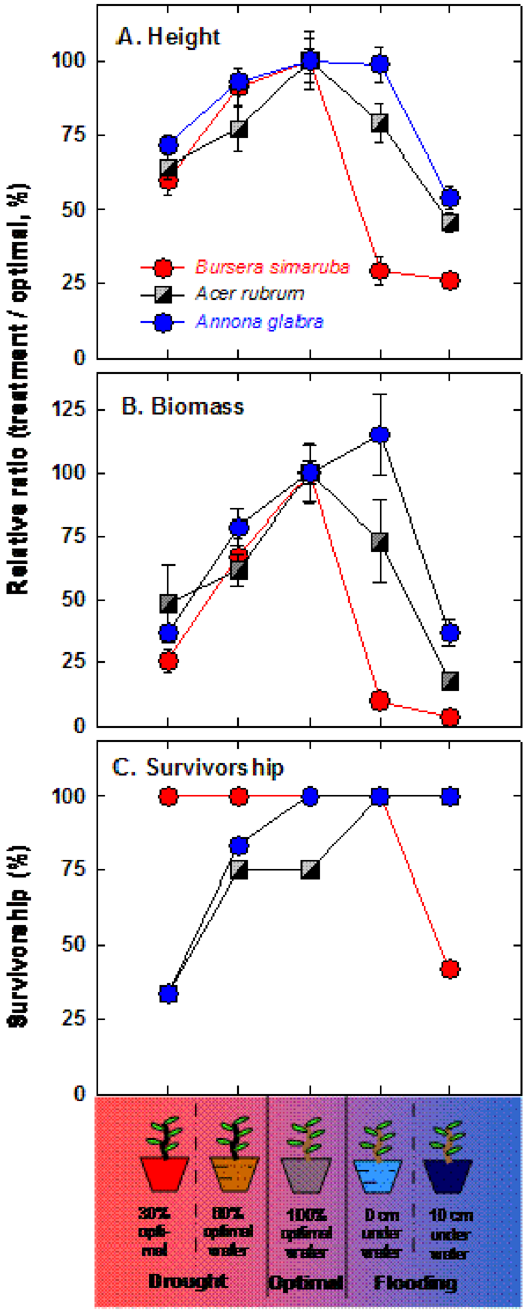


Figure 6-17. Species-specific responses to a constant hydrological gradient of an approximate duration of one year for gumbo limbo (*Bursera simaruba)*, red maple (*Acer rubrum*), and pond apple (*Annona glabra*). Relative ratios of height (A) and biomass (B) were the ratios of height and biomass growths of surviving seedlings under the experimental treatments to those under optimal conditions (4 ≤ n ≤ 12 for each treatment). Survivorship (C) was the percentage of surviving seedlings at harvest (n = 12).

TREE ISLAND ROOT EVALUATION

Understanding tree island ecology remains an integral need of water managers because the impacts associated with extensive flooding and drying over the last 60 years have eliminated 90 percent of the tree islands in WCA-2A and 60 percent of the tree islands in WCA-3 (Sklar and van der Valk, 2002). It is hypothesized that that the decrease of tree islands is directly associated with changes in hydrology, which in turn has created a disequilibrium between processes associated with both soil accretion and subsidence. The root of this disequilibrium may be the roots themselves. Emerging evidence suggests that roots, like leaves, possess suites of interrelated traits that are linked to their life spans (Eissenstat et al., 2000), productivity, and soil creation and accretion in forested wetlands (Chen and Twilley, 1999). Additional data on below-ground production and the factors controlling fine root dynamics, which includes production, decomposition, and mortality, are needed if water managers are going to understand why many islands have disappeared, how CERP can restore these forested wetlands (Baker et al., 2001), and what environmental thresholds limit long-term sustainability.

Below-ground production and biomass, both measured by fine root presence, have not yet been studied on woody species located on tree islands of the Everglades. In fact, only a few investigations have characterized below-ground productivity and processes that contribute to fine root dynamics in forested wetlands (Powel and Day, 1991; Megonigal et al., 1997; Grier et al., 1981). In forest ecosystems, fine roots are responsible for nutrients and water absorption, are associated with mycorrhizal transfer and incorporation of limiting nutrients (especially nitrogen and phosphorus), and aid in the addition of organic mater and nutrients to the soil through rapid turnover (Berish and Ewel, 1988). The amount of carbon and nitrogen cycled via fine root decomposition may be as much as or more than returned to the soil from above-ground litterfall (Majdi, 1996). It has been suggested that fine root production accounts for up to 75 percent of total net primary production in some forests (Nadelhoffer and Raich, 1992). As root production has been suggested to contribute about half of the carbon being cycled annually in many forests and 33 percent of the global annual net primary production, obtaining accurate estimates of below-ground biomass is important (Vogt et al., 1998). Indeed, the failure to include below-ground data will seriously underestimate forest ecosystem productivity (Vogt et al., 1986), resilience, and sustainability (Day and Megonigal, 1993).

The objectives of the current study were to (1) estimate fine root production across nutrient and hydrological gradients on tree islands with contrasting hydroperiods, and (2) to understand how woody species, located in poor-nutrient environments and hydrologically-stressed environments, allocate biomass, and acquire and cycle nutrients.

Field Methodology

Three tree islands were used to estimate fine root production and standing stock (3AS2, 3AS3, and 3AS5). These tree islands are indicative of the contrasting hydrological conditions found in the Everglades ecosystem. Number 3AS2 is a tropical hammock island which has a short hydroperiod (about 0 months inundation). Number 3AS3 is a cocoplum (*Chrysoblanus icaco*) dominated tree island with a moderate hydroperiod (< 6 months inundation). Number 3AS5 is an artificially flooded environment with an extended hydroperiod (> 6 months inundation) and is dominated by willow (*Salix caroliniana*).

Previously established plots are used on each of the three tree islands as part of this study. These plots (10 m x 10 m) were set up earlier in order to gather data on above-ground production as well tree species composition, size of trees, relative tree health, and growth rate of trees. A total of four plots were set up on each tree island, two on the head of the island and two on the near-tail. Over a two-year period, growth of roots into root-free soil cores was used to estimate fine root production in the field (Vogt et al., 1986; Vogt et al., 1990; Vogt et al., 1998; Gill and

Jackson, 2000; Priess et al., 1999), Sundarapandian, S.M., and Swamy, P.S. (1999)]. For this study, each plot contained 16 in-growth soil cores, set up on a grid system (4 x 4 cores). The time interval for the collection of the in-growth cores was every six months beginning at T0 after the first year. At the 12, 18, 24, and 30 month marks, a total of four in-growth cores per plot were extracted per each sampling period. At the time of in-growth core deployment, the composition of the tree/trees surrounding the core was noted, as well as the corresponding diameter breast height of the surrounding tree/trees, the tree/trees average distance from core, and water levels immediately surrounding the soil core.

To estimate standing stock mass, four soil cores were taken in each of four 10 x 10 m plots on each tree island. Soil cores were taken randomly from a theoretical grid system in each plot. The cores themselves were 10 x 20 cm maximum, extracted by a stainless steel coring device with extruder.

Preliminary Results and Discussion

The environmental conditions of tree islands chosen to carry out this study strongly indicate that islands with contrasting short/long hydroperiods, 3AS2 and 3AS3, show not only higher amounts of total phosphorus (TP) overall (low nitrogen:phosphorus ratios), but the greatest difference in TP levels between the heads and near-tails (**Figure 6-18, Panel A**). On the other hand, tree islands experiencing similar long hydroperiods (3AS5) have lower amounts of nutrients and less contrasting levels of nutrients between heads and near-tails (**Figure 6-18, Panel B**).

The spatial patterns observed in fine root production and standing stock had contrasting results. For instance, root production measured in grams per square meter in a year's time (g m^{-2} yr^{-1}) was relatively higher at the head of tree islands 3AS2 and 3AS3. In contrast, the near-tails of tree islands under study had lower root production relative to that of the head, except on tree island 3AS5 where both head and near-tail had low root production (**Figure 6-19, Panel A**). The spatial pattern of root production contrast to that of the standing stock mass (g m^{-2}) that was higher on the near-tail and lower on the head of the 3AS2 and 3AS3, with the head and near-tail of 3AS5 having the highest standing stock mass (**Figure 6-19, Panel B**).

Below-ground fine root production results indicate that that the woody plant community associated with nutrient-poor and long-hydroperiod environments produced less fine root biomass, suggesting that environmental conditions measured on the near-tails of these tree islands constrained the production of fine roots. In contrast, nutrient-rich conditions (high TP) measured on short-hydroperiod locations promoted the production of fine roots. These results suggest that environmental conditions played an important role in controlling fine-root production along the nutrient–hydrology gradient. As documented in *2005 SFER–Volume I, Chapter 6* (Sklar et al., 2005), previous results have shown that leaf production patterns are similar to that of fine root production with high leaf production on tree islands with short hydroperiods and rich-nutrient soils and low leaf production on tree islands with long hydroperiods and poor-nutrient soils. Thus, the spatial pattern of fine root and leaf fall production indicates that dominant tree species allocate more organic matter where environmental conditions are optimal, such as tree islands with relatively short hydroperiods and nutrient-rich soils.

Fine root turnover refers to the process by which roots are produced, die, and decompose. Turnover has been also defined as the ratio of annual fine root production to the belowground standing stock mass (Dahlman and Kucera, 1965; Gill and Jackson, 2000). As such, turnover rate is an indirect estimation of root decomposition. In this model, turnover rate equals annual below-ground production/below-ground standing stock mass; an annual plant would have a turnover of 1.0 yr^{-1} if all roots that it produced were to die within one year. Results from turnover rates indicate that, as with fine root production, fine root turnover values were higher on the low water depth and nutrient-rich soil environments and lower on the high water depth and nutrient-poor environments (**Figure 6-19, Panel C**).

Although these results are preliminary, they suggest that fine roots might be decomposing at lower rates on the near-tails than on the heads, where both hydrologic and nutrient conditions are more optimal. Furthermore, low turnover rates observed on the near-tail may help to explain why standing stock mass values are higher on the near-tails than those of the heads. Similarly, high standing stock mass on the near-tails might be conducive to increased soil elevation; however, due to hydrologic and nutrient-poor conditions, processes associated with root decomposition and soil subsidence may hinder the formation of new soil. In contrast, fine root production is high and roots may decompose faster on the heads where environmental conditions associated with soil formation are more suitable. Our results and those of Chen and Twilley, 1999; Jones et al., 2003; and Poret et al., 2007, suggest that soil formation on forested wetlands primarily occurs through organic matter production, both as a litterfall and fine root production/turnover, and provides new evidence for the importance of fine root production as an ecological process associated with soil formation on tree islands in the Everglades.

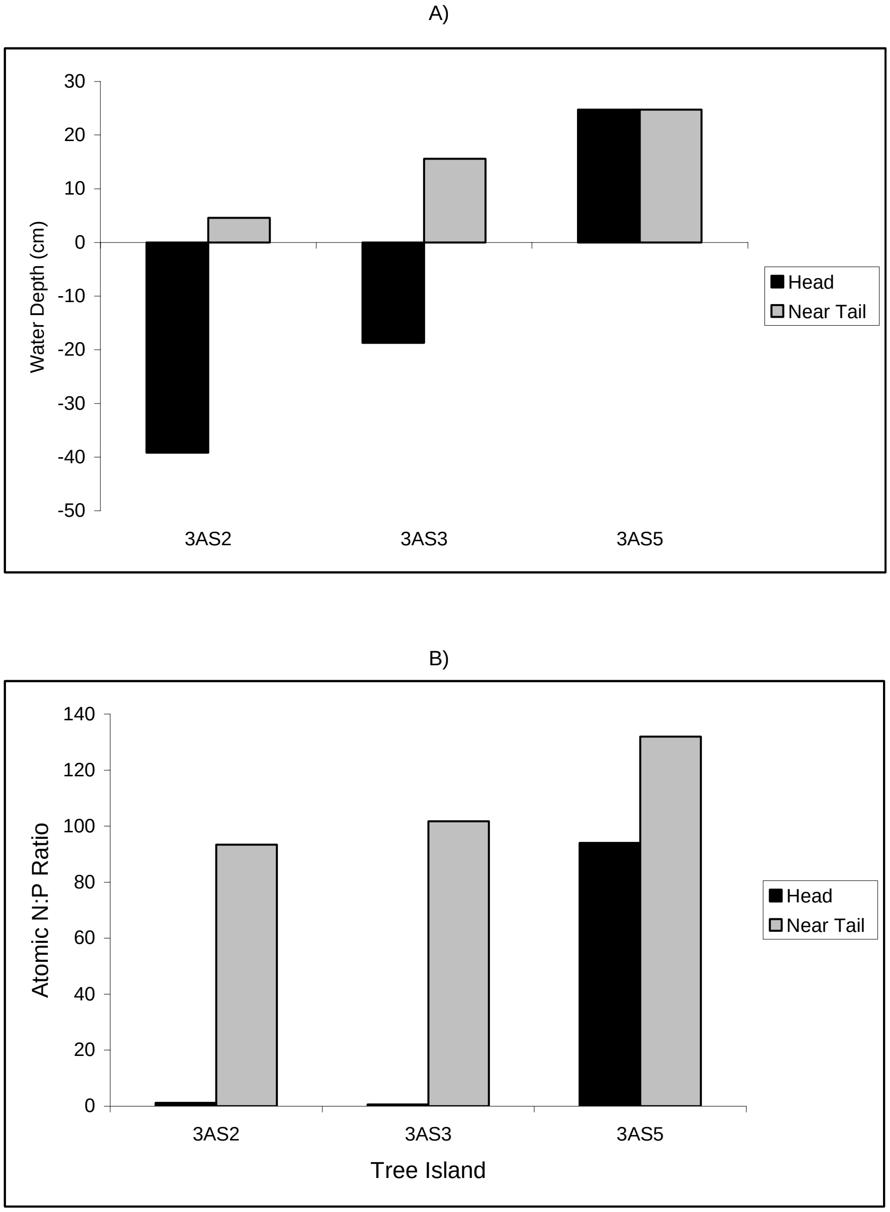


Figure 6-18. Environmental characteristics of tree islands with significantly different hydrologic regimes. (A) Average water depth (cm) on the head and near-tail. (B) Nitrogen:Phosphorus (N:P) atomic ratios measured on the head and near-tail.

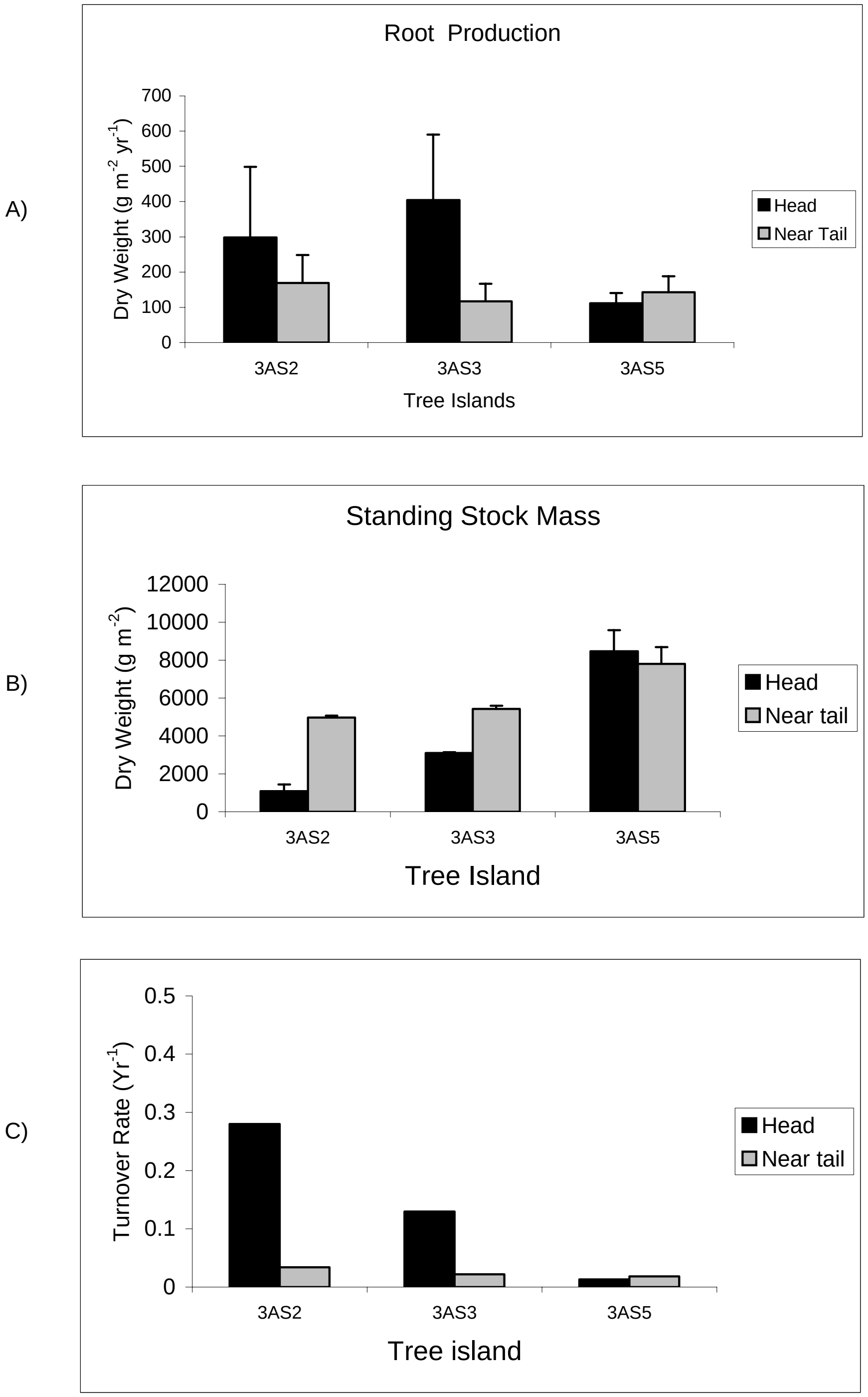


Figure 6-19. Belowground root mass on the head and near-tail of tree islands 3AS2, 3AS3, and 3AS5. (A) Spatial pattern of root production biomass (g m^{-2} yr^{-1}). (B) Spatial pattern of standing stock mass (g m^{-2}). (C) Spatial pattern of turnover rate (yr^{-1}).

ECOSYSTEM ECOLOGY

The Everglades is a mosaic of ecosystems. The ecosystem most studied by the District is the "corrugated" system of tree islands, ridges, and sloughs. The goals of ecosystem research are to identify ecotypes of special concern and focus studies on biogeochemical linkages within and among the habitats and populations within that ecotype. It is at this scale that the indirect implications of water management and restoration plans are evaluated. During WY2006, District staff looked at flume measures of sediment movement and designs for projects to accelerate the natural recovery of cattail impacted habitats in WCA-2A. This year (WY2007), the focus was on the community structure of periphyton, the phosphorus (P) dynamics of reflux, and year-one results of the projects to accelerate recovery of impacted zones.

RAPID ASSESSMENT OF EVERGLADES PERIPHYTON USING CHEMOTAXONOMY

Periphyton, comprised of algae, bacteria, fungi, and other microorganisms, is a ubiquitous component of the Everglades landscape. Periphyton is routinely utilized to assess the ecological status of the Everglades because the species that comprise periphyton are sensitive to changes in environmental conditions (McCormick and Stevenson, 1998). Long-term monitoring by SFWMD and others has established strong relationships between individual algal species and specific water quality conditions like low and high TP and salinity (Browder et al., 1994; McCormick et al., 2002; Gaiser et al., 2006; Hagerthey et al., in review). However, taxonomic identification down to species level of algae is expensive, requires highly skilled individuals, and generally has a lengthy turnaround time (6 months to 1 year). These limitations significantly reduce the utility of periphyton to assess ecological conditions rapidly and quickly detect changes within the Everglades.

On a much broader taxonomic level, phylogenetic groups of algae also appear to be loosely associated with environmental conditions. For example, cyanobacteria (blue-green algae) are abundant in nutrient-poor, slightly alkaline environments like the ENP and chlorophytes (green algae) are common in nutrient-poor, slightly acidic environments like WCA-1. This suggests that periphyton methods other than identification to lowest taxonomic unit (species) might be used to rapidly assess ecological conditions. Chemotaxonomy is commonly used to assess algal composition in marine, estuarine, and freshwater ecosystems. The method is based on the principle that different groups of algae have unique and diagnostic chlorophyll and carotenoid pigments that can be used to assess biomass and phylogenetic composition (Millie et al., 1993). These principles have been used to assess phytoplankton and periphyton composition in freshwater ecosystems of South Florida (Winfree et al., 1997; Steinman et al., 1998; Havens et al., 1999). Since pigments can easily be extracted from algae using chemical solvents then quantified on a variety of instruments (e.g., high performance liquid chromatography), chemotaxonomy may be a rapid, low-cost method to assess the biological conditions within the Everglades.

The District is currently in year one of a three-year study to perform a chemotaxonomic analysis of periphyton samples collected in conjunction with two system-wide biological monitoring programs. One primary objective for the study is to develop a mechanism to rapidly assess ecological conditions using the phylogenetic composition. That is, can the relative abundance of cyanobacteria, diatoms, chlorophytes (green alage), and cryptophytes in periphyton be used to ascertain the environmental conditions (e.g., nutrient status, mineral status, oxygen status) in the location the sample came from? In this section, a brief overview of an assessment method that utilizes classification regression tree analysis (CART) of phylogenetic groups of algae collected from periphytometers to estimate six water quality parameters is presented.

Methods

Chemotaxonomic analyses were performed by Dr. J. William Louda and Panne Mongkronsri at the Department of Chemistry and Biochemistry, FAU. Periphytometers are artificial substrates which are comprised of glass microscope slides suspended vertically at the air-water interface. A total of 279 periphytometers were deployed and collected within WCA-1, WCA-2A, WCA-3A, WCA-3B, and the ENP between 2004 and 2006. Samples were stored frozen (-80° C). Extraction methodology of periphyton pigments and chemotaxonomic assessment followed Hagerthey et al. (2006). Briefly, periphyton was freeze-dried and pigments extracted using the methanol/acetone/dimethylformamide (MAD) solvent. This method is a significant improvement over conventional pigment extraction methods, for example, 90 percent acetone (Hagerthey et al., 2006). Separation and identification of pigments was by reverse-phase HPLC and photodiode array detection (PDA). Proportional estimates of cyanobacteria, green algae, diatoms, dinoflagellates, and cryptophytes were made using the equation specific to the Everglades:

$$\sum Chla = [1.1(zea - ech) + 11(ech)] + [3.2(chlb)] + [1.2(fuco)] + [1.5(peri)] + [3.8(allo)]$$

where: chl a is derived from cyanobacteria marker pigments zea and echinenone (ech), the green algal pigment chl b (chlb), the diatom pigment fucoxanthin (fuco), the dinoflagellate pigment peridinin (peri), and the cryptophyte pigment alloxanthin (allo). Regression coefficients were derived from diagnostic pigment/Chl a ratios obtained from regional field and laboratory data studies of representative taxa (> 30) conducted by J. W. Louda. Taxonomic analysis of long-term datasets was also used in the development of the equation. Recently, it was demonstrated that the accuracy of chemotaxonomic assessment may be more dependent on the extraction method then pigment/chl a ratios, especially for mix assemblages like those found in the Everglades (Hagerthey et al., 2006). Nonetheless, this Everglades-specific equation has been derived to compare the relative differences in periphyton phylogenetic compositions collected from a variety of environmental conditions.

CART was used to predict water quality conditions: total phosphorus (TP), total Kjeldhahl nitrogen (TKN), which is organic nitrogen plus ammonia, pH (a standard measure of acidity), temperature, specific conductance, and dissolved oxygen (DO) from periphytometer periphyton composition. Paired water-quality data was available for 245 of the periphytometer samples. CART provides a classification/regression tree through recursive partitioning that can be used to predict water quality based on the relative abundance of different algal groups (McCune and Grace, 2002).

Results

In general, algal biomass for the 245 periphytometer samples ranged from 0.01 to 10.9 μg chl *a* cm^{-2}. Pigment composition varied widely among the samples. Pigments associated with ultraviolet (UV) protection (scytonemin) and bacteria chlorophylls were sometimes present in addition to the common algal pigments. Algal composition also varied greatly with some, albeit relatively few, samples comprised entirely of cyanobacteria (n = 3), green algae (n = 1), or diatoms (n = 1). Dinoflagellates and crypotophytes were identified in 7 and 22 percent of the samples, respectively. Their relative abundance was typically less than 10 percent.

Six regression trees were developed to estimate TP, TKN, and DO, pH, temperature, specific conductance, and dissolved oxygen using the relative abundance of the five phylogenetic groups of algae. Regression trees are analogous to dichotomous keys. For example, the regression tree for pH is shown in **Figure 6-20**. If the relative abundance of green algae is > 33.5, the user is directed to the left branch were the next decision is based on the proportion of diatoms. If diatoms comprise more than 14.5 percent, the user is directed to the right branch with a terminal node representing a pH of 7.3 ± 0.3 (mean ± standard deviation). Individually, the amount of variation explained within a tree was low (TP = 23.2 percent; TKN = 32.1 percent, DO = 41.7 percent, pH = 38.0 percent, temperature = 38.9 percent), but when viewed collectively, estimates of individual water quality parameters provides insight into the general environmental conditions at the time the periphyton sample was collected.

Figure 6-21 shows the average compositional makeup of algal assemblages along the nutrient gradient in WCA-2A (**Panel A**) and the temporal pattern at site Y4 in WCA-1 (**Panel B**) and site South Meso in WCA-3A (**Panel C**). The ecological assessment inferred from the CART analysis is provided in **Table 6-6,** along with the measured and predicted water quality. For these three examples, the chemotaxonomic-based ecological assessment matched the average conditions along the nutrient gradient and the temporal variability at the South Meso site. However, assessments differed slightly for individual samples from site Y4 in WCA-1. Site Y4 lies within a transition zone that experiences sudden changes in salinity due to canal water intrusion that can significantly alter periphyton composition (Hagerthey et al., in review); thus, the differences may be due to periphyton integrating the "true" environmental conditions over the period of deployment (~60 days) whereas water quality is represented by only one or two data points. In contrast, consistent results were obtained for the South Meso site located in the center of WCA-3A presumably because water quality is less variable. The lack of correspondence between measured and predicted conditions for this site should not be viewed as a poor model fit, but instead should be viewed as a "site of concern". Traditional taxonomic analysis should then be conducted to derive the final ecological assessment.

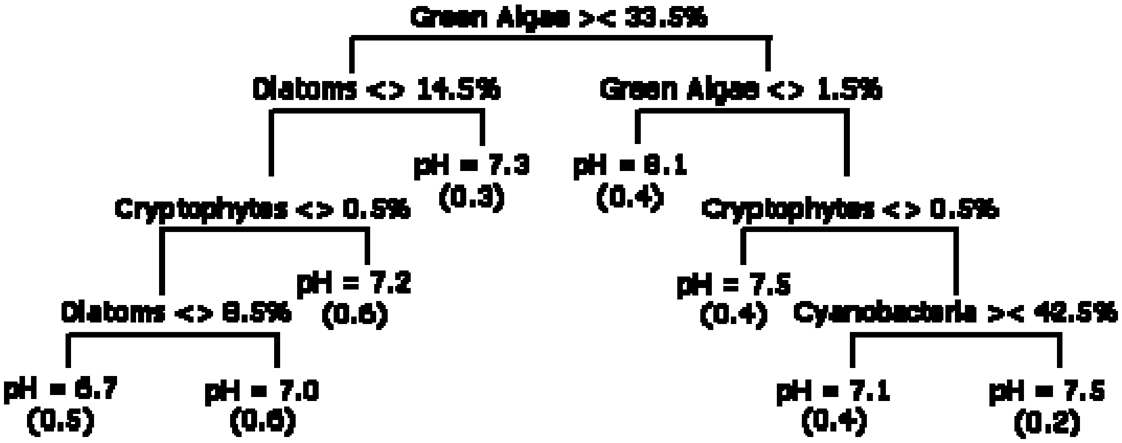


Figure 6-20. Example of a regression tree used to estimate pH using the relative abundance of different algal groups.

Conclusions

Chemotaxonomy provides a rapid, less expensive means to assess biological conditions within the Everglades. The six regression trees were developed to predict water quality from phylogenetic groups of algae on periphytometers. Initial indications are that, when used in combination, chemotaxonomy and regression trees provide a rapid gross assessment of ecological conditions. These models will be verified over the next two years by comparing predicted water quality with independently collected water samples. In addition, we are currently evaluating an alternative method (CHEMTAX; Mackey et al., 1996) for improving the accuracy of the phylogenetic estimates. The CHEMTAX data matrix will be developed from paired analysis of taxonomic information with chemotaxonomic data along with ongoing studies of pigment/chl a ratios determination for the dominant Everglades taxa and how ratios may vary within a taxa in response to environmental variability (e.g., light and nutrients). We will also develop a regression tree analysis to predict periphyton nutrient content from periphyton grab samples. This metric may be a more accurate assessment of environmental conditions since periphyton nutrient content is a better indication of nutrient conditions of a longer time period (Gaiser et al., 2004). Finally, the District will evaluate the UV-protecting pigment, scytonemin, as an indicator of hydrologic conditions.

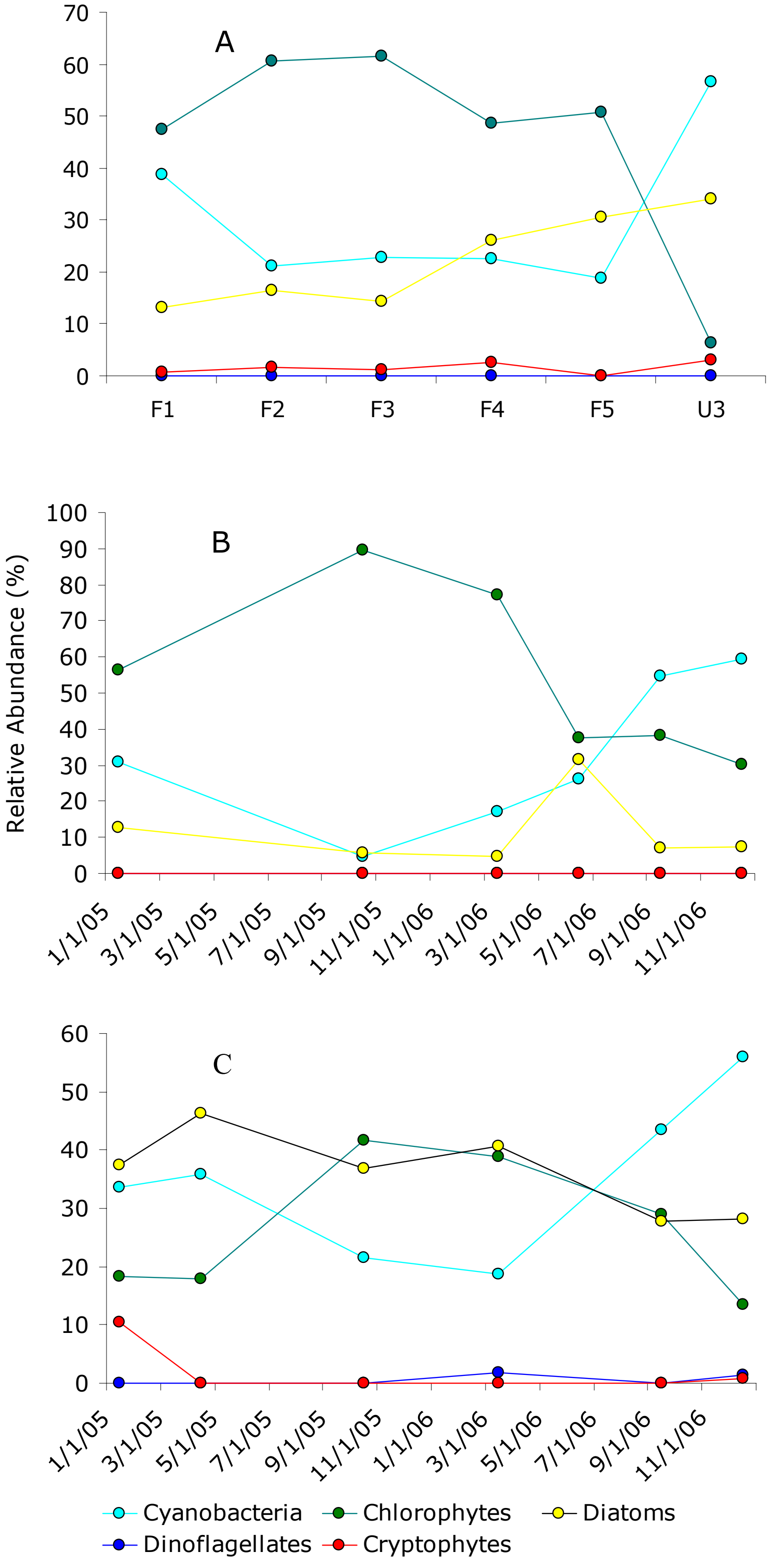


Figure 6-21. Relative abundance of major algal groups along a nutrient gradient in WCA-2A (A), time-series at site Y4 in WCA-1 (B), and time-series at site South Meso in WCA-3A (C).

Table 6-6. Comparison of measured (M) and predicted (P) total phosphorus (µg TP L^{-1}), total Kjeldhahl nitrogen (mg TKN L^{-1}), dissolved oxygen (mg DO L^{-1}), pH, and specific conductance (µS cm^{-1}) for sites along a nutrient gradient in WCA-2A and time-series at sites Y4 in WCA-1 and South Meso WCA-3A. Predicted values were derived from CART analysis of chemotaxonomically derived phylogenetic groups. Ecological assessments were based on the collective interpretation of water quality parameters. Bold text indicates differences in predicted and measured ecological assessments.

		TP	TKN	DO	pH	Cond.	Ecological Assessment
Nutrient Gradient WCA-2A							
F1	M	30	2.3	0.8	7.4	1312	eutrophic- alkaline- mineral rich
	P	17	1.7	2.5	7.2	656	mesotrophic- alkaline- mineral rich
F2	M	24	2.3	0.5	7.1	1029	eutrophic- alkaline- mineral rich
	P	20	1.7	1.9	7.3	734	eutrophic- alkaline- mineral rich
F3	M	16	2.2	1.3	7.4	1200	mesotrophic- alkaline- mineral rich
	P	17	2.0	2.7	7.3	840	mesotrophic- alkaline- mineral rich
F4	M	14	2.0	0.8	7.6	896	mesotrophic- alkaline- mineral rich
	P	12	1.6	2.5	7.2	527	mesotrophic- alkaline- mineral rich
F5	M	10	2.0	4.6	7.6	872	oligotrophic- alkaline- mineral rich
	P	11	1.5	4.1	7.2	695	oligotrophic- alkaline- mineral rich
U3	M	8	2.2	4.8	7.8	921	oligotrophic- alkaline- mineral rich
	P	9	1.6	4.9	7.5	662	oligotrophic- alkaline- mineral rich
WCA-1 (Y4)							
1/6/05	M	6	1.1	4.2	6.6	137	oligotrophic- acidic- mineral poor
	P	12	1.5	1.9	7.0	535	**mesotrophic- neutral- mineral rich**
10/19/05	M	10	0.5	4.1	6.4	118	oligotrophic- acidic- mineral poor
	P	12	0.9	3.8	6.7	273	**mesotrophic- acidic- mineral poor**
3/30/06	M	4	1.2	6.3	6.9	207	oligotrophic- acidic- mineral poor
	P	12	0.9	5.6	6.7	273	**mesotrophic- acidic- mineral poor**
6/15/06	M	13	1.5	3.5	6.7	180	mesotrophic- acidic- mineral poor
	P	10	2.0	3.1	7.3	474	**oligotrophic- alkaline- mineral rich**
9/21/06	M	8	0.6	1.7	6.1	103	oligotrophic- alkaline- mineral rich
	P	15	0.9	3.8	6.7	360	**mesotrophic- acidic- mineral poor**
12/12/06	M	8	0.9	2.1	6.3	128	oligotrophic- acidic- mineral poor
	P	15	0.9	2.4	7.4	360	**mesotrophic- neutral- mineral rich**
WCA-3A (South Mesocosm)							
1/6/05	M	4	1.1	2.7	7.2	322	oligotrophic- alkaline- mineral rich
	P	10	2.1	4.5	7.4	571	oligotrophic- alkaline- mineral rich
4/7/05	M	6	1.6	3.9	7.3	360	oligotrophic- alkaline- mineral rich
	P	10	1.2	4.5	7.5	571	oligotrophic- alkaline- mineral rich
10/19/05	M	4	0.6	1.0	7.0	302	oligotrophic- alkaline- mineral rich
	P	10	1.2	2.5	7.3	571	oligotrophic- alkaline- mineral rich
3/20/06	M	4	1.5	7.5	7.6	409	oligotrophic- alkaline- mineral rich
	P	10	1.8	5.6	7.3	571	oligotrophic- alkaline- mineral rich
9/21/06	M	8	1.0	1.9	7.0	334	oligotrophic- alkaline- mineral rich
	P	10	1.0	2.4	7.5	474	oligotrophic- alkaline- mineral rich
12/12/06	M	8	1.9	4.8	7.3	385	oligotrophic- alkaline- mineral rich
	P	10	1.8	4.7	7.4	474	oligotrophic- alkaline- mineral rich

EVALUATING PHOSPHORUS FLUX

It has been argued that even very low total phosphorus (TP) concentrations in the overlying waters of the Everglades will not prevent cattail from spreading because chemical equilibrium dynamics will cause legacy phosphorus to move out of the soil, into the water column, and degrade downstream habitats (Reddy et al., 1999a, b; Fisher and Reddy, 2001). The movement of TP out of the soil under these conditions is referred to as reflux. 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 2008. The principal objectives of the Reflux Study are to (1) quantify *in situ* sediment phosphorus flux rates to the water column in an impacted area of WCA-2A, (2) use field enclosures to evaluate management practices to immobilize phosphorus in the sediment, and (3) use a dynamic model to simulate sediment phosphorus flux under different management scenarios (Kent, 2007). All these objectives are related to the Long-Term Plan mandate for improving wetland regions considered to be impacted by excess phosphorus.

Methods

The Reflux Study is located within the northern, cattail region of WCA-2A, which is a large (42,706 hectacre), shallow, diked impoundment, characterized by marsh, slough, and tree islands. Cattail (*Typha domingensis*) occupies about 8,100 hectacres of northeast WCA-2A (Davis and Ogden, 1994). Experimental enclosures (1.5 m in diameter and 1.5 m tall) were installed in WCA-2A, south of the S-10 structures **(Figure 6-22)**.

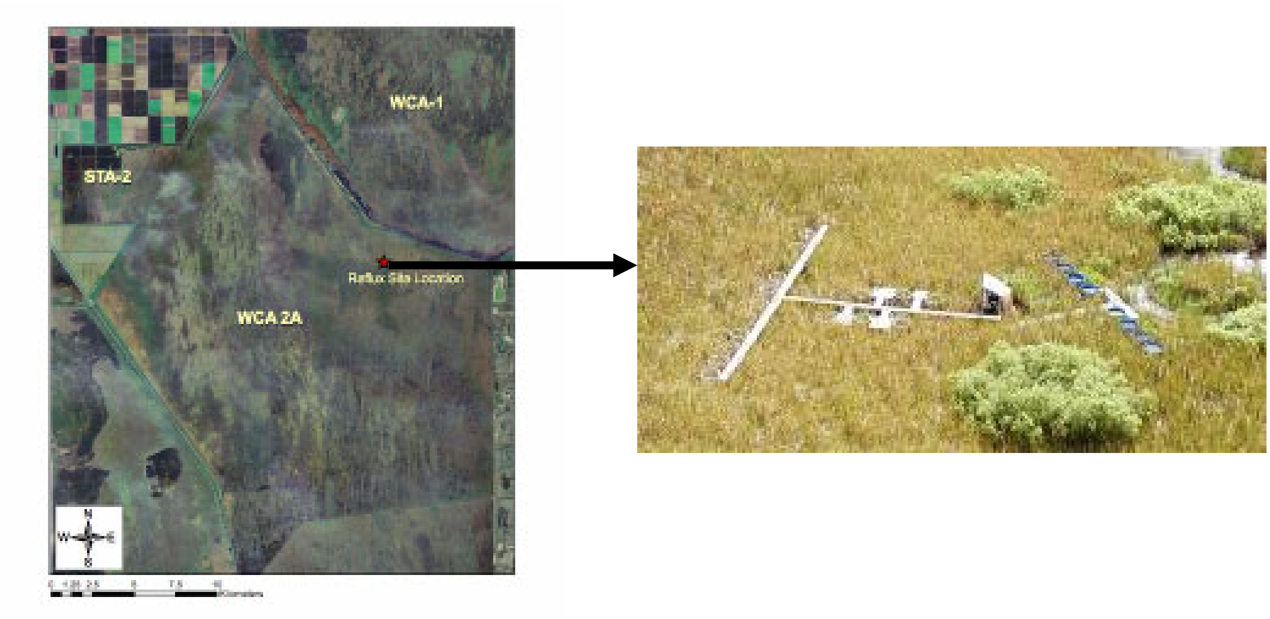


Figure 6-22. Location map and photo of the experiment enclosures at WCA-2A, south of the S-10 structures.

Significant Results

PHOSPHORUS FLUX RATES

Phosphorus Concentrations: Three control and three treatment enclosures had inflow from ambient water with a TP concentration of 47 + 3 µg/L from August 12–24, 2005 **(Figures 6-23** and **6-24)**. The outflow TP concentration during this period was 53 + 8 µg/L for both the control and treatment enclosures.

Beginning September 23, 2005, SAV-treated water was introduced to the treatment enclosures. The average SAV water TP concentration through October 18, 2006, was 21 + 7 µg/L, significantly less than the 56 + 54 µg/L water provided to the control enclosures. There was no significant difference between average control (65 + 39 µg/L) and treatment (54 + 44 µg/L) outflow TP concentrations, despite significantly lower treatment inflow concentrations. This suggests that the treatment enclosures are exporting phosphorus.

In contrast to the control, the average treatment outflow TP concentration (54 + 44 µg/L) was significantly greater than inflow concentration (23 + 10 µg/L) **(Figure 6-24)**. One conclusion is that porewater soluble reactive phosphorus (SRP) is released to the water column from the sediments and largely converted to dissolved organic phosphorus (DOP) and particulate phosphorus (PP) through biotic cycling. The alternative, degradation of enclosure biota and concomitant release of phosphorus, was not observed, but cannot be eliminated as a factor.

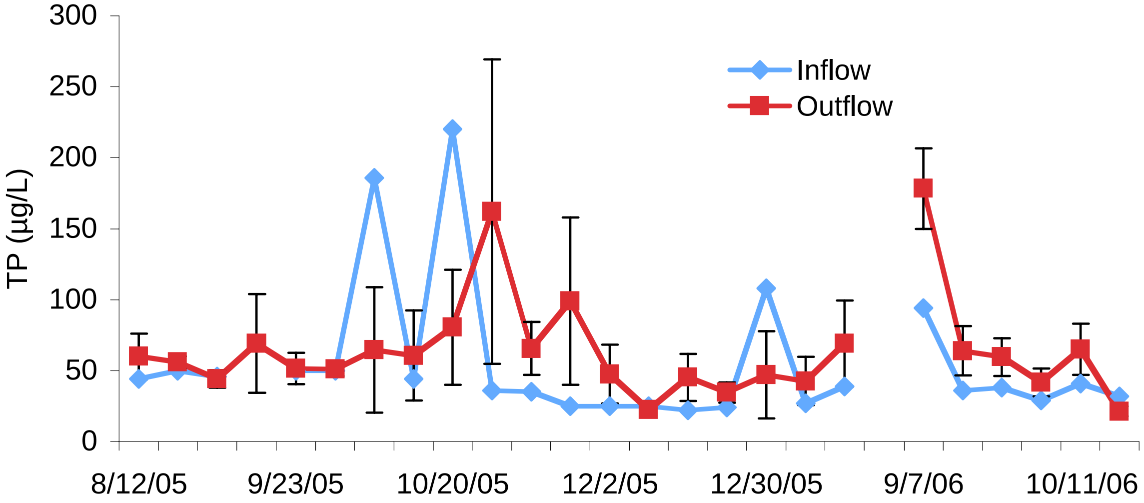


Figure 6-23. Control inflow and outflow TP concentrations for enclosures in an impacted area of WCA-2A.

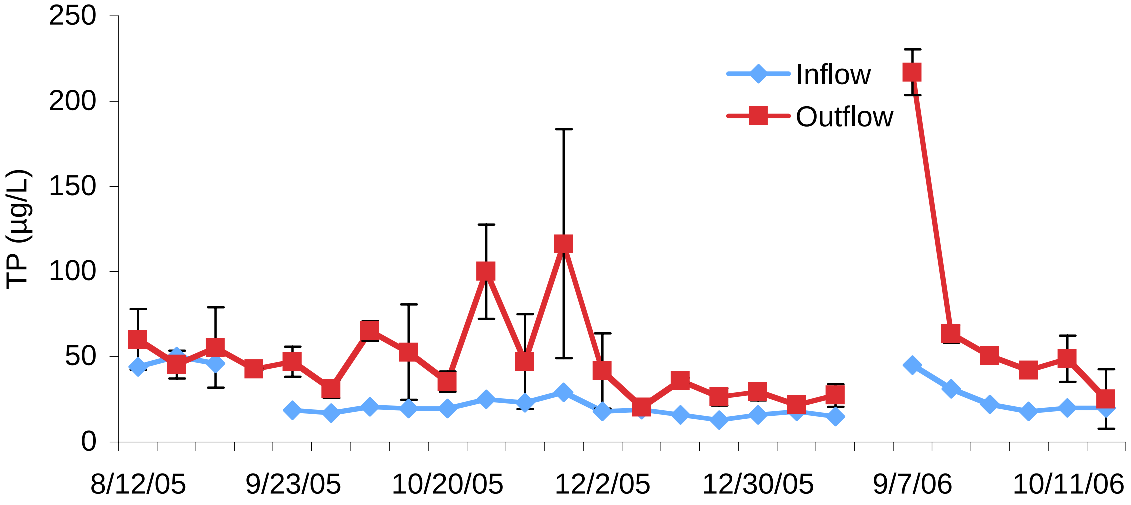


Figure 6-24. Treatment inflow and outflow TP concentrations for enclosures in an impacted area of WCA-2A.

Porewater Equilibrator Flux Measurement: Seven porewater equilibrators were deployed in the six flux measurement enclosures from August 9–23, 2005 (prior to the introduction of SAV treated water in to the treatment enclosures). Surface water TP at the site averaged 47 + 5 µg/L during the sampling period. Overlying water SRP in the equilibrators ranged from 46 to 60 µg/L.

Porewater SRP increased with depth, ranging from 104 µg/L at 1 cm depth to 479 µg/L at 13 cm depth **(Figure 6-25)**. The average flux rate was low, 0.05 + 0.11 mg SRP/m^2/day (milligrams of SRP per square meter per day). By comparison, Fisher and Reddy's (2001) porewater equilibrator flux measurements at a site about 0.5 km to the west ranged from 0.08 to 0.29 mg P/m^2/day. The flux rates were similar in enclosures designated for control and treatment.

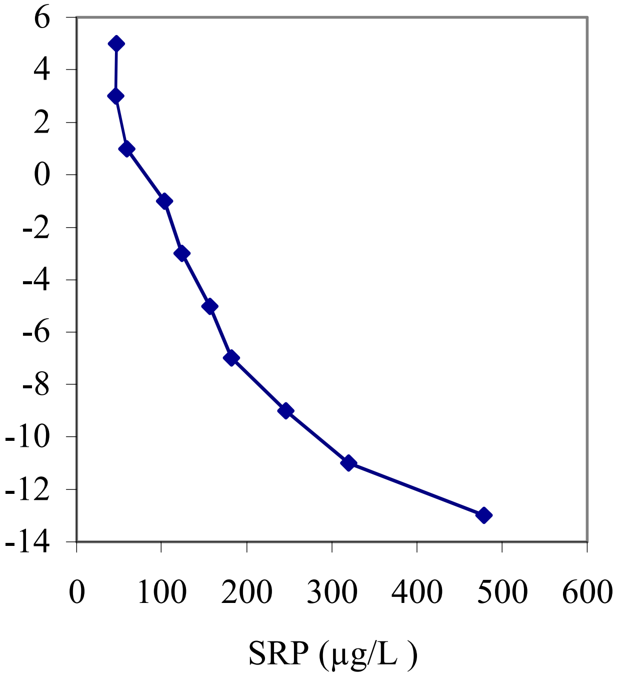


Figure 6-25. Average (n = 7) surface water and porewater soluble reactive phosphorus (SRP) concentrations in porewater equilibrator chambers in enclosures in an impacted area of WCA-2A.

MANAGEMENT PRACTICES EVALUATION

Nine enclosures were installed at the field site in February and March 2006, and plumbed in July 2006 for evaluating cattail management alternatives which include herbicide and SAV establishment. All of the enclosures received SAV-treated water. Three of the enclosures served as controls. The other six enclosures were treated with herbicide (Rodeo® [glyphosate]) on October 4, 2006. Three of the six enclosures treated with herbicide were inoculated with coontail (*Ceratophyllum demersum*).

Pre-treatment surface water samples were collected for the nine enclosures on six occasions between September 7 and October 18, 2006. The SAV mesocosms significantly reduced ambient TP an average of 14 µg/L (40 + 18 µg/L to 26 + 10 µg/L). The reduction in TP was the result of significant DOP removal and apparent SRP removal. Relatively low ambient water phosphorus concentrations (40 + 18 µg/L) likely limited removal by the SAV mesocosms.

Enclosure outflow TP was comparable among control (63 + 43 µg/L) and treatment (60 + 53 µg/L) enclosures through October 4, 2006. Herbicide was applied to the six treatment enclosures after water quality measurements were completed on October 4, 2006. Thereafter, TP was apparently greater in the treatment outflow (124 + 21 µg/L) than in the control outflow (49 + 13 µg/L, **Figure 6-26**). The increased TP in treatment enclosures was apparently due to an herbicide-induced release of DOP.

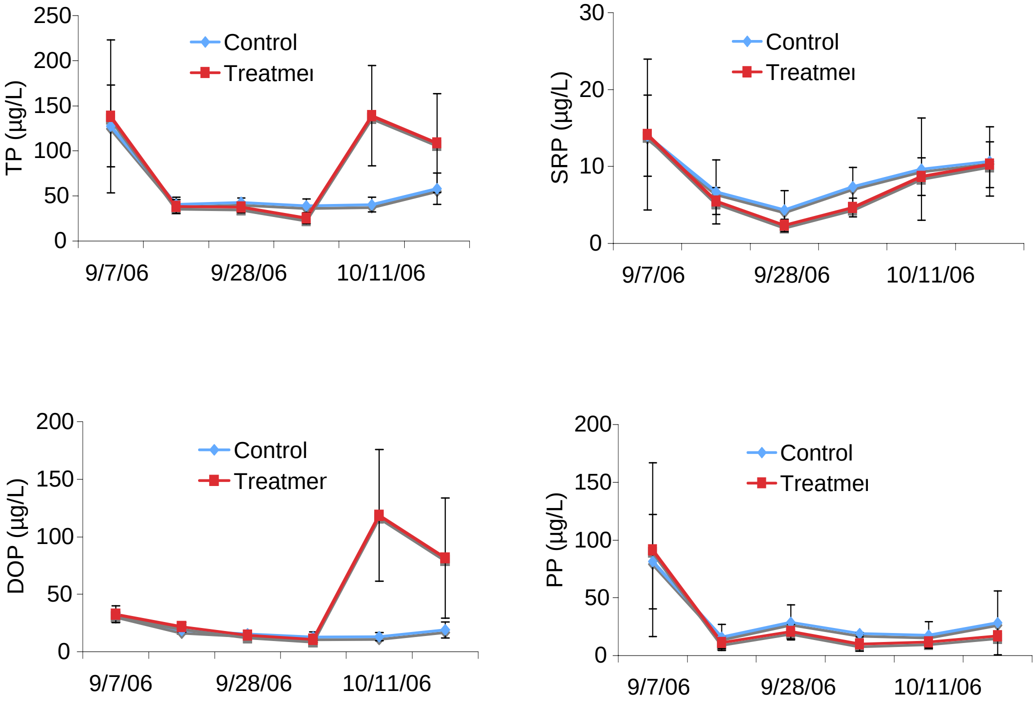


Figure 6-26. Control and treatment outflow total phosphorus (TP), soluble reactive phosphorus, (SRP), dissolved organic phosphorus (DOP), and particulate phosphorus (PP) concentrations for enclosures in an enriched area of WCA-2A.

Discussion

In addition to inflow, porewater is another source of phosphorus to the water column in the highly impacted area of WCA-2A. This was demonstrated by the measurements of outflow TP in the enclosures receiving SAV-treated water and direct porewater phosphorus flux. Recovery of the cattail-dominated area will not be likely until both sources are significantly reduced. Because STAs will only lower the inflow TP concentration, recovery will not be achieved until the trend of sediment-water column flux is reversed. More research is needed to understand the rates and mechanisms determining the phosphorus flux from porewater to surface water. The results of the current study also suggest that methods which aim to prevent or reduce porewater TP flux are required to accelerate the restoration process.

Removal of cattail via herbicide or fire has been tested as a management tool to accelerate the recovery process in the Everglades. This approach may create conditions (i.e., more light penetration and growth space) that favor reestablishing historic periphyton communities. This study reveals increases in water column TP after herbicide was applied to cattail in short time scales. However, the duration of high TP concentration and timeline for periphyton appearance remain unknown. More studies are needed to understand these processes, which will help the restoration of the impacted Everglades.

ACCELERATED RECOVERY OF IMPACTED AREAS

The Fire Project is part of the Acceler8 research component of the Long-Term Plan and is designed to evaluate fire as a tool for accelerated recovery of the WCA-2A impacted zone, where decades of phosphorus enrichment resulted in a species shift from sawgrass (*Cladium jamaicense*) to cattail (*Typha domingensis*). Fire is a natural phenomenon in the Everglades and may have important impacts on phosphorus cycling and storage. The objectives of the Fire Project are to encourage a species shift back to sawgrass and accelerate the burial of high-phosphorus-content peat such that it is below the active root zone and inaccessible for plant uptake.

There are two main questions driving the ongoing Fire Project study: (1) will multiple fires cause a shift in the dominant vegetation from mono-specific cattail stands to a more native mixture of cattail and sawgrass? and (2) will multiple fires increase soil phosphorus sequestration? The first question addresses the hypothesis that multiple fires may cause cattail to decline since it is less fire adapted than sawgrass. The second question addresses the hypothesis that as phosphorus loading to the area is reduced, newly generated low-phosphorus-content peat may accumulate on top of the high-phosphorus-content peat and eventually bury the high-phosphorus-content peat below the active root zone, sequestering the phosphorus. Fire may accelerate peat burial through pulsed events that convert biomass to detritus.

In the summer 2005, six experimental plots (that are currently studied) were established in a Before-After-Control-Impact-Paired Series (BACIPS) design, with paired plots that follow the soil phosphorus gradient in northern WCA-2A (**Figure 6-27**). Treatment sites are paired with control sites in the highly-enriched sites (cattail dominated), and moderately-enriched sites (cattail/sawgrass mix). The treatment plots are burned periodically while the control sites are not. There are also two reference sites in the un-enriched area, one dominated by sawgrass and the other a mix of sawgrass and cattail. Each plot is 300 x 300 m and has upstream, within plot, and downstream sampling stations.

Many sub-studies have been initiated under the Fire Project to capture the many ecosystem processes that may be impacted by fire. They fall under the broad categories of water quality, soil and vegetation nutrient biogeochemistry, plant biomass production and storage, plant species dynamics, and ecosystem modeling.

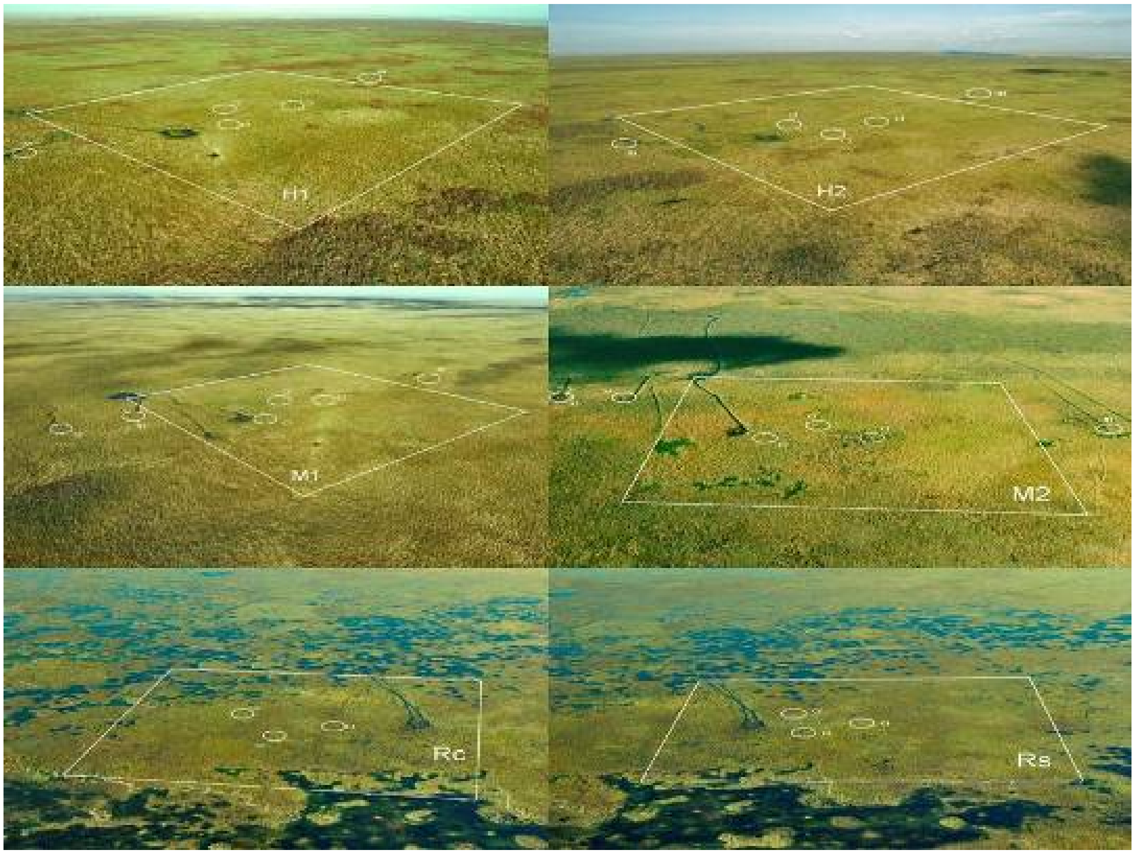


Figure 6-27. Six experimental plots in WCA-2A (photos by J. Godin, SFWMD).
H1 – highly enriched/unburned; H2 – highly enriched/burned;
M1 – moderately enriched/ unburned; M2 – moderately enriched/burned;
RC – reference cattail; RS – reference sawgrass.

Project Milestones

The first of the Fire Project's multiple fires occurred in 2006. A wildfire occurred at the moderately enriched, mixed sawgrass/cattail plot on February 20, 2006, and a prescribed fire was ignited at the highly-enriched, cattail-dominated plot on July 25, 2006 (**Figure 6-28**). In addition to long-term sampling, samples were collected immediately before and several times after each fire, allowing the short-term ecosystem response to fire to be investigated. Most results presented in this section are from the prescribed fire in the highly enriched area.

The impacts of the prescribed fire at the highly-impacted cattail-dominated plot on surface water and pore water chemistry, periphyton growth, seed germination, and soil phosphorus changes are being explored. The impacts of both the wildfire and the prescribed fire on vegetation characteristics such as biomass and shoot height are also being examined.

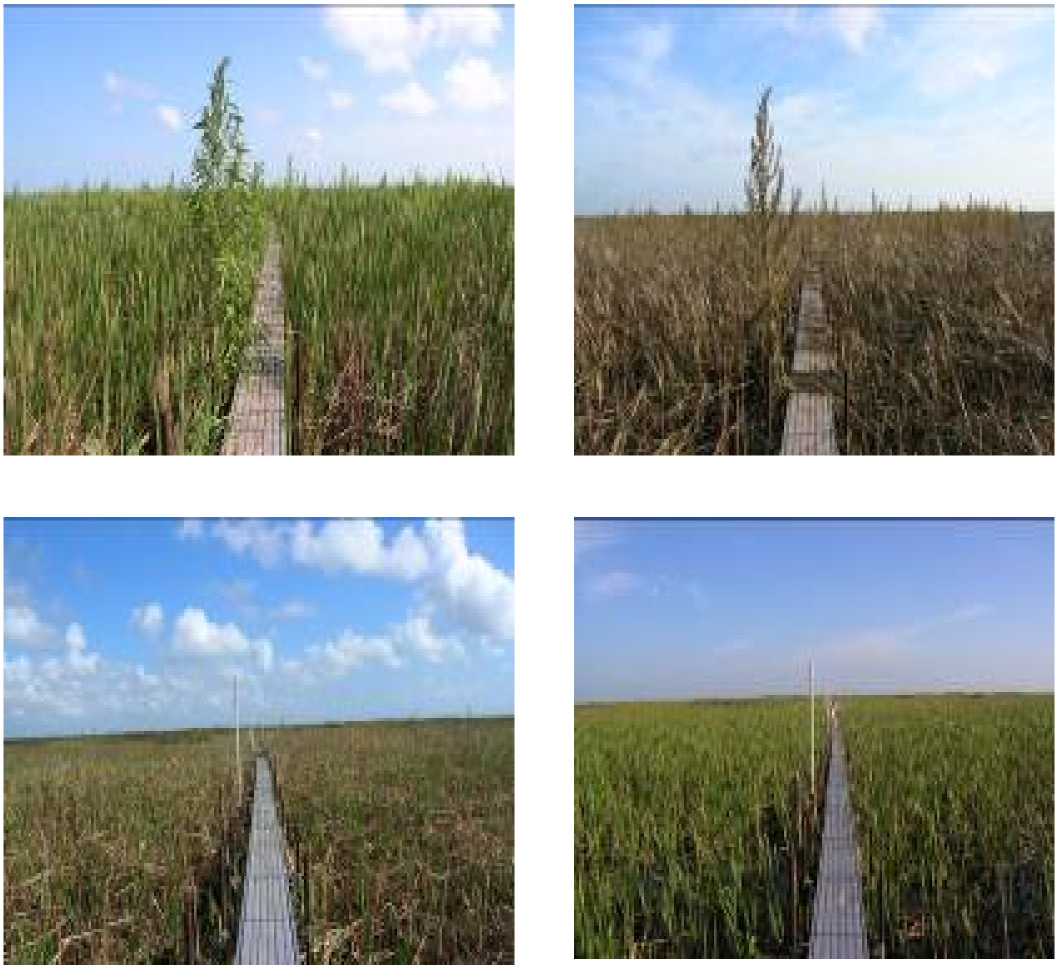


Figure 6-28. Highly enriched plot recovery from prescribed fire on July 25, 2006, pre-fire, one day later, 3 weeks later, and 6 weeks later (clock-wise from top left) (photos by C. Edelstein, TBE, Inc.).

Preliminary Results

Fire was predominately fueled by the standing dead biomass. The fire at the highly-impacted cattail-dominated site consumed 78 percent of the standing dead biomass but less than 15 percent of the live standing biomass. The remaining live leaves were still standing several days following the fire. However, they finally all died and eventually were incorporated into the dead litter layer (**Figure 6-29**).

Figure 6-29. Ash deposition post-fire (photo by C. Edelstein, TBE, Inc.).

The ecosystem response to fire in the highly-enriched cattail site was immediate. Ash deposition from the burned biomass resulted in an increase in surface water pH within 30 minutes of the fire (**Figure 6-30**). SRP concentrations within the burned plot increased over 1,000 percent when compared to upstream concentrations by the first day post-fire (**Figure 6-31**). The phosphate concentrations in the burn and downstream sampling stations returned to pre-fire levels within two weeks. Pore water phosphorus concentrations increased almost 330 percent over upstream concentrations post-fire. However, the duration of the increase in phosphorus concentration in the pore water lasted over three weeks.

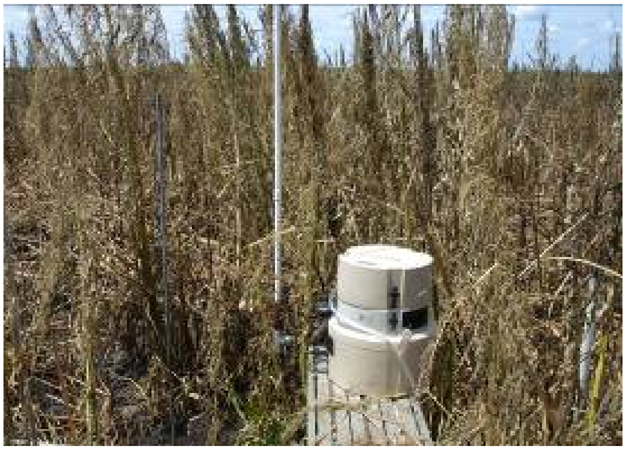


Figure 6-30. Surface water collection (photo by C. Edelstein, TBE, Inc.).

The fire opened up the vegetation canopy allowing greater light penetration to the surface water. Temperature was measured at one station in each plot every 30 minutes. Increased temperature **(Figure 6-32a)** and nutrients in the surface water resulted in a periphyton bloom within two weeks of the fire. The phosphorus concentration in the initial periphyton bloom was twice what it was several months later (**Figure 6-32b**).

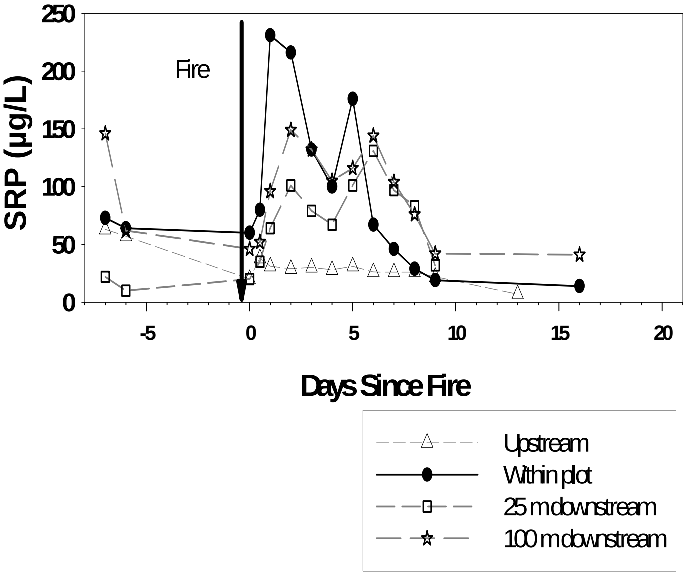


Figure 6-31. Soluble reactive phosphorus (SRP) concentrations before and after fire.

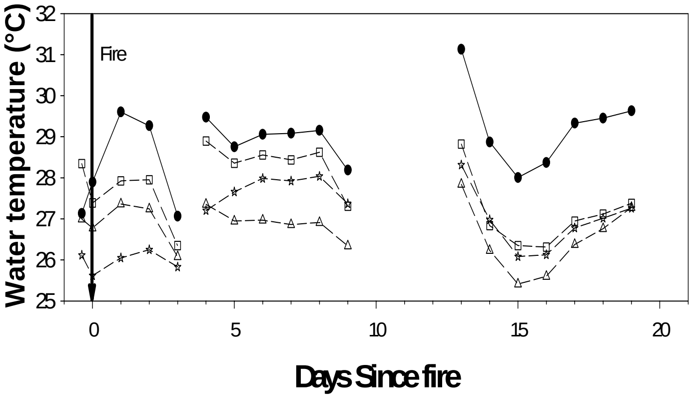


Figure 6-32a. Surface water temperatures before and after fire (see legend in **Figure 6-31**).

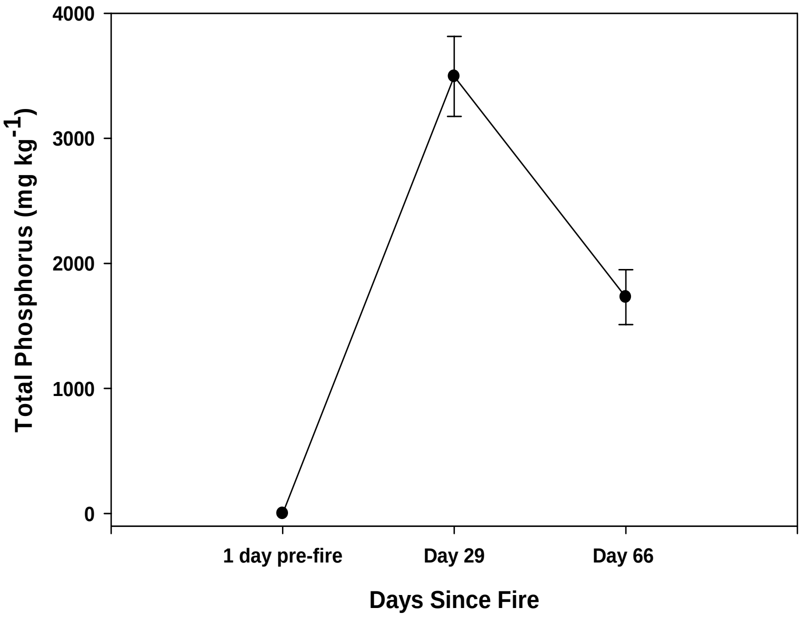


Figure 6-32b. Periphyton phosphorus concentration within the highly enriched plot before and after fire (n=3).

The increase in surface water pH and phosphate created conditions favorable for calcium-phosphate precipitation. This resulted in a significant increase in the CaMg-bound phosphorus fraction and a decrease in the FeAl-bound phosphorus fraction of total inorganic phosphorus two weeks post-fire (**Figure 6-33**). By the fifth week post-fire, there was a 22 percent increase in the FeAl-bound phosphorus fraction from pre-fire concentrations. The increase is most likely the result of the periphyton bloom, which increased the dissolved oxygen concentration in the surface water. Labile inorganic phosphorus gradually decreased from pre-fire to five weeks post-fire. There was not change in total phosphorus concentration.

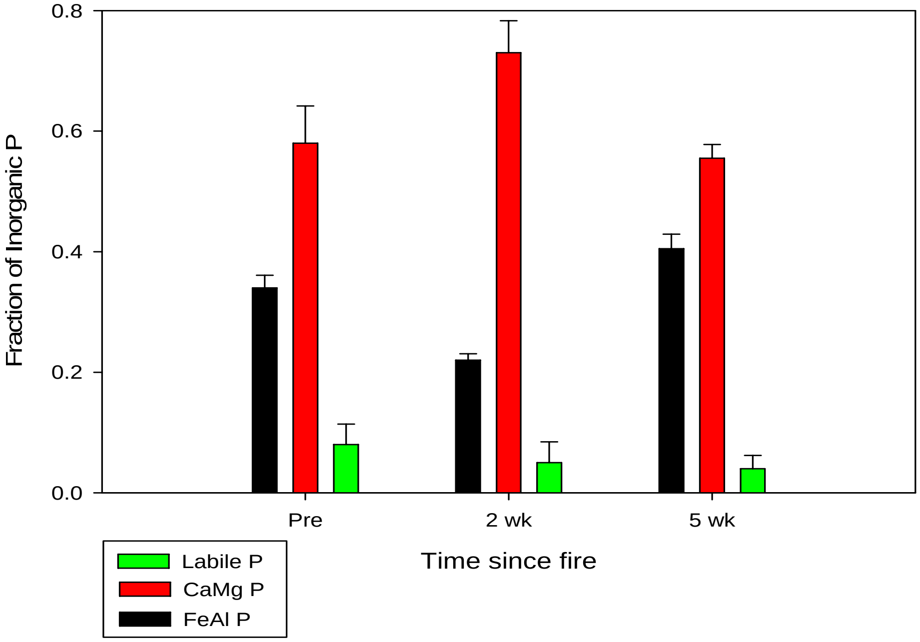


Figure 6-33. Depth-averaged inorganic phosphorus form as a fraction of total inorganic phosphorus before and after fire (n=1).

The soil seedbank was also affected by fire. Cattail seed germination was decreased by fire at the highly-impacted site though it was still the dominant germinating species. There was a small increase in sawgrass and other species germination from pre-fire to post-fire. Within a week of the fire, cattail growth was observed as both new ramet growth and re-growth of plants burned in the fire but not killed.

Cattail regrowth was surveyed at both the highly-enriched and the moderately-enriched burned plots. Cattail culm density rebounded quickly after both fires and within six months was at least 50 percent greater than pre-fire levels (**Figure 6-34**). Cattail plant height increased rapidly following both fires until mean plant height was 70 percent of pre-fire levels and then cattail height stopped increasing. While the response of cattail height and density to fire did not seem to be affected by either site enrichment level or seasonal timing of the fire, plant biomass responded quite differently (**Figure 6-34**). Biomass in the highly-enriched plot decreased five months post-fire, while it increased in the moderately-enriched plot. These contrasting effects are most likely the result of a combination of the timing of each fire and seasonal growth patterns.

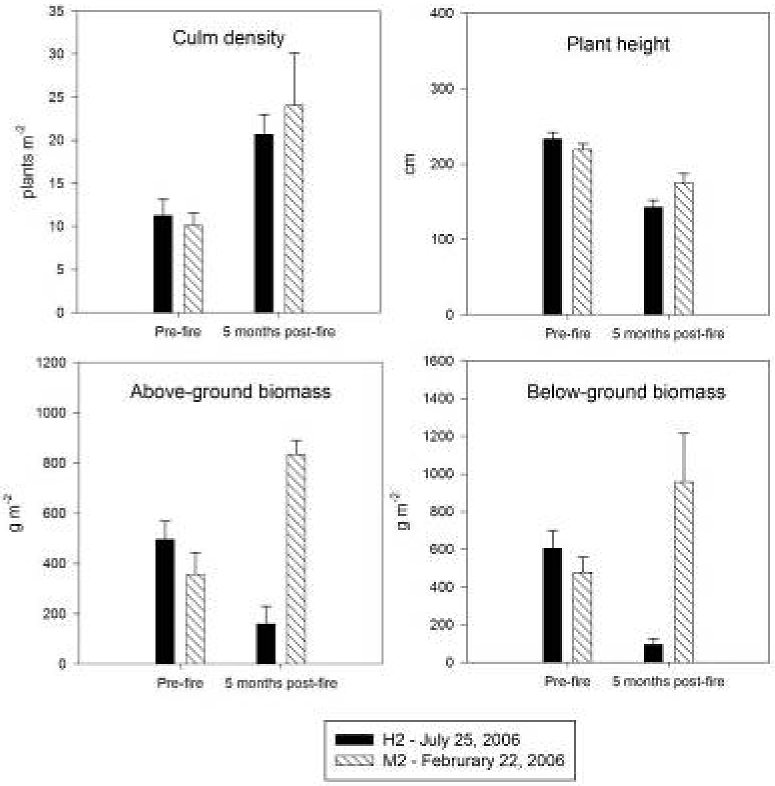


Figure 6-34. Cattail (*Typha domingensis*) response to fire at the individual and community-level following a prescribed fire in the highly enriched area (H2) and a wildfire in the moderately enriched area (M2).

Conclusions

The first year of examining fire as a possible management tool for vegetation recovery has shown that fire does affect vegetative and biogeochemical processes within the impacted areas of WCA-2A. Water and soil changes appear to be short-term but may have longer-term implications as evidenced by the changes in plant biomass at five months post-fire. With additional application of fire treatments, the role of fire as a management tool to accelerate recovery of nutrient-enriched areas of the Everglades will become clearer. This study will also help advance the design and analysis of large-scale ecosystem studies through the employment of the BACIPS design.

CATTAIL HABITAT IMPROVEMENT PROJECT

In *2007 SFER – Volume I, Chapter 6*, the hypothesis, experimental design, and rationale behind the research project, the Cattail Habitat Improvement Project (CHIP) is presented. A detailed project description and methodologies can be found on the District's web site at www.sfwmd.gov under the *What We Do, Watershed Management, Everglades/Florida Bay* section (see *Projects* tab). In brief, CHIP is a large-scale *in situ* study, using fifteen 6.25 hectacre plots, initiated to test our ability to rehabilitate cattail (*Typha* spp.) areas. The two primary objectives are to assess whether creating openings in dense cattail areas will sufficiently alter trophic dynamics such that wildlife diversity and abundance is increased and determine to what extent these created open areas' functions compare to the natural Everglades. Our fundamental hypothesis is that creating openings in phosphorus-enriched areas will cause the ecosystem to shift from one dominated by an emergent macrophyte-detrital system to one dominated by algae or submerged aquatic vegetation. This shift, in turn, will cause changes in critical ecosystem processes and food web dynamics. We hypothesize that open plots will experience greater nutrient fluxes, lose higher percentages of production to herbivores, channel lower percentages of primary production to detritus, experience faster decomposition rates, and as a result, store less carbon and nutrients – while also supporting higher wading bird foraging.

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 July 20 and 21, 2006. The following section documents the application of herbicide necessary to maintain the openings, followed by the results of initial water quality sampling, and our first comprehensive sampling of the experiment in January and February 2007. At this early stage in the project, the focus of these preliminary results will be on the first of the two objectives, although the reference site information will also be presented as appropriate. For all results, sites are delineated based on their location; enriched (E), transitional (T), reference (Ref- ridge and slough sites within phosphorus-unenriched areas of WCA-2A), and whether or not they were burned, open (O), or controls (C).

Maintaining the treatments: There was rapid regrowth of cattail following the burn, but treatment differences were still readily apparent (**Figure 6-35**). With the experimental design objective to maintain the plots at ≤ 10 percent cover of cattail, plots were re-sprayed in August 2006, with a combination of glyphosate and imazapyr. The herbicides that were applied are routinely used by the District to maintain plants throughout the SFWMD. A combination of 7.5 pts/acre AquatNet™ (aquatic labeled glyphosate), 1 qt/acre Habitat™ (aquatic labeled arsenal), 1 qt/acre SunWet™ (mentholated seed oil) and 4 oz/acre NuFilm are applied via helicopter to maintain the open plots. The helicopter applies the herbicide at an altitude of 25 ft, with an airspeed of 50 mph using a 40 ft boom.

With the exception of a couple of small swaths that were missed during helicopter application and subsequently treated by a ground crew, this herbicide treatment resulted in low cattail density and cover for almost six months. A third spray was conducted following the intensive sampling in March 2007. Surficial floc and soil samples are regularly collected at one week, one month – and then quarterly if levels are still above background – to assess any accumulation of glyphosate, its primary degradation product aminomethylphosphonic acid, or imazapyr.

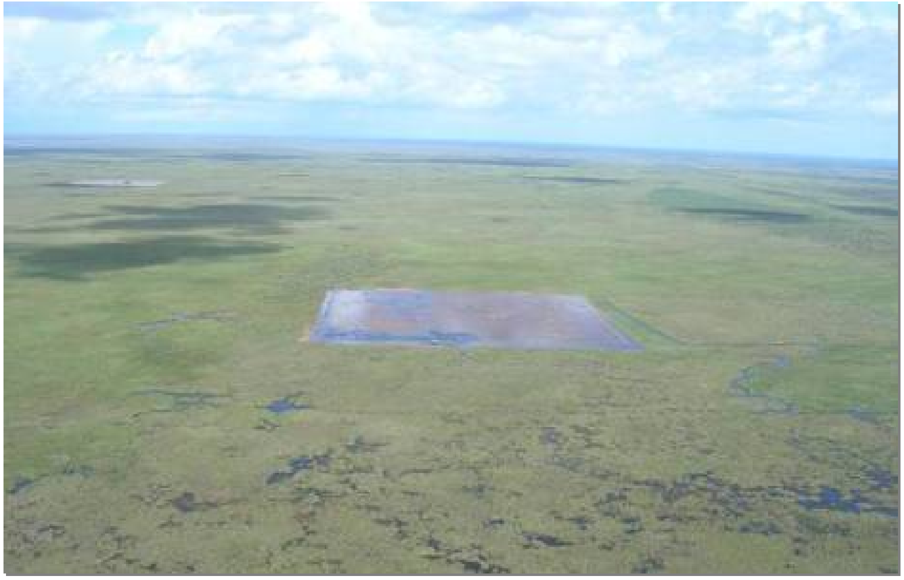


Figure 6-35. View looking north of plots within the Cattail Habitat Improvement Project (CHIP) (photo by S. Hagerthey, SFWMD). In the middle of the image is a pair of plots in the transition area, showing the boundary of the transition and unenriched slough area to the south. In the upper left, one of the open plots from an enriched site is apparent.

Changes in Water and Floc Nutrient Chemistry

Water: Due to weather and logistics, water samples were generally collected over a two day period; these days were considered one sampling event. Sampling events occurred during 3–4, 10–13, 18–19, and 24–26 days post-burn. Surface water samples were analyzed for TP, TKN, SRP, TDP, TDKN, NH_4-N, NOx-N, DOC, SO_4, pH, specific conductivity, temperature and DO. As expected, open plots generally had higher phosphorus and nitrogen concentrations, with maximum differences occurring immediately, 3–4 days, following the burn **(Table 6-7)**; however, only the phosphorus species in open plots were significantly higher than those in control plots. Mean TP concentrations increased from 0.038 to 0.155 mg/L in EC versus EO, compared to an increase from 0.026 to 0.056 mg/L at T sites. Similarly, total dissolved phosphorus (TDP) concentrations averaged 0.015 and 0.032 mg/L at TC and EC sites, increasing to 0.033 and 0.136 at TO and EO sites, respectively. During the initial 3–4 days sampling event, the majority of this increase was attributable to an increase in the labile phosphorus pool, as evidenced by increased SRP concentrations and subsequent redistribution of phosphorus species in the soil, as described below. While significant treatment effects were not observed for SO_4, concentrations in all plots were higher and more variable during the first 3–4 days of sampling compared to later time periods. This is likely due to the fact that sampling occurred shortly after rewetting following the dry season and equilibrium following an initial flush of sulfur from the soil. No distinct patterns were observed for DOC.

Floc: Six months following the burn, both total carbon (TC) and total organic carbon (TOC) concentrations were significantly lower in floc from open plots compared to controls. There was no change in total nitrogen (TN) or ash content. TP concentrations in the floc in open plots were significantly higher, by 200 to 300 mg/kg, than control plots, at both E and T sites (**Table 6-8**). TP concentrations were significantly different between enriched and transitional sites as well as between treatments. The species of phosphorus that changed were determined using the (Ivanoff et al., 1998) fractionation procedures, which is a sequential procedure that emphasizes organic pools. As might be expected given the previously noted elevated phosphorus concentrations observed in the overlying water, while overall floc TP increased, the labile pool decreased significantly. The bicarbonate extractable phosphorus, an indicator of labile phosphorus, was significantly reduced in the open plots compared to controls. Both the inorganic and organic bicarbonate pools decreased, though the highest percentage reduction was observed for bicarbonate Pi, which decreased from mean values of 36 and 42 mg/kg to 4 and 5 mg/kg (**Table 6-8**). Similarly, the bicarbonate organic phosphorus pool also decreased from C to O sites, with the additional observation that the pool was significantly higher at enriched compared to transitional sites. Phosphorus fractions that significantly increased in open plots compared to controls were HCl extractable organic and inorganic forms, suggesting the phosphorus became bound to acid hydrolysable minerals, such as calcium and magnesium. A key initial hypothesis was that the creation of the openings would result in an increase in microbial activity and, thus, more phosphorus was expected to be bound in microbial pools. Phosphorus concentrations associated with biomass were higher in enriched open plots compared to the controls, although not significantly.

Table 6-7. Initial water quality characteristics in CHIP following burning [mean (1 SE)].

Days	Site	n	pH		DO		Sp. Cond		temp		depth		TP		TDP		SRP		TKN		TDKN		NH_4-N		NO_x-N		SO_4		DOC	
3-4	EC	3	7.39	(0.14)	1.0	(0.36)	856	(273)	25	0.2	0.18	(0.04)	0.038	(0.000)	0.032	(0.003)	0.009	(0.001)	2.38	(0.59)	2.50	(0.74)	0.033	(0.006)	0.004	(0.000)	50	(36)	44	(10.17)
3-4	EO	3	7.46	(0.03)	1.6	(0.99)	892	(182)	31	3.3	0.17	(0.02)	0.155	(0.055)	0.136	(0.054)	0.099	(0.048)	2.80	(0.49)	2.73	(0.52)	0.071	(0.035)	0.007	(0.003)	39	(21)	48	(7.54)
3-4	TC	3	7.47	(0.10)	1.1	(0.13)	841	(91)	27	0.6	0.26	(0.03)	0.026	(0.004)	0.015	(0.004)	0.013	(0.004)	2.37	(0.33)	2.43	(0.23)	0.035	(0.006)	0.005	(0.001)	53	(24)	45	(4.10)
3-4	TO	3	7.59	(0.16)	1.8	(0.84)	896	(28)	29	2.1	0.21	(0.06)	0.056	(0.013)	0.033	(0.008)	0.021	(0.005)	2.87	(0.34)	2.45	(0.24)	0.048	(0.011)	0.009	(0.005)	66	(22)	47	(3.71)
3-4	Ref	3	8.06	(0.04)	5.2	(0.51)	925	(58)	30	0.0	0.53	(0.04)	0.010	(0.002)	0.004	(0.000)	0.015	(0.005)	2.73	(0.12)	2.60	(0.17)	0.038	(0.001)	0.004	(0.000)	44	(8)	41	(2.91)
10-13	EC	3	7.16	(0.14)	2.7	(1.66)	1144	(89)	27	0.0	0.21	(0.00)	0.066	(0.017)	0.030	(0.005)	0.009	(0.001)	3.57	(0.12)	3.17	(0.12)	0.050	(0.005)	0.006	(0.001)	34	(11)	59	(3.61)
10-13	EO	3	7.39	(0.02)	2.7	(0.92)	1348	(153)	32	1.3	0.23	(0.01)	0.046	(0.005)	0.032	(0.004)	0.013	(0.002)	3.75	(0.61)	3.23	(0.32)	0.050	(0.005)	0.012	(0.005)	46	(10)	58	(5.36)
10-13	TC	3	7.07	(0.20)	1.3	(0.39)	872	(158)	28	0.4	0.21	(0.01)	0.020	(0.003)	0.013	(0.002)	0.005	(0.000)	2.10	(0.31)	2.20	(0.31)	0.035	(0.004)	0.012	(0.004)	27	(10)	42	(5.13)
10-13	TO	3	7.28	(0.20)	3.5	(1.56)	909	(128)	31	0.3	0.19	(0.02)	0.055	(0.033)	0.017	(0.004)	0.008	(0.003)	2.83	(0.15)	2.33	(0.24)	0.034	(0.001)	0.005	(0.000)	30	(10)	45	(3.28)
10-13	Ref	3	7.59	(0.14)	4.5	(1.15)	872	(22)	30	0.3	0.54	(0.03)	0.006	(0.001)	0.004	(0.000)	0.004	(0.000)	2.37	(0.07)	2.47	(0.03)	0.045	(0.010)	0.007	(0.003)	31	(1)	37	(0.33)
18-19	EC	3	7.14	(0.06)	0.4	(0.12)	1420	(223)	27	0.3	0.17	(0.00)	0.084	(0.033)	0.033	(0.005)	0.011	(0.003)	3.90	(0.57)	3.87	(0.52)	0.038	(0.001)	0.009	(0.005)	20	(4)	64	(5.24)
18-19	EO	3	7.26	(0.01)	3.2	(1.91)	1408	(181)	31	2.1	0.21	(0.02)	0.102	(0.060)	0.026	(0.001)	0.009	(0.000)	4.82	(0.94)	3.62	(0.49)	0.040	(0.002)	0.015	(0.005)	24	(3)	59	(6.01)
18-19	TC	3	7.30	(0.01)	2.3	(0.42)	990	(115)	28	0.4	0.16	(0.03)	0.015	(0.001)	0.013	(0.001)	0.006	(0.000)	2.57	(0.15)	2.50	(0.10)	0.024	(0.001)	0.009	(0.005)	23	(6)	49	(1.33)
18-19	TO	3	7.43	(0.09)	5.4	(0.92)	1040	(77)	32	0.7	0.12	(0.02)	0.022	(0.005)	0.016	(0.003)	0.008	(0.001)	2.67	(0.09)	2.70	(0.12)	0.033	(0.004)	0.015	(0.005)	27	(5)	52	(0.88)
18-19	Ref	3	7.59	(0.03)	4.3	(0.40)	905	(1)	28	0.2	0.35	(0.08)	0.006	(0.001)	0.004	(0.000)	0.005	(0.001)	2.63	(0.12)	2.37	(0.09)	0.035	(0.003)	0.020	(0.000)	32	(0)	39	(0.33)
24-26	EC	3	7.21	(0.10)	1.4	(0.13)	1260	(148)	27	0.7	0.13	(0.01)	0.046	(0.010)	0.028	(0.002)	0.009	(0.000)	3.03	(0.22)	3.17	(0.20)	0.077	(0.014)	0.015	(0.003)	14	(2)	54	(2.65)
24-26	EO	3	7.46	(0.08)	3.3	(1.09)	1291	(123)	33	1.8	0.18	(0.02)	0.054	(0.009)	0.021	(0.001)	0.007	(0.000)	3.07	(0.20)	3.17	(0.28)	0.050	(0.005)	0.020	(0.000)	16	(2)	53	(2.52)
24-26	TC	3	7.26	(0.04)	2.2	(0.30)	1038	(121)	27	0.1	0.17	(0.04)	0.016	(0.001)	0.012	(0.000)	0.005	(0.001)	2.40	(0.06)	2.43	(0.09)	0.048	(0.003)	0.004	(0.000)	22	(3)	45	(2.02)
24-26	TO	1	7.17		1.9		910		29		0.12		0.027		0.016		0.006		2.30		2.40		0.061		0.020		23		46	
24-26	Ref	3	7.97	(0.02)	9.9	(0.42)	981	(17)	33	0.5	0.22	(0.17)	0.008	(0.001)	0.005	(0.001)	0.004	(0.000)	2.58	(0.14)	2.62	(0.07)	0.051	(0.001)	0.004	(0.000)	29	(1)	41	(0.33)

Table 6-8. Chemical composition and phosphorus fractionation of surficial floc collected in January 2007 [mean (1 standard deviation)].

Treatment	Moisture		Ash		TP		TN		TC		TOC	
	%		%									
EC	96	(0.38)	11	(0.60)	1300	(78)	27320	(877)	483500	(9751)	457670	(3055)
EO	97	(0.58)	13	(1.91)	1650	(68)	28530	(1198)	463330	(5840)	425830	(12473)
TC	98	(0.34)	19	(3.89)	930	(86)	26030	(2589)	485500	(6602)	444500	(8047)
TO	97	(0.36)	16	(3.69)	1160	(112)	27570	(1135)	459000	(3786)	417670	(9238)
Ref	95	(0.79)	61	(1.28)	220	(15)	16470	(960)	263670	(10477)	153000	(14422)

P Fraction Means																
Treatment	Bicarb Po		Bicarb Pi		HCl Po		HCi Pl		Biomass P		Fulvic P		Humic P		Residual TP	
EC	68	(6)	42	(4)	60	(10)	160	(12)	328	(35)	191	(19)	269	(9)	213	(41)
EO	31	(5)	5	(1)	97	(9)	223	(18)	575	(96)	231	(29)	265	(11)	214	(14)
TC	32	(13)	36	(15)	44	(10)	55	(7)	405	(61)	130	(8)	140	(30)	85	(30)
TO	17	(1)	4	(0)	87	(15)	157	(9)	446	(77)	167	(23)	172	(18)	127	(6)
Ref	16	(0)	4	(0)	23	(6)	66	(2)	62	(8)	37	(9)	19	(3)	15	(3)

Note: all units are mg/kg except where noted.

Microbial Activity

Microbial respiration was measured after a 24-hour incubation of material (Wright and Reddy, 2001). Incubations were conducted under aerobic and anaerobic conditions. Higher microbial activities were generally observed in open compared to control plots. For example, floc incubated for a 24-hour period produced mean aerobic respiration values that were 25 to 46 percent higher in open plots (**Figure 6-36**). In addition to increased heterotrophic activity, the experimental opening of plots and subsequent increased light penetration resulted in an immediate appearance of periphyton community. While there was some evidence of this in higher point dissolved oxygen measurements in **Table 6-7**, this was clearly demonstrated in diel oxygen concentrations (**Figure 6-37**). There was a distinct difference in diel profiles between open and control plots. Open plots had both higher maximum and lower minimum values than their paired control plots, hence, indicating higher production and consumption of oxygen within the open areas. Within three weeks post-burn, diel dissolved oxygen patterns were similar to those observed at reference sites, with the exception that minimum values were close to zero in plots other than the reference sites.

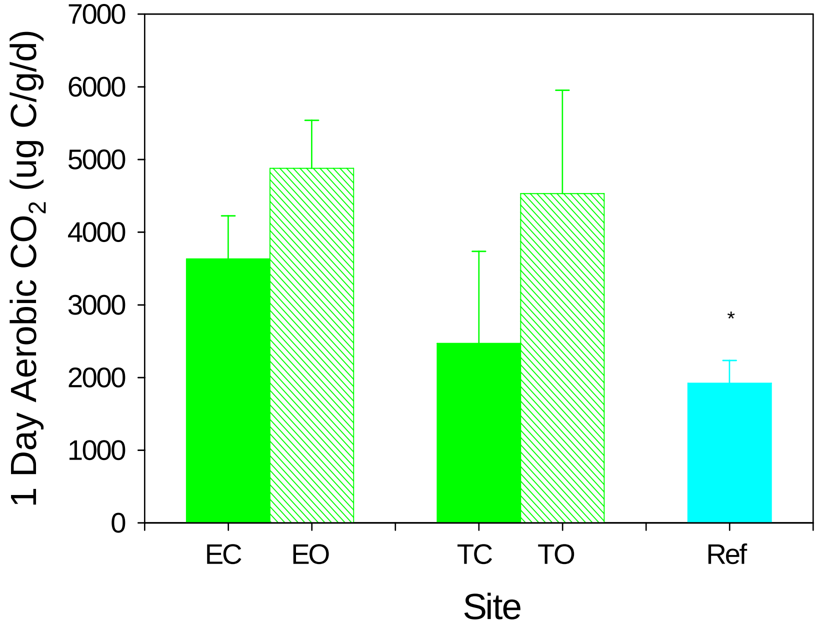


Figure 6-36 Heterotrophic respiration determined after a 24-hour incubation of floc collected from CHIP plots in January 2007, six months following creation of the openings (mean ± 1 SE). * Indicates significant difference from other bars. Sites are identified based on their location; enriched (E), transitional (T), reference (Ref), and whether or not they are being maintained as open areas (O), or controls (C). For more details and project description see Newman et al. (2006).

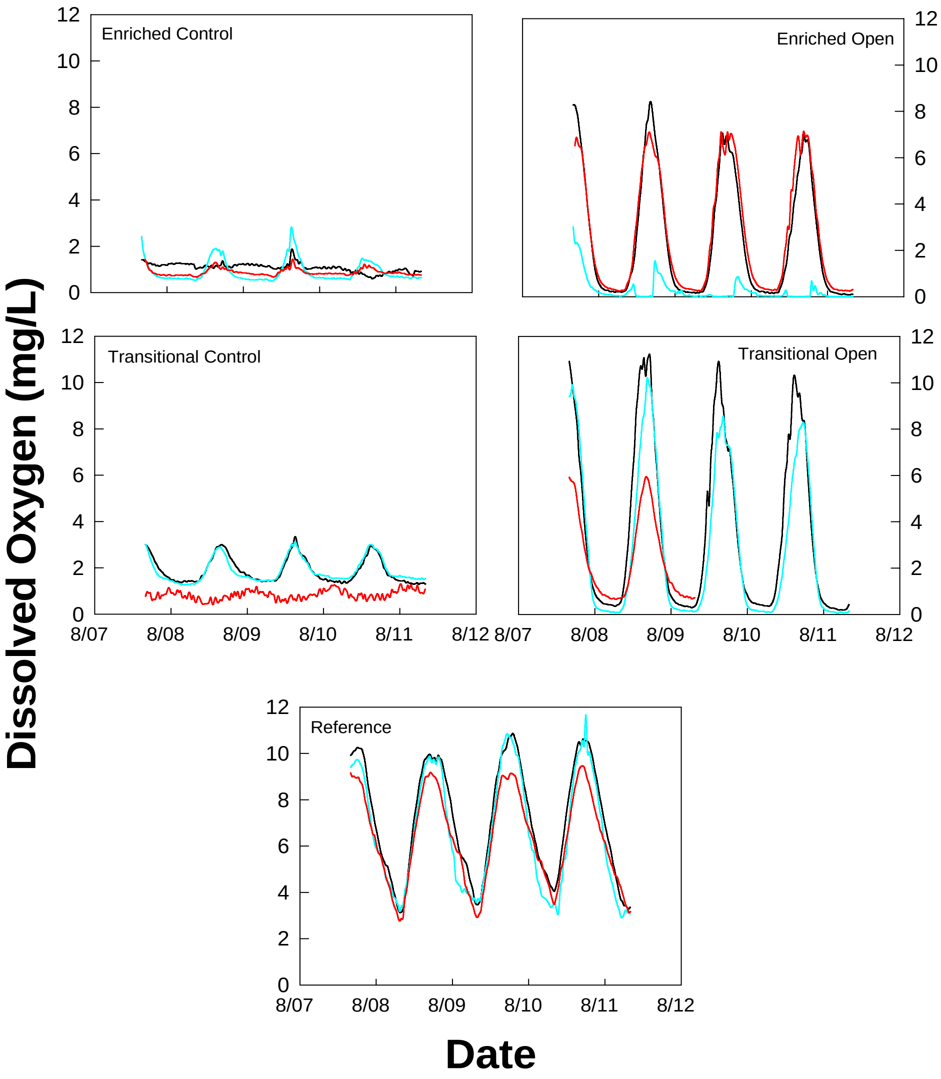


Figure 6-37. Diel dissolved oxygen curves in CHIP plots measured 2.5 weeks post-burn. Dissolved oxygen readings collected every 30 minutes.

Higher Trophic Level Responses

Wading Birds: Unfortunately, rapidly lowering water levels during the January 2007 sampling event precluded the collection of invertebrate and fish community composition. However, wading-bird and secretive-marsh-bird surveys were able to be conducted. In the CHIP open plots, District staff counted 11 species of wading birds including white ibis, glossy ibis (*Plegadis falcinellus*), great egret (*Casmerodius albus*), snowy egret (*Egretta thula*), great blue heron (*Ardea herodias*), tri-colored heron, little blue heron (*Egretta caerulea*), black-crowned night-heron (*Nycticorax nycticorax*), wood stork, roseate spoonbill (*Ajaja ajaja*), and limpkin (*Aramus guarauna*). Only four species were found in the control plots.

As predicted, significantly more wading birds were observed in open plots than in control and unenriched plots (**Figure 6-38**). Densities in open plots were frequently high, sometimes over 200 birds per plot. It should be noted that birds in control plots were not observed in dense vegetation, but in small open-water areas within the vegetation matrix. Bird density was a function of water level, but the response to depth appeared to differ somewhat between plots. Birds in the T and E plots attained maximum density between 10 and 20 cm depth and birds remained in the plots until almost dry. With the exception of the spike in May 2007, wading birds in reference plots did not reach comparable numbers to those in the E and T plots until water depths fell below 5 cm. It is possible that thick mats of calcareous periphyton may have affected foraging in the reference plots. However, prey sampling work (P. Gawlik, personal communication) suggests that prey densities in WCA-2 were relatively low this year and might have suppressed foraging in the reference sites.

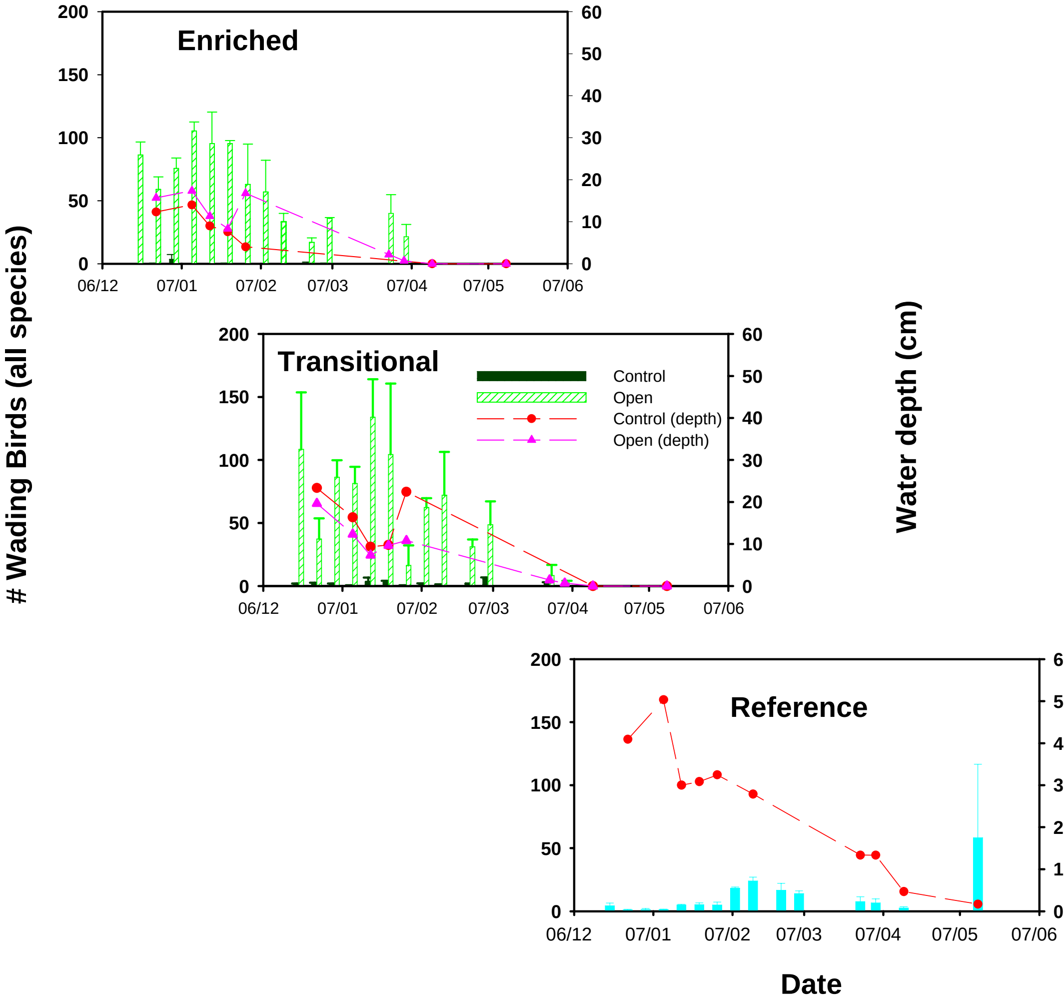


Figure 6-38. Wading bird numbers and water depth in CHIP plots from December 2006 through June 2007 (mean ±1 SE). Sites are identified based on their location; enriched (E), transitional (T), reference (Ref), and whether or not they are being maintained as open areas (O), or controls (C). For more details and project description (see Newman et al., 2006).

Secretive Birds: Our knowledge of wildlife use of densely vegetated habitats is very limited. However, with the loss of the vegetative cover, it is hypothesized that this would result in a decrease in the use of the habitat by secretive bird species. Five species of over-wintering secretive marsh birds were detected: king rail (*Rallus elegans*), sora rail (*Rallus carolinus*), American bittern (*Botaurus lentiginosus;* a USFWS bird of conservation concern), least bittern (*Ixobrychus exilis*; a Florida species of special concern), and pied-billed grebe (*Podilymbus podiceps*). 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. For example, the American bittern rarely calls during winter and detection of this species based solely on visual sightings is probably a considerable underestimate. Highest numbers of secretive birds were found in enriched control plots, followed by transitional control plots (**Figure 6-39**).

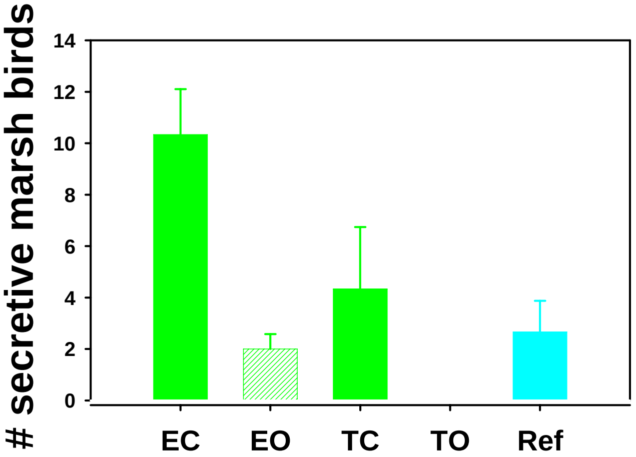


Figure 6-39. Mean (± 1 SE) number of secretive marsh birds observed in CHIP plots in March 2007. Sites are identified based on their location; enriched (E), transitional (T), reference (Ref), and whether or not they are being maintained as open areas (O), or controls (C). For more details and project description (see Newman et al., 2006).

Conclusions

Data presented for this project were generally collected within the first six months of its creation. Given the intensity of the disturbance, the observance of vast differences in function was not anticipated. However, these preliminary results support the original hypotheses that open plots will experience greater nutrient fluxes, be comprised of more nutritional plants (i.e., algae), and support higher wading bird foraging. Floc and sediment phosphorus speciation suggests that phosphorus cycling is being modified in these open plots. Continued sampling and analysis over the next two years will allow a better assessment to whether there is a sustained change in trophic dynamics and that the open plots head in a trajectory towards functioning as natural sloughs.

LANDSCAPE ECOLOGY

The District continues to develop ways to examine long-term, large-scale structure and function as part of its synthesis and integration approach. It is at this scale that broad, baseline inferences can be related to past and future hydrologic regimes, land-use practices, and changes in ecosystem structure and function. Last year, the District updated the Everglades soil map, vegetation map and tree island elevation map. This year, the District reports on a broader spectrum of landscape issues that have direct relevance to water management, and research done at smaller, more focused scales.

Ten years in the making, the long-awaited book by the District with the working title *Pre-Drainage Everglades* describing the pre-drainage hydrology and ecology of the Everglades nears completion. The forensic approach to pre-drainage observations by naturalists, developers and government officials sheds important light on what might be possible for CERP and what might require new scientific investigations, particularly for the formation and movement of floc for creating the ridge-and-slough landscape. This section shows, for the first time, how old aerial photos can be spatially analyzed to capture the rates of habitat conversion from sloughs to ridges in different regions of WCA-3. This allows other scientists to ask more focused biogeochemical questions associated with critical flow velocities and water management regulations (assumed to be needed for ridge and slough sustainability). This, in turn, relates to our new paleoecological work and its use of seed markers to validate our photo interpretations of past vegetation change, and to explore pre-historical habitat stability. These paleoecological studies may provide new baseline conditions for both restoration and operation. Finally, this section provides a description of a landscape muck fire index. This index is an excellent example of how information is integrated at the population and ecosystem levels up into a landscape–scale tool for, in this case, drought management.

CERP VEGETATION MAPPING

Restoration Coordination and Verification (RECOVER) is designed to organize and provide the highest quality scientific and technical support during CERP implementation. RECOVER has developed a system-wide Monitoring and Assessment Plan (MAP), which is designed to document how well CERP is performing. The Water Resources Development Act of 2002 authorized CERP as a framework to restore the Everglades and established the U.S. Army Corps of Engineers (USACE) together with the SFWMD as co-sponsor agencies responsible for MAP implementation. One component of the MAP will involve vegetation mapping to be used as a monitoring tool and to document any changes in the spatial extent, pattern, and composition of plant communities within the landscape.

The CERP vegetation mapping effort got under way in 2004 with the collection of approximately 1,400 1:24,000-scale, color-infrared aerial photographs. The second step in the mapping process involves the geo-referencing of the aerial photographs. Currently, 77 percent of the aerial photographs have been geo-referenced. Another 20 percent of the photographs, encompassing WCA-3, are currently being geo-referenced. Geo-referencing of all fourteen hundred images is expected to be completed by October 2007.

The final step in the vegetation mapping process requires the photo-interpretation of each quarter hectare (50 x 50 meter) grid cell located within the boundaries of the mapping project, totaling approximately 4.4 million grid cells. The grid network is superimposed over 1:24,000-scale, color-infrared aerial photographs, and each grid cell is labeled according to the majority vegetation community as described in the Vegetation Classification System for South Florida Natural Areas (Rutchey et al., 2006).

To date, vegetation mapping products have been completed for WCA-2A and Rotenberger Wildlife Management Area. The Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge) and portions of the ENP are currently being mapped. The Refuge is approximately 75 percent complete and was projected to be completed by October 2007, at the time of this report. Mapping is also under way for a 67,900-hectare area (approximately 11 percent) of the ENP. These vegetation mapping products will provide a baseline for the RECOVER vegetation mapping project.

BOOK STATUS: THE PRE-DRAINAGE EVERGLADES

The District is preparing a book manuscript for publication in 2008 which describes the landscape and hydrology of the Everglades in the mid 1800s and includes the soils, vegetation, hydrology and the borders of the Everglades from that time period. The description includes Lake Okeechobee, the custard apple swamp, the sawgrass plains, the ridge-and-slough topography which includes tree islands, the marl marshes and the bordering landscapes. This description has been prepared by hindcasting, using information from various pre-drainage and early post-drainage sources. These sources include:

- Vegetation, soil and topographic mapping from the 1940s
- Government township surveys beginning from 1855
- Accounts of expeditions into the Everglades from 1883 to 1907
- Early maps beginning from 1838
- Firsthand narrative accounts of pre-drainage Everglades
- Early photographs
- Construction surveys and profiles
- Hydrologic, climate and soil records
- Scientific studies (pre-drainage as well as post-drainage)

The approach taken to reconstruct the pre-drainage Everglades was to use a form of “forensic ecology” which, in process, is similar to archeology and paleontology. It involves the reiterative reconstruction of the past environment through the synthesis of soil science, hydrology, botany, logic, and analysis of historical sources (**Figure 6-40**). It provides a “time machine” that allows comparison of the pre-drainage Everglades to the current system, similar to a paleontologist comparing extinct plants and animals reconstructed from the fossil record to current forms or an archaeologist comparing extinct cultures, reconstructed from artifacts, to current cultures.

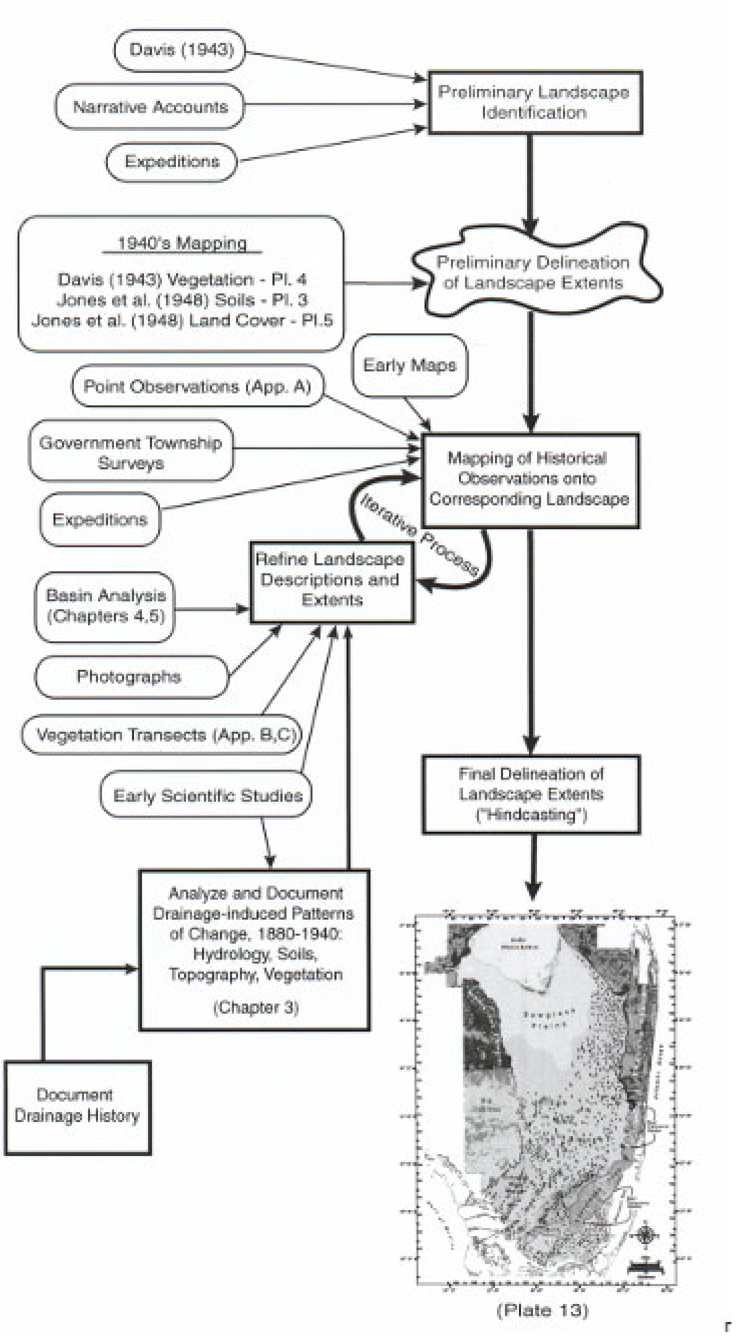


Figure 6-40. A diagram of the process used in hindcasting the pre-drainage Everglades.

SOIL PROFILES OF MACROFOSSILS

The construction of the Tamiami Trail in 1928 and consequent flood control and water management over the latter 20th century altered the hydrology of the historical Shark River Slough (SRS), the central flow path in Everglades National Park, likely impacting the suitability of Shark Slough as habitat for wildlife (Hoffman et al., 1994). Paleoecological studies that focused on tree islands suggest that water management has increased nearby sawgrass ridges at the expense of deepwater sloughs (Willard et al., 2006). Such observations are useful, but important landscape questions remain in resolving the timing and magnitude of past vegetation changes. For instance, have vegetation changes in marshes adjacent to tree islands mirrored those of the greater ridge-and-slough landscape? What are the patterns of vegetation change across smaller scales (tens of meters), for instance, along the border of a ridge and slough? In other subregions of Shark Slough, studies of vegetation changes in marshes are altogether lacking: e.g., northeast Shark Slough (which is now mostly sawgrass) and sawgrass marshes in the estuarine ecotone (which may be affected by drainage as well as sea-level rise). These questions are important because they highlight the degree of restoration that may be needed by CERP and the extent of the operational changes that may be needed to prevent further landscape change. It also represents an expansion of the Everglades Division's research scope into the ENP.

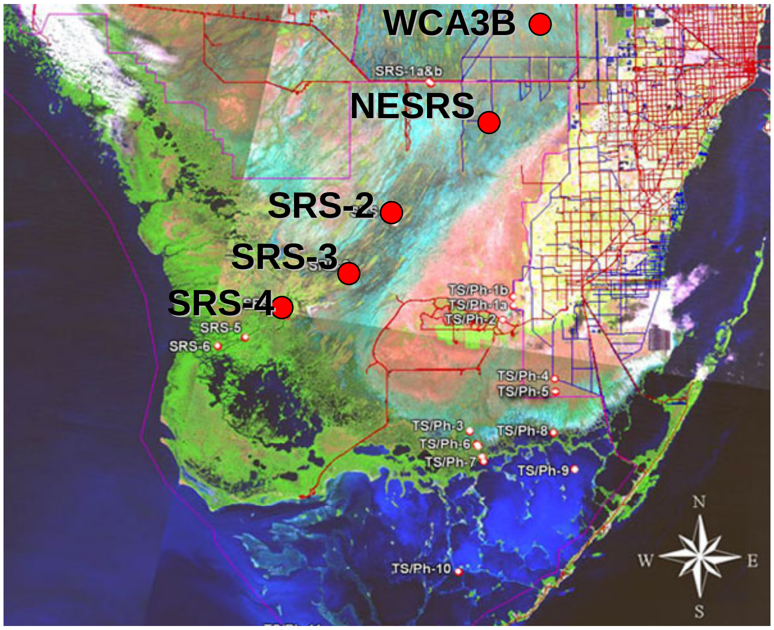


Figure 6-41a. Study sites located along historical Shark Slough.

Starting in 2005, researchers at FIU (C. Saunders, PI; R. Jaffe; M. Gao; and D. L. Childers), the ENP (V. Engel), North Central College (J. Lynch), and Indiana University (C. Craft) began developing a method using macrofossils (mainly seeds) in conjunction with biomarker proxies (e.g., n-alkane proxy P_{aq}, lignin phenols and *ent*-kaurenes) to reconstruct historical vegetation throughout Shark Slough **(Figure 6-41a**) and determine whether this method could also characterize vegetation changes over short spatial scales (tens of meters) to characterize patterns of boundary movements between ridge and slough communities. The main objective of this study (to be completed in 2008) was to characterize Everglades vegetation change over the twentieth century, and specifically address the hypothesis that increased sawgrass abundance has occurred throughout Shark Slough.

The method entails recovering macrofossils (mainly seeds) of sawgrass and other Everglades plant species from soil and complements other proxies such as fossil pollen and spores. Novel molecular approaches are currently being developed to quantify past changes in emergent/aquatic plants (from profiles of P_{aq} and lignin phenols) and in sawgrass root biomass (from downcore concentrations of *ent*-kaurenes) (Gao, 2007). A key advantage of macrofossils is that they may also detect vegetation changes over a scale of 10 meters or less (Saunders et al., 2006), providing suitable methods for analyzing past changes in ridge and slough boundaries over the past several decades. In this study, soil cores were collected at sites distributed along length of historical Shark Slough (**Figure 6-41a**), from WCA-3B (north of the Tamiami Trail) to the estuarine ecotone of Shark Slough (site SRS-4). A modified piston-corer was used to obtain duplicate deep cores (to bedrock) in both sawgrass and slough habitats (4 cores per site). A 10-cm diameter core was used to provide sufficient material for macrofossil analyses (30-40 gfw per 1-cm soil layer, per Saunders et al., 2006 and 2007), radiometric analyses for ^{210}Pb and ^{137}Cs soil dates (characterizing circa 1880 to present), and for fossil seed material required for accelerated mass spectrometry 14C dates (> 4 mg dry weight; only SRS-4 data are available for this report). Molecular marker analyses were conducted on duplicate cores, but these data are not available for this report.

All cores were extruded at 1-cm intervals, and soil subsamples from each layer were used for counting macrofossils. Macrofossils were recovered by washing soil samples through different mesh screens (> 1 mm and 500 µm-sized openings) to capture the material containing macrofossils. This material was dispersed in water, and seeds and other macrofossils (exoskeletons, shells, plant tissues) were identified using 30× monocular lenses. Fossil seeds and plant tissues were identified using archived and photographed specimens obtained *in situ* from live plants and surficial soils (top 4 cm), as well as published descriptions of seeds and plant phytoliths (Bonilla-Barbosa et al., 2000; Winkler et al., 2001).

Downcore profiles from modern sawgrass communities at WCA-3B, NE-SRS, SRS-2, and SRS-3 are all suggestive of wetter conditions prior to 1940 and drier conditions afterward (**Figure 6-41b**). At SRS-2 and SRS-3, the recent drier conditions are indicated by the dominance of sawgrass seeds and reduced abundance of deepwater slough taxa in the top 10 cm. At NE-SRS and WCA-3B, there is no corresponding increase in sawgrass seeds after 1940. Analyses of additional macrofossil taxa, including phytoliths, and molecular markers are underway to further resolve the vegetation changes that have occurred at these sites. Soil collected from the SRS-4 site was too young to characterize pre-1940 conditions, although a recent increase and subsequent decline in sawgrass since 1950 is suggested.

Although methodology is still somewhat preliminary, additional study sites, soil dates, and paleo-proxies (as outlined in the Strategic Plan) will provide greater resolution for understanding the timing and patterning of vegetation changes in Shark Slough and other subregions of the Everglades landscape. Previous research has shown that with some refinement, macrofossil profiles can be used to calibrate and test simulation models that help us predict or understand long-term vegetation and soil changes in wetlands, including the feedbacks with hydrology that govern those dynamics (Saunders, 2003). Applying this integrative research to Everglades wetlands could potentially refine performance measures of vegetation structure (biomass) and function (productivity) as well as increase our understanding of how ridge and slough boundaries might respond to adaptive management experiments such as the CERP WCA-3 Decompartmentalization and Sheetflow Enhancement Project.

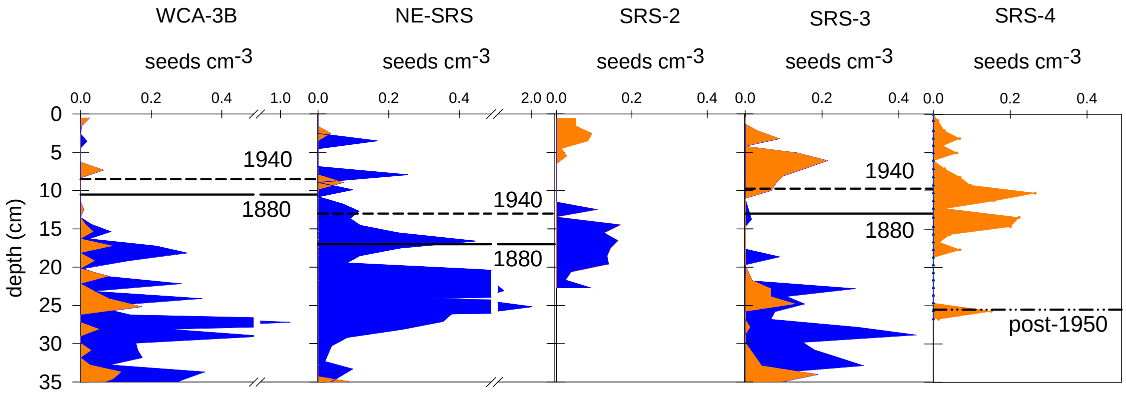


Figure 6-41b. Soil profiles of fossil seeds in sawgrass marshes at each site; blue-shaded area represents the deep-water taxa (*Nymphaceae* and *Nymphoides* spp.) and orange-shaded area represents sawgrass. Dashed line corresponds to 1940, and solid line corresponds to 1880 (based on ^{210}Pb dating). Dashed-dotted line at SRS-4 corresponds to post-1950 (accelerated mass spectrometry 14C date of seeds recovered at 25 cm). Soil dates for were not yet available for SRS-2, but 20th century changes are likely reflected in the top 15 cm, given similar soil-age relationships for the freshwater marsh sites (WCA-3B, NE-SRS, and SRS-3).

LANDSCAPE PATTERN CHANGE

Ridge-and-slough patterned peatlands were an integral part of most of the Everglades marshes in their original pre-drainage condition (SCT, 2003; McVoy et al., in review). Regularly spaced, long (up to 4 km long) sawgrass ridges and teardrop-shaped tree islands developed parallel to the pre-drainage flow direction, embedded within interconnected sloughs throughout the landscape. While some areas today retain strong and stable patterning, particularly in western and central WCA-3, as this study will show, much of the remaining Everglades patterning has degraded.

Patterned peatlands are most commonly found in boreal regions of North America, Europe, and Asia; the Everglades appears to be unique among tropical and subtropical peatlands in its patterning. WCA-3 contains both the largest areas of original patterning remaining in the Everglades as well as areas that have lost nearly all original landscape structure. Aerial photography taken roughly every 10 years (1940, 1954, 1972, 1980, 1995, and 2004) provides invaluable insights into temporal and spatial changes in Everglades landscape patterning.

Three landscape-scale rectangles, each 4 km x 6 km, in WCA-3 were selected out of 15 established quadrants as a pilot study to determine the direction, timing, and details of pattern change in the extant ridge-and-slough landscape. The site with the most degraded landscape pattern was located east of the Miami Canal (I1), the moderately degraded site was west of the Miami Canal (N2), and the still strongly patterned site, serving as the control, was in the west-central part of WCA-3 (G2).

Aerial photographic images for five time periods were scanned and geo-referenced; data for 1995 was derived from a published digital vegetation map (Rutchey et al., 2005). Ridges and tree islands in each quadrant for each time period were manually digitized as polygons (**Figure 6-42**) with associated data on area, perimeter, length, width, and orientation. Quadrant values for width, total area, mean perimeter, length/width and perimeter/area ratios, variability of orientation, and polygon size distribution were calculated. The methodology follows that of Nungesser et al. (submitted) which indicate that differences in length/width ratios, perimeter/area ratios, variability of the orientation, and total area of ridge versus slough differentiate strong from weak or degraded patterning.

One unexpected result was that patterns appeared degraded already by 1940, contrary to original expectations that the system was still mostly intact in 1940. Even the 1940 image of G2 revealed much dryer conditions (**Figure 6-43**). Drainage resulting from the construction of the Miami, New River, and Hillsboro canals between 1912 and 1921 lowered water levels substantially (Stephens and Johnson, 1951; Alexander and Crook, 1973) and exacerbated the effects of droughts throughout the 1930s and 1940s. Patterns in the control area (G2) have remained relatively stable and improved slightly since 1940 (**Figure 6-43**). N2 has retained patterns (**Figure 6-43**), but after 1972, ridge vegetation increased 15 percent by expanding into sloughs and reducing slough connectivity. Patterning in I1 declined from 1940 through 1972 (**Figure 6-43**) from severe drainage and probably frequent fires; then patterns disappeared abruptly between 1972 and 1980. In I1, slough area decreased by 21 percent with resulting loss of slough connectivity. These results indicate that the original landscape patterns were stable over decades and perhaps centuries under natural conditions and that surface patterning can appear relatively unchanged for several decades following severe changes in hydrology and other environmental conditions, such as in N2, but then fail rapidly once some threshold is passed (as in I1). The threshold may relate to elimination of the microtopographic relief between ridges and sloughs.

This analysis will expand to cover all 15 quadrants throughout WCA-3. Through the collected historical records, it will be possible to discern the timing and magnitude of pattern alterations resulting from the earliest drainage through modern water management practices. Knowing the extent of to-date pattern change will provide insights into potential mechanisms of change, identify regions of low resilience, and suggest effective restoration practices.

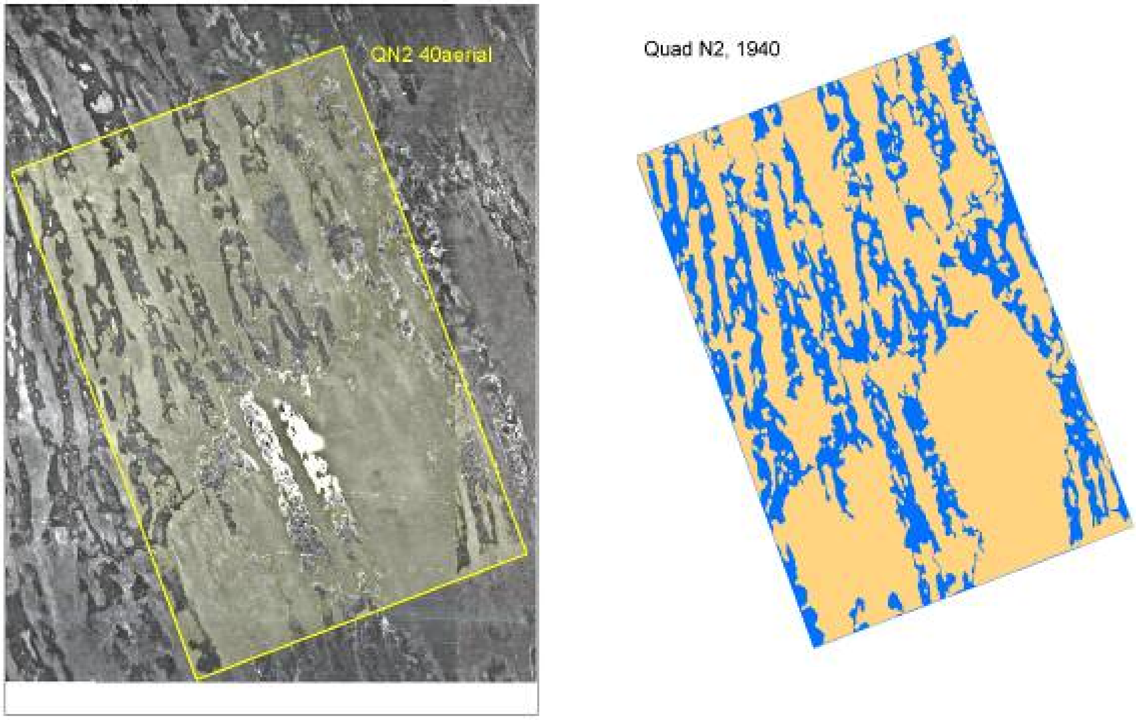


Figure 6-42. Aerial imagery is digitized to produce map of ridges/tree islands and sloughs (photos produced by Aero Science Corp, Philadelphia, PA). Yellow indicates ridges and tree islands; blue and sloughs.

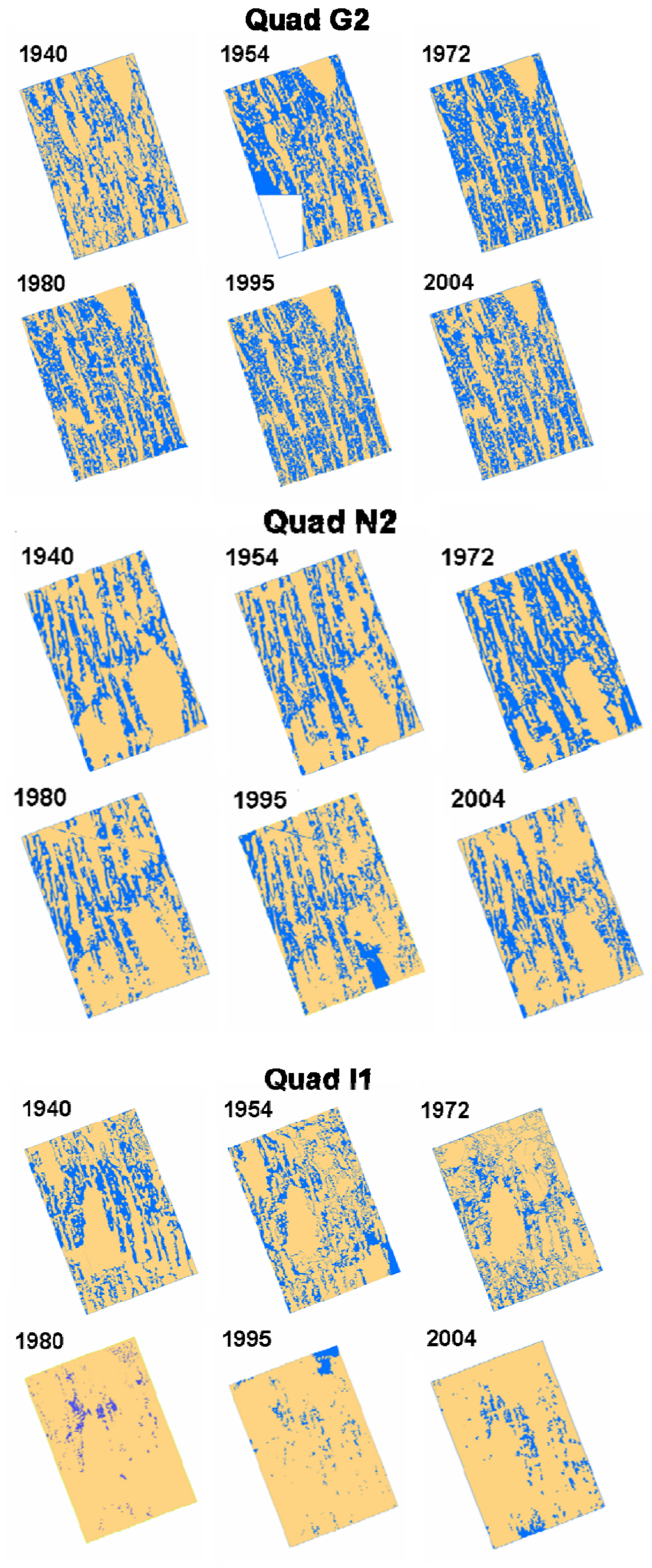


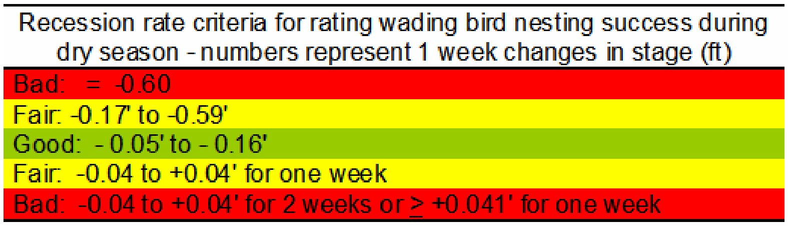
Figure 6-43 Changes in patterns in WCA-3 quadrants for 1940, 1954, 1972, 1980, 1995, and 2004, for G2 (top), N2 (middle) and I1 (bottom). Blue indicates slough and yellow indicates ridges and tree islands.

MUCK FIRE MODEL: ECOLOGICAL ANALYSIS PERFORMED FOR THE 2007 DROUGHT

Further refinement through calibration and continued evolution of conceptual models for assessing ecological risk is needed to describe the system in a way that provides a meaningful perspective. Increasingly, such methods of translating scientific information into practical tools for managers and decision makers are becoming an integral component of environmental management. Attempting to balance the environment and water supply needs during extreme events (e.g., drought, flooding) is both challenging and continually evolving. Better methods must be provided to show assessments through time, but must also be able to evaluate and predict how various water management alternatives might exacerbate or alleviate ecological stress during extreme events. During the winter/spring 2007, South Florida experienced one of the worst droughts in recorded history. An interagency team was formed to evaluate the situation and consider temporary hydrologic deviations for the system, which included potentially lowering the targets for water levels within the WCAs. Beginning April 1, 2007, predicted water level stages from the South Florida Water Management Model were calculated for a baseline (no change) and three alternative operational schemes that each sought to lower the minimum allowable stages for the WCAs for the benefit of water supply. This ecological risk assessment was conducted to investigate the potential impacts of the alternatives to the WCAs ecosystem. Many ecological concerns arose, but it was clear that the potential for catastrophic peat fire and impacts on wading bird reproduction were of the greatest concern. The indices describe two ecological conditions that are considered extremely important to the physical and biological integrity of the Everglades. The predicted base and three alternative model runs were compared to evaluate how the proposed deviations might further affect conditions across the system.

To evaluate the impacts to wading bird reproduction, wood stork and white ibis colonies were given priority over colonies of other wading bird species because the wood stork is a federally endangered species and the white ibis is a state-listed species of special concern. Historical nesting data (Crozier et al., 2000) have also shown that in years with drought conditions, few herons and egrets attempt to nest. The wading bird nesting period (March through May) was divided into three simple hydroperiod recession rate categories (red, yellow, and green) based upon foraging observations in the Everglades (Gawlik, 2002), as presented in **Table 6-9**. These are the same classifications described in the *Hydrologic Patterns for Water Year 2007* section in this chapter.

Table 6-9. Wading bird nesting indicators used during the 2007 drought.



Recession rate criteria for rating wading bird nesting success during dry season - numbers represent 1 week changes in stage (ft)
Bad: = -0.60
Fair: -0.17' to -0.59'
Good: - 0.05' to - 0.16'
Fair: -0.04 to +0.04' for one week
Bad: -0.04 to +0.04' for 2 weeks or ≥ +0.041' for one week

The analysis included a subset of gauges (**Figure 6-44**) based on areas where birds have been foraging and also eliminating gauges based on water levels going below ground elevation before April 20, 2007, where it is less likely that foraging would continue. Water level stage was the primary factor in determining the combustibility of vegetation and soils (Wade et al., 1980). Water depths were calculated as stage minus ground elevation. These values were then ranked according to their inclusion in one of three categories (> 1 foot below ground, between 0.0 and 1 foot below ground, and above 0.0 foot above ground) under different water scenarios. Although the potential for peat fire is high when water drops to 1 foot below ground (Stephens and Johnson, 1951), the ranges took into consideration the fact that capillary action from a subsurface water table can keep upper level soils moist, and organic soils can retain moisture for considerable lengths of time following water level recession. In general, organic soils fail to ignite when moisture content is above 65 percent (Wade et al., 1980). At 1 foot or below, however, the potential for muck fire is high. Historical evidence for this was provided by a severe muck fire that occurred in the Rotenberger Wildlife Management Area in May 1999. At that time, water levels were 1 foot below ground for over two months.

In summary, there were no detectable differences between the baseline and alternative deviations for the WCAs when comparing the predicted interior marsh gauges within each of these impoundments. However, an adverse affect was noted by the elimination of foraging areas for birds adjacent to canals. The deviations appeared to have little effect on further creating favorable conditions for muck fires, but again, caution was noted near canals where a substantial drop in water level in the marshes adjacent to the canal occurred. There was a considerable decrease in water levels for Alternative 1 and again a sizeable difference between Alternative 1 and Alternatives 2 and 3 along marshes adjacent to canals (**Figure 6-45**).

On April 4, 2007, the District declared a water shortage emergency and activated its Emergency Operations Center to full status. In a letter to the USACE dated March 30, 2007, the District provided a Request for Temporary Deviations to the Regulation Schedules for the WCAs, followed by the Ecological Risk Assessment document and the predicted modeling results. These materials were reviewed by multiple agencies including the USACE and USFWS. A preliminary Finding of No Significant Impact (FONSI) was issued by the USACE on May 17 and a recommendation that Alternative 1 for WCA-1 and WCA-2A could be implemented when and if indicated by coastal well field triggers (e.g., salinity) established by the Emergency Management Task Force. Alternative 1 was selected because the USACE considered that the other more extreme alternatives would have more adverse effects on plant communities, habitat, and forage species for wildlife, including listed endangered species, with each deeper increment of deviation. The deviation for WCA-3 was denied to maintain the remaining forage refugia for the endangered snail kites within this impoundment.

The muck file potential continued to be a key concern and a task initiative was issued to provide muck fire hazard index reports weekly to the Emergency Operations Center. The muck fire hazard index was expanded to include 74 hydrologic monitoring gauges within the WCAs, ENP, and Holeyland and Rotenberger Wildlife Management Areas. The EdenWeb (established by the USGS) was utilized to obtain weekly, real-time water levels at each of these gauges (**Figure 6-46**). The indices utilized to monitor this year's drought described two ecological conditions that are considered extremely important to the physical and biological integrity of the Everglades. In addition to providing continuous, updated assessments throughout the drought period, we were able to evaluate how various water management alternatives might exacerbate or alleviate ecological stress during this time.

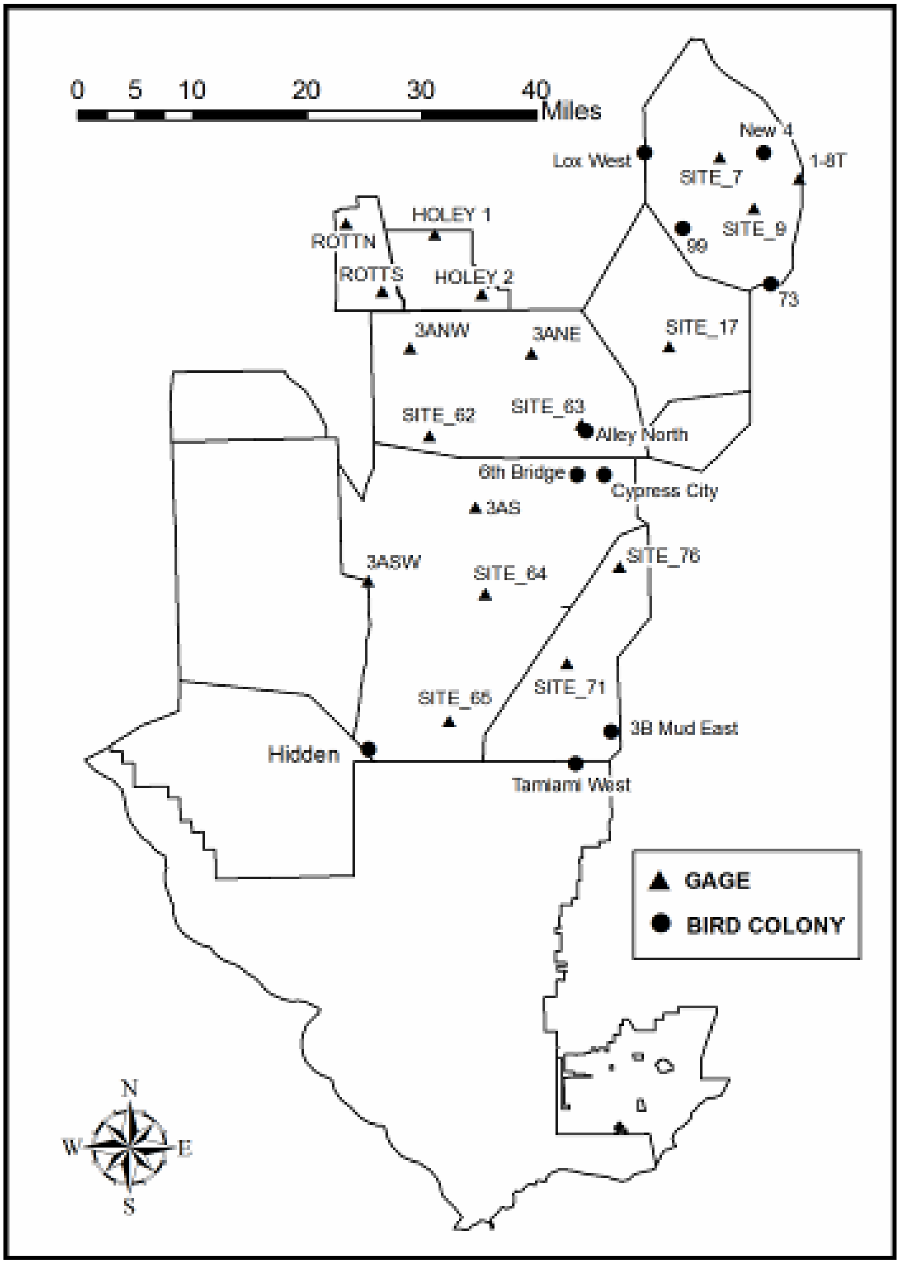


Figure 6-44. A map of the greater Everglades indicating the locations of gauges and bird colonies used to evaluate the alternatives.

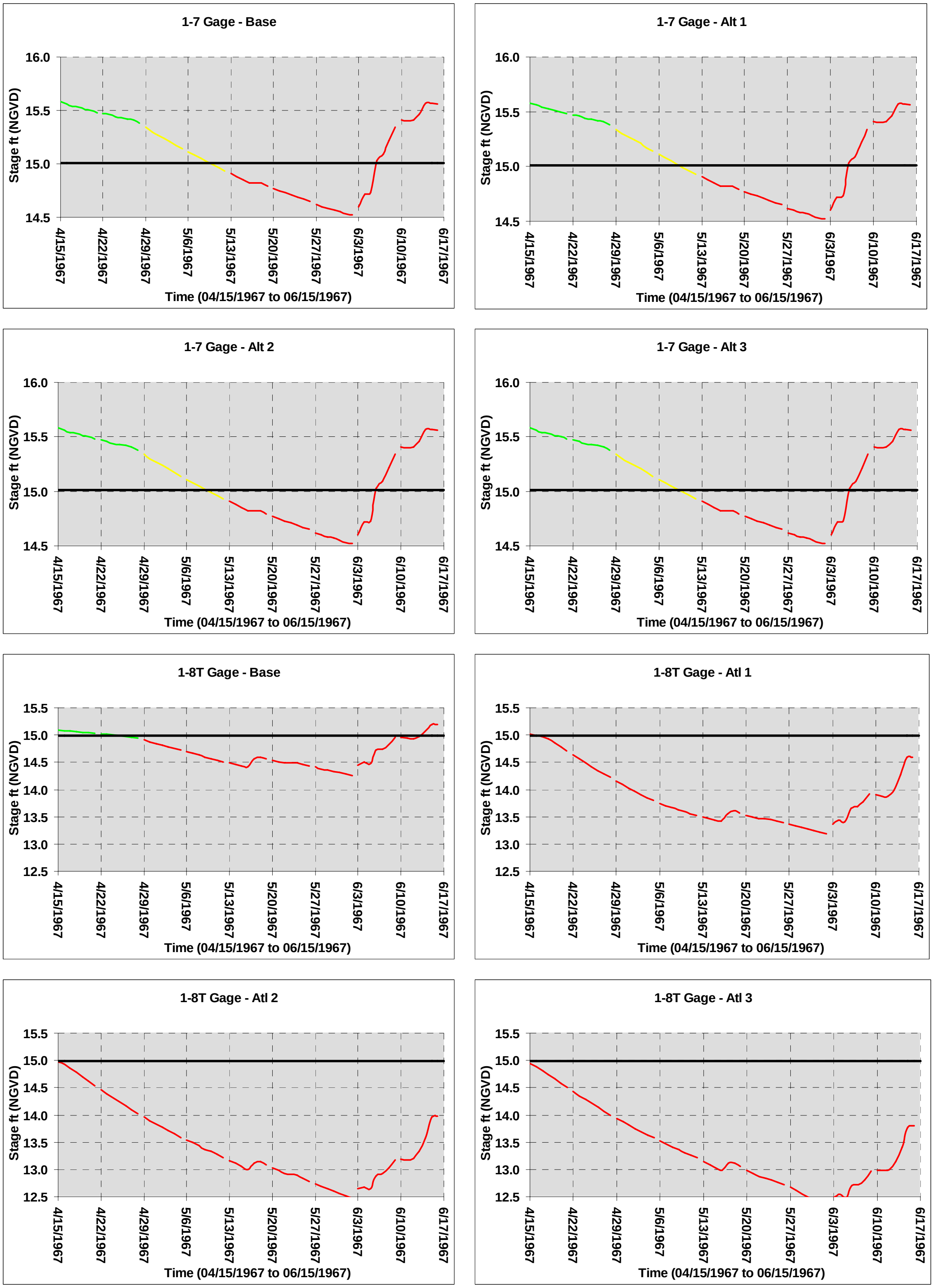


Figure 6-45. An example of the evaluation of recession rates for wading bird foraging and nesting for the baseline and alternative deviation runs. Green indicates good, yellow indicates fair, and red indicates bad; the black line represents the ground elevation.

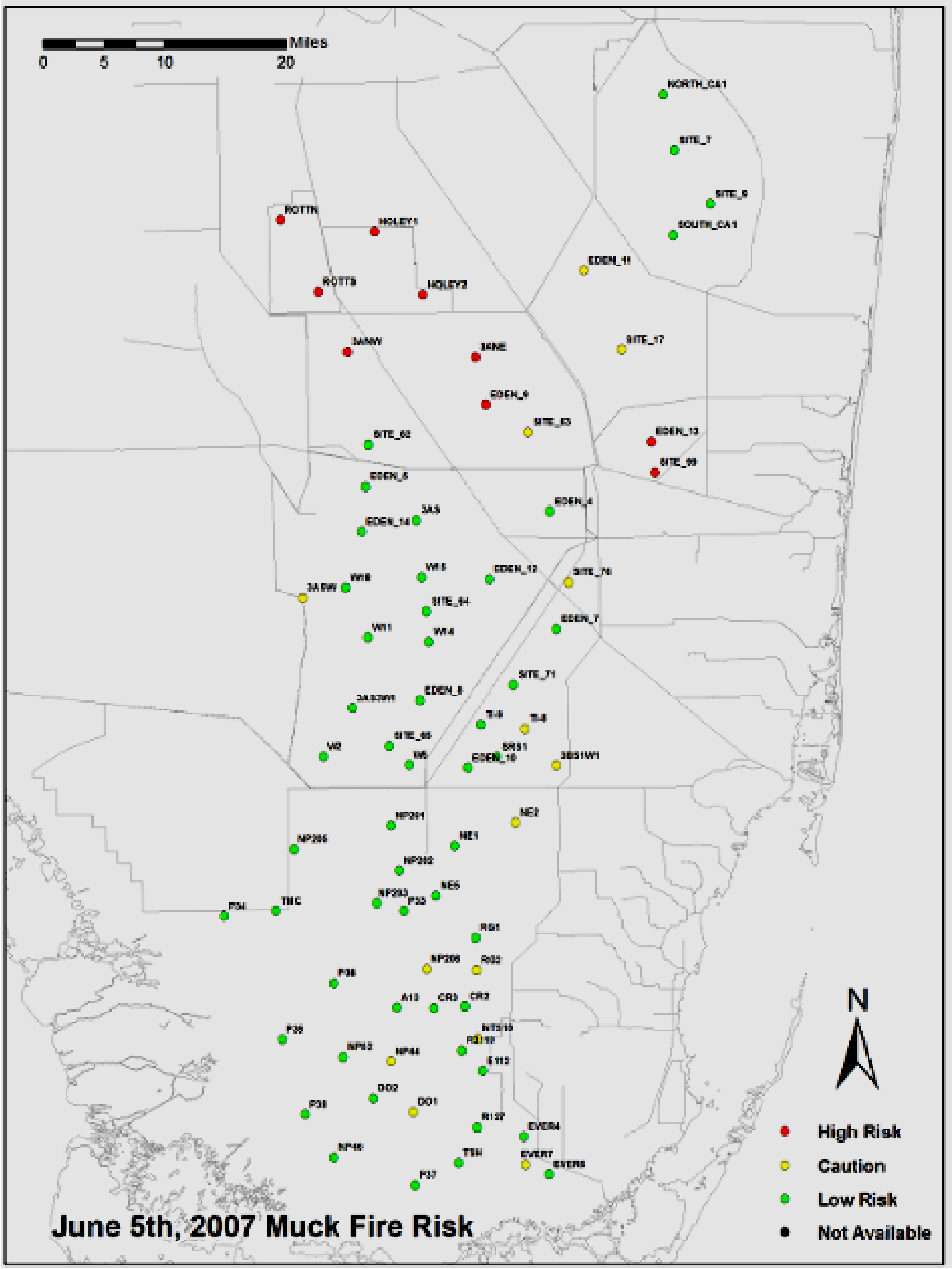


Figure 6-46. Example of a weekly update for the muck fire index. Green represents above-ground elevation, yellow represents below-ground elevation, and red represents 1 foot below-ground elevation.

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