Chapter 6: Ecological Effects of Hydrology

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SUMMARY

The studies and findings discussed in this chapter are presented within four main fields: wildlife ecology, plant ecology, ecosystem ecology, and landscape ecology. Programs of study were based on the short-term and long-term needs of South Florida Water Management District operations, regulations, permitting, environmental monitoring, Everglades Forever Act mandates, and the Comprehensive Everglades Restoration Plan (CERP).

Monitoring of wading bird nesting success is a coordinated effort between the South Florida Water Management District, Everglades National Park, University of Florida, U.S. Fish and Wildlife Service, National Audubon Society, Big Cypress National Preserve, Florida Fish and Wildlife Conservation Commission, National Oceanic and Atmospheric Administration, and Solid Waste Authority of Palm Beach County. Each year, this coordination results in the production of the Annual Wading Bird Report. This overview is critical for the evaluation of Everglades restoration and is summarized in this chapter.

Also included in this year's report is a discussion of the role of periphyton as basic nutrition for wildlife food webs. Previous studies have focused on periphyton community structure (McCormick et al., 1998), biogeochemistry (Reddy et al., 1999), and the importance of periphyton as an indicator of environmental degradation (McCormick and Stephenson, 1998). The studies summarized in this chapter demonstrate that the base of the Everglades food web has yet to be identified, even for the dominant invertebrates and fish. Many of the taxa that consume periphyton appear to select for diatoms and green algae and do not ingest cyanobacteria. Increasing the areal extent of native periphyton assemblages is one of the targets and performance measures for CERP, and therefore further investigation is necessary to understand how higher trophic levels are affected.

Wildlife on tree islands is poorly understood (Sklar and van der Valk, 2002), and the South Florida Water Management District (SFWMD or District) has been exploring ways to close this information gap. As a result, included in the *2004 Everglades Consolidated Report* are the design and initial results of a ground surveillance system used to document faunal activity on tree islands.

Previous Everglades Consolidated Reports (ECRs) have discussed plant nutrient and biomass allocations, hydrologic tolerances, competition for nutrients, physiological mechanisms used for soil aeration, and general growth patterns under various soil and water conditions. The District is beginning to use this information at its weekly operational meetings where issues of water supply, flood control, and environmental restoration are discussed. However, these three District missions operate at very different time scales. Although plants are the most obvious and critical component of the Everglades, it is no simple matter to understand and create a hydrologic condition that will both reduce the spread of invasives, such as cattail (*Typha* spp.), and foster natural plant growth and succession for slough plants, such as bladderwort (*Utricularia* spp.) – while at the same time not flood urban areas or interfere with water supplies. Consequently, plant studies continue.

In the Rotenberger Wildlife Management Area, hydrologic restoration has led to an increase in hydroperiods and water depths, and to more desirable plant species. However, cattail densities have not been reduced, and the nutrient content of the plant leaves indicates that the high nutrient soils can interfere with hydrologic restoration. On tree islands, belowground biomass dynamics seem to be influenced by both hydrology and aboveground forest characteristics. The tree islands subjected to the longest hydroperiods had the highest amount of belowground biomass. In contrast, the tree islands with the shortest hydroperiods had the lowest amount of belowground biomass. It is not clear why this occurs. It may be that more roots are needed in the flooded environment to aerate the soil, mine for nutrients, and stabilize the aboveground structure. These mechanisms will be discussed in the *2005 Everglades Consolidated Report*, after belowground root penetration cores are examined.

In 2002, permanent vegetation plots were established on tree islands to examine how hydrology has shaped the current distribution and abundance of woody tree species throughout Water Conservation Area 3 (WCA-3). Results show that in general, tree species diversity in WCA-3 tended to be highest on those centrally located tree islands with steep hydrologic gradients from head to tail. Although species richness might be a potentially useful indicator for CERP, it may not provide the best indication of the overall health of a tree island. A better possible indicator of long-term tree island health may be the complexity index (CI), which takes into consideration basal area, stem density, and canopy height, as well as the number of species.

Plant ecology studies in Florida Bay, which are needed to establish Minimum Flows and Levels, parameterize a submerged aquatic vegetation (SAV) model for CERP utilization. These studies indicate that the productivity of an important seagrass, turtlegrass (*Thalassia testudinum*), begins to fall off at between 45 and 50 Practical Salinity Units (PSU), levels that have been frequently observed in Florida Bay. The *Thalassia* models also indicate that the combination of elevated salinity greater than 50 PSU and a slight rise in average water temperature can cause collapse of the seagrass community.

The District continues to look at the total system. Previous ECRs have shown vegetation maps created with specially developed remote sensing and photointerpretation techniques. This year's ECR presents new information on tree island change detection, cattail change in WCA-2A, and the use of IKONOS imagery to detect Old World climbing fern (*Lygodium microphyllum*). Results show that cattail continues to spread throughout WCA-2A. In addition, sparse cattail continues to spread along distinct cattail-sawgrass boundaries and throughout the southern regions of WCA-2A. However, the rate of spread appears to be slowing down when compared to the 1991–1995 period. This decrease in rate may be due to the reduction in annual total phosphorus loads to WCA-2A during the 1995–2003 period, but it also may be due to hydrologic alterations, invasive habitat availability, and fire. Remote sensing results for *Lygodium* show that despite a significant amount of interference from cloud cover, as well as signal interference from cattail, there are 1,431 acres of *Lygodium* within WCA-1.

IKONOS imagery may be critical for *Lygodium* control and large-scale evaluations of current conditions. To illustrate this concept, this chapter covers the use of landscape-scale indices of pattern and structure to describe regions of healthy and degraded ridge and slough. In the future, these will be used to parameterize a heuristic model of ridge and slough development and sustainability.

Finally, this chapter outlines the construction and design of the Loxahatchee Impoundment Landscape Assessment (LILA), a new District ecosystem research facility designed to experimentally and reproducibly manipulate flow velocity and depth across a tree island/ridge-slough landscape.

INTRODUCTION AND BACKGROUND

Drainage of the Everglades changed South Florida from a subtropical wetland to a human-dominated landscape with a strong retirement, tourism, and agricultural economy. As a result, the Everglades is half its original size, water tables have dropped, hydroperiods have been altered, flows have been diverted, wetlands have been impounded, wildlife has been reduced, water quality has been degraded, and habitats have been invaded by nonindigenous plants. All of these impacts are caused directly or indirectly by an altered hydrology. Previous reviews of the ecological impacts of altered hydrology in the Everglades (Davis, 1943; Loveless, 1959; Craighead, 1971; McPherson, et al., 1976; Gleason, 1984; Tropical BioIndustries, 1990; Gunderson and Loftus, 1993; Davis and Ogden, 1994; Sklar and Browder, 1998; Sklar and van der Valk, 2002; Science Coordinating Team, 2003) have done much to increase public and scientific awareness of problems associated with altered hydrologic regimes and drainage. We will update this natural history by highlighting some of the recent research findings and experimental approaches sponsored by the South Florida Water Management District (SFWMD or District).

It is not always easy to show direct cause-and-effect relationships between altered drainage and ecosystem disturbance. It is difficult because a long period of record is required to filter out changes caused by climatic variability. In addition, many factors are associated with an altered hydrologic regime. It is recognized by wetland ecologists around the world that source, timing, duration, and depth of water will influence the biogeochemical processes in soils and water, the physiological processes of plant growth and decomposition, and the reproduction and migration of fauna (Sharitz and Gibbons, 1989; Patten, 1990; Mitsch and Gosselink, 2000, to name a few). In turn, soils, plants, and animals affect the hydrology. These ecological feedbacks allow for self-organization and succession (Odum, 1983). Usually, environmental restoration programs are attempts to redirect an altered rate or direction of succession. However, the available gene pool, climate, and antecedent conditions will affect succession. It is clear that the decreased extent of the Everglades and surrounding uplands, changes in the soil and topography, presence of exotic species, and the current system of canals and levees all constitute constraints on restoration to pre-drainage (pre-1880) conditions. The challenge facing science and society is to determine which key ecological driving forces will be restored to guide future succession in the remaining Everglades. The direction taken in the past has been deemed inappropriate for society and legally indefensible by the federal Settlement Agreement of 1991 and the state of Florida's Everglades Forever Act of 1994. Now, to redirect succession, a better ecological understanding must be developed of the differences between the current system and the pre-drainage Everglades.

This chapter should be viewed as a brief overview of just a few of the recent ecological research programs sponsored by the Everglades Division of the SFWMD. This chapter is divided into four major sections: wildlife ecology, plant ecology, ecosystem ecology, and landscape ecology. The wildlife section includes current wading bird statistics, a discussion of past and present research that supports the notion that periphyton forms the base of the Everglades food web, and a description of a motion detector/camera technique to document wildlife use of tree islands. In the plant ecology section, new data from the Rotenberger Wildlife Management Area, Florida Bay, and tree islands are used to illustrate recovery trends, physiological constraints, and root dynamics, respectively. The ecosystem section has a relatively in-depth description of the community composition found on tree islands in WCA-3. The landscape ecology section covers some of the large-scale observations associated with tree island loss in WCA-3, ridge and slough patterns, the use of the IKONOS satellite, and the three fields of study associated with the new Loxahatchee Impoundment Landscape Assessment (LILA).

WILDLIFE ECOLOGY

SUMMARY

Monitoring of wading bird nests in South Florida is a coordinated effort between the District, Everglades National Park (ENP or Park), University of Florida, U.S. Fish and Wildlife Service (USFWS), National Audubon Society, Big Cypress National Preserve, Florida Fish and Wildlife Conservation Commission, National Oceanic and Atmospheric Administration, and Solid Waste Authority of Palm Beach County. Each year, this coordination results in the production of the Annual Wading Bird Report by Dale Gawlik at Florida Atlantic University and Gaea Crozier at the SFWMD. This overview is critical for the evaluation of Everglades restoration and is summarized below. Also included in this year's report is a discussion of the role of periphyton as the basic nutrition for wildlife food webs. Previous studies have focused on periphyton community structure (McCormick et al., 1998), biogeochemistry (Reddy et al., 1999), and the importance of periphyton as an indicator of environmental degradation (McCormick and Stephenson, 1998). The studies summarized in this section demonstrate that the base of the Everglades food web has yet to be identified, even for the dominant invertebrates and fish. Many of the taxa that consume periphyton appear to select for diatoms and green algae and do not ingest cyanobacteria. Increasing the areal extent of native periphyton assemblages is one of the targets and performance measures for CERP. Therefore, further investigation is required to understand how higher trophic levels are affected. Wildlife on tree islands is also poorly understood (Sklar and van der Valk, 2002), and the District has been exploring ways to close this information gap. Therefore, included in this report are the design and initial results of a ground surveillance system used to document faunal activity on tree islands.

WADING BIRD MONITORING

Performance measures based on wading birds are an important component of CERP. The number of wading bird nests in the Everglades is used to set targets for CERP. The location of nesting colonies, the number of nests, and the timing of nesting initiation within the Everglades will be monitored to evaluate the progress of the Everglades restoration effort. The information reported here on wading bird nesting efforts represents a compilation of data collected by a variety of investigators who are monitoring wading bird nesting in South Florida (Gawlik and Crozier, in prep). The time period covered by this report is the nesting season that began January 2003 and ended in the summer of 2003.

The estimated number of wading bird nests (excluding cattle egrets, which are not dependent on wetlands) in South Florida in 2003 was 33,739. This is a 51-percent decrease from last year, which was the best nesting year since the 1940s. It is also a 12-percent decrease from 2001, which was one of the best years in a decade. The lower nesting effort this year can be attributed to almost 20,000 fewer white ibis and 12,000 fewer snowy egret nests in the Water Conservation Areas compared to last year. There was also a 19-percent decrease in wood stork nests in South Florida compared to last year. Although the 2003 nesting year had fewer nests than the past two years, it was still one of the better nesting years over the last decade.

Nesting effort differed among regions in the Everglades. WCA-3 supported the largest number of nests (54 percent), while Everglades National Park supported the lowest number of nests (8 percent). WCA-1 supported about 38 percent of the nests in the Everglades. This is consistent with last year, although WCA-3 supported a larger percentage of nests (70 percent) last year. WCA-1 and ENP supported 25 percent and 5 percent, respectively.

Unfortunately, 2003 was noteworthy in that there was considerable nest failure by wood storks. Heavy rains during the nesting season caused water levels to increase rapidly multiple times during the breeding season. Approximately 70 percent of the wood stork nests were abandoned between the first week of March and the second week of April. During this time period, birds had eggs or small chicks in their nests. Only minor abandonment was observed for wood storks between mid-April through June, when chicks were older, even though water level reversals continued to occur. These observations are consistent with information gathered in previous years suggesting that birds may be more sensitive to water level reversals during the earlier part of the nesting cycle. In contrast to wood storks, abandonment by white ibises appeared to be relatively minor.

The 2003 nesting season was also noteworthy in that there appeared to be a higher than normal nesting asynchrony in comparison to previous years. During a typical nesting season, the number of wading bird nests peaks in April then rapidly decreases. However, this year wading birds initiated new nests throughout the entire breeding season, even as late as mid-June. Nesting asynchrony is likely a response to reduced food availability due to periodic rainfall events during the dry season. Rainfall events increase water levels, allowing prey to disperse (i.e., producing lower densities) and thereby reducing their vulnerability to capture.

Three species groups met the numeric nesting targets proposed by the South Florida Ecosystem Restoration Task Force (**Table 6-1**). Two other targets for Everglades restoration are an increase in the number of nesting wading birds in the coastal Everglades and a shift in the timing of wood stork nesting to earlier in the breeding season (Ogden, 1997). The 2003 nesting year showed no improvement in the shift of colony locations or the timing of wood stork nesting.

Table 6-1. Numbers of wading bird nests in the Water Conservation Areas and Everglades National Park in comparison to what is considered the historic base. The three-year running averages are reported because Ogden et al. (1997) recommends this measure as a way to smooth the effects of large, interannual variation and to make trends more obvious in the number of nests among years.

Species	Base low/ high	1994–1996	1995–1997	1996–1998	1997–1999	1998–2000	1999–2001	2000–2002	2001--2003	Target
Great Egret	1,163/ 3,843	4,043	4,302	4,017	5,084	5,544	5,996	7,276	8,535	4,000
Snowy Egret/ Tricolor Heron	903/ 2,939	1,508	1,488	1,334	1,862	2,788	4,269	8,614	8,089	10,000-20,000
White Ibis	2,107/ 8,020	2,172	2,850	2,270	5,100	11,270	16,555	23,983	20,725	10,000-25,000
Wood Stork	130/ 294	343	283	228	279	863	1,538	1,868	1,554	1,500-2,500

FOOD WEB STUDIES, PAST AND PRESENT

Periphyton, a complex matrix of algae, bacteria, and other microorganisms, is often heralded as the base of the Everglades food web (Gunderson and Loftus, 1993; Browder et al., 1994; Rader, 1994). Despite a relatively high periphyton standing crop (88.2 g m^{-2}), the Everglades supports a surprisingly low standing stock of invertebrates (0.64 g m^{-2}) and fish (1.2 g m^{-2}) (Turner et al., 1999). While there is good reason to suspect that periphyton is the base of the Everglades food web, the supporting research is notably sparse compared to other aquatic ecosystems. Because the structure of food webs is dependent, in part, on the physico-chemical environment, an understanding of current food web dynamics is required to better predict responses to Everglades restoration and contaminate transport. This is especially important when one considers that, in some cases, the length of the food chain is very short (periphyton → fish → wading birds). The results of Everglades food web studies are summarized briefly here to highlight both their importance and the lack of understanding surrounding them.

The conclusion that periphyton is the base of the Everglades food web comes from studies of gut content analysis of invertebrates and fish (Hunt, 1953; Browder et al., 1991; Rader, 1994). More recently, the stable isotopes ^{13}C, ^{15}N, and ^{34}S have been successfully used to elucidate aquatic food webs. An organism's isotopic signature reflects what it consumes (i.e., you are what you eat). Stable isotopes are the nonradioactive form of an element. Using stable isotopes, trophic levels are discerned. For example, true herbivores in the Everglades will have C ($\delta^{13}C$) and N ($d^{15}N$) isotopic signatures that are 2 to 4 percent greater than their food resource (e.g., periphyton).

Stable isotope analyses of Everglades plants and animals suggest that periphyton is consumed but that detritus (organic matter that results from the decomposition of plant material) may also be an appreciable carbon source for some taxa (Wankel and Kendall, 2001; Kendall et al., 2002). Moreover, isotopic analysis of samples collected as part of the U.S. Environmental Protection Agency's Regional Environmental Monitoring and Assessment Program (REMAP) suggests that there is considerable spatial and temporal variation in the signatures of all components of the food web (Bemis et al., 2003; Wankel et al., 2003). Whereas stable isotopes have been used to successfully determine the trophic structure of lakes and estuaries, spatial and temporal variation in biogeochemical processes within the Everglades complicates the determination of the Everglades food web (Kendall et al., 2002). Concerns over the mercury levels in sport fish and known deleterious health effects led Cleckner et al. (1997) to study the trophic transfer of methylmercury in northern Everglades food webs. Based on mercury bioaccumulation, the basic food web model for the Everglades is: periphyton → amphipods → shrimp → fish → predatory hemipterans, when present. This pattern varies spatially along hydrologic and nutrient gradients and temporally. Although studies of mercury biomagnification provide necessary and important ecological information, the use of mercury as a tracer to understand the complexities and nuances of Everglades food webs is limited, because the mechanisms regulating mercury bioconcentration and bioaccumulation are poorly understood. Nevertheless, these studies indicate that food webs among habitat types (e.g., sloughs, sawgrass stands, and cattail) and along nutrient and hydrologic gradients are very different.

Everglades periphyton consists of metaphyton (floating mats), epiphyton (attached to plants), and epipelon (attached to the bottom). The most common algae in the Everglades are cyanobacteria, followed by diatoms, green algae, and desmids, a unique green algae associated with soft water (Swift and Nicholas, 1987; Browder et al., 1994; McCormick et al., 2002). Periphyton distribution is tightly coupled to hydrology and water quality. As a food resource, periphyton differs in its quality. Many cyanobacteria are considered poor quality food, because they lack specific omega-3 fatty acids or they have mucopolysaccharide sheaths or toxins that inhibit consumption (Browder et al., 1991; Browder et al., 1994). In addition, it is hypothesized that calcium carbonate precipitation, a common occurrence in pristine regions of the Everglades, may also make cyanobacteria unpalatable (Browder et al., 1991). Diatoms and green algae have a higher food quality, because they tend to have low C:N ratios and high lipid content. Little is known as to whether invertebrates or fish select for certain periphyton or detritus.

A major uncertainty is what the organisms at intermediate trophic levels are using as their carbon source. Stable isotope and gut content analyses of the most common invertebrates indicate that diets are species-specific and in some cases are not periphyton. For example, stable isotopic signatures of scuds (*Hyalella azteca*) and mayflies (*Caenis diminuta* and *Callibaetis floridana*) collected along the nutrient gradient in WCA-2A are similar to the sampled plant matter (**Figure 6-1**, panels A and B) (Wankel and Kendall, 2001). This suggests that these animals are not consuming periphyton, benthic detritus, or macrophytes. Gut content analysis of animals collected concomitantly supports the isotope data (Anderson, 1999). Anderson concluded that approximately 80 percent of the production for these two taxa was attributed to amorphous detritus (**Figure 6-1**, panels C and D). Analysis of other taxa indicated that crayfish (*Procambarus* spp.) consumed amorphous detritus, vascular plant detritus, and animals. These results differed from those of Browder, et al. (1991) who found that 50 percent of the diet of crayfish was algae. Grass shrimp (*Palaemonetes paludosus*) consumed mostly chironomids, ostracods, and oligochaetes. However, gut content analysis results should be cautiously interpreted, as consumption does not equal assimilation. In other words, although detritus or algae may comprise the bulk of material in an organism's gut, this is not evidence that the organism is deriving any nutritional value from the material.

Snails (Planorbidae, Physidae, and Hydrobiidae) consumed mostly periphyton. Shuford (unpublished data) has shown that the composition of invertebrates differs among habitat types. Assemblages within sawgrass ridges and within cattail habitats and sloughs were not similar to one another. To understand food web dynamics in relation to hydrology, it may be necessary to evaluate species-specific diets at the local level (i.e., within a slough or sawgrass stand).

Small fishes are an important intermediate trophic level within the Everglades ecosystem (Hunt, 1953; Gawlik, 2002). The six most numerous species are the least killifish (*Heterandria formosa*), eastern mosquitofish (*Gambusia holbrooki*), golden topminnow (*Fundulus chrysotus*), bluefin killifish (*Lucania goodei*), sailfin molly (*Poecilia latipinnis*), and flagfish (*Jordanella floridae*) (Loftus and Kushlan, 1987; Loftus, 2000). The diets of four of these fish consist of periphyton, but the proportion consumed differs among species. Algae are typically abundant within the guts of the sailfin molly, flagfish, least killifish, and eastern mosquitofish (Hunt, 1953). Of these, the sailfin molly and flagfish are herbivores, whereas the least killifish and eastern mosquitofish are omnivores. Work by Browder, et al. (1991) suggests preferential consumption of diatoms and green algae rather than cyanobacteria. Proportions of these two groups of algae tended to be higher than cyanobacteria in the guts and stomachs of the least killifish and sailfin molly. Both the golden topminnow and bluefin killifish are carnivorous. Rotifers, copepods, cladocerans, dipterans, ostracods, and other insects are common prey for omnivores, whereas ephemeropterans and mollusks are occasionally consumed. Diets of the golden topminnow and bluefin killifish are not well documented.

In conclusion, the Everglades food web is poorly understood. The studies summarized here clearly demonstrate that the base of the Everglades food web has yet to be identified, even for the dominant invertebrates and fish. Limited data suggest that consumers may select for diatoms and green algae and avoid cyanobacteria. Detritus appears to be a major proportion of the diets of some numerically dominant invertebrates. However, detritus in the Everglades is poorly characterized. Alterations in the periphyton structure and function in response to hydrologic restoration could have either positive and/or negative effects on Everglades food webs. These effects might be dramatic, considering that the energy pathway from periphyton to wading birds consists of three levels (**Figure 6-2**). Alternatively, pathways for other organisms may be more complex (**Figure 6-2**).

Because increasing the areal extent of native periphyton assemblages is one of the targets and performance measures for the Comprehensive Everglades Restoration Plan (CERP), further investigation is required to understand how higher trophic levels are affected. Within CERP, the food web research effort will include spatial and temporal surveys conducted as part of the Monitoring Assessment Plan as well as experiments conducted within the Loxahatchee Impoundment Landscape Assessment (LILA) macrocosms.

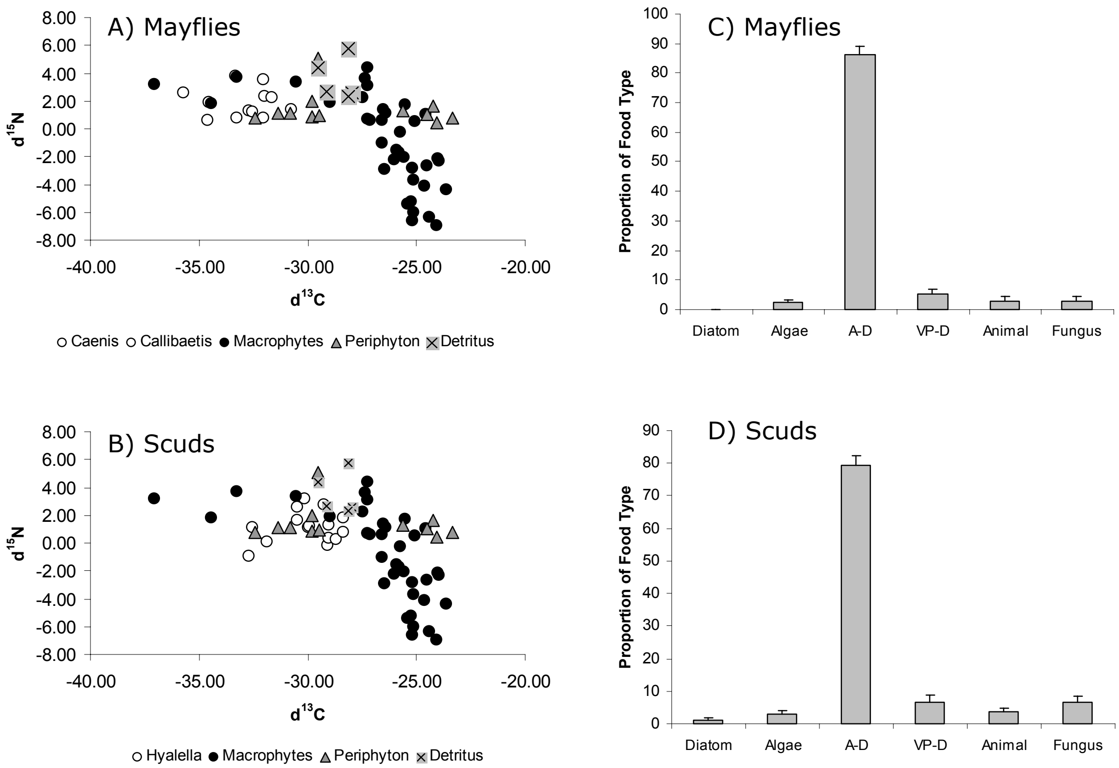


Figure 6-1. Panels A and B: Stable isotopic signatures for two taxa common to the Everglades (mayflies and scuds) and their potential food resources. Note that the mayfly and scud signatures overlap those of periphyton and macrophytes, indicating that these are not the food resource. Panels C and D: Results of gut content analysis of mayflies and scuds. Note that amorphous detritus (A-D) can be attributed to the majority of production. Stable isotope and gut content data are from Wankel and Kendall, 2001, and Anderson, 1999, respectively. VP-D is vascular plant detritus.

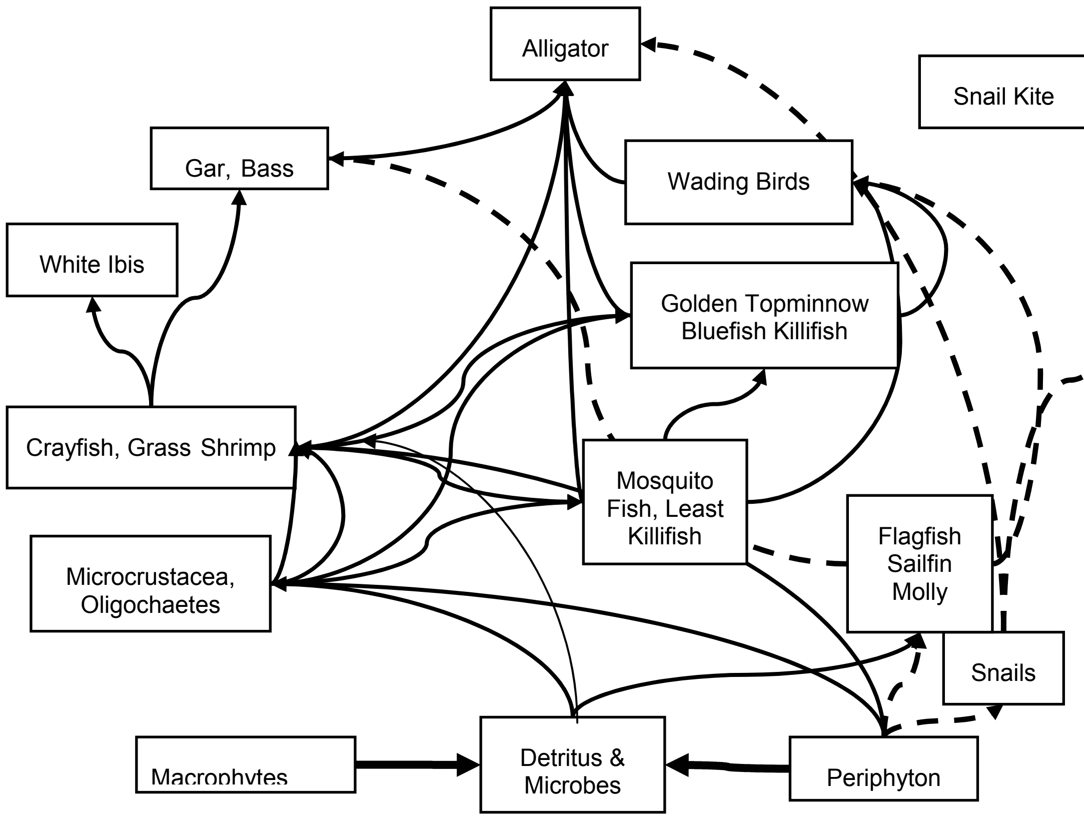


Figure 6-2. Diagram of the Everglades food web showing short chains (dashed lines) and complex food chains (solid lines).

NONINVASIVE CAMERA TRAPPING TECHNIQUE TO MONITOR WILDLIFE ON TREE ISLANDS

Numerous wildlife species utilize Everglades tree islands as refugia, foraging grounds, and nesting sites (Gawlik et al., 2002; Mashaka et al., 2002; Gaines et al., 2002; Mazzotti and Brandt, 1994; Gunderson and Loftus, 1993). Therefore, tree islands are viewed as important habitat for a multitude of terrestrial, arboreal, avian, and semiaquatic species. Aquatic turtles within these areas of the northern Everglades are of special concern, because they require sites that are not inundated with water for nesting (SFWMD, 2003). There are nine aquatic turtle species known to exist in and around the northern Everglades watershed that may potentially use tree islands as nesting sites (SFWMD, 2003; Ashton and Ashton, 1991; Iverson and Etchceger, 1989). While some of these turtles and other types of wildlife may be dependent on tree islands for nesting and foraging sites, little information currently exist documenting wildlife usage. Available nesting sites in the northern Everglades include tree island heads, alligator nests, and levees surrounding the impounded areas (Kushlan & Kushlan, 1980; Enge et al., 2000). There is a high probability that those nests built on or near levee roads may be crushed by traffic or desiccated due to the dryness of these areas.

There are no known methods for trapping large aquatic turtles that utilize tree islands. Pitfall traps tend to fill with water, as they are only 0.00 to 0.15 meters (Heisler et al., 2002) above the surrounding waterline (many tree island heads can be inundated with water during the wet season). Flooded pits allow many species to simply climb out, while other smaller faunal species would potentially drown. Funnels traps are too small, and radio tracking is expensive and time consuming. Therefore, a pilot study is currently being conducted using trail monitors to record the presence or absence of small- to medium-size fauna on tree island heads. This method is commonly referred to as camera trapping. Camera trapping uses self-triggering cameras to capture photographs of animals. Camera trapping has generally been used to record larger species, such as deer, moose, bears, tigers, and coyotes (Kucera and Barrett, 1993; Wilton et al., 1994; Garrison et al., 1999). There are also records of studies capturing on film various smaller species, such as raccoons, muskrats, mice, and several other small mammals, utilizing camera trapping techniques (Kucera and Barrett, 1993; Foresman, 2001). For this study, the trail monitors were placed on the ground of the tree island head in order to record the presence of small- to medium-size faunal species, with an emphasis on aquatic turtle species.

Trailmaster 1550© units were connected to Canon A-1© cameras modified by Trailmaster©. Modified U.S. Army surplus ammunition boxes (30 cm x 20 cm x 15 cm) were used to house the units (Silvy, 1999). A transmitter sends an infrared beam of light to the receiver over a distance that can be as great as 25 meters or as little as 1 meter or less (Goodson, 1992). When the receiver is no longer receiving the infrared beam, this indicates that an object is blocking the beam. The receiver counts this blockage as an event. Events are numbered and logged along with the date and timestamp of each event in the receiver's memory. At the same moment, the receiver sends a signal to an attached camera to take a photo of the source of the beam blockage.

The units can capture wildlife photos 24 hours a day, as long as there is still film to be exposed. Adjustments can be made to the receiver's sensitivity (this is the amount of time the beam must be blocked to send a signal to the camera). The receiver can also be set to have a temporal delay between consecutive pictures being taken. For example, if a particular animal remains in front of the unit for 20 minutes, only four pictures will be taken (not the entire roll) when the receiver is set with a 5-minute delay. For this study, the receiver was given a sensitivity setting of three (where one is the most sensitive setting, and thirty is the least sensitive setting) and a camera delay of 5 minutes.

To test this methodology, an elevated tree island (3AS2) head in the southwest portion of Water Conservation Area 3A was monitored. Trail monitoring units were set on the ground close to the water where there was little vegetative debris to impede turtles and other animals from freely exiting and entering the water. The housings were staked into the ground so that animals could not move the units. Each transmitter was approximately 2.5 meters away from a corresponding receiver. Seven complete units were set up in January of 2003, and the film was checked every two to three weeks and changed when necessary.

As of July 2003, 25 faunal species had been captured on film and identified. Five of these species were aquatic turtles (**Table 6-2**). **Figure 6-3** is a photographic sample from this camera trapping methodology. In March, as the nesting season for many turtles began, the number of turtles photographed increased. Species such as the eastern narrowmouth toad (*Gastrophynes carolinensis*), which is known to exist on some tree island heads, would most likely be too small in size and too fossorial in nature to trigger the camera units. Species like these are better captured using traditional trapping methods. This camera trapping methodology has proven to be a good, noninvasive methodology to document the presence or absence of several wildlife species for Everglades tree islands.

Table 6-2. Species documented utilizing the camera trapping method on tree island 3AS2 in Water Conservation Area 3A.

Common Name	Scientific Name
Redbelly Turtle	*Pseudemys nelsoni*
Peninsular Cooter	*Pseudemys floridana*
Florida Softshell Turtle	*Trionyx ferox*
Snapping Turtle	*Chelyndra serpentina*
Striped Mud Turtle	*Kinosternon baurii*
Gray Catbird	*Dumetella carolinensis*
Carolina Wren	*Thryothorus ludovicianus*
Northern Cardinal	*Cardinalis cardinalis*
Ovenbird	*Seiurus aurocapillus*
Common Grackle	*Quiscalus quiscula*
King Rail	*Rallus elegans*
Green Heron	*Butorides virescens*
Unidentified Rodent Species	Possibly Two Species
Marsh Rabbit	*Silvilagus palustris*
Eastern Gray Squirrel	*Sciurus carolinensis*
Whitetail Deer	*Odocoileus virginianus*
Southern Black Racer	*Coluber constrictor*
Eastern Garter/Ribbon Snake	*Thamnophis sirtalis/sauritus*
Eastern Mud Snake	*Farancia abacura*
Southeastern Five-lined Skink	*Eumeces inexpectatus*
American Alligator	*Alligator mississippiensis*
Southern Leopard Frog	*Rana sphenocephala*
Various Invertebrates	Five Distinct Orders/Species

Figure 6-3. An example of the photo quality created by the camera trapping technique to document wildlife utilization of tree islands. A redbelly turtle (*Pseudemys nelsoni*) is pictured.

PLANT ECOLOGY

SUMMARY

Previous ECRs have discussed plant nutrient and biomass allocations, hydrologic tolerances, competition for nutrients, physiological mechanisms used for soil aeration, and general growth patterns under various soil and water conditions. The District is beginning to utilize this information at its weekly operational meetings where issues of water supply, flood control, and environmental restoration are discussed. However, these three District missions operate at very different time scales, and although plants are the most obvious and critical component of the Everglades, it is no simple matter to create a hydrologic condition that will both reduce the spread of invasives, such as cattail, and foster natural plant growth and succession for slough plants, such as bladderwort – while at the same time not flood urban areas or interfere with water supplies. Consequently, plant studies continue.

In the Rotenberger Wildlife Management Area (RWMA), hydrologic restoration has resulted in increased hydroperiods and water depths, and in more desirable plant species. However, cattail densities in this marsh environment have not been reduced, and the nutrient content of the plant leaves indicates that the high-nutrient soils can interfere with hydrologic restoration. On tree islands, belowground biomass dynamics seem to be influenced by both hydrology and aboveground forest characteristics. The tree islands subjected to the longest hydroperiods had

the highest amount of belowground biomass. In contrast, the tree islands with the shortest hydroperiods had the lowest amount of belowground biomass. It is not clear why this occurs. It could be that more roots are needed in the flooded environment to aerate the soil, mine for nutrients, and stabilize the aboveground structure. These mechanisms will be discussed in the *2005 Everglades Consolidated Report*, after belowground root penetration cores are examined.

Finally, plant ecology studies in Florida Bay, which are needed to establish Minimum Flows and Levels, parameterize a submerged aquatic vegetation (SAV) model for CERP utilization. These studies indicate that the productivity of an important seagrass, turtlegrass (*Thalassia testudinum*), begins to fall off at between 45 and 50 Practical Salinity Units (PSU), levels that have been frequently observed in Florida Bay. The *Thalassia* models also indicate that the combination of elevated salinity greater than 50 PSU and a slight rise in average water temperature can cause collapse of the seagrass community.

RESTORATION OF ROTENBERGER VEGETATION

For the past two years, the Rotenberger Wildlife Management Area has experienced an improved wet/dry-season cycle more closely resembling a natural hydrology based on stage predictions from the Natural System Model (NSM). A primary goal of hydropattern restoration in the marsh is to reduce the risk of muck fires and soil oxidation brought on by extended dry seasons. This is achieved through increased hydroperiods utilizing STA-5 discharges. Keeping the soils saturated for extended periods of time into the dry season will aid in preventing excessive soil drying, thereby stemming the conditions conducive to muck fires, soil oxidation, and subsequent soil loss. In 2002 and 2003, no reported muck fires were recorded. Additionally, water levels were maintained at sufficient levels through 2003 to adequately retain soil moisture.

Since STA-5 began discharging into the RWMA (July 2001), the hydroperiod (the length of time the marsh is flooded) has increased from a pre-discharge (prior to July 2001) length of 3.25 months to an average post-discharge length of 7 months at the 404 permit monitoring stations. Corresponding with the increase in hydroperiod was an increase in overall water depth. On average, water levels have risen from 13 cm (pre-discharge) to 21 cm (post-discharge), as recorded at the 404 monitoring stations.

The change in hydrology stems from the hydropattern restoration plan for the RWMA as outlined by the Clean Water Act section 404 and the Everglades Forever Act (EFA) operating permits. Currently, the RWMA hydropattern restoration, which is monitored by an interagency group, is in a phased approach. Water deliveries from Stormwater Treatment Area 5 (STA-5) are based on average stage levels within Rotenberger and on the phosphorus concentration of the inflows. Present operations plans dictate the circumstances in which G-410, which pumps water from STA-5 into the RWMA, is operated, based on water needs and water quality. When total phosphorus (TP) concentrations in STA-5 effluent are greater than 50 ppb, no water flows into Rotenberger. The interim operations will allow time to assess the potential impacts associated with STA discharges into the marsh. Several biological and environmental parameters are being monitored to evaluate the potential effects on ecological processes occurring in Rotenberger. One process under study is vegetation community shifts associated with hydrology changes. Another process is cattail expansion located downstream of the discharge site and overall spatial coverage throughout the tract.

While long-term changes in a vegetation community require longer periods of time to develop, short-term changes in response to improved hydrology are currently evident. As reported last year, due to the increase in saturated and flooded soil conditions, an increase in percentage of obligate plants along with a corresponding decrease in facultative wetland plants continues to be a current trend (**Figure 6-4**). Moreover, virtually no facultative plants have been recorded since the increase in water depths and hydroperiod began in July 2001. It should be noted, however, that species composition in these categories is an important factor and should be taken into consideration when assessing vegetation shifts.

While an increase in the occurrence of obligate plants is desirable, some of these obligate species are indicative of high-nutrient conditions. Obligate species such as arrowhead (*Sagittaria lancifolia*), pickerelweed (*Pontederia cordata*), and spikerush (*Eleocharis cellulosa*) are present throughout the area and are considered desirable marsh species. In contrast, winged loosestrife (*Lythrum alatum* var. *lanceolatum*) and coastal plain willow (*Salix caroliniana*), which also are obligate species, are not as desirable because they can reduce diversity as they expand. Each plant is associated with high-nutrient conditions and has been recorded on each macrophyte survey performed since the 404 monitoring program began in 1997. Furthermore, stand densities of southern cattail (*Typha domingensis*), another obligate species, have increased as a result of favorable growing conditions (i.e., improved hydrology and nutrient-rich soils), although this is an expected event. The persistence of wetland plants indicative of high-nutrient conditions is attributed to past and current soil conditions.

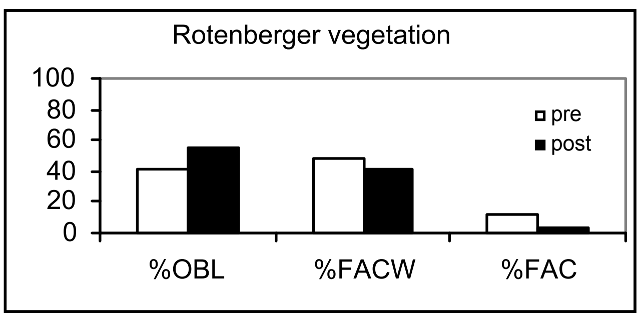


Figure 6-4. Continuing with the qualitative shift in 2002, an increase in the occurrence of obligate species with a corresponding decrease in facultative wetland species is related to changes in hydrology.

Although TP concentrations in post-discharge surface water from the RWMA have decreased, soil nutrient levels remain relatively constant both on a concentration basis (mg kg^{-1}) and a mass basis (mg cm^{-3}) (**Table 6-3**). One explanation for the lower surface water TP in post-discharge samples may be that the plant community located immediately downstream of STA discharge is taking up most of the phosphorus. Evidence of TP immobilization by the plant community is indicated by the high increase of TP tissue nutrient concentrations (**Table 6-3**). Tissue nutrient concentrations in sawgrass and cattail have increased in live leaves and roots of post-discharge samples relative to pre-discharge samples. Due to the increase in hydroperiod and nutrient input (favorable growing conditions), a corresponding increase in plant biomass per unit area for both sawgrass and cattail was recorded in 2003.

Based on the current plant community composition, as well as the surface water quality downstream of the STA, it appears that increases in water level and hydroperiod can be, in the short-term, beneficial to the restoration of RWMA vegetation communities. However, water quality flowing from the STA into Rotenberger has to improve in order to decrease cattail expansion. Currently, when TP is above 50 ppb, water is not discharged in order to avoid long-term effects in the soil properties of Rotenberger. Eventually, the water quality criteria will be revised to further reduce P-loading rates, thereby facilitating the shift of the current vegetation community to more desirable obligate wetland species. Restoring Rotenberger from a short-hydroperiod, fire-prone wetland to a wetland with a more natural hydroperiod that is dominated by native wetland species will required a long-term adaptive monitoring program to assess water-soil-plant interactions and to refine long-term water discharge operations.

Table 6-3. Total phosphorous (TP) concentrations for pre-discharge and post-discharge comparisons in the RWMA for surface water (SW) and soil, and in live leaves (LL) and roots for sawgrass (Saw) and cattail (Cat).

	SW mg/L	Soil mg/kg	Saw, LL mg/kg	Cat, LL mg/kg	Saw, roots mg/kg	Cat, roots mg/kg
Pre-discharge	0.032	633	418	697	361	353
Post-discharge	0.017	607	505	946	1206	900

BELOWGROUND BIOMASS ON CONTRASTING TREE ISLANDS

Belowground biomass, measured by the presence or absence of roots, has not yet been studied for trees on Everglades tree islands. Measurement of belowground biomass is crucial to understanding organic matter dynamics of tree islands, especially hydrology – which is directly related to the creation of organic matter – and its effect on root dynamics. It is important to note that belowground processes are not only affected by hydrology but also by forest structure characteristics and soil nutrients.

In most ecosystems, fine roots comprise only a small proportion of total root biomass, but they are associated with many important processes. For instance, fine roots are responsible for nutrient and water absorption, mycorrhizal nutrient transformations, and addition of organic matter and nutrients to the soil through rapid turnover. Moreover, fine root systems of plants play an important role in the storage of organic matter and nutrients and in the fluxes of energy and matter in the biosphere. The amount of carbon and nitrogen cycled via fine root decomposition may be as much as or more than that returned to the soil from aboveground litterfall (Majdi, 1996). It has been suggested that fine root production accounts for up to 75 percent of total net primary production (NPP) in some forests (Nadelhoffer and Raich, 1992). Fine root dynamics represent a significant source of energy and nutrient flow through forested systems, particularly for those systems that are subject to periodic disturbances that increase the frequency and extent of fine root turnover (Baker et al., 2001).

The objective is to determine the effect of longer hydroperiod on belowground biomass of woody vegetation located on Everglades tree islands, with the hypothesis being that there are differences in belowground biomass between tree islands that experience a longer hydroperiod (flooded) relative to tree islands with a shorter hydroperiod (wet). A wet condition refers to tree islands that experience no more than six months inundation at a 0- to 20-cm water level. A flooded condition refers to tree islands that experience inundation for greater than six months at a greater than 20-cm water level. This is a preliminary study, designed to evaluate techniques, and it will be expanded if results prove valuable for better hydrologic management for restoration of tree islands.

Methodology

The three tree islands used for this study were chosen based on their contrasting hydrological patterns found in the Everglades ecosystem. The three tree islands are basically the same. However, they differ in terms of their community composition and their hydrologic regimes. 3AS2 is a tropical hammock island that has a short hydroperiod (~3 months inundation). 3AS3 is a cocoplum (*Chrysoblanus icaco*)-dominated tree island with a moderate hydroperiod (3–6 months inundation). 3AS5 is a flooded environment with an extended hydroperiod (>6 months inundation) and is dominated by willow (*Salix caroliniana*).

A total of 48 soil cores were taken among the three islands. Four soil cores were taken in each of four measured plots on each tree island. Two of these 10 x 10-m plots were located on the head of the island, and two were located on the near tail. Island zones are described in Sklar and van der Valk (2002). The cores were taken randomly from an established grid system in each plot. Each core was rinsed so only the roots remained. The roots were then separated by size, by depth, and into live and dead categories by a method that used colloidal silica (Robertson and Dixon, 1993). Both live and dead roots were then dried at 60^{o} C and were weighed.

Results

Belowground biomass results indicate that 3AS5, the flooded island, had the highest amount of total belowground biomass, with approximately 100 metric tons per hectare (mt ha^{-1}) (**Figure 6-5**). The dry island, 3AS2, had the lowest total belowground biomass, with approximately 37 mt ha^{-1}. Tree island 3AS3's values were in the middle, with total belowground biomass at approximately 53 mt ha^{-1}. For all three islands, on both head and near tail, biomass of dead components was significantly greater than live components. On 3AS2 and 3AS3, the near tail biomass for both live and dead components was more abundant compared to biomass on the head of the tree islands. In contrast, on 3AS5, head and near tail biomasses were relatively similar.

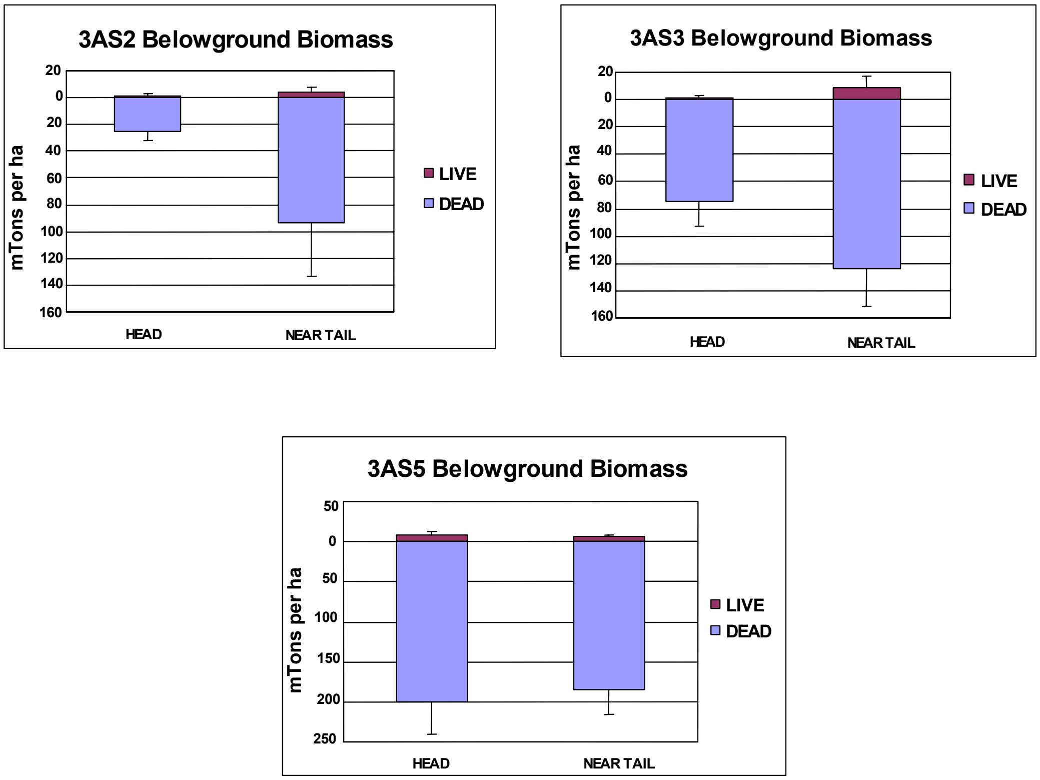


Figure 6-5. Belowground biomass estimates from three tree islands in WCA-3A expressed as metric tons live and dead per hectare.

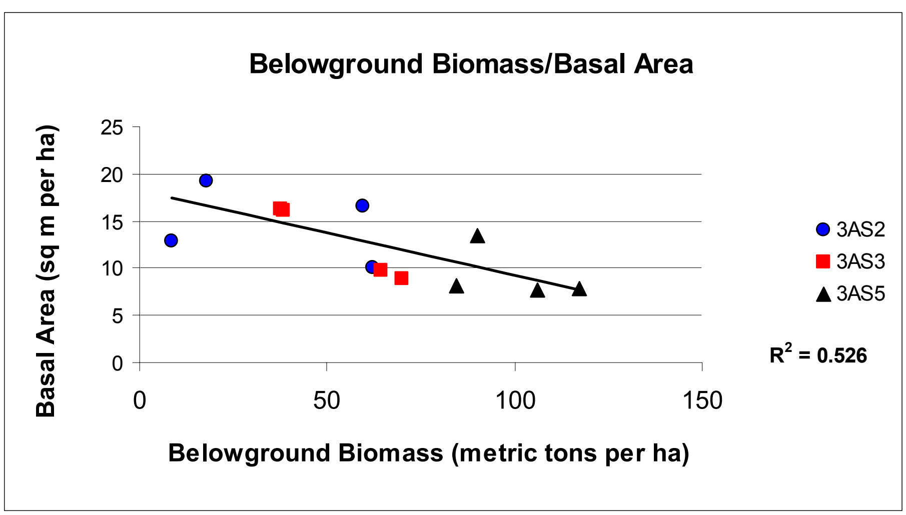


Figure 6-6. The relationship between the belowground biomass and basal area of the heads and near tails of three tree islands in WCA-3A.

Discussion

Belowground biomass dynamics seem to be influenced by both hydrology and aboveground forest characteristics. Results suggest a pattern that links belowground biomass dynamics to hydrology. The tree island subjected to the longest hydroperiod (3AS5) had the highest amount of belowground biomass. In contrast, the tree island with the shortest hydroperiod (3AS2) had the lowest amount of belowground biomass. These results suggest that woody vegetation subjected to longer hydroperiod allocate more organic matter to the belowground component, and woody vegetation subjected to shorter hydroperiod allocate less organic matter to belowground components. Why this occurs is not clear. It may be that more roots are needed in the flooded environment to aerate the soil, mine for nutrients, and stabilize the aboveground structure. These mechanisms will be discussed in the *2005 Everglades Consolidated Report*, after belowground root penetration cores are examined.

However, hydrology is not the only factor influencing biomass partitioning. Accordingly, species composition, forest age, forest structure, soil type, and nutrients also play important roles in the way woody vegetation allocates organic matter. Basal area is a forest property that indicates how woody vegetation allocates organic matter to the aboveground component. Results indicate that there is a relationship between the belowground biomass and basal area of the heads and near tails of each tree island (**Figure 6-6**). The higher the basal area, the lower the belowground biomass. Aboveground and belowground biomass allocation may be influenced by the hydrological patterns that characterize each tree island. Thus, woody vegetation on the tree island subjected to the shortest hydroperiod (3AS2) may allocate more resources toward aboveground biomass and less toward belowground biomass, while woody vegetation on tree islands subjected to a longer hydroperiod may allocate more resources to the belowground component. This could explain why the heads of 3AS2 and 3AS3 show not only a higher basal area but also a lower belowground biomass compared to their near tails. At 3AS5, belowground allocation was similar between the head and near tail; this is because both zones are subjected to the same long hydroperiod. However, aboveground allocation in this tree island was the lowest among the tree islands under study. This suggests that woody vegetation subjected to longer hydroperiod allocates more organic matter to the belowground component to cope with anoxic conditions developed under an extended hydroperiod.

Belowground dynamics are crucial to understanding the role that roots play in environments subjected to longer hydroperiods. Since root production has been suggested to contribute about half the carbon being cycled annually in many forests, and 33 percent of the global annual net primary production, obtaining accurate estimates of belowground biomass is important (Vogt et al., 1998). It is important to note that the failure to include belowground data will seriously underestimate forest ecosystem productivity and dynamics (Vogt et al., 1986). This omission might even cause previously accepted relationships between hydrology and vegetation to be less accurate (Day and Megonigal, 1993). Thus, an understanding of the role of belowground biomass on tree islands is important to gaining a complete picture of the ecological processes governing tree islands.

RESPONSES OF SUBMERGED AQUATIC VEGETATION (SAV) TO HIGH SALINITY

The ecology of submerged aquatic vegetation (SAV) in Florida Bay is intimately linked to the Everglades. Fresh water enters Florida Bay via the slow, diffuse output from the southern Everglades – through channels, overland sheetflow, and groundwater. Freshwater input is important in any estuarine system to maintain the estuarine salinity gradient. Without a regular seasonal input of fresh water, the estuary would convert to a strictly marine system or can become hypersaline (above 40 Practical Salinity Units [PSU]), where salinity is significantly greater than is normally found in the ocean (about 36 PSU). Unnaturally high salinity (as in the Dead Sea, an extreme case) leads to the demise of desirable estuarine flora and fauna.

Causes and Effects of Hypersalinity in Florida Bay

Natural variations in precipitation rate, the onset date of the rainy season, and air temperature normally determine the salinity regime of Florida Bay, which in turn helps determine plant and animal productivity, viability, and distribution. Human perturbations, which can exacerbate high salinity, include high rates of groundwater withdrawal and diversions of fresh water from natural flow paths through the Everglades to Florida Bay. When the summer season of high evaporation begins in May and June – and if there is a deficit of precipitation and/or water flow from the Everglades – salinity can begin to rise above normal oceanic levels. In the recent past, salinity as high as 53 PSU has been observed in the bay (summer 2001), while in the late 1980s, salinity higher than 75 was measured. Excessive salinity can force mobile estuarine species to shift to different areas of the bay or to leave the bay entirely. However, nonmotile species, such as rooted plants, suffer reduced productivity or may die off completely. For this reason, it is important to understand the salinity distribution in Florida Bay and its effects on the dominant plant community.

Turtlegrass (*Thalassia testudinum*) has been called a keystone species in the bay because of the myriad, important functions it performs, along with companion SAV species shoalweed (*Halodule wrightii*) and widgeongrass (*Ruppia maritima*). These species act as nutrient filters, reducing noxious algal blooms; as sediment filters, increasing water clarity; and as a refuge, spawning area, and food source for numerous important fish and invertebrate species. Recent die-offs of large swaths of the seagrasses in the bay have caused alarm about potentially serious and even permanent damage to the ecology of Florida Bay. These concerns relate specifically to decreased water clarity, increased nutrient concentrations, and loss of important fish species.

The causes of the SAV die-off are complex and difficult to determine exactly, but several promising lines of evidence have led to progress in understanding the phenomenon. Elevated salinity greater than 50 PSU places *Thalassia* in a state of stress. Special compounds, called osmolytes, must be mass-produced by the plant to counter the high salinity gradient from outside to inside the plants' cells. When coupled with any small, additional environmental stresses, such as high temperature or low oxygen, the plant's metabolism can quickly collapse, leading to die-off.

Submerged Aquatic Vegetation (SAV) Restoration

One of the primary elements of CERP is the restoration of freshwater flow to Florida Bay. This would be accomplished by redirecting flows to critical areas as well as by carefully managing the timing of flow in order to mimic, as nearly as possible, the natural, historical flow regime. The goal is to infuse parts of the upper bay with water that is reduced in salinity, thereby restoring the natural estuarine gradient. The South Florida Water Management District is currently undertaking several studies to determine the best way to maintain optimal salinity in the bay and to calculate the amount of fresh water required to prevent significant harm to plants and animals due to high salinity. This research will tie into a program called Minimum Flows and Levels for Florida Bay, whose outcome will be a series of regulations determining the amount of fresh water required to flow into Florida Bay. These studies include bay-wide monitoring of salinity and rates of freshwater inflow; laboratory studies of salinity effects on plants; and computer models of the relationships between rainfall, managed water flows, salinity distribution, and SAV responses.

A District-funded study of plant tolerance to high salinity is currently tracking the growth rates of *T. testudinum*, *H. wrightii*, and *R. maritima* in large tanks at a mesocosm laboratory at Florida Atlantic University (Koch, 2003; **Figure 6-7**). Results indicate that productivity of *Thalassia* begins to fall off at between 45 and 50 PSU, levels that have been frequently observed in Florida Bay (**Figure 6-8**). A study of seed and seedling response has shown that both seed germination and seedling growth of *Thalassia* are negatively impacted by hypersalinity. Seedlings that are grown in salinity above 50 PSU die off completely within less than 10 days (Durako, 2003).

Rapid surveys of the bay's salinity distribution can be made using a high-speed instrument called Dataflow, which measures and records salinity every two seconds from a moving boat. This enables sampling of the salinity regime and development of a "snapshot" of bay salinity at any point in the year, producing month-to-month pictures of the salinity distribution. In contrast to conditions during the last hypersalinity event in 2001, there was little evidence of hypersalinity in 2002. Indications are that hypersalinity will be light or nonexistent within the bay in 2003 (**Figure 6-9**).

Computer models of the bay's plant communities are showing some interesting results based on calibrations using data from the mesocosm studies (Madden et al., 2003). The models show that, although *Thalassia* plants can tolerate a relatively high level of salinity, the combination of elevated salinity greater than 50 PSU and a slight rise in average water temperature can cause collapse of the seagrass community. Furthermore, the timing and duration of the salinity event is important. Modeling analysis shows that the earlier in the year the hypersalinity occurs, the more damaging it is to the plants. For example, if hypersaline conditions occur in May, the seagrass plants are projected to be 66 percent less productive than if the same conditions occur in June.

Figure 6-7. The SAV mesocosm facility at the Florida Atlantic University-Gumbo Limbo Nature Center laboratory. This facility consists of 16 temperature- and light-controlled 1,000-liter mesocosm tanks (left). Experiments are performed either on sods containing sediments and many plants, or in hydroponic mode, where three shoots are placed in each of eight sealed cores per tank (center). The sealed cores are placed in the large mesocosm tanks for uniform temperature and light control (right) and are instrumented for automated recording of data.

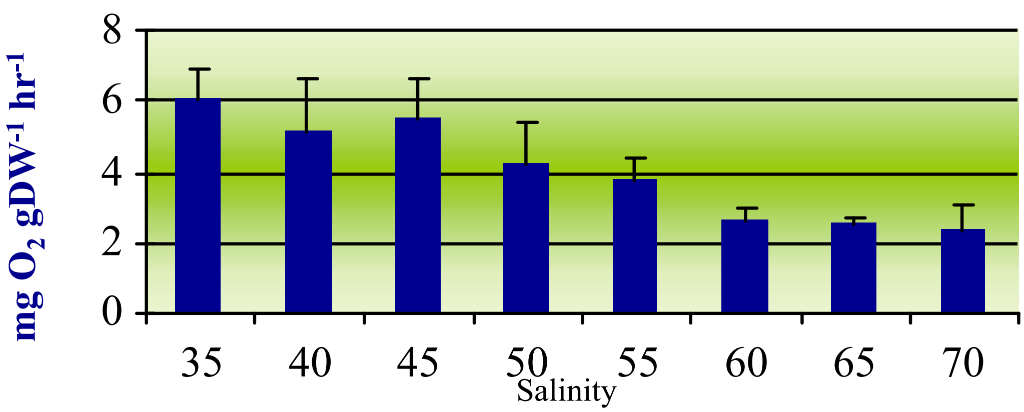


Figure 6-8. Photosynthetic response (measured as oxygen released) of turtlegrass (*Thalassia testudinum*) in mesocosm experiments subjecting plants to different levels of high salinity for one month.

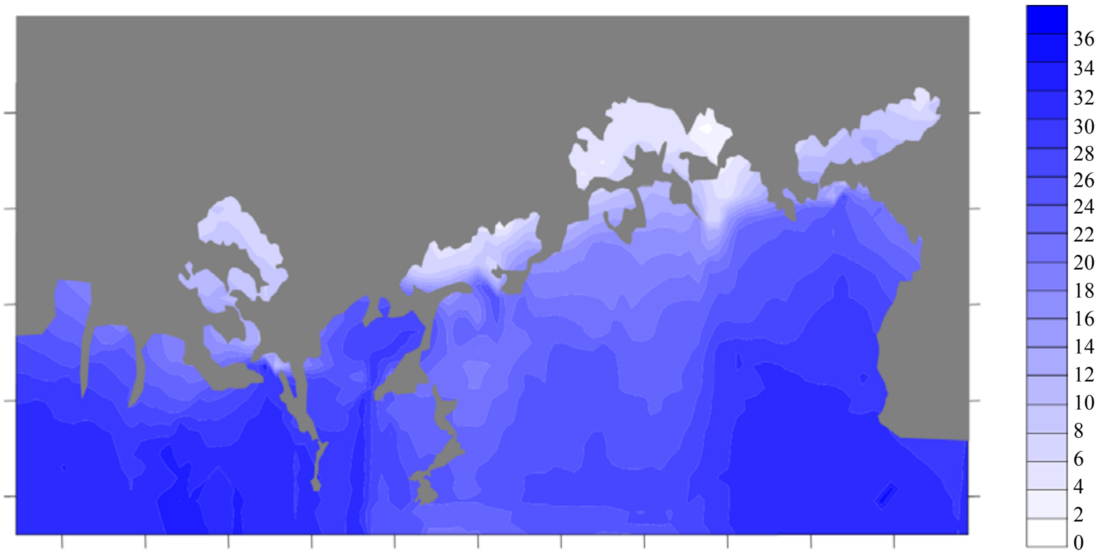


Figure 6-9. High resolution Dataflow map of salinity distribution in northern Florida Bay on June 30, 2003. Units are PSU (Practical Salinity Units). For reference, full-strength seawater is approximately 36 PSU.

ECOSYSTEM ECOLOGY

TREE ISLAND VEGETATION ECOLOGY

Tree islands are a major spatial feature of the Everglades landscape that have historically provided suitable habitat for a variety of terrestrial plants and animals. The maximum elevations of these habitats are often elevated only slightly from the surrounding marsh, making them quite vulnerable to changes in hydrology. With their extreme sensitivity to water levels, the continued existence of tree islands can provide a good indication of the overall condition and success of hydrological management of the Everglades. Determining the causal background of the structure of vegetation, through long-term field research and monitoring before and during the Comprehensive Everglades Restoration Plan (CERP), will allow managers to make adjustments in hydrology to ensure tree island persistence. In order to accomplish this, it is necessary to know how the vegetative composition, diversity, and structure vary over a range of environmental conditions.

In 2002, permanent vegetation plots were established on tree islands to examine how hydrology has shaped the historic distribution and abundance of woody tree species in Water Conservation Area 3 (WCA-3). The objectives of this program include characterizing the existing vegetation, creating a baseline data set, describing patterns of distribution and abundance, relating forest structure to current hydrologic conditions, and monitoring changes in tree island forest structure over time as physical gradients are altered. Results from this program will be utilized to create performance measures for Everglades restoration.

To address these objectives, tree species composition, diversity, and distribution were surveyed on nine tree islands in WCA-3A and 3B in the central Everglades. Vegetation sampling followed the North Carolina Vegetation Survey (NCVS) protocol, using two 10 x 10 m (0.01 ha) plots at the head and two at the near tail of each tree island. In each sampling unit, the height and canopy cover were recorded for all tree species >2.5cm in diameter at breast height (dbh). Every woody tree stem (>2.5 cm) within the vegetation plots was identified and marked with an aluminum nail and numbered tag at approximately 1.3 m above the ground. Dbh was measured for each woody stem rooted inside the plot. In addition to vegetation sampling, data on the physical characteristics of each island were measured, including soil nutrients, organic contents, and peat depths as well as current hydrologic conditions (**Table 6-4**).

Table 6-4. Tree island survey data summary. Data is reported for the head and near tail (NT) of the nine study tree islands, including 10-yr average annual water level (WL), average annual number of days per year, inundated number of species, average total density, average total basal area, average canopy height, and complexity index. Negative values indicate that the water level falls below soil surface. Density, basal area, and canopy height are reported with standard deviations.

Island	Area	WL (cm)	Days Innun.	Island Type	# of Sps	Density (ind/ha)	Basal Area (m^2/ha)	Canopy Height (m)	Comp. Index
3AN1	Head	-2.1	163	Wet	4	3500 ± 1556	8.4 ± 0.3	4.6 ± 0.8	47
	NT	-1.8	167	Wet	3	5600 ± 283	12.6 ± 4.5	3.6 ± 0.9	81
3AN2	Head	-2.1	163	Wet	5	1550 ± 212	13.5 ± 10.7	4.4 ± 0.1	37
	NT	-2.1	163	Wet	4	4150 ± 495	7.2 ± 1.0	3.3 ± 0.1	33
3AS1	Head	13.1	270	Wet	3	3350 ± 1202	23.1 ± 12.9	5.6 ± 0.4	146
	NT	23.5	310	Flooded	5	6450 ± 1061	15.4 ± 4.0	4.4 ± 0.1	194
3AS2	Head	-32.9	27	Wet	6	5300 ± 1131	16.1 ± 4.4	4.1 ± 0.5	212
	NT	10.9	249	Flooded	7	5050 ± 636	13.3 ± 4.6	4.2 ± 0.5	146
3AS3	Head	-12.1	87	Wet	5	3750 ± 1061	16.2 ± 0.0	4.9 ± 0.4	75
	NT	24.8	315	Flooded	6	3600 ± 849	9.3 ± 0.6	4.0 ± 0.0	75
3AS4	Head	-4.2	149	Wet	6	4550 ± 1485	22.9 ± 1.8	4.2 ± 0.2	207
	NT	20.1	299	Flooded	6	4600 ± 566	15.4 ± 1.6	4.2 ± 0.0	146
3AS5	Head	31.4	329	Flooded	5	6100 ± 424	10.7 ± 4.0	4.1 ± 0.1	147
	NT	30.8	338	Flooded	5	5650 ± 778	7.9 ± 0.4	3.6 ± 0.5	82
3BS2	Head	10.1	269	Flooded	4	7750 ± 1626	24.0 ± 4.9	4.8 ± 0.2	245
	NT	10.0	265	Flooded	3	8800 ± 1414	25.1 ± 2.9	5.1 ± 0.1	342
3BS1	NT	14.5	280	Flooded	4	9550 ± 1202	15.8 ± 4.5	4.1 ± 0.2	190

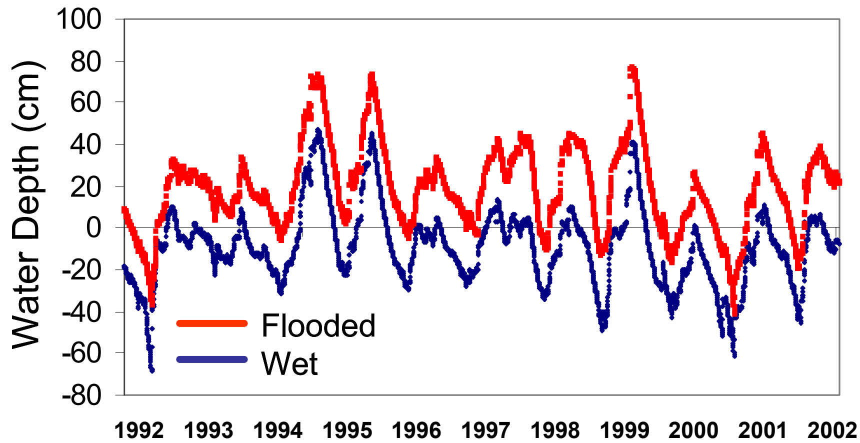


Figure 6-10. Tree island water depths from 1992-2002. Water depths from each plot were separated into two hydrologic categories based on average water depth and hydroperiod over the 10-year period: wet versus flooded.

Sampling plots have been separated into two distinct hydrologic regimes: wet versus flooded. To accomplish this, water depth on study tree islands was estimated by using a meter stick to take depth measurements in each of the sampling plots. This data, combined with data from nearby SFWMD stage gauges, were used to create regressions to estimate water depths on the islands over the past 10 years. **Figure 6-10** shows the daily water depth over a 10-year period averaged for all plots within the flooded and wet island types. In general, wet island types are inundated for less than six months per year and have average annual water depths of less than 20 cm. In contrast, flooded island types have standing water present for seven to 12 months per year and have average annual water depths exceeding 20 cm. It should be noted that due to the extreme topographic gradient from the head to the tail of most islands, study plots on an island can have two distinct hydrologic regimes.

Study sites represent a hydrologic gradient ranging from low water levels with short hydroperiods in the northern regions of WCA-3 to high water levels with longer hydroperiods in the southern regions. Both 3AN1 and 3AN2 in the northern portion of WCA-3 have negative annual water levels, indicating that on average, the water table generally falls below the soil surface during the dry season. This is accompanied by a short annual hydroperiod of less than six months. On the other extreme of the hydrologic gradient, 3AS5, 3BS1, and 3BS2 are classified as flooded island types. These islands are located toward the southern portion of WCA-3, where water tends to pond up against Tamiami Trail. Similarly, 3AS5 has the highest average annual water depth (30.8-31.4 cm) and is inundated for more than 11 months per year (**Table 6-4**). In the middle of the hydrologic gradient lie islands with moderate hydroperiods. These islands (3AS1, 3AS2, 3AS3, and 3AS4) possess elevated wet heads followed by deeper waters on the near tail (**Table 6-4**).

In general, tree species diversity in WCA-3 tended to be highest on these centrally located tree islands with gently sloping hydrologic gradients from head to near tail. Species diversity was lowest on tree islands with hydrologic extremes, i.e., very dry or very wet. Some authors

(Heisler et al., 2003) have suggested that species richness might potentially be a useful indicator in assessing tree island response to Everglades restoration; however, this may not provide the best indication of overall tree island health. In the case of 3BS2, species diversity is low (**Table 6-4**), with the islands being dominated by pond apple (*Annona glabra*). Although this island has few other tree species present, this island has the highest density and basal area, indicating that 3BS2 supports mature and long-lived trees.

A better possible indicator of long-term tree island health may be a complexity index (CI), which takes into consideration basal area, stem density, and canopy height, as well as the number of species (**Table 6-4**). The low CI values for islands in the northern portion of WCA-3 show the effects that extended periods of drought and fire events have had on forest structure. In contrast, islands in WCA-3B have the highest CI values. This is due to the extremely high basal area and stem densities present on those islands. More work on defining a CI is recommended. While individual islands should not be compared to one another due to the inherent differences in forest structure, these data may provide a starting point from which changes in forest structure can be monitored, as hydrologic conditions are altered with the onset of CERP.

Basal area and stem density data suggest that present-day forest structure on tree islands has been shaped by the historic hydrologic regime in WCA-3. **Figure 6-11** illustrates four distinct tree island hydrologic environments. 3AN2 and other islands located north of Alligator Alley are subject to shorter hydroperiods (inundated less than 6 months per year) and shallow water depths (**Table 6-4**). Some of these islands have experienced fire events, allowing for the introduction of invasive species such as Brazilian pepper (*Shinus terebinthifolus*). Results from 3AN2 show a reduced number of species, along with low basal area and stem densities. In contrast, 3AS2 represents an island with a natural hydrologic gradient from head to tail. This island has a dry, elevated head followed by a flooded tail. A large number of species are present on this island, with tropical hardwood hammock species on the head (e.g., *E. axillaris*, *C. oliviforme*), followed by more water-tolerant species (e.g., *M. cerifera*, *S. caroliniana*) on the near tail (**Figure 6-12**). This island has both high total basal area and high stem densities, indicating that this is a well-developed and mature forest structure. It also suggests a community of cohorts. Similar trends in basal area are seen in several of the centrally located tree islands: 3AS1, 3AS3, and 3AS4.

While some islands in the central portion of WCA-3 are exposed to moderate hydroperiods, 3AS5 is constantly inundated with perhaps only a month of drydown per year on average (**Table 6-4**). This island is dominated by water tolerant species, such as willow (*S. caroliniana*), and it is characterized by low basal area and high stem densities. The high stem densities combined with low total basal area suggest that the individuals present on this island are mostly younger trees. The smaller size of the trees may indicate that this is a recent colonization by long-hydroperiod pioneer species, such as *S. caroliniana*. In contrast, 3BS2 is a low-elevation island that appears to be able to withstand extended hydroperiods. While 3BS2 is flooded on average nine months per year, high stem densities and basal area of the water-tolerant and slow-growing species, pond apple (*Annona glabra*), indicate that this island is actually a mature forest.

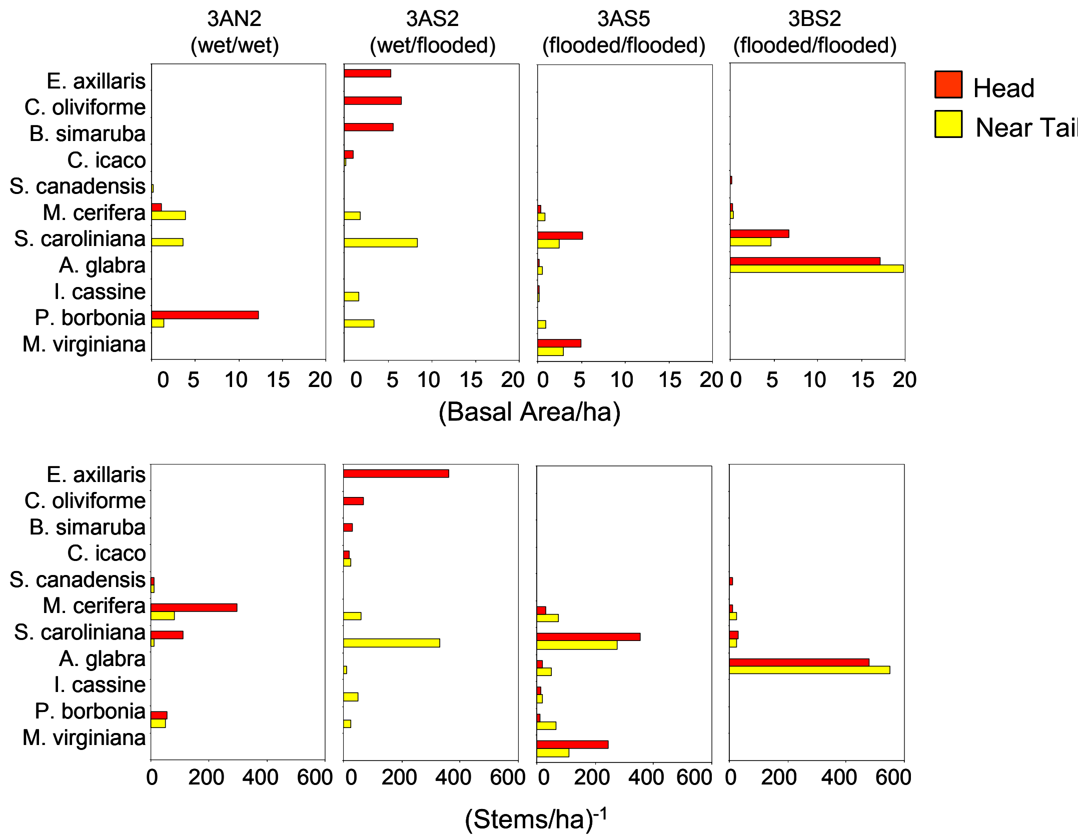


Figure 6-11. Total basal area of stems with ≥ 2.5-cm dbh (top) and stem densities (bottom) of woody species on the head (red) and tails (yellow) occurring on select tree islands. Island type according to hydrologic environment is given in parentheses as (Head/Near-Tail).

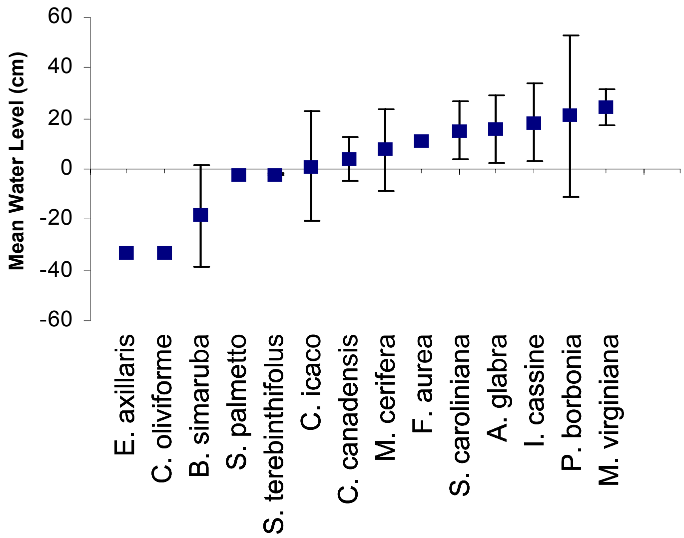


Figure 6-12. Average water level (cm) for woody species occurring on nine study tree islands in WCA-3. Water depth ranges are based on the 10-year average depth for each permanent plot. Mean water depths are displayed with standard deviations where applicable.

Data collected on the species composition of each sampling plot suggests hydrology can affect the distribution of species along this hydrologic gradient. **Figure 6-12** illustrates the mean water depth at which each species was found within permanent plots. Individual species appear to have different water-depth tolerances, and some species may be able to thrive only in a narrow range of hydrologic conditions. Tropical hammock species *E. axillaris*, *C. oliviforme*, and *B. simaruba* are found at the dry end of the hydrologic range. Species such as *C. icaco*, *S. canadensis*, and *M. cerifera* appear to tolerate a moderate level of inundation. The most water-tolerant species seen included *S. caroliniana*, *A. glabra*, *I. cassine*, and *M. virginiana*. These species occur in areas both with longer annual hydroperiods and higher average water depths. Notably, *P. borbonia*, while at the high end of the hydrologic gradient, shows the widest distribution of water levels.[1] This species is found on many islands with differing hydrologic regimes; however, it seems to prefer a more moderate water level, as those individuals found on flooded islands tend to be small in size. The water ranges found for the species in WCA-3 are similar to water level optimum and tolerance ranges for the same species on tree islands in Shark River Slough (Armentano et al., 2003).

[1] It was recently discovered that some *P. borbonia* may actually be *P. palustris*, which would help explain this wide distribution.

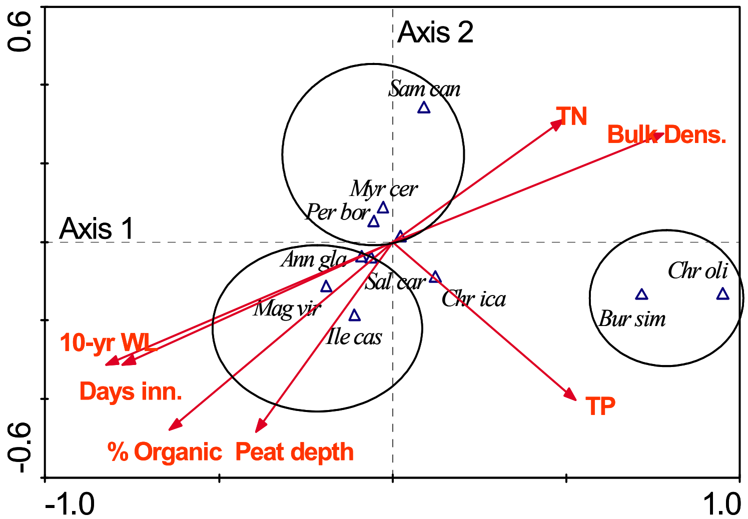


Figure 6-13. Canonical correspondence analysis of woody species as related to environmental variables, including soil total nitrogen (TN), soil total phosphorus (TP), soil bulk density, percent (%) organic content, peat depth, number of days inundated, and the 10-year mean water level for each plot.

A major hypothesis of tree island study is that there exists a hydroperiod and depth envelop within which tree island stability, diversity, and productive are maximized. Those islands with very short or long hydroperiods are susceptible to destruction due to fire or drowning, respectively. To test this hypothesis, canonical correspondence analysis (CCA) was used. This is a direct gradient analysis that relates species presence or abundance to environmental variables on the basis of species and environment data from the same set of sample plots (Gauch, 1982). Since plant species experience the conditions provided by many environmental variables, it is important to analyze their joint effects. Thus, a method is needed to analyze and visualize the relationships between many species and many environmental variables. Canonical correspondence analysis is designed to statistically quantify the importance of environmental variables in determining species presence or distribution (Ter Braak and Smilauer, 2002). The CCA helps to visualize patterns of plant community variation and also unveils the main features of species' distribution along environmental gradients.

CCA was used in this study to unveil the relationship between the presence/absence of nine woody tree species and environmental parameters that characterize tree islands in WCA-3 (**Figure 6-13**). These environmental parameters included the 10-year mean water level, number of days inundated, as well as soil characteristics such as percent organic content, peat depth, total phosphorus (TP), total nitrogen (TN), and bulk density (**Table 6-4**). Results from this analysis indicate that ten-year water level and number of days inundated were most closely correlated to axis 1; this axis will be referred to as the hydrologic axis (**Figure 6-13**). Axis 1 explained 26 percent of the variability of the presence/absence of woody species along this hydrological gradient. Similarly, axis 2 correlated most closely with soil TN and TP, and peat depth; this axis will be referred to as the nutrient soil axis. Axis 2 explained only 10 percent of the presence/absence variability of woody species along this soil nutrient gradient. It should be noted that 10-year water level, days inundated, percent organic content, and peat depth were highly correlated to one another, indicating that hydrology has a strong influence on the soil composition. The statistical analysis (the Monte Carlo test) indicates that axis 1 was highly significant (p-value = 0.002), stressing the importance of hydrology in driving the distribution and abundance of woody species in tree islands.

Using CCA, three groups of species were grouped based on their water level tolerance (**Figures 6-12** and **6-13**). Results from this analysis confirm the qualitative results depicted in **Figure 6-13** and discussed above. First, *B. simaruba* and *C. oliviforme* were found on the extreme dry end of the hydrologic axis. These species were also associated with high bulk densities and high TP values. These two hammock species are found mostly on the very dry head of islands and cannot tolerate extended periods of flooding. The high soil bulk densities are indicative of soil oxidation causing a reduction in organic material on these dry tree island heads. The second grouping, the wet species, is located in the middle of the hydrologic axis. These moderately water-tolerant species include *P. borbonia*, *M. cerifera*, and *S. canadensis*. They are also found on the high side of the soils axis associated with low percent organic content and shallow peat depths. These species are located on islands with shorter hydroperiods and on some islands that have been subject to drought and fire events, causing a subsidence of peat in those areas. The species that appear to be most tolerant of flooded areas include *A. glabra*, *S. caroliniana*, *I. cassine*, and *M. virginiana*. These species are found at the flooded end of the hydrologic axis and tend toward deeper peat and high organic soil contents associated with wetter conditions. These species are also found in soils with low TP and TN values, indicating a net transport of nutrients from the islands

These data, along with the estimates of basal area and stem densities, strongly suggest that species distribution and abundance are heavily dependent on the hydrologic conditions of tree islands. Hydroperiod and water depth seem to control most aspects of soil chemistry, as shown by a high degree of correlation between hydrology and soil characteristics. These physical characteristics also appear to play a significant role in determining the species composition of the islands, as determined through CCA. The estimations of basal area and stem densities show that islands with hydrologic gradients from head to near tail support the highest diversities of species and allow for the establishment and continuation of mature and well-developed forest structures.

LANDSCAPE ECOLOGY

SUMMARY

The District continues to look at the total system. Previous ECRs have shown vegetation maps created with specially developed remote sensing and photointerpretation techniques. This year's ECR presents new information on tree island change detection, cattail change in WCA-2A, and the use of IKONOS imagery to detect *Lygodium*. Results show that cattail continues to spread throughout WCA-2A. In addition, sparse cattail continues to spread along distinct cattail-sawgrass boundaries and throughout the southern regions of WCA-2A. However, the rate of spread appears to be slowing down when compared to the 1991–1995 period. This decrease in rate may be due to the reduction in annual total phosphorus loads to WCA-2A during the 1995–2003 period, but it also may be due to hydrologic alterations, invasive habitat availability, and fire. Results for *Lygodium* show that despite a significant amount of interference from cloud cover, as well as signal interference from cattail, there are 1,431 acres of *Lygodium*

within WCA-1. IKONOS imagery may be critical for *Lygodium* control and large-scale evaluations of current conditions. To illustrate this concept, this section covers the use of landscape-scale indices of pattern and structure to describe regions of healthy and degraded ridge and slough. In the future, these will be used to parameterize a heuristic model of ridge and slough development and sustainability. Finally, this section outlines the construction and design of the Loxahatchee Impoundment Landscape Assessment (LILA), a new District ecosystem research facility to experimentally and reproducibly manipulate flow velocity and depth across a tree island/ridge-slough landscape.

TREE ISLAND CHANGES, 1940 TO 1995

One of the most sensitive indicators of problems caused by modified water management practices has been changes in the physical and biological character of tree islands. Losses of tree islands have been noted in the WCAs in various reports, but the extent of these losses has never been adequately documented.

In 1998 the District began initiating a mapping program to study the changes in the extent of tree/shrub habitats in WCA-3 from 1940 to 1995. The objective of the mapping project was to gain a better understanding of the physical changes that have occurred to the tree/shrub habitats of WCA-3, the largest WCA impoundment (912 square miles), located in western Broward and Miami-Dade counties. This work is part of a larger tree island program designed to increase understanding of how to prevent hydrologic stress to tree island communities and how to manage water as part of CERP to restore tree islands that have disappeared.

Tree islands in WCA-3 can be highly variable in their physical shape, size, and vegetative makeup. Typical tree and shrub species found on tree islands can include, but are not limited to, willow, wax myrtle, cypress, maple, pond apple, red bay, swamp bay, strangler fig, and various tropicals and/or exotics. Tree islands in WCA-3 can be categorized as either floating or fixed varieties. Only fixed tree islands were evaluated in this study. Fixed tree islands have three characteristic features: (1) They are tear-shaped, and their long-axis is parallel to surface-water flows; (2) the tallest trees and shrubs are found at the upstream end of the island, the “head,” which is typically the widest part of the island; and (3) behind the head is an elongated, v-shaped area, the “tail,” which has a lower elevation than the head. The vegetation of the tail is dominated by shrubs or marsh species (e.g., sawgrass or cattail) or a combination of the two.

The first phase of this project was to search and acquire aerial photography, by decade, for WCA-3, starting with the 1940s. This resulted in a total of five data sets (**Table 6-5**). Unfortunately, a complete aerial photography data set was unavailable for the 1960s. All photography data sets were brought into a State Plane NAD83 datum using various map projection methods. Photointerpretation was then performed utilizing several types of instruments, including a Zeiss P3 analytical stereoplotter, a Bausch and Lomb 95 zoom stereoscope, a Bausch and Lomb zoom transfer stereoscope, and a Cartographic Engineering stereoscope. For this study, the outer boundaries of tree/shrub habitats were defined as the outermost extent of continuous trees and/or shrubs with at least 5 percent ground coverage and with a minimum mapping unit of one hectare. All final mapping delineation results were transcribed into ArcInfo coverages for each of the decades. Change detection maps were then created from the individual decade maps, which show the differences in tree/shrub habitat boundaries between the compared time periods or eras. This process produced change polygons by combining the attribute information from each layer. Losses and gains were then calculated by comparing the attributes from the two eras and registering matches and mismatches.

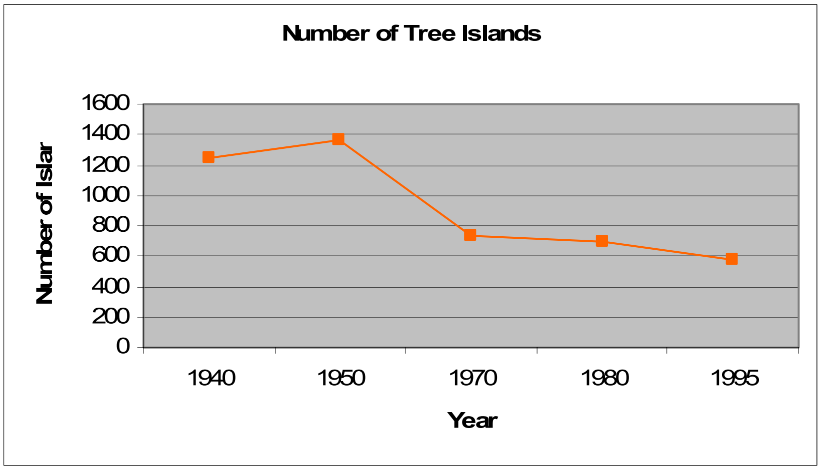
Table 6-6 details the total trees, trees to no trees, trees to trees, and no trees to trees polygon numbers and acres that were calculated from the change detection maps. **Figure 6-14** illustrates the change in number of tree/shrub habitat polygons and acres. These results will provide a significant contribution to the knowledge base in understanding the fate of tree islands during this time period. The insights gained from this knowledge will enable additional guidelines to be put forth for the CERP process in restoring the Everglades. Research is currently focusing on understanding why there was an increase in tree/shrub habitat from 1940 to 1950 and then a sudden loss of this habitat from 1950 to 1995. A timeline graphic is being developed to help guide the process of understanding these data, which will include such details as when canals, levees, pump stations, and roadways were completed within the study area. All available hydrological, rainfall, and fire history data will also be included. This work has just begun but is already showing some interesting trends, which will be reported in future Everglades Consolidated Reports.

Table 6-5. Aerial photography data sets used in this study.

Year	Scale	Photography Type
1940	1:40000	Black and White
1952/4	1:20000	Black and White
1972/3	1:80000	Color Infrared
1980	1:40000	Black and White
1994/5	1:24000	Color Infrared

Table 6-6. Change in total number of polygons and acres of trees, including changes in cover types between each era. Note: Trees also include shrub habitat.

	Total Tree Polygons by Era		Cover type change from previous era					
			Trees to No Trees Polygons		Trees to Trees Polygons		No Trees to Trees Polygons	
Era	# of	Acres	# of	Acres	# of	Acres	# of	Acres
1940	1251	24795						
1952/54	1365	29146	919	6620	1039	18175	1054	10970
1972/73	739	12225	2118	18041	665	11105	1468	1120
1980	695	11303	224	1425	683	10799	206	504
1995	576	8604	439	3111	566	8193	200	412



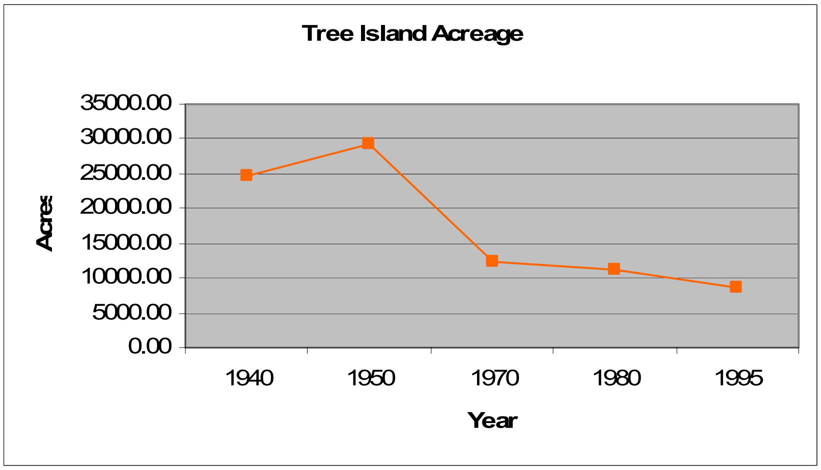


Figure 6-14. Trend in the number of tree islands (top) and acres (bottom), by era.

SPATIAL PATTERNS IN THE RIDGE AND SLOUGH LANDSCAPE

Much of the original Everglades landscape was dominated by ridges, wooded islands, and open sloughs arranged in a linear pattern oriented parallel to the pre-drainage flow direction. This corrugated microtopography, called "ridge and slough," consisted of elevated bands of peat supporting a predominantly sawgrass (*Cladium jamaicense*) community. The sloughs were open water expanses usually consisting of floating water lilies (*Nymphea odorata*) and spatterdock (*Nuphar luteum*). A substantial portion of the originally patterned Everglades has changed over the last century as a result of drainage and water management (Science Coordinating Team, 2003). With efforts to restore the ecosystem to a more natural condition, baseline information characterizing existing ridge and slough landscape patterns – both degraded and relatively intact – is needed.

Indices to describe the range of existing patterns and their spatial arrangements were developed to assist scientists and managers identify baseline conditions, measure changes over time, and assess the effects of restoration efforts. These indices were developed using 18 quadrants, each 4 x 6 km in size, to represent the range of patterning in the remnant Everglades landscapes. The quadrants were selected to represent the existing range of patterning (**Figure 6-15**). Using a Thematic Mapper satellite image, all shapes in these quadrants representing ridges, strand, and other tree island types were digitized (**Figure 6-16**).

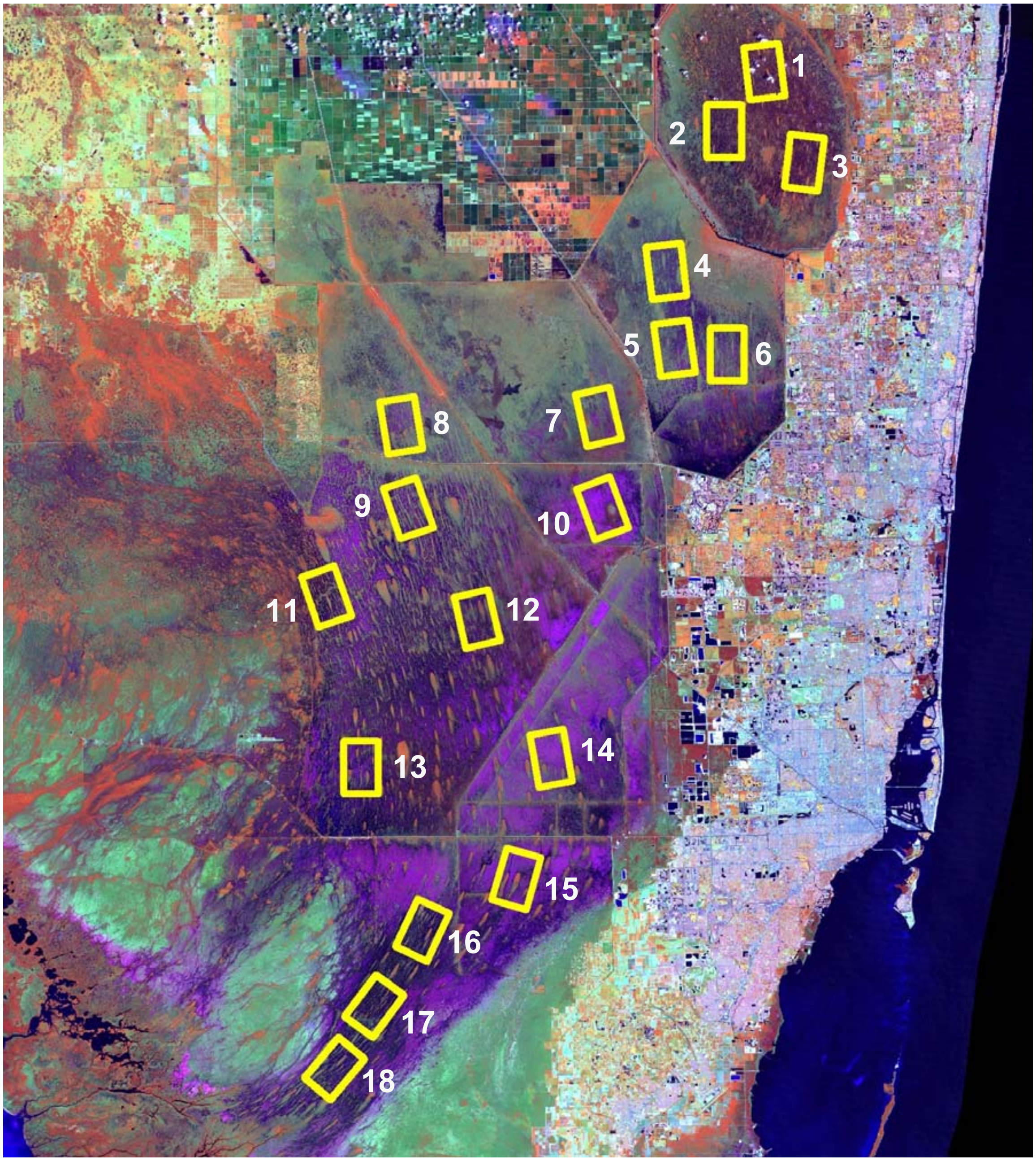


Figure 6-15. Quadrants used to characterize the patterning within the ridge and slough landscape. The photo is georeferenced Thematic Mapper imagery from 1993–94 covering Water Conservation Areas 1, 2, and 3 and the Everglades National Park.

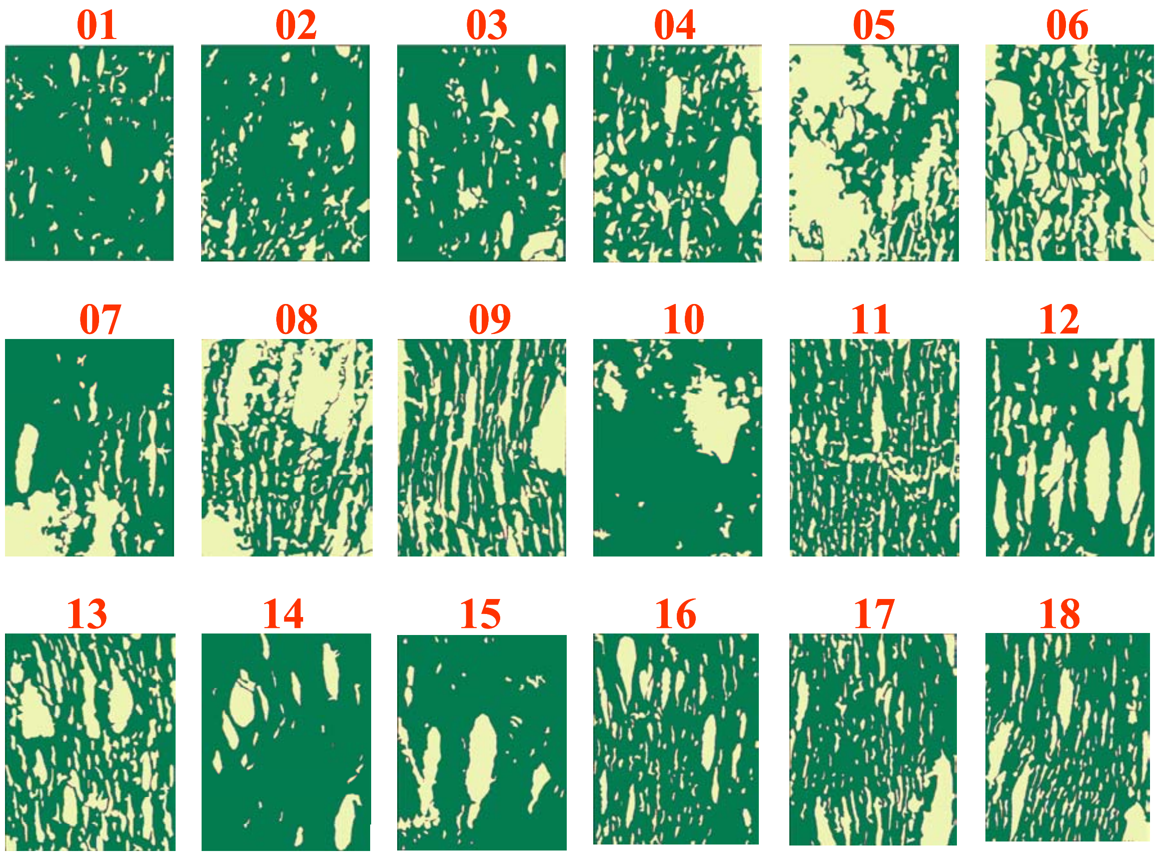


Figure 6-16. Ridges and islands (polygons) in the 18 quadrants, each 4 x 6 km in size. This arrangement represents their locations generally north to south in the Everglades Protection Area. Their orientation has been adjusted to reflect the linear axis.

Most polygons lie parallel to the probable pre-drainage flow directions, even in quadrants in which most of the original ridge and slough microtopography has disappeared. In quadrants thought to most closely resemble pre-drainage patterning, ridge and tree island polygons together covered roughly 20 to 40 percent.

Two nonspatial indices of polygon elongation and smoothness differentiated intact patterning from degraded patterns and arranged them along a gradient. The graph below, illustrating one of these nonspatial indices, shows how the Length/Width number (LeWN) was used to measure the average elongation of the ridges and tree islands in a quadrant (**Figure 6-17**). The LeWN index is calculated as the average length-width ratio of the longer ridges and islands in the quadrant multiplied by the number of polygons; values range from 50 to 750, with higher numbers representing stronger patterning. A second index, the Perimeter-Area number (PAN), was used to quantify the average perimeter-to-area ratio of the polygons in a quadrant. Both indices separate the quadrants along a gradient from poorly patterned to well-patterned, with higher values representing stronger patterning. The LeWN index captures the long, thin aspects of the ridges and islands, while the PAN index stresses the smoothness of these shapes.

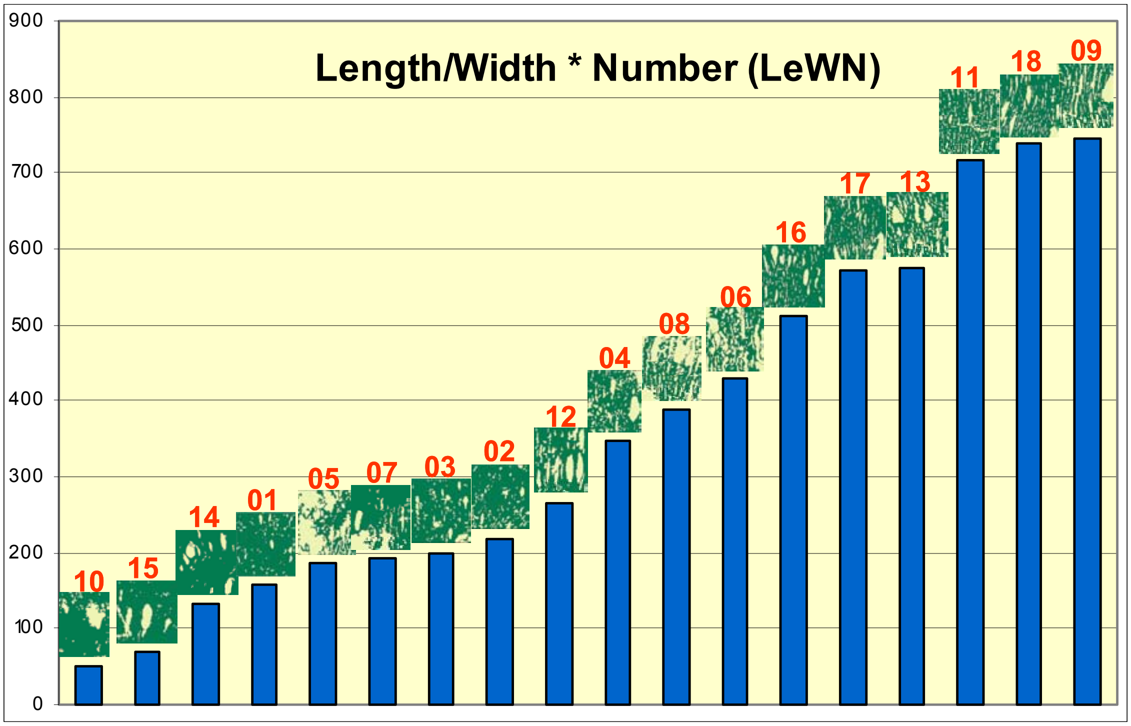


Figure 6-17. The gradient produced by the Length-Width (LeWN) index for the 18 quadrants from the ridge and slough landscape.

Three spatial indices of polygon elongation and location were used to distinguish intact spatial patterning from degraded patterns in the ridge and slough landscape: lacunarity, length of flow, and width of slough. Results of one of these three indices are illustrated below. The Lacunarity Index (LI) (Wu et al. 1997; Plotnick et al., 1993) was used to calculate scale-dependent spatial patterns, essentially the size and shape of connections between the ridges. The LI indicates that degraded patterns are marked by LI values below 1.75 or above 4.45, while those in between are intact or deteriorating (**Figure 6-18**). The Average Length of Straight Flow (ALS) measures the distance of possible straight line flows from the top (generally north) to the bottom of the quadrant before encountering a ridge or island. The ALS measures how far water can flow straight before encountering a ridge or island. This index is the mean uninterrupted lengths of 100 such lines in each quadrant. Similarly, the Average Width of Slough (AWS) is used to measure the average uninterrupted lengths along 100 lines east to west (side to side). The AWS measures how far one can move across sloughs before encountering a ridge or island. These two indices measure the spacing of the ridges and islands in the quadrant from top to bottom and side to side.

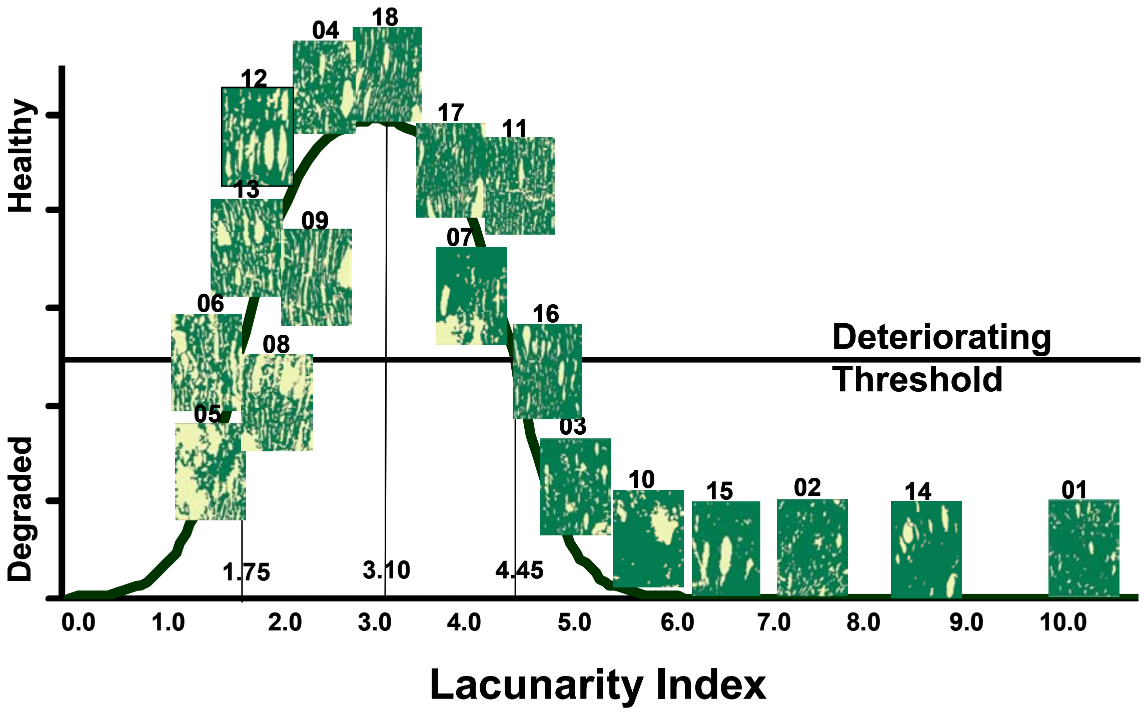


Figure 6-18. The Lacunarity Index (LI) of "natural patterns" appears to range between 1.75 and 4.45. The LI of "deteriorating patterns" below 1.75 or above 4.45 appears to identify degraded patterns.

These indices demonstrate that different aspects of the shapes of the ridges and islands (LeWN and PAN), as well as their placement within a quadrant (LI, ALS, AWS) in the remnant Everglades, can be distinguished. They can be used in combination to describe patterning, to discriminate degree of ridge and slough patterning, to track changes over time as flow is restored, and to provide quantitative goals for restoration. This approach will give CERP guidance for the establishment of ridge and slough performance measures and goals. When used in comparison with historic aerial photos, it may be possible to determine how greatly the patterns have changed, when they changed, and perhaps even how rapidly these changes occurred.

APPLICATION OF IKONOS SATELLITE IMAGERY FOR DETECTING *LYGODIUM MICROPHYLLUM* IN THE EVERGLADES

Lygodium microphyllum is an exotic species that is currently invading extremely remote and undisturbed areas in the Everglades. In particular, *Lygodium* is primarily invading higher topographic areas such as northern Everglade tree islands, but it has also been observed growing in places as far away as the coastal prairie and scrub habitats within Everglades National Park. Numerous sightings have been reported throughout the Everglades and Big Cypress regions. Previous experience with other highly invasive plants has shown that plant populations tend to reach a "critical mass" of coverage and then begin an exponential rate of expansion, spreading faster than management efforts can effectively contain them. *Lygodium* may now be in that phase. Of particular concern for the Everglades is that *Lygodium* is disrupting the flora and fauna of the native ecosystem at an alarming rate.

Lygodium is currently being monitored by utilizing System Reconnaissance Flights (SRFs). In 1993, the District initiated biennial SRF aerial surveys for investigating the spread of exotics. The SRFs include 50 east-west flight lines spaced at 2.5 miles apart for the entire region south of the north rim of Lake Okeechobee. If an SRF reveals one sighting of an exotic within a square km grid, then the area is considered to be completely infected. It has been speculated that the use of SRFs may be resulting in the overestimation of the absolute spread of exotics. However, the use of SRFs is still thought to be a viable monitoring method and is the only tool currently available that documents the relative spread of exotic species within this large landscape area. The IKONOS satellite system, launched in 1999, is one of several newer satellite systems that collects higher resolution (multispectral is 4 x 4 meter) and more robust digital information (11 bit) of the Earth's surface than previous satellites. Image processing of IKONOS satellite data was evaluated for its effectiveness in mapping *Lygodium* in finer detail than what is currently being collected by SRFs.

Five IKONOS satellite images encompassing Water Conservation Area 1 (WCA-1) were collected in March 2002 (**Figure 6-18**). Unfortunately, with the limited funds available, cloud-free IKONOS images for WCA-1 were not obtainable. As a result, approximately 8.5 percent of the area, consisting of clouds and shadows, were eliminated from the analysis. Scene four from **Figure 6-18** was initially used as the test case data set. Time-tested image processing techniques originally developed by NASA were used in a hybrid unsupervised/supervised classification. Seeding signature statistics for *Lygodium* within the image scene, along with analyzing signature separability statistics such as transformed divergence, were also undertaken. Most of the habitats being invaded in WCA-1 are tree/shrub habitats. Therefore, an attempt at mapping these specific areas was also undertaken, although there is less confidence in the accuracy of the results.

Initial results showed that the classification procedures did not work well in areas where there is high nutrient influence and hence greater mixing of species. These areas are primarily found on the outer fringe edges of WCA-1, where nutrient enrichment is believed to have influenced the vegetation communities. These outer fringe areas were excluded from further image processing analysis, resulting in the ability to spectrally separate *Lygodium* from the other species within the vegetation community (**Figure 6-19**). Helicopter ground-truthing was conducted by acquiring high-definition digital images along four demonstration plots within scene four (**Figure 6-18**). These were used to assess the accuracy of the final classification results. **Figure 6-20** illustrates one of these digital images compared to a true color composite of the IKONOS data, along with the same area that was classified using the previously described classification methods. This comparison was done for many areas, and results showed good registration between the high-definition digital images to the final classification. The methods utilized in scene four were then applied to the other four scenes, and then a mosaic was done for all five scenes to create an overall composite image for WCA-1 (**Figure 6-21**). Results show that 11.6 percent of the tree/shrub habitat in WCA-1 has been invaded by *Lygodium*, which encompasses a total area of 1,431 acres.

Final acreage results of *Lygodium* are believed to be an underestimate of true *Lygodium* coverage for WCA-1. This is because of the following: (1) 8.5 percent of the area could not be analyzed due to cloud/shadow cover, and (2) a pixel (4 x 4-meter area on the ground) had to be covered by *Lygodium* and observable from above in order to be classified as such. The cloud/shadow problem can be eliminated with future acquisitions of IKONOS by explicitly specifying that all scenes must all be free of clouds. Overcoming the observation factor of having an entire 4 x 4 meter-pixel *Lygodium* area on the ground is more difficult, because the satellite sensor is able to detect only what is observable from above. It is believed that the understories of many other tree islands have already become infected with *Lygodium* but are not yet observable from above. There might never be a resolution to this problem using only remotely sensed data. Ground-truthing may be the only solution. However, the analysis of satellite data such as IKONOS for detecting the relative spread of *Lygodium* provides a better tool than what is otherwise available. Determining the rate of spread is critical for determining how to plan for control mechanisms and also for modeling the future spread of *Lygodium*. There are plans in the budget to purchase additional IKONOS-type satellite data in 2004 to look again at *Lygodium* coverage in WCA-1 and possibly in some areas within Everglades National Park. CERP aerial photography is also being obtained for WCA-1, which will be utilized to assess the accuracy and trade-offs of using photointerpretation methods verses image processing of satellite data for detecting *Lygodium*.

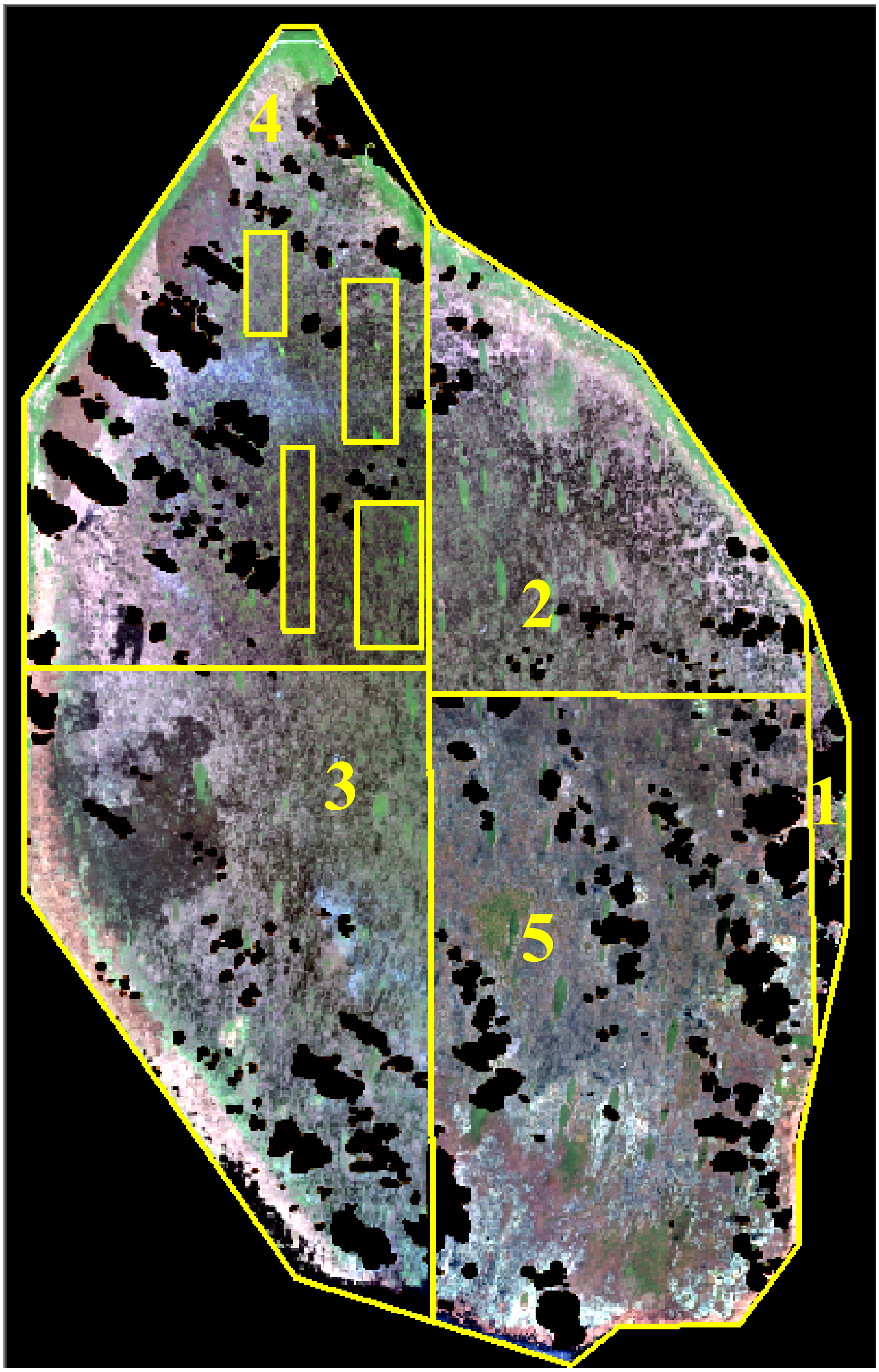


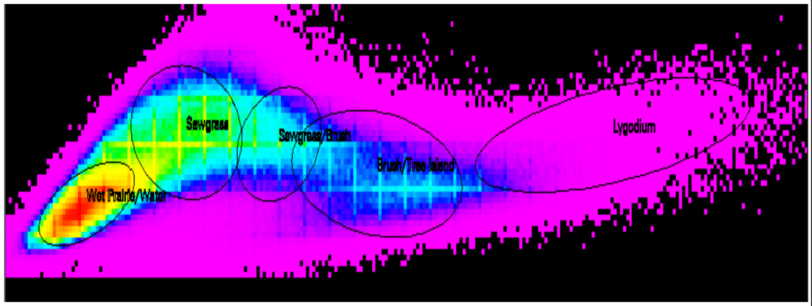
Figure 6-18. Natural color composite of five IKONOS scenes collected in March 2002 for WCA-1. Note: Clouds and shadows have been removed, and four demonstration plot areas where helicopter ground-truthing occurred within scene 4 are displayed.

Distance measure: Transformed Divergence

Using bands: 1 2 3 4

Taken 4 at a time

	Class
1	Wet Prairie/Water
2	Sawgrass
3	Sawgrass/Brush
4	Brush/Tree Island
5	Lygodium



Best Minimum Separability

Bands	AVE	MIN	Class Pairs:						
			1: 2	1: 3	1: 4	1: 5	2: 3	2: 4	2: 5
			3: 4	3: 5	4: 5				
1 2 3 4	1935	1764	1859	2000	2000	2000	1764	1976	2000
			1793	2000	1959				

Figure 6-19. Color image represents a plot in red verses color infrared feature space of measurement vectors for the five land cover types. Bottom table numbers represent transformed divergence values. Note: All pairing combinations with *Lygodium* (class 5) are 2000, which is the highest value obtainable and hence has the best statistical measure of difference between two classes.

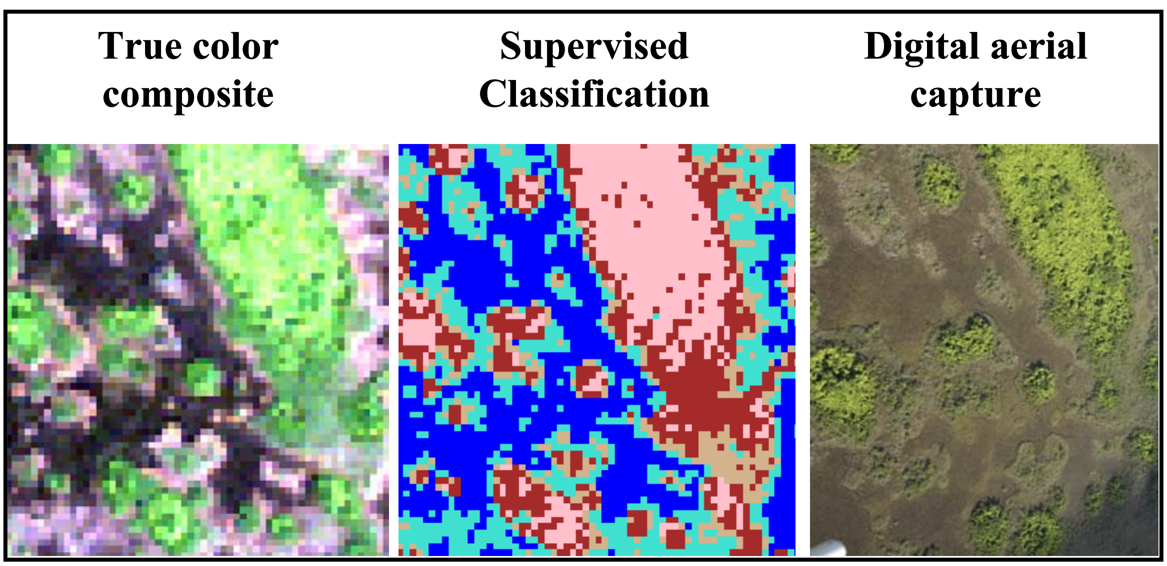


Figure 6-20. Three images representing the same location on the ground. Lime green areas in the digital aerial capture image (right) and pink areas within the supervised classification image (center) are *Lygodium*.

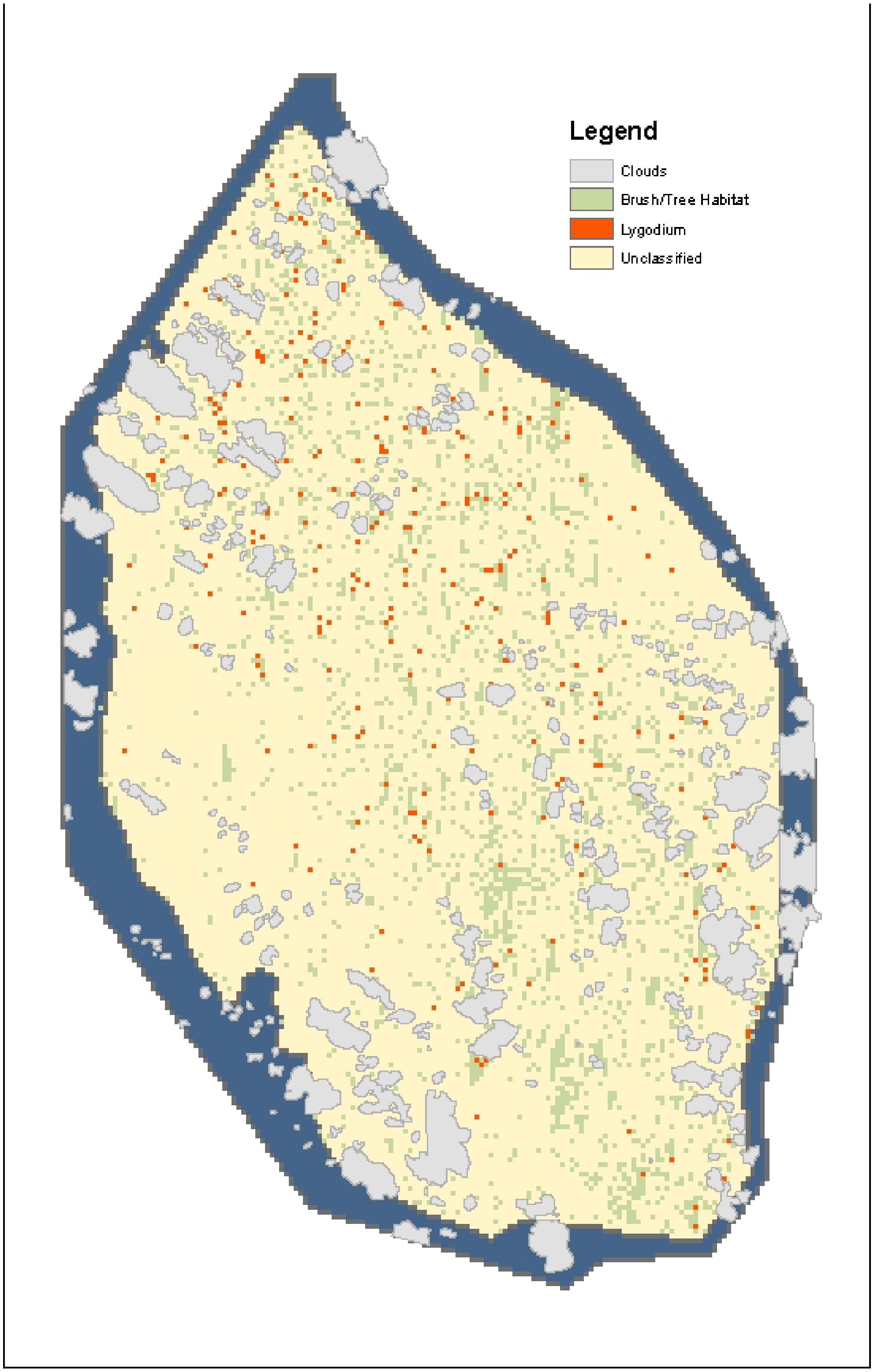


Figure 6-21. Classified map of *Lygodium* and shrub/tree habitat from IKONOS satellite data. Areas not included in the analysis include clouds and the blue border areas, which represent the clipped nutrient enriched areas.

CATTAIL CHANGES 1991 TO 2003

The District continues to use remote sensing for monitoring cattail to understand its invasive tendency in relation to hydrology, nutrients, and restoration plans. Time series trend analysis of cattail (*Typha* spp.) within Water Conservation Area 2A (WCA-2A) was performed utilizing 1:24,000 scale color infrared aerial photography captured in 1991, 1995, and 2003 (**Figure 6-22**). Each cattail map was generated utilizing stereo photointerpretation techniques. The 1991 and 1995 cattail maps were delineated using a vector system with a minimum mapping unit of one acre. (Further discussion of the 1991 and 1995 maps can be found in the February 1999 issue of *Photogrammetric Engineering & Remote Sensing*.)

New color-infrared aerial photography for WCA-2A was captured in January/February 2003 and adjusted to a UTM coordinate system. Cattail located on the aerial photographs was compiled utilizing a quarter-hectare (50 x 50 meter) grid method constituting a minimum mapping unit of 0.6 acres. The quarter-hectare grid was generated and superimposed over the 2003 aerial photography, resulting in 170,500 individual grid cells covering all of WCA-2A.

Vegetation within each individual grid cell was observed utilizing a Leica SD2000 stereo-plotter. Cattail cover was estimated for each grid cell and assigned one of four possible categories. The categories of this classification are: “cattail monotypic” (greater than or equal to 90 percent cattail), “cattail dominant mix” (50 to 89 percent cattail), “cattail sparse mix” (10 to 49 percent cattail), or “other" (less than 10 percent cattail). For ground-truthing, 742 locations within WCA-2A were visited using differential GPS navigation by airboat or helicopter. These points where determined to be areas in question or "unknown" during the photointerpretation process.

Advantages of the grid system mapping include greater time efficiency and cost efficiency. This technique also provides the unique ability to classify vegetation within the same quarter-hectare grid cells from this analysis during future mapping efforts. This allows for the past, present, and future analysis of each individual quarter-hectare of the entire area under study. In addition, the grid system more accurately depicts the overall heterogeneity of Everglades vegetation.

Results show that cattail continues to spread throughout WCA-2A (**Table 6-7**), with monotypic cattail patches expanding throughout the eastern portion of the impoundment and along the southwestern boundary (**Figure 6-22**). In addition, sparse cattail continues to spread along distinct cattail-sawgrass boundaries and throughout the southern regions of WCA-2A. The rate of spread appears to be slowing down, however, when compared to the 1991–1995 period. This decrease in rate may be due to the reduction in annual total phosphorus loads to WCA-2A during the 1995 to 2003 period.

Excess nutrients, hydrologic alterations, invasive habitat availability, and fire have been shown to influence successful establishment of cattail in the Everglades. The relative importance of these factors influencing cattail coverage in WCA-2A from 1995 to 2003 still needs to be determined. A small area in the northern tip of WCA-2A shows a decrease in cattail coverage. It is hypothesized that the loss of cattail in this area is due to a combination of events that include fire, a reduction in phosphorus loading, and altered water levels due to the closing of structure S-10E in 1996. Structure S-10E regulated water flow from the Hillsboro Canal into northern WCA-2A.

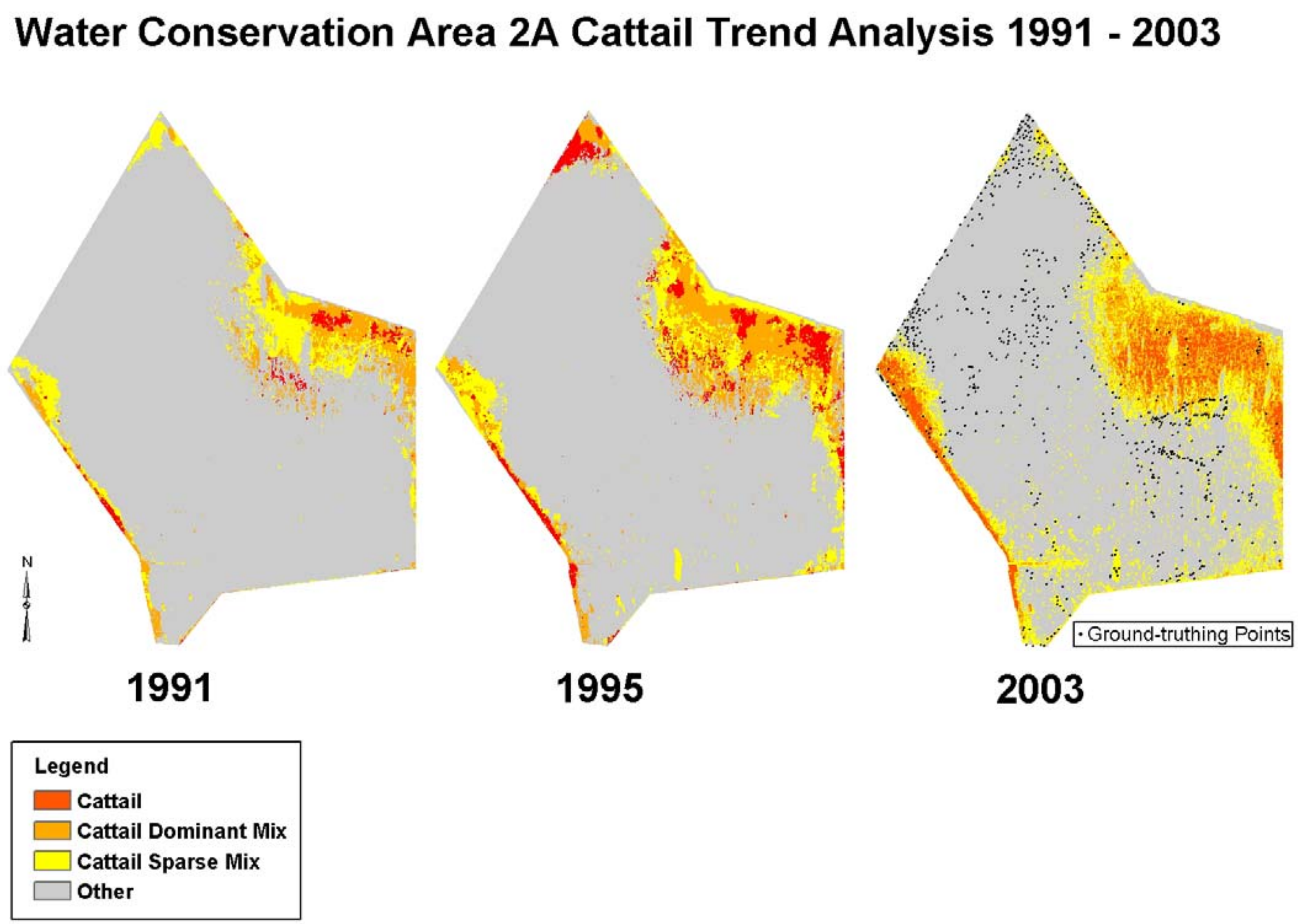


Figure 6-22. Cattail trend analysis in WCA-2A using color infrared aerial photography, 1991 to 2003.

Table 6-7. Cattail coverage in WCA-2A, 1991 to 2003.

Cattail Coverage of Each Sampling Date

	Cattail	Cattail Dominant Mix	Cattail Sparse Mix	Other
1991	421.6	2287.3	2760.9	36528.6
1995	1646.3	3944.0	3721.7	32686.5
2003	1982.5	3680.0	6191.5	30164.5

* Coverage is in hectares

THE LOXAHATCHEE IMPOUNDMENT LANDSCAPE ASSESSMENT (LILA)

There is broad agreement that enough is known about the Everglades ecosystem to move ahead with the Comprehensive Everglades Restoration Plan (CERP) but that key uncertainties must be reduced as it progresses. The restoration of the Everglades relies on an adaptive assessment framework that evaluates progress based on performance measures with quantitative targets. The Loxahatchee Impoundment Landscape Assessment (LILA) project is a tool for interpreting the complex patterns that come from monitoring biological performance measures in the natural system. LILA does not replace monitoring; rather, it supplements monitoring and makes the results more certain and more cost effective.

LILA involves sculpting the physical features of the Everglades landscape from two existing impoundments and then manipulating water depths and flow rates to induce a response by wildlife, tree islands, and ridge and slough communities (**Table 6-8**, **Figure 6-23**). LILA links hydrology (e.g., flow, seasonal water level fluctuations) with these three CERP high-priority features of the greater Everglades ecosystem. As such, LILA will serve as a pilot study for hydrologic regimes proposed under CERP but which have yet to be implemented on a broad scale. From a scientific perspective, LILA acts as a bridge between the results of small-scale microcosm experiments and large-scale ecosystem monitoring. From a restoration and management perspective, LILA's strength is that the certainty of data interpretation is high, because hydrology and other critical processes are controlled and replicated.

Macrocosm Conditions, Design, and Operation

LILA is located in two existing impoundments in the Arthur R. Marshall Loxahatchee Wildlife Refuge (Refuge) headquarters area in Boynton Beach, FL. The impoundments are part of a 10-impoundment wildlife enhancement management area constructed in the 1960s. The impoundment complex attracts a variety of wildlife and is very popular with the public. LILA involves constructing four small impoundments (8 ha in size) called "macrocosms" from the two existing impoundments (**Figure 6-24**). All macrocosms will receive the same hydrologic treatment (flow rate, water depths, etc.). In each macrocosm, a shallow and a deep slough will be sculpted from the existing marsh surface. Ridges, the tops of which will be at existing ground surface elevation, will separate the sloughs. Constriction in the sloughs will produce areas of higher flow velocities within each macrocosm. LILA is capable of producing flow velocities similar to those thought to occur in the Everglades during historic times. Each slough will contain both a shallow hole and a deep hole of 6 m in diameter and will be designed to simulate alligator holes and provide deep-water refuges for fishes. Access to the refuges by aquatic animals will be controlled with plastic mesh fencing. Deep sloughs will contain two tree islands that are each 14 m x 49 m in size and 0.91 m higher than the slough bottom. One tree island in each macrocosm will be built entirely from peat, and one tree island will be built from peat that sits on a limestone rubble core. Construction of this facility is shown in **Figure 6-25**.

To provide flowing water to the project, a recirculating water system will be established using an electric pump, gravity flow, and gated structures. A second portable diesel pump will be used as a backup and to pump water out of the central canal and into the Lake Worth drainage canal during extreme high-water events.

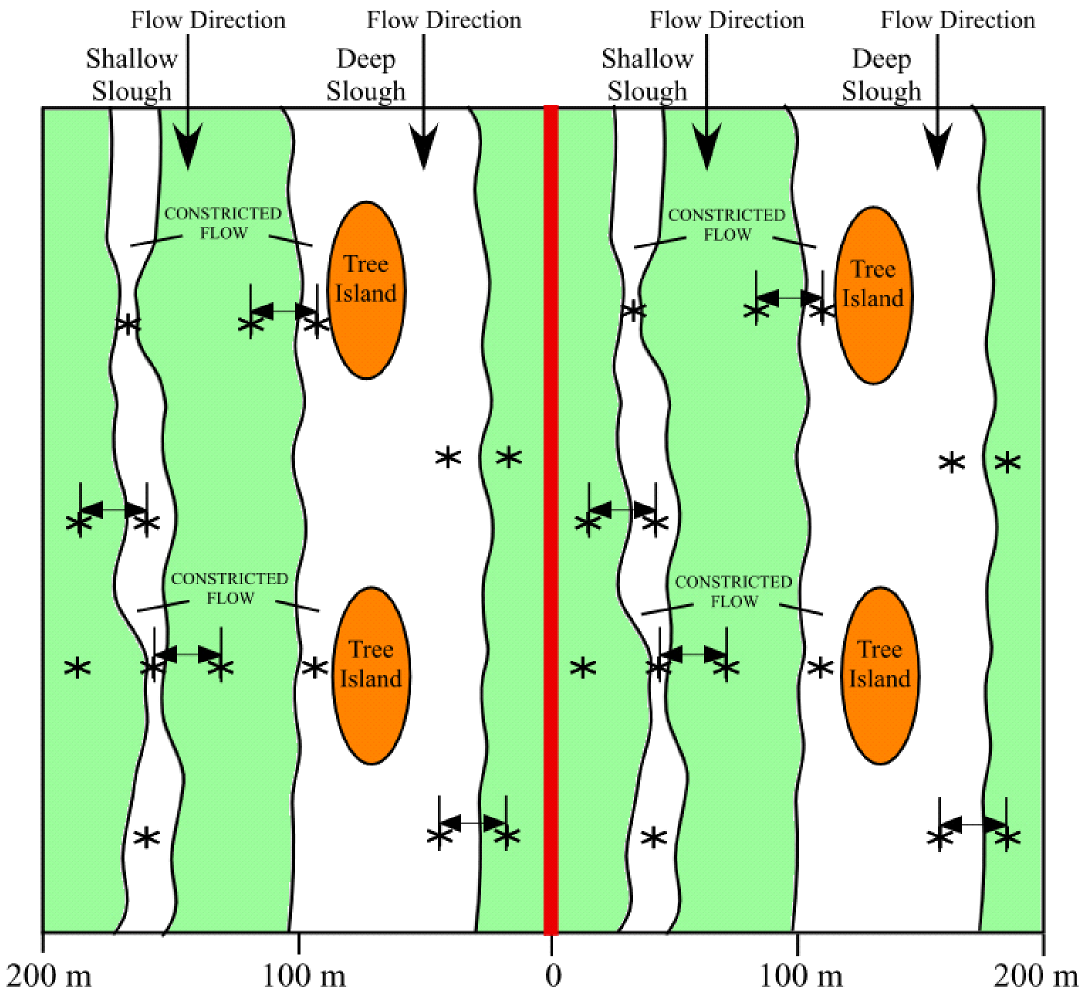


Figure 6-23. General design for two of the four macrocosms that will be used in the Loxahatchee Impoundment Landscape Assessment (LILA) to assess the ecological effects of water flow, depth, and hydroperiod on ridges, sloughs, and tree islands. Stars indicate vegetation sampling locations.

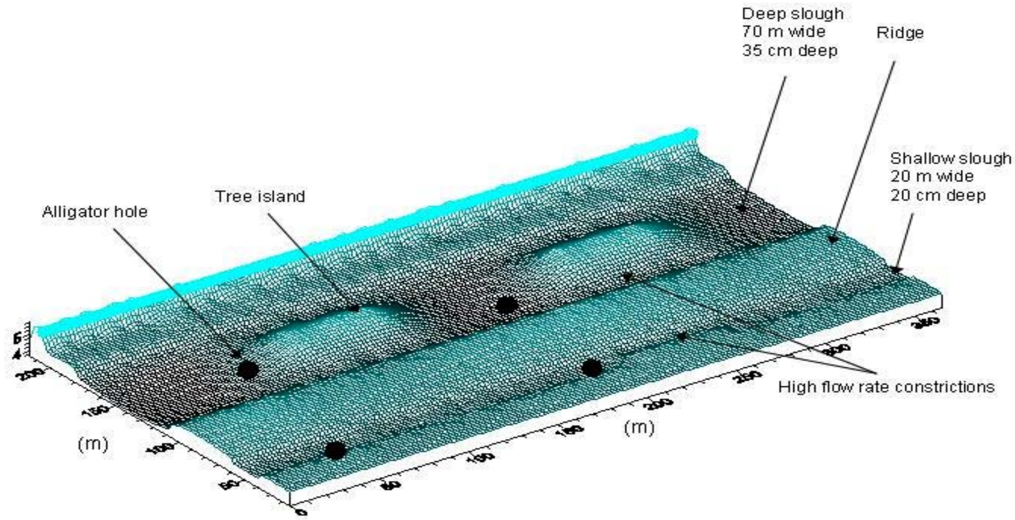


Figure 6-24. Overview of landscape elements in a LILA macrocosm.

Figure 6-25. Looking west across two LILA macrocosms. For scale, note the large dump trucks in the photograph's northernmost macrocosm (right), which is still under construction. Tree islands in the deep slough and a flow constriction in the shallow slough are clearly shown in the more southern macrocosm (center).

Public Outreach

Besides being scientifically advantageous, LILA provides an ideal opportunity to educate the public about CERP and its goals. It will be important to sustain public support for CERP, because it is a large-scale, long-term project that takes place largely out of the public's view. In contrast, LILA provides the public easy access to a site where construction work, which is so much a part of CERP, is visibly producing restored tree islands, restored ridge and slough habitats, increased wildlife use, and an obvious example of the integration of science into the restoration process. For example, members of the public can spend a morning watching a flock of wading birds feed in a restored slough habitat at the same time that scientists are collecting valuable information to support CERP. LILA also reinforces the fact that government agencies are cooperating and leveraging their limited funds to achieve more than they could by acting alone.

An information kiosk was constructed in the northeast corner of the LILA facility, near the observation tower. The kiosk will assist visitors in understanding the purpose of the construction activity and the link between short-term disturbances and long-term restoration. LILA also provides opportunities around the impoundments for guided tours for schools and other groups.

Wading Bird Studies

One of the leading explanations for the population declines of Everglades wading birds is that there has been a change in the way food becomes available to the birds because of changes in hydrologic patterns. There is more to prey availability than the density of prey. Prey availability is linked to the seasonal drydown in water levels, but there is very little understanding of the specific conditions that produce patches of highly available prey. The objective of the wading bird component of LILA is to determine the effect of fish community composition, physical features of the Everglades, and hydrologic factors on prey availability during the seasonal drydown. Three sets of studies focusing on wading bird foraging success, fish concentration events, and fish community composition will be conducted to quantify those effects. Both components of prey availability (i.e., prey density and vulnerability to capture) will be manipulated. Fish studies will measure fish density and movement patterns in relation to microtopography and deep-water refuges.

1. Wading bird foraging studies: Surveys and video sensing techniques will be used to measure the numerical response of wading birds and energy intake in relation to prey density, water depth, and vegetation structure. Indirect effects from microtopography and deep-water refuges will also be examined, but it is assumed they will affect wading birds through changes in prey density.
2. Fish concentration events: The objective of this study is to determine the effects of microtopography, vegetation density, and characteristics of the fish community on maximum prey density (i.e., the magnitude of prey concentration). Movement patterns will be monitored with radio tracking to determine the degree of exchange between fishes on ridges and in sloughs, the maximum distance moved by fishes during the drydown, and which movement patterns contribute to high fish density patches during the drydown. Movements will also be monitored to determine the timing and duration of high fish density patches in relation to the drydown.
3. Fish community composition: The species composition of the fish community differs greatly between places where large and small numbers of wading birds nest. The degree to which small fish movements and habitat use are affected by the presence of predatory fish will be

examined during the seasonal drydown. A response of small fishes to the predator fish treatments will be measured for habitat use, movements, and the use of deep-water refugia.

Tree Island Studies

More than half the tree island habitat in WCA-3 has been lost since 1940. Tree island losses have been attributed to abnormally high or low water levels; changes in tree island size and shape have been attributed to reduced flow rates. The restoration of the Everglades may require not only preventing additional tree island losses but also restoring tree islands where they have been lost. A pilot project to assess tree island restoration techniques is an essential first step in that process.

Assessment of tree island restoration techniques consists of four types of studies: (1) effects of water flow on tree island development, (2) significance of limestone cores for tree island health and development, (3) flooding tolerances of trees, and (4) seed dispersal of dominant trees.

1. Effects of water flow: During flooding, particulate organic carbon produced on the tree island head is expected to be carried off the head by water currents. This downstream movement of organic carbon is thought to be necessary for the maintenance of the near- and far-tail areas of the tree island. The objective of the flow study is to determine the importance of water flow in moving organic matter downstream for tail development. At the head, near tail, and tail, measurements of vertical soil accretion of peat, sediment erosion tables, and vegetation structure will be used to assess changes in island topography due to erosion and deposition.
2. Significance of limestone cores: Many fixed-type tree islands have an underlying limestone core. Limestone may provide a stable rooting environment for trees and may be an important source of phosphorus. Field observations indicate that the roots of many tree species on the heads of tree islands penetrate the limestone pedestals. A rock core may also physically stabilize the overlying peat. Limestone will be available on the levees that are to be removed as part of CERP. The objective of the limestone study is to determine if a limestone core is needed for island restoration and whether it enhances wood plant growth. The deep slough in each macrocosm will contain one tree island with a limestone core and one tree island made only of peat. Comparisons will be made between the island types for growth parameters of trees and root penetration into limestone. Also, comparisons of island morphology will be made from aerial photographs.
3. Flooding tolerances of trees: Tree species on islands occur along elevation gradients, presumably because of differences in flooding tolerances. However, flooding tolerances of most common tree island trees are not well known. The objective of the flooding tolerance study is to determine water depth tolerances of 10 common woody plant species. On each island, plant species will be planted in rows across a hydrologic gradient stretching from the island center to the edge. Measurements will include plant structure and survivorship.
4. Tree seed dispersal: The seeds of most species of trees that occur on tree islands appear to be dispersed by songbirds. Bird dispersal often gives a seed an advantage by increasing germination probability or survival. From a practical standpoint, if seed dispersal by birds can be increased, then the cost of planting trees will be reduced. The objective of the seed dispersal study is to determine the relative effectiveness of artificial perches and a single, large planted tree for establishing native woody tree seedlings on tree islands. This study has three treatments: constructed, three-dimensional wooden perches; a large, multibranching wax myrtle tree; and no perch (control). It is expected that this experiment can be conducted for two to three years after the construction of LILA until the trees planted for the flood tolerance study are also tall enough to attract birds. Measurements include bird use, plant density, and plant structure.

Ridge and Slough Studies

In much of the Everglades, the clear pattern of ridges and sloughs has partially or completely disappeared. This landscape feature has been lost to invasion by cattail, sawgrass, and possibly sedimentation. It is hypothesized that this loss of spatial pattern reflects a "flattening" of the landscape, that is, a diminishing of the difference in elevation between ridges and sloughs. Key questions include the hydrologic conditions that are needed to maintain a ridge and slough landscape under moderately enriched conditions, and the processes that keep sloughs open. LILA will test some of the mechanisms that are thought to be important to maintaining a ridge and slough landscape, that is, sediment transport, differential primary production, and differential decomposition rate. Testing of these mechanisms is an essential step for understanding and modeling this defining feature of the Everglades. Many of the same approaches being proposed for the study of tree island origin and development will be used to study ridge and slough formation and persistence. Sedimentation, erosion, and plant community responses will be examined in four studies: (1) water velocity profiles, (2) sedimentation and elevation change, (3) vegetation density, composition, and succession, and (4) peat accumulation rates.

1. Water velocity profiles: The objective of this study is to provide baseline flow data to evaluate sedimentation, decomposition, sediment movement, primary production, and elevation change. LILA will experience roughly the same range of flow velocities that occur "naturally" in the ridge and slough habitats of the Water Conservation Areas, with the capability of producing the higher rates thought to have occurred historically. Flow velocities will be measured with acoustic Doppler meters deployed along transects in areas of high and low flow.
2. Sedimentation and elevation change: The accumulation of inorganic and organic material on or within the marsh soil can allow marsh ground elevation to increase. Maintenance of the Everglades landscape components (e.g., tree islands and ridge and slough patterns) requires a balance between organic and inorganic sedimentation components and other forces, such as subsidence, acting on the whole landscape. The objective of this study is to assess the effects of water management on marsh sediment transport, erosion, and deposition. Deposition of water-borne sediment on the marsh surface can only occur when the marsh is flooded. Deposition requires both the availability of suspended sediment and the opportunity for that sediment to be transported by floodwaters over the marsh. Soil deposition will be measured at stations where flow velocity and decomposition and primary production are also measured.
3. Vegetation characterization: Vegetation communities are integrative indicators of soil processes, water quality, and hydrologic regimes. The objectives of this study are as follows: (1) quantify differences in aboveground ecological processes between ridge and slough, (2) determine what hydrologic conditions enhance ridge expansion into sloughs, and (3) determine whether directional flow affects seed dispersal of ridge vegetation. Plant community structure and function will be monitored at the habitat scale within ridges and sloughs, at the ecotone scale between ridges and sloughs, and at the landscape scale by comparing macrocosms. This will require ground surveys of plant composition, density, biomass, nutrient content, and aboveground production. It will also require aerial photography and remote sensing techniques to quantify and interpolate ground surveys up to the macrocosm scale.
4. Peat accumulation rates: The objective of this study is to test the idea that ridges accumulate peat at a faster rate than sloughs due to greater aboveground and belowground standing biomass and slower decomposition rates. Permanent vegetation plots will be established in slough and sawgrass areas in each of the treatments in each macrocosm. Aboveground and net belowground production will be measured by collecting soil cores from each plot at

minimum and maximum growth periods. Annual decomposition rates will be determined using litter and root bags. Water lily, spikerush, and sawgrass will be placed in each of their respective habitats, either ridges or sloughs. Belowground decomposition will also be obtained at the same locations using air-dried dead roots of each species. To consider relative differences in decomposition rates between the ridge and slough treatments, cotton strips will be used as a standard substrate to assess responses.

5. Periphyton food-web studies: Two experiments will be conducted in LILA to test hypotheses about mid-trophic level fish. Both experiments will test the hypothesis that periphyton structure and function are regulated, in part, by top-down forces (i.e., grazing by fish); each has seasonal patterns incorporated into the experimental design. The first hypothesis is that small fish directly influence the structure and function of periphyton assemblages and that the effects differ between deep and shallow sloughs. The second hypothesis is that higher trophic levels (predatory fish) regulate intermediate trophic levels, which in turn influence periphyton structure and function.

Table 6-8. Primary components of the LILA project. The first three components are assessment studies, and the last is the public outreach portion.

Project Component	Questions	CERP Performance Measures Addressed by Each Component	Response Variables
Wildlife Studies			
Wading Bird Foraging Success	How do prey density, water depth, and vegetation structure affect the foraging success of wading birds during drydown?	Wading bird foraging activity	Wading bird habitat use Wading bird feeding success
Fish Concentration Events	How do microtopography and deep-water refugia affect the concentration of fish during drydown?	Fish distribution and abundance Fish concentration events	Fish density on ridges and in sloughs Fish movement patterns
Fish Community Composition	How does the presence of piscivores affect the habitat use and movement of small fish during drydown?	Fish distribution and abundance Fish concentration events	Fish density on ridges, in sloughs, and in refugia Fish movement patterns
Tree Island Studies			
Tree Island Restoration Techniques	Is a limestone core needed to support tree island vegetation?	Tree island health	Aerial mapping of island morphology Vegetation growth Root penetration and biomass
Water Velocity and Tree Island Development	Are directional, moving waters needed to maintain tree islands?	Tree island elevation	Soil accretion Vegetation community coverage
Flooding Tolerances	What are the hydrologic water tolerances for the major woody species needed for tree island restoration?	Tree island composition	Plant growth parameters Canopy density Transpiration Survivorship
Seed Dispersal Enhancement	Which perch types are most effective at enhancing seed dispersal and seedling establishment?	Tree island health Tree island composition	Number, size, and species of seedlings and bird use of perches

Table 6-8. Continued.

Ridge and Slough Studies			
Ridge and Slough Sustainability	Is the threshold velocity for sedimentation and erosion different for ridges and sloughs?	Peat soil accretion, deposition, and erosion rates	Organic matter deposition in ridges and sloughs Total suspended solids in sloughs Peat subsidence/accretion
Ridge and Slough Restoration	What are the hydrologic conditions needed to maintain a ridge and slough landscape in moderately enriched conditions?	Plant community composition, distribution, and production	Above and belowground productivity Vegetation density/composition Seed dispersal Decomposition
Small Fish Grazing and Slough Depth	Determine if grazing by small fish directly or indirectly influence the structure and function of periphyton in deep and shallow sloughs	Periphyton species composition, biomass, and productivity. Invertebrate and vertebrate species composition, density, and gut content analysis	Initially, then twice a year at peak and off-peak wading bird nesting periods
Top-Down Effects and Slough Depth	Determine if periphyton structure and function are regulated by the number of trophic levels	Periphyton species composition, biomass, and productivity. Invertebrate and vertebrate species composition, density, and gut content analysis	Initially, then twice a year at peak and off-peak wading bird nesting periods
Public Outreach			
LILA as a CERP demonstration project for Everglades restoration	How is CERP going to restore the Everglades and benefit wildlife and tree islands?	CERP goal: Increase general public support and awareness of CERP	N/A

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