Final Report

Assessment of Marsh Vegetation Responses to Hydrological Restoration in Shark Slough, Everglades National Park

Introduction:

Shark Slough is the main artery by which surface water sheetflow passes through the southern Everglades to Florida Bay and the Gulf of Mexico. The nature of water flow in Shark Slough has, over many centuries, yielded the linear vegetation pattern that epitomizes the Everglades. This pattern consists of a series of slightly elevated strands of dense, tall sawgrass or woody vegetation, separated by lower, more open marsh communities, or "wet prairies". Shark Slough vegetation structure and dynamics have been examined by a number of researchers during the last half century (Kolipinski and Higer, 1969; Craighead, 1971; Hofstettter, 1976; Hofstetter and Pearson, 1976; Wade et al., 1980; Gunderson, 1994; Davis et al., 1994; Olmsted and Armentano, 1997). For the most part, changes appear to be regional rather than Slough-wide, with sawgrass invading wet prairies in some places, dying back elsewhere, and being replaced by woody (sometimes non-native) plants in others yet. As Everglades restoration proceeds, a more comprehensive and current view of the Shark Slough landscape is needed, along with a better understanding of the processes by which it has developed and is maintained.

Below we report on research addressing several aspects of Shark Slough landscape ecology, carried out by a group of FIU scientists during 1997-2001. The specific objectives of the study were: (a) to examine associations between vegetation, hydrology, and soils in Shark Slough, (b) to assess historical changes in vegetation patterns, and (c) to establish a monitoring network that included previously sampled sites near the center of the Slough, as well as peripheral sites that may be more sensitive to future environmental alterations. Our results are organized into the six separate but interdependent documents that follow.

Section 1

Vegetation:Environment Relationships and Water Management in Shark Slough

Introduction:

Plans under development for revising water management in South Florida to benefit the Greater Everglades ecosystem (USACOE 1994) represent one of the most ambitious ecological restoration efforts ever attempted. The problems which have motivated this effort include: (a) sharp declines in populations of wading birds and other animals of special concern (Powell et al., 1989; Ogden, 1994; Curnutt et al., 1998); (b) deteriorating conditions in the Florida Bay estuary, the terminal receiving basin for Everglades surface water (Fourqurean and Robblee, 1999); (c) rapid expansion of cattails (Typha domingensis Pers.), associated with the outflow of phosphorus-enriched canal water into the Water Conservation Areas (WCA's) and adjacent marshes north of Everglades National Park (Davis, 1991; Craft and Richardson, 1997; Doren et al., 1997; Wu et al., 1997); (d) loss of tree islands due to excessive flooding or fire in some parts of the WCA's (Brandt et al., 2000); (e) expansion of sawgrass at the expense of wet prairie communities (Davis et al., 1994); and (f) the rapid growth of exotic plant and animal populations throughout the Everglades (Schmitz and Brown, 1994; O'Hare and Dalrymple, 1997). With the exception of (e) and (f), the problems listed above are primarily manifested in wetlands peripheral to Shark Slough, the main pathway of surface water drainage through Everglades National Park (ENP). However, as a result of its central location, the Slough's hydrology will be affected by water management measures undertaken to benefit other portions of the Everglades ecosystem. Furthermore, long term alterations in the hydrologic regime of Shark Slough may result in parallel biotic changes, especially in the distribution and abundance of native plant and animal communities.

Hydrologic restoration activities currently being developed follow on the heels of a long sequence of structural, operational, and regulatory changes in water management in South Florida, beginning well before the creation of ENP in 1947. During the early period of water management, the primary objectives were drainage, flood control and water storage. These goals were achieved through construction and operation of an extensive network of pumps, canals, and levees, which effectively compartmentalized the central Everglades north of US Highway 41 (Figure 1.1). Since congressional passage of Public Law 98-181 in 1983, legally mandated concerns for the restoration and maintenance of natural Everglades ecosystems have stimulated a series of regulatory changes within the existing structural network. However, in the southern Everglades, one management direction has remained consistent during the 1980's and 1990's: the routing of southbound water to the west at Highway 41, away from its primary pre-development flow-way (Light and Dineen, 1994; Van Lent et al., 1999). In this area, concentration of delivery through control structures west of the L-67 levee has eliminated the historic northeast-southwest flow of water in the northern portions of ENP (Figure 1.1). This distribution pattern has served to decrease water level and flooding duration in Northeast Shark Slough, while accounting for wetter conditions in Northern Shark Slough. The

spatial pattern of water delivery may have had less hydrologic impact on the more remote southern portions of the Slough. Effects of these management activities on regional vegetation patterns have not been addressed in detail.

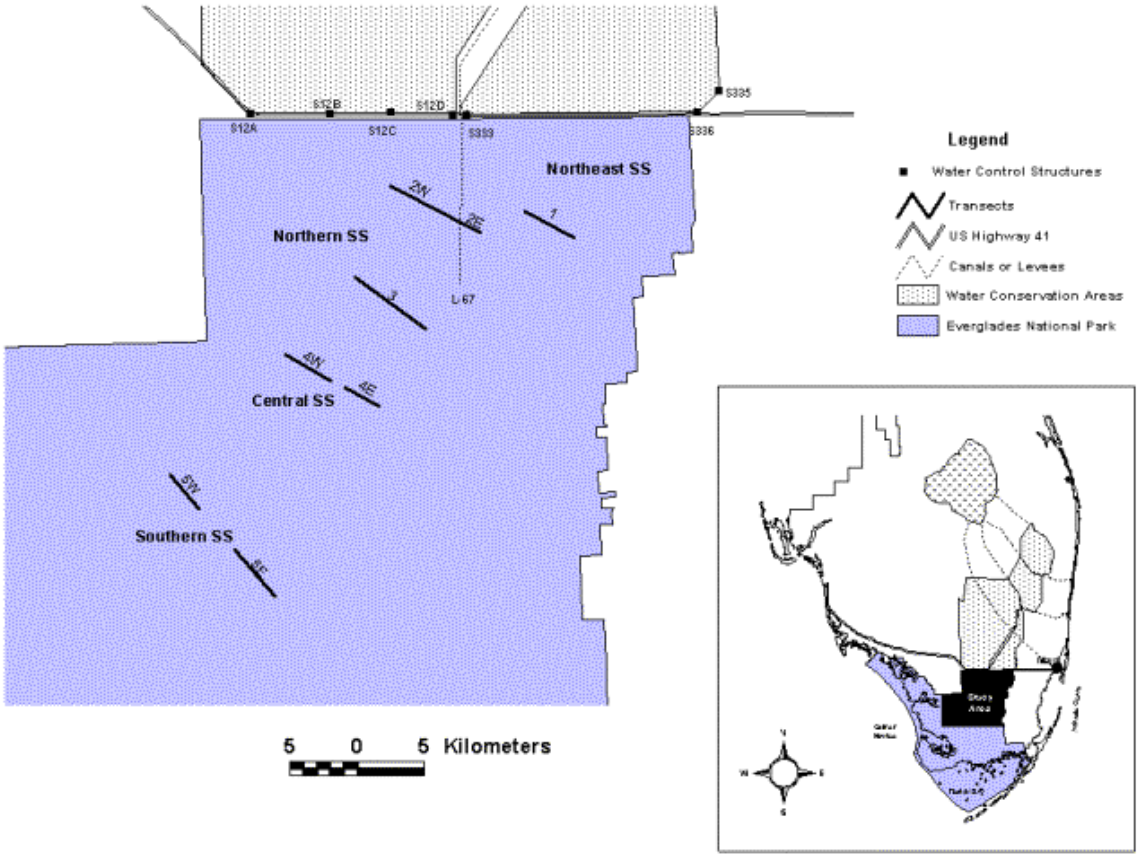


Figure 1.1: Study area with location of sampling transects.

From a distance, the vegetation of the Slough appears rather homogeneous, but closer inspection reveals a complex mosaic of marsh assemblages, spotted liberally with distinct wooded parcels called tree islands. Within the marsh, large acreages supporting monodominant stands of the large sedge Cladium jamaicense Crantz (sawgrass) are interrupted, sometimes abruptly, by more open communities featuring a relatively rich mixture of smaller aquatic plants and periphyton (an integrated mat community consisting of algae, bacteria, and microheterotrophs). These habitat units are frequently elongated in shape and oriented parallel to the predominant NE-SW direction of water flow, suggesting a strong functional connection between hydrology and vegetation. Recent investigations (Gunderson, 1989; Olmsted and Armentano, 1997; Busch et al., 1998) documented small differences in mean hydrologic regime among community types, e.g., flooding was usually deeper and more persistent in open marsh types dominated by spikerush (Eleocharis cellulosa Torr.) or maidencane (Panicum hemitomon

Schult.) than sawgrass marsh, which in turn was wetter than forested cover types. However, these conclusions were based on data from a limited number of Shark Slough settings, and quantification of variation in the vegetation:hydrology relationship at the broad landscape scale remains incompletely understood.

The relationship of hydrology and vegetation in the Everglades is complicated by interactions with other dynamic environmental factors, including soil characteristics and disturbance regime (Duever et al., 1986). For instance, data presented by Olmsted and Armentano (1997) indicate that soils underlying sawgrass marsh were, on average, deeper than soils of spikerush/maidencane communities, though overlap was substantial. Everglades soils are biological entities whose development reflects a balance of accretionary v. degradational processes, i.e., root production, sedimentation, decomposition, and erosion rates; all of these processes may be functionally related to the overlying plant communities (e.g., Craft et al., 1993; Day et al., 1999). These relationships are largely unquantified, but may account for much of the variation in marsh surface topography (and in the depth of the soil profile), with associated feedbacks on hydrology.

In the research reported below, our objectives were: (1) to clarify the associations of hydrology, soil depth, and plant community structure in Shark Slough, focusing especially on regional variation in these relationships, and (2) to evaluate the possible role of water management in creating such variability, if present. Our approach was to sample vegetation, soils, and water depth at regular intervals along cross-Slough transects, construct a hydrologic record for each point by referencing the nearest water level recorder, then control for local spatial effects and the covariance among soil and hydrologic variables in the analytical phase.

Current water management practices and their antecedents:

Efforts to drain South Florida wetlands began as early as 1850. Rising population and agricultural development throughout central Florida provided the stimulus for state, federal, and privately funded diversion projects whose purposes were drainage, flood protection, and irrigation (McCally, 1999). Beginning with the dredging of the Caloosahatchee River in the 1890’s, and continuing with the West Palm Beach, Hillsboro, North New River, and Miami Canals in the early years of the twentieth century, water that had previously overflowed Lake Okeechobee and moved south by sheetflow was instead directed to the coastal estuaries. Construction of the Tamiami Canal (1915-1928) also intercepted and diverted flows to Shark Slough and the Southern Everglades. With the issuance of the 'Comprehensive Report on Central and South Florida for Flood Control and Other Purposes' in 1948, the Army Corps of Engineers initiated the construction of a network of interconnected levees and canals to create water-storage and agricultural areas along the Everglades trough. This network, completed in 1963, compartmentalized the northern Everglades into a patchwork of Water Conservation Areas (WCA’s), designed to store water during dry periods and

release it to the Southern Everglades when flooding conditions became imminent (Light & Dineen, 1994).

In the first decades after the establishment of ENP in 1947, retention of water in the WCA's clearly conflicted with water supply to the central and southern reaches of Shark Slough. In 1967, the L-67 levee and canal was extended southward in order to direct water further into the Slough. A side effect of the extension was to prevent water delivered through control structures west of the levee from flowing to Northeast Shark Slough (Walters et al., 1992; Light and Dineen, 1994) (Figure 1.1). Regional disputes over supply responsibilities to ENP led to congressional action in 1970, whereby a minimum annual delivery was guaranteed. During the 1970's, minimum deliveries were generally achieved by increasing flows during the wet season, while dry season flows remained low.

Until 1983 water releases from the WCA's into ENP were solely through four control structures located along the Tamiami Canal, west of the L-67 levee. Both the Experimental Water Deliveries Program (1983) and the Modified Water Deliveries Program (1989) attempted to reproduce the natural timing and distribution of precipitation inflow to Shark Slough by balancing flows to Northern and Northeastern Shark Slough. However, regulations for both programs required moderate conditions in order to achieve target deliveries to the two areas. Currently, the Modified Water Deliveries Program anticipates a 45-55% split of flow between structures west and east of the L-67 levee, respectively. However, during wet years, regulations call for the closing of the eastern structures to prevent flooding in adjacent areas, and 100% of flow is released through the western structures (Van Lent et al., 1999).

Methods:

Vegetation and environmental sampling:

Five transects were established to examine the variability in vegetation, hydrology, and soils along the length of Shark Slough in Everglades National Park (Figure 1.1, Table 1.1). Transects were oriented perpendicular to the apparent direction of water flow, and ranged in length from 4 to 12 km. Three transects were effectively divided into eastern and western portions, because they were interrupted for at least 1 km by impassable terrain or disturbance associated with a canal or airboat trail. Sampling stations were established every 100 meters along each transect. To address smaller-scale variation, each km of transect also included a 200-meter section that was sampled at 20-meter intervals. In all, 569 points were sampled. Vegetation sampling was conducted when water levels were high in Shark Slough, i.e., during the periods November 1998 - January 1999 and July 1999 - December 1999. Sampling within individual transects was generally completed within six weeks or less.

Table 1.1. Transect and plot layout in four Shark Slough (SS) hydrologic regions.

Region	Transect	Transect Length (km)	Number of Plots
Northeast SS	1	4.0	73
	2E	1.4	22
Northern SS	2W	5.0	91
	3	6.0	110
Central SS	4E	3.0	55
	4W	4.0	73
Southern SS	5E	4.6	87
	5W	3.3	58

A nested plot design was chosen for quantitative vegetation sampling, because of the range of plant growth forms present in the Slough. At each station, a PVC tube driven into the sediment marked the SE corner of both a 10 x 10 meter tree plot and a 5 x 5 meter shrub/herb plot. In the former, we measured the DBH, crown length and width of each tree (defined as woody stems ³ 5 cm DBH), then calculated species cover assuming elliptical crown form. In the latter, we estimated the cover class of each species of shrub (vines and woody stems ³ 1m height and < 5cm DBH), using the following categories: < 1%, 1-4%, 4-16%, 16-33%, 33-66%, and > 66%. Species cover class of herbs and woody plants < 1 m height was estimated in similar fashion in three randomly located 1-m2 subplots within the 5 x 5 m plot. Plot averages were calculated using the midpoints of the cover classes. Species present in the plot but not found in any of the subplots were assigned a mean cover of 0.01%. Data analysis was based on the total of tree, shrub, and herb stratum estimates for each species.

In addition to the quantitative observations described above, we also characterized vegetation cover every five meters along the transects, based on a visual assessment of several broad structural and compositional attributes. We assigned each point to one of six cover types defined in Table 1.2: spikerush marsh, sparse sawgrass, tall sawgrass, bayhead swamp, cattail marsh, and dead sawgrass/open water. The first four of these units were equivalent to types described by Olmsted and Armentano (1997).

Table 1.2 Criteria used t distinguish major cover types in Shark Slough.

Vegetation Type	Criteria
Spikerush Marsh	Dominant species *E. cellulosa*, *P. hemitomon*, or *P. geminatum*; canopy height < 1.5 meters.
Sparse Sawgrass	Dominant species *C. jamaicense*; canopy height < 2 meters.
Tall Sawgrass	Dominant species *C. jamaicense*; canopy height 2 meters or more.
Bayhead Swamp	Woody vegetation dominant or co-dominant with *C. jamaicenes*.
Cattail Marsh	Dominant species *Typha domingensis*; canopy height 2 meters or more
Dead Sawgrass - Open Water	Total live vegetation cover < 20%; evidence of large dead culms of *C. jamaicense*

Concurrent with vegetation sampling, soil depth was measured at the SE corner of each plot and at the three herb subplots. Soils were probed to bedrock with a 1 cm diameter aluminum rod, and mean depth was calculated from the four measured values. Water depths were likewise recorded during vegetation sampling at the same four locations. Referencing the average of these values to the datum for the same day at the nearest longterm water recorder, daily water level at each plot was estimated for the period January 1, 1990 - December 31, 1999; these data were used to calculate hydroperiod (number of days per year when the surface was inundated), mean water depth (average of all days when water was above the surface), and maximum water depth (highest 30-day running mean) for each year during the decade.

The assumption on which estimates of the above hydrologic parameters are based is that daily change in water level is equal at the reference recorder and at all plots along a transect. Comparison of water levels along the transects and at the reference recorders for two days in October 1999 and February 2000 - a recession period when water remained well above the surface throughout the Slough - indicated that the 95% confidence limits for daily estimates were approximately ± 1 cm. However, the assumption of equal change along the transect is violated when water at the recorder recedes below the soil surface, after which its level changes more rapidly than at any still-flooded plots, because water occupies pore spaces only. Therefore, during periods when water level dropped below the surface at the water level recorder, we assumed that water level at the flooded plots fell at a rate of 0.5 cm/day until reaching the surface; and rose, ahead of the water surface at the recorder, at the same rate. The above rate is a reasonable maximum, based on inspection of recorded recession rates at several recorders, supported by estimates of daily evapotranspiration in the Everglades (German, 2000; Gunderson and Stenberg, unpublished manuscript) and an emergent aquatic macrophyte-dominated wetland in Central Florida (Dolan et al., 1984). The situation

described above constituted a minor proportion of the data base, because most of the water level recorders were situated in open slough conditions where water depths rarely dropped below the soil surface.

Data analysis:

We examined compositional variation in Shark Slough vegetation and its environmental correlates through ordination and other multivariate analytical techniques, using data from all five transects. To downweight the effects of very abundant species, a square root transformation was applied to the cover percentages, and the transformed data were relativized within plots. A site-by-site dissimilarity matrix was created based on the Bray Curtis metric, and the data were ordinated with the non-metric multidimensional scaling (NMS) algorithm in PC-ORD version 4.10 (McCune and Mefford, 1999). The site ordination was examined with respect to the distribution of (a) the three hydrologic variables, (b) soil depth, and (c) the vegetation categories defined in Table 1.2. To test the strength of the relationships between plant species composition and the environmental variables while accounting for spatial structure, we applied partial Mantel tests, using the R-Package program (Legendre, et al. 1996-99).

In addition to the ordination approach described above, in which vegetation was treated as a continuous variable, we also tested for differences in hydrologic and edaphic measures among discrete vegetation and management units, using two-way, Model 1 analysis of variance. Four management units were defined (Table 1.1, Figure 1.1). Northeast Shark Slough (NESS), which included the water-deprived marshes east of the L-67 levee, was represented by Transect 1 and the east end of Transect 2. Northern Shark Slough (NSS), the water-enhanced wetlands immediately west of the L-67 levee, were represented by points along Transect 3 and the west side of Transect 2. Central Shark (CSS) was represented by Transect 4, and Southern Shark Slough (SSS) by Transect 5. Only plots characterized as spikerush marsh, sparse sawgrass, or tall sawgrass were considered in the analysis of variance, because the other cover types were not sufficiently well-represented throughout the study area. Soil depth, hydroperiod, mean water depth, and maximum water depth were the environmental variables analyzed. We analyzed data from 1991 and 1997, which were dry and average water years, respectively, in comparison to other years in the 1990's.

Results:

Based on characterization of points at five-meter intervals along each transect, rank abundances of the three major marsh cover types were identical in the four regions: sparse sawgrass > spikerush marsh > tall sawgrass (Figure 1.2). However, regional trends in the relative abundance of individual communities were noteworthy. Vegetation in NESS and SSS was relatively uniform, with Sparse Sawgrass occupying more than 60% of the landscape. Dominance was more evenly distributed among cover types in NSS and CSS, where open spikerush marsh covered nearly one-third of the surface. Tall

sawgrass was least abundant in the two southern regions, and never exceeded 20%. Bayhead swamp, dead sawgrass/open water, and cattail marsh were minor components in the three southern regions.

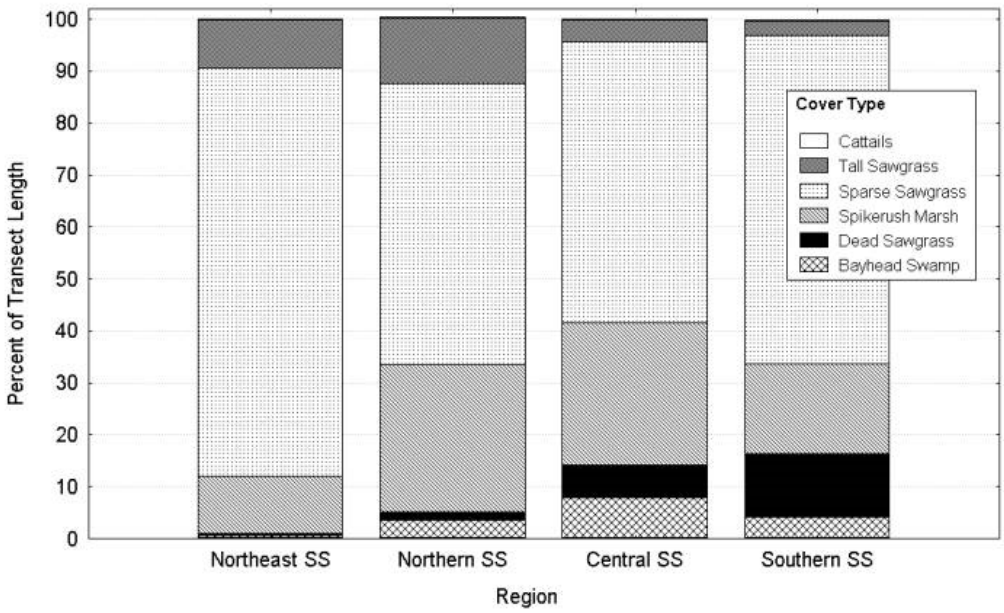


Figure 1.2: Cover type distribution in four Shark Slough (SS) hydrologic regions.

Analysis of the compositional data within transects indicated considerable small-scale spatial structure in marsh vegetation. Typically, mean Bray-Curtis dissimilarities for pairs of points 1, 2, 20, and 40 meters apart were considerably smaller than those for points further apart. Hydrology and soil depth likewise exhibited spatial patterning. To eliminate redundancy associated with spatial structure, ordination of the vegetation data was therefore based on points separated by 200 meters or more. The two-axis NMS site ordination derived from these data (Figure 1.3) was characterized by a low stress value (13.1), and explained about 96% of the total variation in the dissimilarity matrix. Plots within four major vegetation units (spikerush marsh, sparse sawgrass, tall sawgrass, bayhead swamp) occupied distinct positions in the ordination, with small areas of overlap between tall and sparse sawgrass, and between the latter and spikerush marsh. The positions of individual species within the ordination, calculated from abundance-weighted distributions among sites, are informative with respect to the ecological niches of minor species. For instance, Crinum americanum L., Peltandra virginica (L.) Schott & Endl., and Justicia angusta (Chapm.) Small were associated with denser sawgrass strands, while Rhynchospora tracyi Britt., Nymphoides aquatica (J. F. Gmel.) Kuntze, P. geminatum and Sagittaria lancifolia L., were more characteristic of more open spikerush marsh.

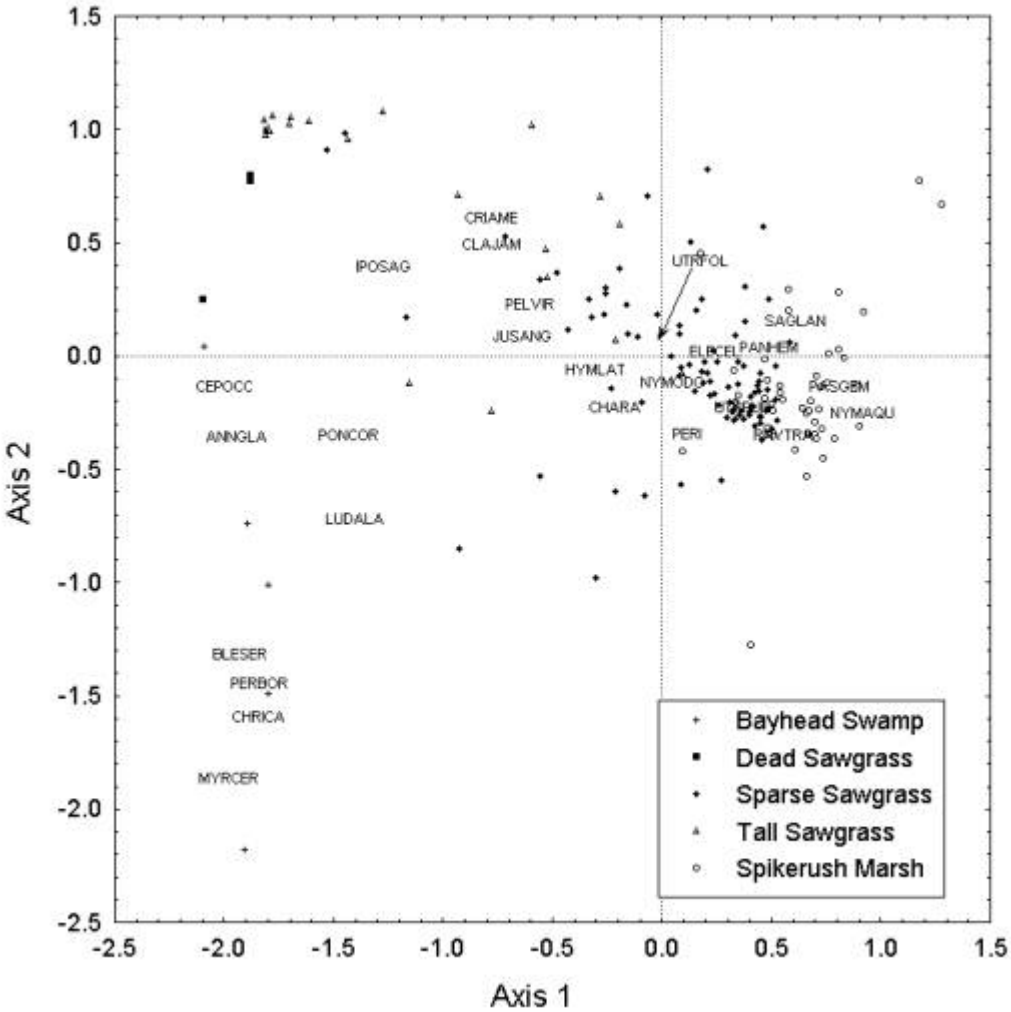


Figure 1.3 NMS site ordiantion, based on plant species composition in 164 plots along five Shark Slough transects. Locations of species centroids are coded with first three letters of genus and first three letters of species name.

Superimposing contour plots based on calculated hydroperiods, maximum water depths, or average water depths for each point on the ordination (Figures 1.4 - 1.6) suggests that hydrology bears a strong influence on the Shark Slough habitat mosaic. During 1991, a dry year, spikerush marsh and sparse sawgrass were generally inundated for nine months or more, with maximum water depths of at least 40 cm, and average water depths of 25 cm or more. Tall sawgrass sites were inundated for 6-10 months and bayhead swamp for 2-6 months, with concomitantly lower water depths (Appendix 1). In 1997, a year in which water levels were about average for the decade, all points were inundated for at least eleven months except in bayhead swamp (range: 4-8 months). Dead sawgrass/open water was found at points intermediate in hydroperiod between tall sawgrass and bayhead swamp.

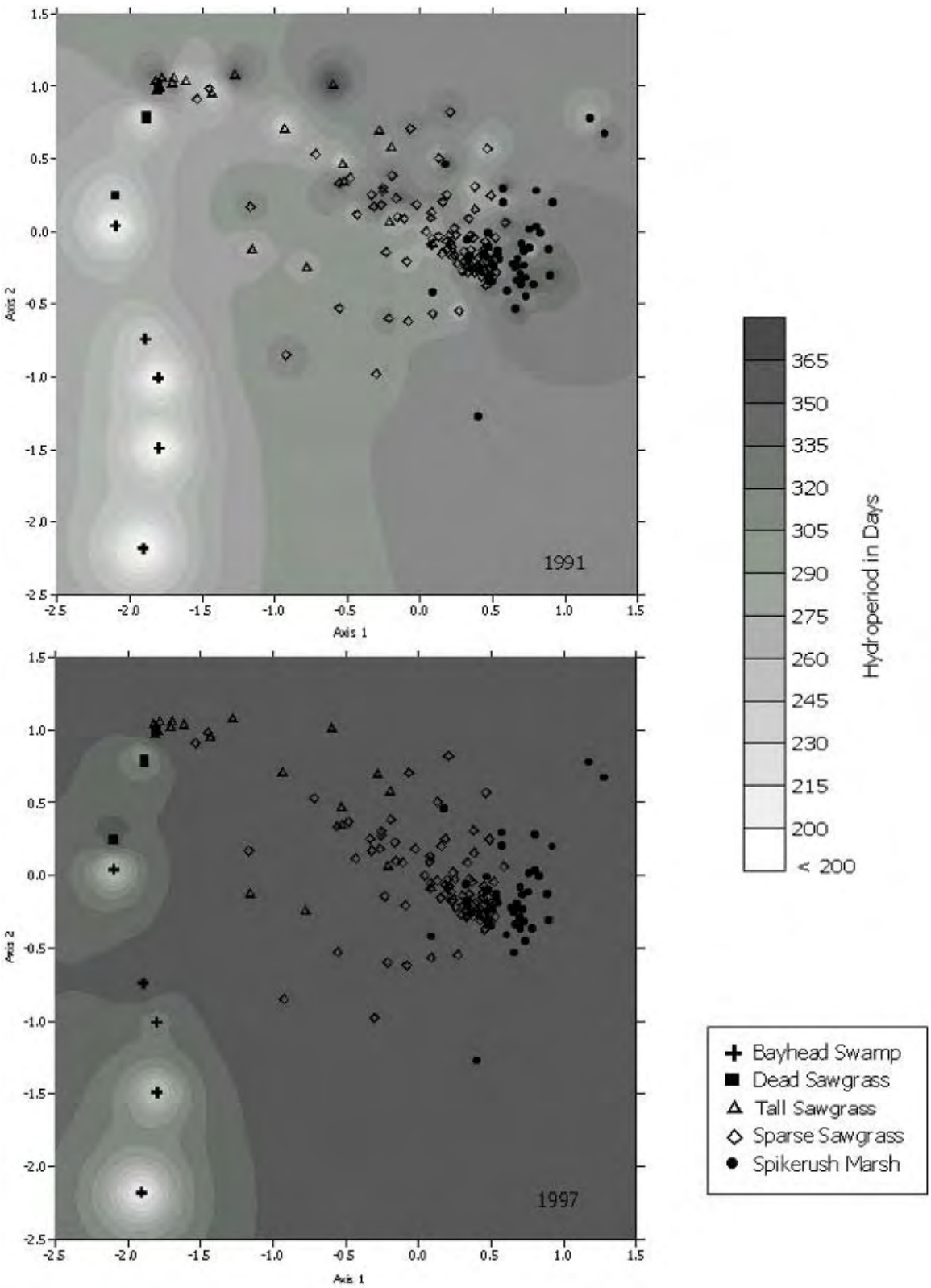


Figure 1.4: Contour plots of hydroperiod during a dry year (1991) and an average year (1997), superimposed on the NMS ordination of vegetation at 164 shark Slough locations.

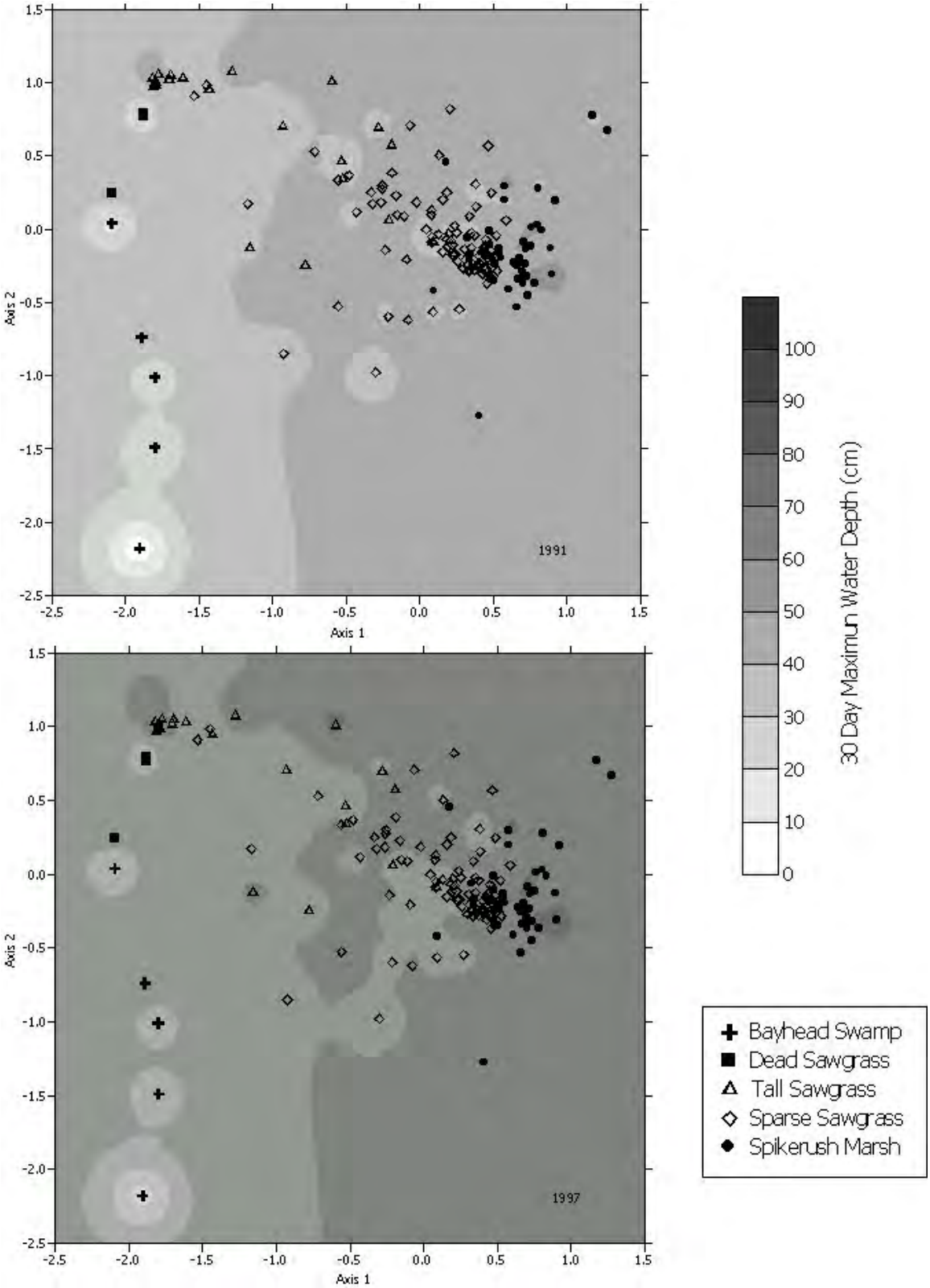


Figure 1.5: Contour plots of maximum water depth during a dry year (1991) and an average year (1997), superimposed on the NMS ordination of vegetation at 164 shark Slough locations.

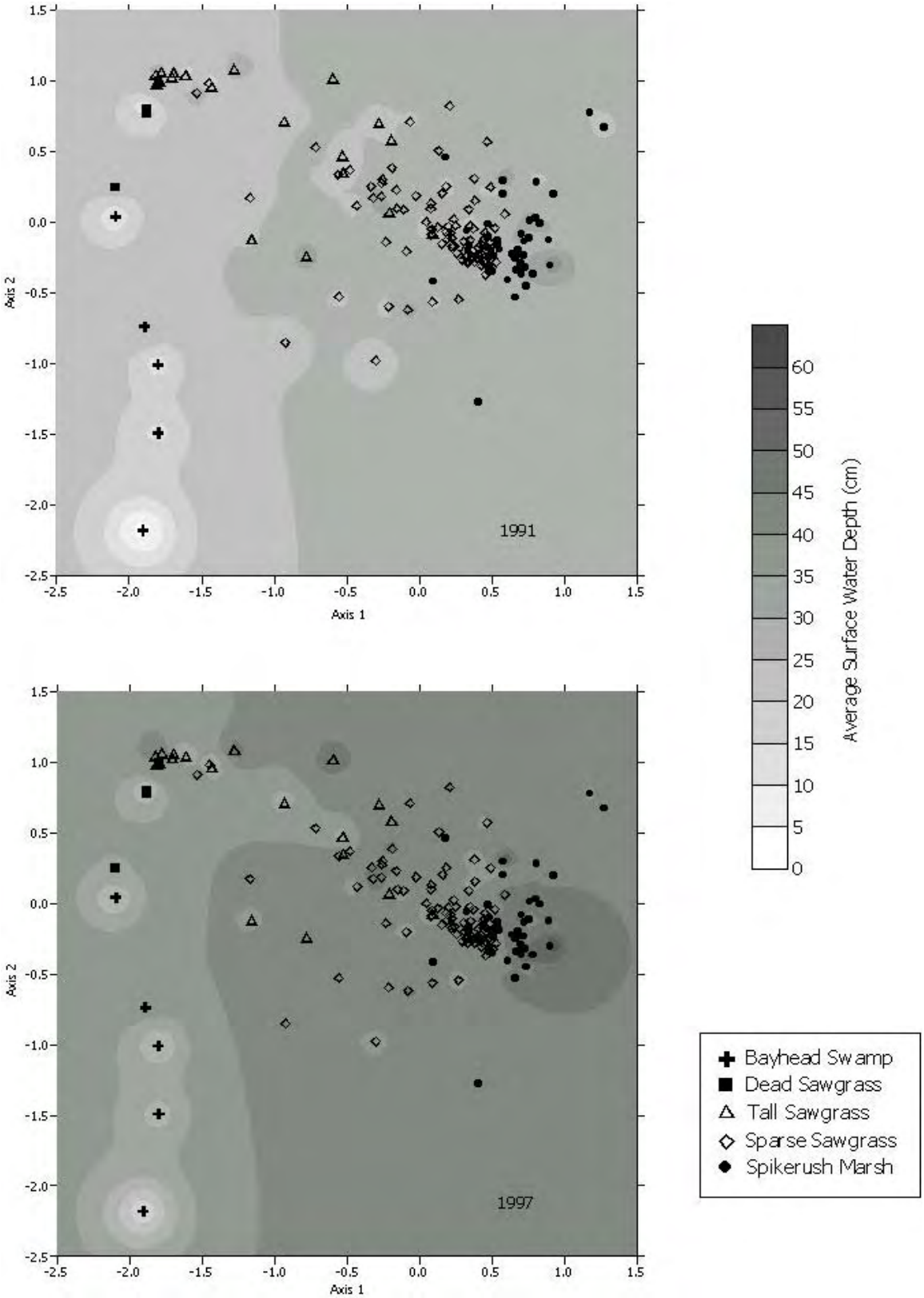


Figure 1.6: Contour plots of mean water depth during a dry year (1991) and an average year (1997), superimposed on the NMS ordination of vegetation at 164 shark Slough locations.

Application of partial Mantel tests to control for spatial effects within regions further supported the correlation of hydrology and plant species composition. Except in NESS, all three hydrologic parameters were strongly correlated with vegetation when spatial effects were removed (Table 1.3: Analysis 1). In contrast, significant Mantel associations between soil depth and vegetation were observed in CSS and SSS only. The relative weakness of the soil:vegetation relationship is also evident when soil depths are superimposed on the NMS ordination, without accounting for region (Figure 1.7).

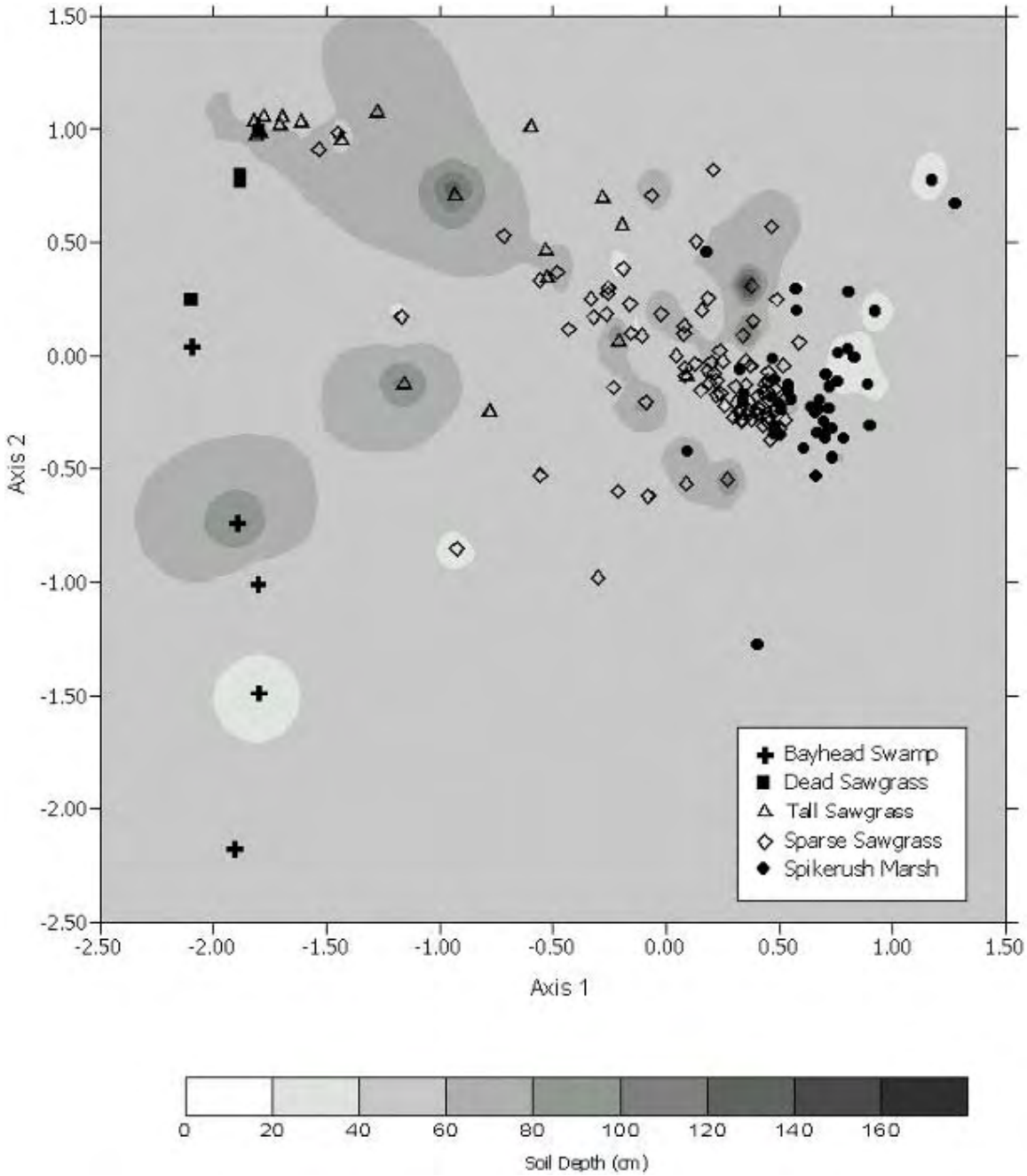


Figure 1.7: Contour plot of soil depth superimposed on the NMs ordination of vegetation at 164 Shark Slough Location.

Partial Mantel tests were also applied to explore associations among environmental variables. The three hydrological parameters were highly inter-correlated (Table 3: Analysis 3), but the strength of their relationships with soil depth were region-specific, with 1-3 significant associations per region (Table 1.3: Analysis 2).

Table 1.3. P-values for partial Mantel statistics, indicating strength of association among plant species composition, soil depth, and three hydrologic variables in four regions, after removing effect of spatial contiguity among sampling points.

	Independent Variable Tested	**Northeast SS (95)[f]**	**Northern SS (114)**	**Central SS (114)**	**Southern SS (113)**
Analysis 1[a]	Hydroperiod[d]	0.113	0.001	0.001	0.007
	Mean Depth[e]	0.085	0.001	0.001	0.002
	Max Depth[e]	0.087	0.001	0.001	0.002
	Soil	0.336	0.235	0.008	0.037
Analysis 2[b]	Hydroperiod	0.026	0.040	0.020	0.140
	Mean Depth	0.009	0.110	0.067	0.026
	Max Depth	0.011	0.030	0.015	0.056
Analysis 3[c]	Mean Depth	0.001	0.001	0.001	0.001
	Max Depth	0.001	0.001	0.001	0.001

[a]associations of species composition with environmental variables
[b]associations of soil depth with three hydrologic variables
[c]associations among three hydrological parameters
[d]hydroperiod data is based on dry year (1991)
[e]mean and maximum water depth are based on an average water year (1997)
[f]sample size.

The analysis of variance indicated highly significant effects of both cover type and region on all three hydrologic variables in both years, 1991 and 1997 (Table 1.4). Interaction effects were mostly non-significant, except for hydroperiod in 1997, when most of the non-forested portions of the Slough were continuously inundated with the exception of several tall sawgrass strands in CSS (Figure 1.8). Inter-regional differences were explored further by applying multiple comparison tests (Tukey's HSD) to sparse

sawgrass locations, which were abundant in all four regions. Differences between regions varied with year and with hydrologic variable. In general, hydroperiod was longest and water level was deepest in NSS, while CSS and SSS were characterized by shorter hydroperiod and shallower water. Differences among regions were comparable in magnitude to differences among cover types within a single region. For instance, in 1991, when mean hydroperiod for spikerush marsh consistently exceeded that of tall sawgrass in the same region by 10-60 days, tall sawgrass sites in NSS had a longer mean hydroperiod than spikerush marsh in any of the other regions (Figure 1.8).

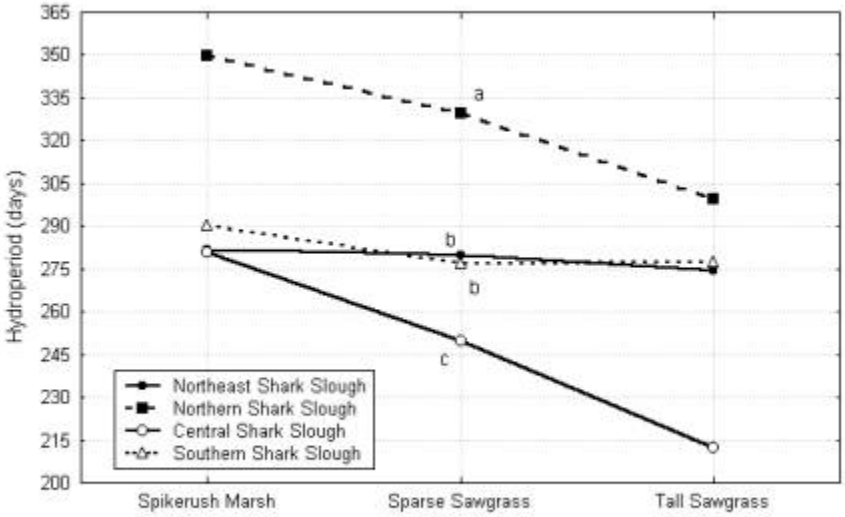


Figure 1.8: Mean hydroperiod in 1991 by cover type and region.

Two-way analysis of variance showed significant effects of both cover type and region on soil depth also (Table 1.4). Soil depth in tall sawgrass was 10 to 31 cm deeper than in spikerush marsh and sparse sawgrass, depending on region. Multiple comparison tests among regions were applied to the widely distributed sparse sawgrass type alone. They indicated that soil depth in NESS exceeded that in NSS, but other regional differences were non-significant (Figure 1.9).

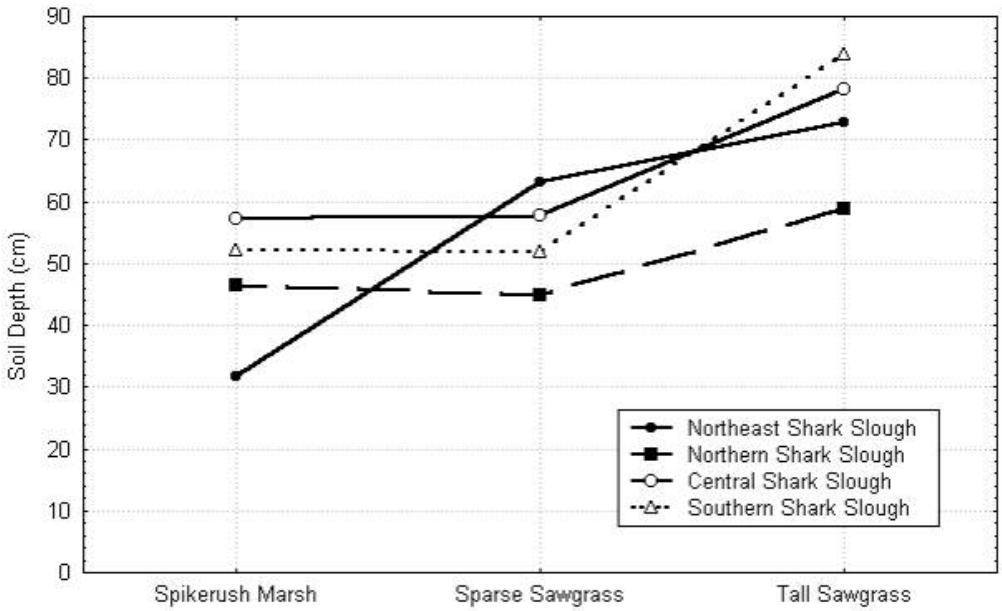


Figure 1.9: Mean soil depth (cm) by cover type and region.

Table 1.4. P-values for two-way analyses of variance, testing fixed effects of region and cover type on soil depth and three hydrologic variables in dry and average water years (1991 and 1997, respectively).

	Hydroperiod		**Mean Water Depth**		**Maximun Water Depth**		
Effect	1991	1997	1991	1997	1991	1997	**Soil Depth**
Region	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0456
Cover Type	< 0.0001	0.0072	0.0002	< 0.0001	< 0.0001	< 0.0001	0.0007
Region x Cover Type	0.2199	< 0.0001	0.40120	0.4153	0.3354	0.3303	0.3854

Discussion:

The results described above support the contention, expressed most comprehensively by Olmsted and Armentano (1997), that Shark Slough plant communties are comprised of several widespread and distinct cover types, arranged roughly along a hydrologic gradient. Owing to the extensive nature of the current data, our analyses go a step further in (a) assessing the strength of relationships among vegetation, hydrology, and soil depth, and (b) defining the range of temporal and spatial variation in hydrology and soils within the major cover types, both for the Slough as a whole and for individual management units within it. Examination of broad spatial variation indicates that water management has contributed to regional hydrologic differences that are large in comparison to those that distinguish cover types in a local area within a single year. Given the observed strength of the vegetation:hydrology association, management that artificially maintains such regional patterns in hydroperiod and water depth on a longterm basis is likely to have important effects on the structure of Everglades plant communities.

Vegetation: environment relationships:

Our examination of vegetation:environment relationships consisted of graphical descriptions of Slough-wide patterns, and statistical analyses that also accounted for regional effects. Statistics included both continuous and categorical approaches; both appear to be justified, based on the clustering within the vegetation ordination (Figure 1.2) of sites assigned to specific wetland community types according to the criteria of Olmsted and Armentano (1997).

A strong association of vegetation with hydrology was evident in our data, whether viewed for Shark Slough in its entirety (Figures 1.4-1.6) or within individual subsections of the marsh (three of four regions in Table 1.3). Outside of the forested areas (Appendix 1), sawgrass-dominated marsh is most common where hydroperiod is shortest and water depth shallowest, and more open spikerush marsh is characteristic of more hydric conditions. Dramatic contrasts in vegetation are typically associated with slight differences in hydrologic regime, e.g., 5-10 cm water depth or 10-60 days annual inundation (Figures 1.4-1.6 & 1.8). The role of hydrologic variables in distinguishing among a broad range of South Florida wetland communities has been noted by many authors (e.g., Davis, 1943; Loveless, 1959; Craighead, 1971; Duever et al., 1986), but the predominant mechanism that drives fine-scale patterning within the narrower range of Shark Slough marshes is a less settled issue. Sampling a set of nine relatively wet Shark Slough sites quarterly over a 10-year period, Busch et al. (1998) attributed the observed variability in species composition primarily to spatial and temporal variation in hydrologic conditions, and secondarily to the effects of a recent hurricane. Olmsted and Armentano (1997) demonstrated that wetland community types were distributed in a predictable elevation (hence, water depth and hydroperiod) sequence along three Shark Slough transects, with modest (£ 15 cm) differences distinguishing tall sawgrass and spikerush marsh. Gunderson (1989) noted an imperfect correlation between cover type and several hydrologic metrics in the vicinity of five longterm Shark Slough water level recorders, which he attributed to factors such as fire history (cf. Herndon, 1991), soil

characteristics, and seed availability. Our results therefore tend to support earlier conclusions regarding Shark Slough marshes, i.e., though other factors may be involved, hydroperiod and water depth variables are important determinants of marsh community composition and structure.

One ecosystem process that may affect vegetation directly or through its interaction with hydrology is soil development. In the southern Everglades, surface topography may result from local variation in soil accretion rates, which are themselves based on the balance of biological and physical processes. Soil depth was not strongly associated with vegetation over the Slough as a whole (Figure 1.7), but clear associations of soil depth and vegetation were observed in two of four regions, and soil and hydrologic variables were generally associated at the regional level (Table 1.3). Marsh soils were deepest in the tall sawgrass type (Figure 1.9), which is characterized by relatively low water (Figure 1.8). Similar results were reported by Olmsted and Armentano (1997), who noted a statistically non-significant tendency toward deeper soils in tall sawgrass than in neighboring plant communities.

The observed interactions between vegetation, hydrology, and soil depth suggest the simple model illustrated in Figure 1.10. The model postulates that hydrology's influence on soil depth is primarily indirect, through its influence on fire and vegetation. Wu et al. (1996) modeled the effects of hydrology (as well as vegetation) on the frequency and nature of Everglades fires, which modify the surface and reduce soil depth by removing accumulated organic matter (cf Arabas, 2000). The pathway through vegetation may involve differential belowground production:decomposition and/or resistance to surface water sheetflow, e.g., in tall sawgrass (deep soils) cf spikerush marsh (shallow soils). Daoust and Childers (1998) found net aboveground primary production to be about seven times higher in sawgrass than adjacent spikerush marsh in the southern Everglades. Root production was not estimated, but may also be relatively high in sawgrass marsh. Rejmankova et al. (1996) observed that Cladium jamaicense decomposed much more slowly than Eleocharis cellulosa under several hydrologic conditions in Yucatan Peninsula marshes. Vegetation-related differences in flow resistance among Shark Slough habitats are complex and not yet completely understood, varying with macrophyte density, periphyton structure, flow rate, and position in the water column (Carter et al., 1999). Nevertheless, it is reasonable to expect that the taller, denser tall sawgrass community would be more resistant to flow under many conditions, including extreme high water conditions when erosion and redeposition processes may be most significant. A net transport from spikerush marsh to tall sawgrass would result, enhancing soil accretion further in the latter type. It is notable that, within the range of the model, the productivity and sedimentation trends cited above would elicit a positive feedback loop, accentuating variability in surface topography, hydroperiod, and water depth until fire or other disturbances intervened. In contrast, a hydrologic mechanism cited by Craft and Richardson (1993) to explain patterns of soil accretion in their northern Everglades study area, i.e., slower decomposition in wetter sites due to anaerobic conditions, would tend to reduce surface variability.

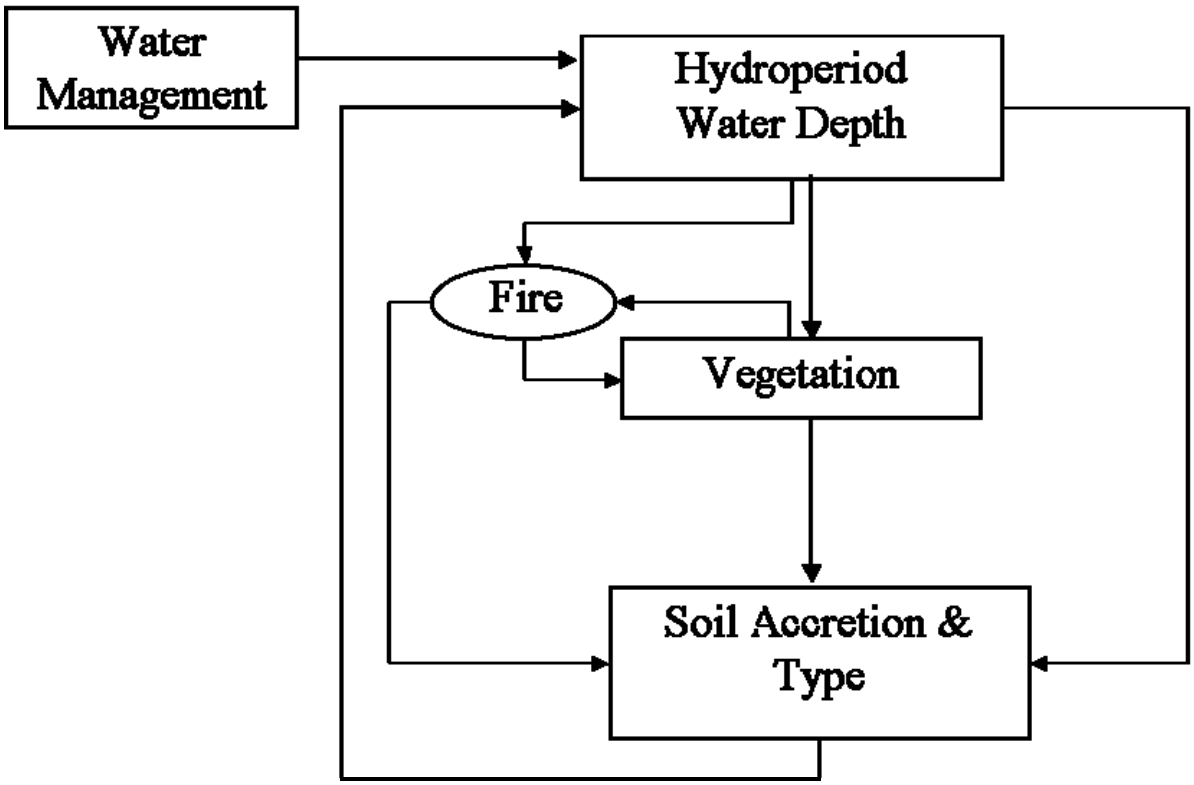


Figure 1.10: Conceptual model of processes underlying variation in Shark Slough wetlands.

The above discussion concerns processes that result in small-scale topographic variation within regions. However, inter-regional variation in soil depth (Figure 1.8) may be more a function of bedrock topography than of soil development. Soils in Shark Slough develop on uneven limestone bedrock, with micro-karst features prominent at the local scale. Regionally, the Slough occupies a slightly inclined bedrock trough bounded by the Miami Rock Ridge on the east and the modestly elevated Big Cypress swamp on the west. Within it, limestone outcroppings and narrow ridges oriented perpendicular to the predominant direction of flow ("rock reefs"; Froehlich 1973) alternate with more extensive areas of lower bedrock. One bedrock depression occurs in the western portion of NESS, where all cover types are underlain by peat soils of more than 1 meter depth (Leighty et al., 1958). Conversely, sections of NSS and smaller portions of NESS and CSS are characterized by frequent bedrock outcrops.

Regional variation and water management effects:

In light of the strong association between vegetation and hydrology discussed above, how are the observed differences in hydrology among regions within the same cover type to be interpreted? These regional patterns may be summarized as follows: (1) NSS, directly below the primary water delivery points from the Water Conservation Areas, experienced the longest hydroperiods and deepest water levels during 1990-99; (2) More remote areas in CSS and SSS were characterized by shorter hydroperiods and shallower waters over the same period; but (3) the relative hydrologic positions of the major cover

types were preserved throughout all regions (Table 1.4, Figure 1.8). The finding of strong regional variation may be taken as evidence of some degree of imbalance between existing vegetation pattern and recent hydrology. This imbalance is also suggested by the nature of the current vegetation mosaic (Figure 1.2). For instance, if current vegetation patterns were in equilibrium with hydrology of the last decade, then CSS would more closely resemble the monotonous sawgrass marsh of NESS and SSS than the more heterogeneous mixture of spikerush-and sawgrass-dominated communities of NSS, as it currently does.

The less-than-perfect concordance of vegetation with recent water level and hydroperiod may reflect a lag in response, and/or the influence of interacting environmental factors, especially fire (Figure 1.10). Little is currently known about the time frame of vegetation response to altered hydrology in the Everglades. Busch et al. (1998) observed annual variation in plant species composition in several Shark Slough wet prairies. Though these small changes did appear to be related to year-to-year variation in water level, they did not result in consistent changes in community type over the ten years of study. Based on an analysis of pairs of aerial photographs encompassing a 15-21 year period from the mid-1960's to the mid-1980's, Davis et al. (1994) documented a general increase in sawgrass marshes at the expense of open slough habitats in portions of Shark Slough and the Water Conservation Areas. However, no attempt was made to relate vegetation changes to hydrology at a local scale. In some cases, the response time of vegetation change to important forcing factors varies with the spatial scale considered. For instance, Williams et al. (1999) found that small-scale effects of salt water intrusion in coastal forests (elimination of tree regeneration) sometimes preceded coarse-scale effects (death of established trees) by many decades. Only the latter would have been detectable on aerial photos. In Shark Slough, when fire is followed by a rapid rise in water level, extensive areas of sawgrass marsh may change to open water habitat within a matter of weeks (Herndon, 1991), but reinvasion by sawgrass may be exceedingly slow (Herndon, unpublished manuscript). In contrast, the open water areas we encountered in southern Shark Slough (Figure 1.3) represent a late stage in a recurring phenomenon Wade et al. (1980) termed "sawgrass decadence". The cause of sawgrass decadence, the successional sequence that typically follows it, and the role of fire or hydrology in the process are currently unknown (Olmsted and Armentano, 1997).

The regional differences in hydrology documented in Figure 1.8 are those of a closely managed wetland ecosystem, rigidly compartmentalized at the upstream end but open downstream. Within these regions, we found clear and consistent differences in the hydrologic regime of the three major marsh cover types, in the direction expected based on the existing literature, i.e., hydroperiod and water depth increased in the order tall sawgrass marsh < sparse sawgrass marsh < spikerush marsh. Locally, these differences were quite subtle; mean annual values for the two water depth parameters typically varied less than 15 cm among types, and hydroperiod by 60 days or less. This narrow range is relevant in assessing the impact of inter-regional variation in hydrology, whose magnitude equaled or exceeded that attributable to cover type within a region. If hydroperiod or water depth are important influences on vegetation pattern within regions, as our data and others' suggest, it is likely that a continuation of current water

management practices will eventually result in large scale changes in vegetation pattern, with possible feedbacks on soil development and fire regime. In other words, hydrologic compartmentalization will inevitably result in a regionalization of Shark Slough ecosystems. Current restoration plans are intended to mitigate such undesirable effects in this pivotal portion of the Florida Everglades.

Section 2

Characteristics of Shark Slough Soils

Introduction:

Shark Slough soils are relevant to considerations of the current vegetation mosaic for several reasons. Most importantly, they serve as media for plant growth and the storage and exchange of nutrients. Second, their structural profiles provide records of site history, although these records may be obscured by diagenetic processes that ensue after sediment deposition. In this document we describe the physical and chemical nature of Shark Slough soils, and how they vary regionally and with vegetation type.

Methods:

In January 2000, we collected composite soil samples from selected Shark Slough sites representing each of the six transects and two sites near the mangrove ecotone north of Mahogany Hammock (P38A & B) (Figure 2.1). Soil properties were determined by field examination and by laboratory methods on selected soils at different depths. During three days of field sampling, several 6” diameter soil cores were taken to bedrock, physically examined for general profile description. Samples were taken from selected depths (usually 3 samples per site representing typical profiles), and brought to the laboratory to determine physicochemical and biological properties. Soil were homogenized in the collection bag and refrigerated until further analysis. A subsample from each bag was transferred to a plastic sample cup, weigh wet (g) and measured for sample volume (cm3). These samples were analyzed for dry weight (80°C), sample bulk density (g dry cm-3), fractional water content, total C, inorganic C, organic C, organic Matter content, total N and P. Another set of sub-samples from the bag was diluted with distilled, deionized water to a nominal 1:1 dilution and homogenized in a blender for 90 seconds. The pH of the soil slurries were recorded. A known weight of approximately 4 g each are added to 20 mL GC vials for the determination of microbial respiration (CO2/CH4 production). A known volume of approximately 100 cc each are processed for root biomass and snail shells.

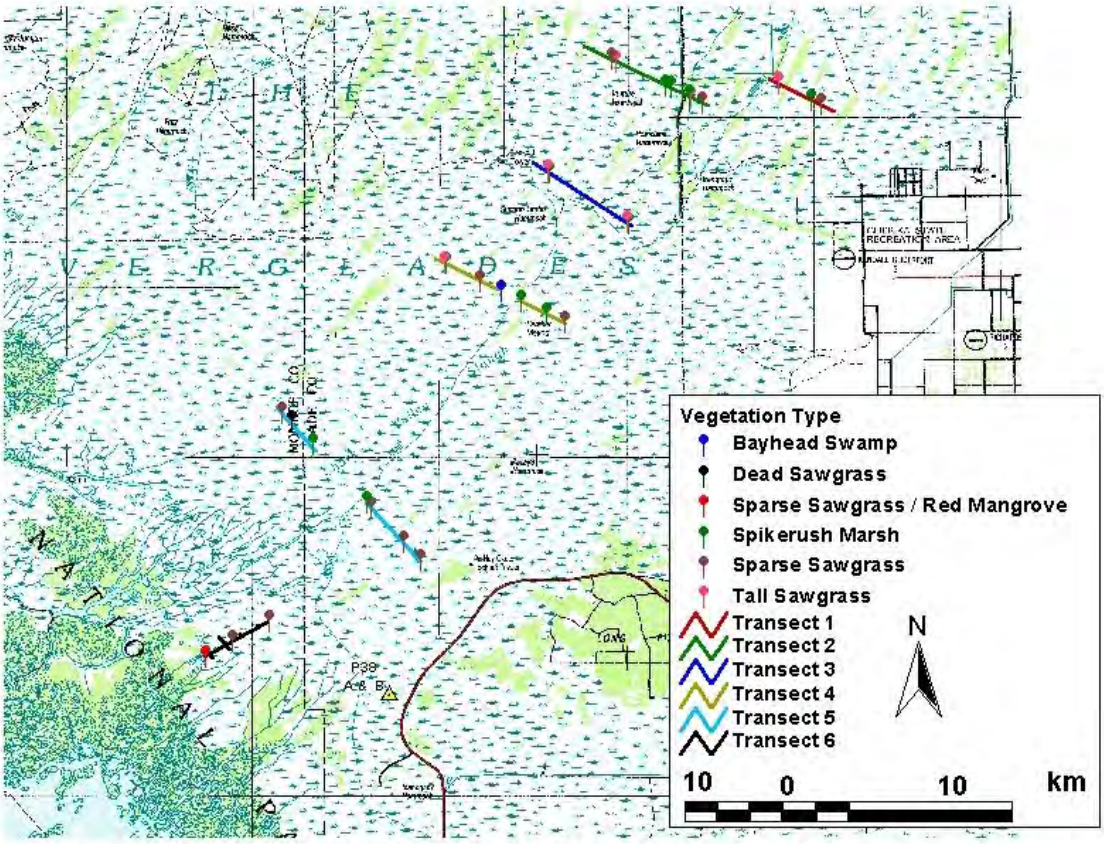


Figure 2.1: Location of the six Shark Slough vegetation transects along with the 33 soil and pore water sampling sites.

Results:

Soil profile descriptions are outlined in Figure 2.2, and presented in detail in Appendix 2. With respect to both depth and profile structure, Shark Slough soils exhibit great variability over distances as small as a few meters, Based on our limited sampling, this variability does not appear to be strongly related to current vegetation, a finding which may result from non-alignment in temporal scale between vegetation and soil. In other words, the vegetation under which the soil was formed may no longer be present. Lack of correlation between vegetation and soil characteristics will make large scale mapping beyond the level of broad soil complexes extremely difficult in Shark Slough. In fact, our brief survey uncovered several discrepancies between current soils and those mapped in the most recent Slough-wide survey (Leighty and Henderson 1958), especially in the more remote southern sections. More significantly, we found no evidence of the light-colored, fibrous Loxahatchee peats described in the earlier survey. Loxahatchee peats are purported to form under water lily cover, which is indicative of deep flooding. The peat soils we observed on all six transects were nearly black, non-fibrous, with a mixture of dead and live roots in the surface (0 - 5 inches), and many fine dead roots in the sub-surface horizons. At all depths, most of the roots appear to be sawgrass, at least superficially.

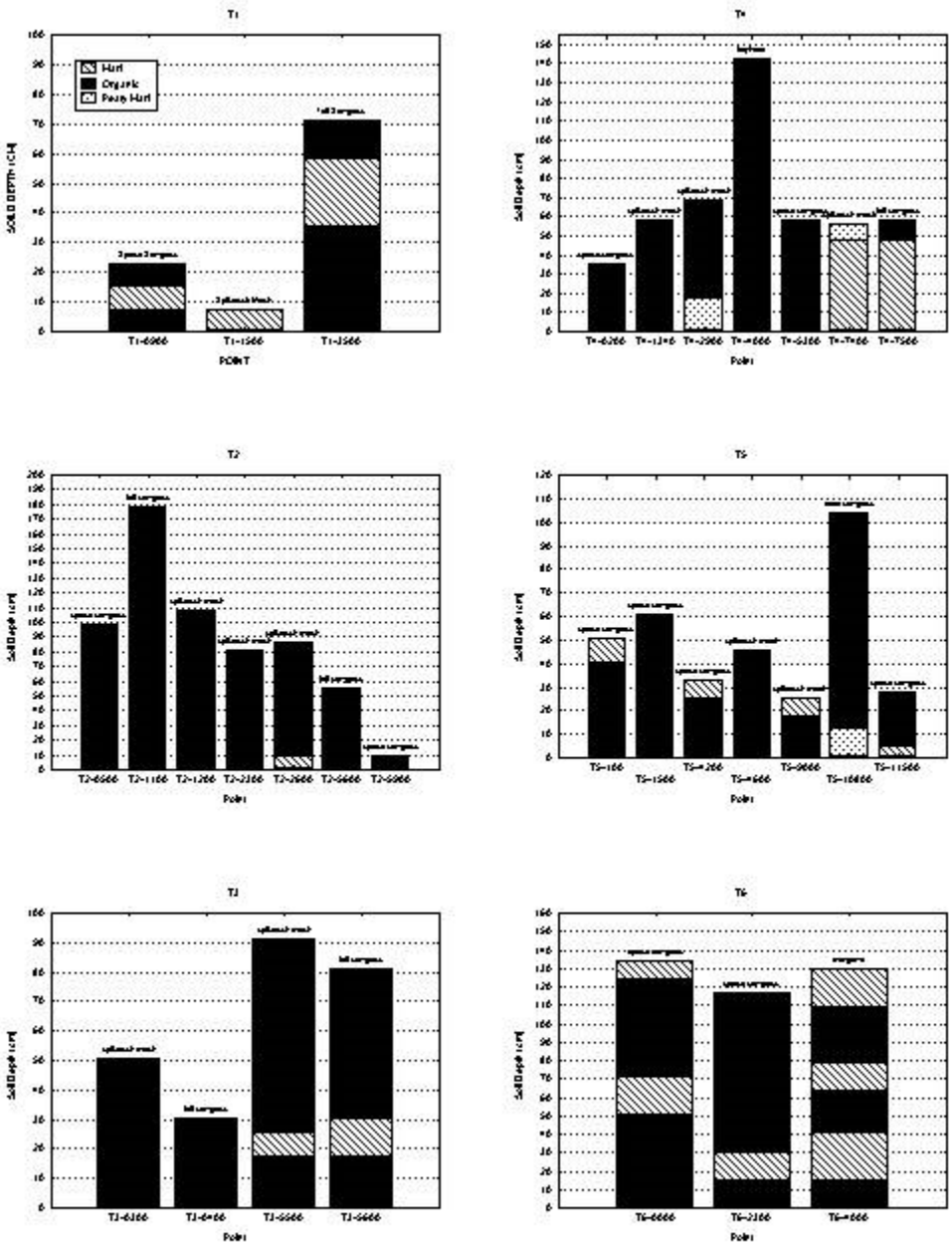


Figure 2.2: The soil profiles & current vegetation at 31 locations along six Shark Slough transects.

Most Shark Slough soils may be characterized as peats, but a significant percentage exhibit interlayering of marl and peat strata. Several soil profiles from Northeast Shark Slough were comprised of a thin surface layer of peat over marl, while other profiles from the western end of Transect 5 feature marl over peat. Soils in the coastal end of

Transect 6 exhibit multiple layering of peat and marl, indicating oscillations in soil-forming processes during their development.

Appendix 3 outline several physicochemical properties of the soils sampled along all six transects. These soils ranged in pH from 6.3 to 8.1; for the most part, relatively acid soils were those with high organic matter content (Figure 2.3D). Total nitrogen ranged from 0.2% to 4.2%, and total phosphorus from 40 to 780 ppm. Nitrogen was almost entirely associated with organic matter content while phosphorus was not (Figures 2.3A and 2.3B, respectively). Consequently, N:P ratios (range 3-380) generally increased from predominantly marl to peat soils (Figure 2.3C). Respiration rates > 0.10 mm/hr/g were generally restricted to peat soils (Figure 2.4A); however, total phosphorus was unrelated to soil respiration (Figure 2.4B). The lone tropical hardwood hammock (tree island) location (Transect 2, Vulture Hammock) was a distinct outlier. The surface soil layer in this site had the highest phosphorus content, the lowest N:P ratio, and the highest pH encountered, despite an unexceptional organic matter content of 20%. Several mechanisms may be postulated for high phosphorus concentrations in Everglades tree islands, including position with respect to pathways of surface water flow, high productivity and efficient recycling, and attraction for wildlife, especially birds.

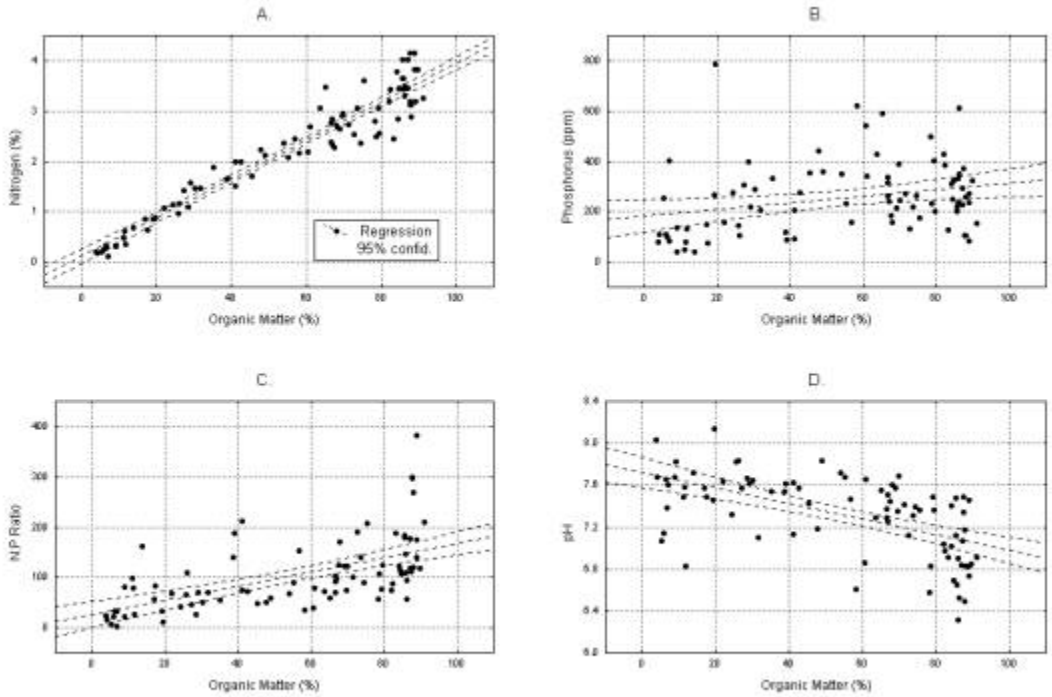


Figure 2.3: Relationship of organic matter content to (A) total nitrogen, r^2= .826; (B) total phosphorus, r^2= .070; (C) N:P ratio, r^2= .351; and (D) pH, r^2= .328 in 85 soil horizons from 32 Shark Slough sites.

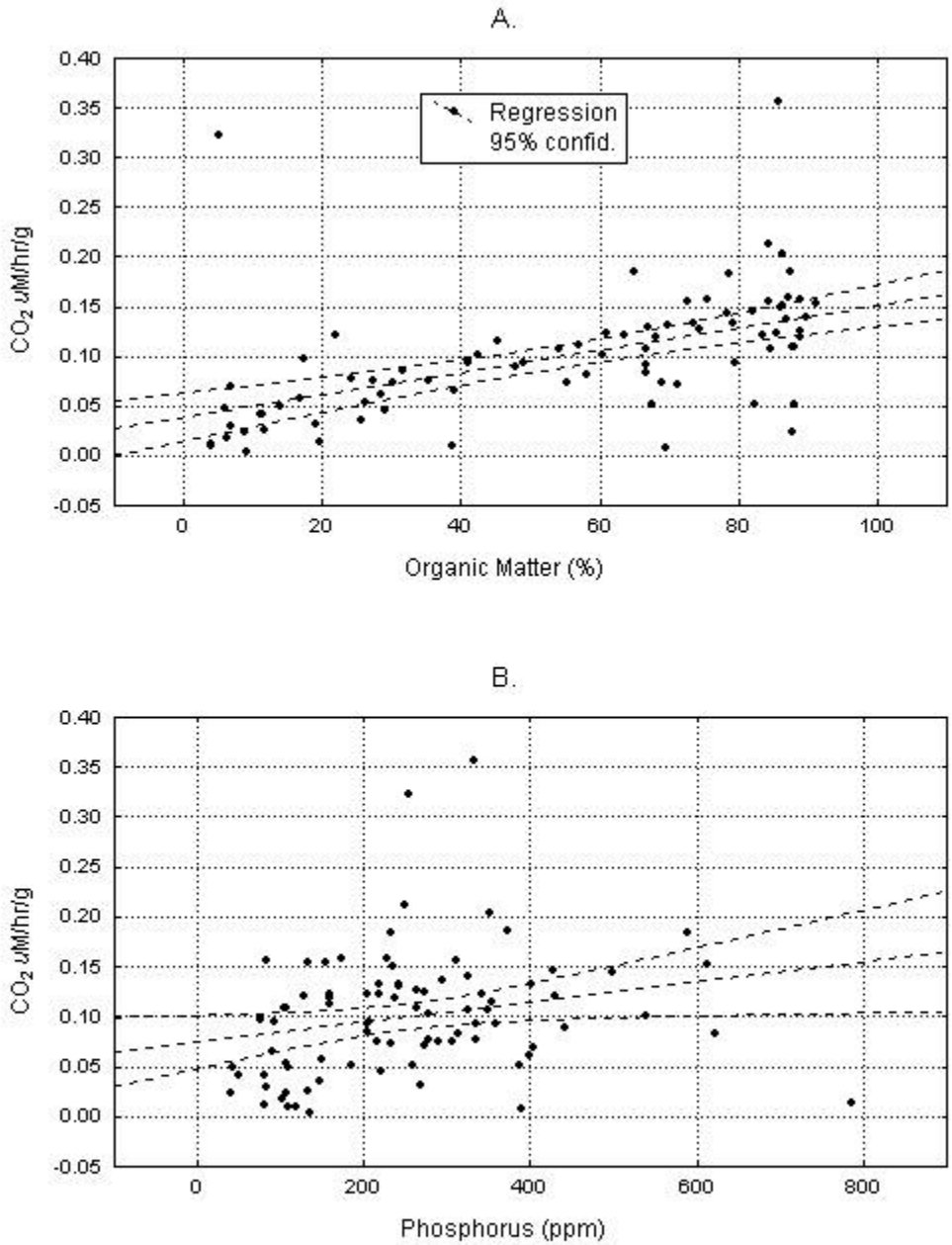


Figure 2.4: Relationship of soil respiration to (A) organic matter content, r^2=.282; and (B) total phosphorus, r^2=.055, in 85 horizons from 32 Shark Slough sites.

Section 3

Pore Water Chemistry and Plant Nutrient Content

Introduction:

Pore water or soil interstitial water physicochemical properties provide important information regarding nutrient availability to plants. Pore water chemistry has been described from the Water Conservation Areas and northern Everglades, but research linking soil physicochemical characteristics, pore water properties, and plant nutrient uptake by the plant communities in the southern Everglades is lacking. In this section, we relate pore water chemistry to the nutrient content of sawgrass (*Cladium jamaicense*) and spikerush (*Eleocharis cellulosa*) from selected locations along the Shark Slough transects described in Section 1.

Methods:

Soil interstitial (pore) water was collected by inserting a permanent sampling device (sipper) into intact soils at selected locations along six transects and two sites (P38A & B) near the mangrove ecotone north of Mahogany Hammock (Figure 2.1). Sippers consisted of a filter (pore size 60 mm, Porex 6810, Interstate Specialty Products) held on to a male slip connector with Teflon tape. The slip connector was attached to a hollow Tygon tube approximately 50 cm in length, the distal end of which was connected to a capped female luer fitting. The filter was inserted into the soil to a depth of 10 cm with an insertion tool. A large syringe (140 mL) was connected to the female luer fitting, suction was applied, and approximately 110 mL of soil solution was withdrawn. Approximately 30 mL sample was filtered through a syringe filter (Whatman GF/F, pore size 0.45 mm) into a 30 mL polyethylene sample bottle. The remaining 80 mL sample was transferred into a 125 mL polyethylene sample bottle. Samples were stored in a cooler box until being returned to the laboratory. Soil pore water samples were either analyzed immediately (<24 h) or stored frozen until analysis (<30 d).

The unfiltered samples were analyzed for pH using a Ag/AgCl reference electrode (McLean, 1982), for electrical conductivity (EC) using a multi-range conductivity meter (Rhoades, 1996) and for total organic carbon (TOC: Shimadzu 500 TOC Analyzer; EPA 415.1), total nitrogen (TN: ANTEK Instruments model 7000), and total phosphorus (TP: ALPKEM Instruments model 305 & 501; Solorzano and Sharp, 1980; EPA 365.1). Pore water samples filtered through glass fiber filters (GF/F) were analyzed for dissolved organic carbon (DOC), NO_2-N (EPA 353.2), NO_3-N (EPA 353.2), NH_4-N (EPA 350.1), and soluble reactive phosphorus (SRP, EPA 365.1).

At each location, leaves of ten randomly selected culms of sawgrass and spike rush were clipped within an area of ~30 m radius. Samples were bulked by species at each location, then placed in a heat resistant plastic bag for transport to the laboratory. Plant leaf samples were dried at 80 °C for 72 h before grinding for nutrient analysis. Samples

were analyzed for TN, TC, and TP and reported as mg g-1 dry tissue as well as percentage.

Results & Discussion:

Pore water physicochemical properties are presented in Appendix 4. Pore water pH was about a half-unit higher than soil pH. Values ranged from 7.35 to 8.12, with no obvious spatial trend across transects.

Electrical conductivity varied considerably within transects, indicating the heterogeneous nature of the wetland ecosystem. EC ranged from 0.33 to 1.36 mS cm-1, with a few high values in each transect. The highest observed conductivity was at the lower end of Transect 6, which was oriented perpendicular to the coast near the southern border of the study area.

TOC in unfiltered and DOC in filtered pore water samples ranged from 20 to 220 mg L-1 and 7 to 47 mg L-1, respectively. Concentrations of TOC were highest along Transect 6 and lowest along Transect 1. In contrast, DOC concentrations did not increase toward the south. It is clear that significant quantities of particulate organic carbon (POC: TOC minus DOC) are present in Shark Slough pore water samples. A detailed analysis of soil organic matter, TOC, POC, and DOC is warranted to interpret the existing dataset.

Significant amounts of nitrogen were measured in unfiltered samples (TN) compared to phosphorus (TP). TN ranged from 1.1 to 6.0 mg L-1, whereas TP was about two orders of magnitude lower (range: 9.6 to 69.1 mg L-1). Expressed as a molar ratio, N:P for all sample locations was 462:1; transect means ranged from 319:1 (Transect 1) to 622:1 (Transect 3). The high ratios in Shark Slough pore water suggest that phosphorus limitation is probably quite extreme for organisms throughout the wetland food chain (Bedford et al. 1999).

Analysis of nitrogen speciation in filtered samples indicated that inorganic forms, especially NH4-N, predominate in Everglades pore water. Concentrations of NH4-N exceeded 2000 mg L-1 at all but two sampling locations, and the total of the three inorganic forms represented an average of 71% of TN across all samples. The accumulation of ammonium does not in itself present a problem, since this form of nitrogen is preferentially utilized by most plants and microorganisms (Paul and Clark, 1996). High soil pH and low phosphorus availability are factors that may inhibit nitrification, thereby causing ammonium to accumulate (Jayachandran et al., 2001 (in prep)). Under certain conditions, unknown organic compounds or elevated salinity may also inhibit nitrification (McClung and Frankenberger, 1985). Nitrate rarely accumulates to high levels in undisturbed ecosystems.

Unlike nitrogen, inorganic phosphorus forms (i.e., SRP) represent a very small proportion (mean 6.4%) of the limited pool of phosphorus in Shark Slough pore water. With the exception of a single Transect 6 location (m 2300), SRP was less than 5 mg L-

1. These data support the contention that readily available inorganic phosphorus is incorporated into organic form as fast as it can be mineralized.

Nutrient content of two dominant aquatic species, C. jamaicense and E. cellulosa, are reported in Appendix 5. Within each species, variation in carbon, nitrogen, or phosphorus content was relatively small (coefficient of variation, <0.25). Compared to most broadleaved species, in which carbon content is typically 48-50%, leaf carbon was low in these two graminoids (45.6% and 40.6% for *C. jamaicense* and *E. cellulosa*, respectively). Low carbon content may reflect the accumulation of silicon in the leaves of both species, though we did not analyze for this element. Leaf nitrogen content was low in both species, but was higher in *E. cellulosa* than in *C. jamaicense* (0.75% and 0.66%, respectively). A similar pattern was observed for phosphorus (mean concentrations of 0.036 and 0.024% for *E. cellulosa* and *C. jamaicense*, respectively).

Several authors (e.g., Koerselman and Meuleman 1996; Bedford et al. 1999) have examined the nature of nutrient limitation in fresh water wetlands on the basis of the relative concentrations of nitrogen and phosphorus in plant tissues. According to this literature, stoichiometric ratios of leaf N:P < 14 indicate nitrogen limitation, ratios >16 indicate phosphorus limitation, and ratios of 14-16 indicate co-limitation by both nutrients. In Shark Slough, N:P ratios of sawgrass (mean=62.2) and spikerush (mean=47.3) indicated extreme phosphorus limitation. Moreover, N:P of both species was higher in the relatively unproductive Spikerush Marsh and Sparse Sawgrass vegetation types than in Tall Sawgrass, where macrophyte aboveground biomass is several times higher (Table 3.1). The single Bayhead Forest site sampled (sawgrass N:P=38.5) continues the trend of decreasing tissue N:P ratio with increasing site productivity. Pore water nutrient characteristics exhibit the same cross-site pattern in molar N:P ratios, though much exaggerated (Table 3.2).

The tissue nutrient patterns described above are unsurprising for the P-limited Everglades marsh, but a closer look at the data reveal two complications: (1) Variation in tissue N:P ratios among vegetation types for the most part reflect differences in N content, not P concentrations, which do not vary much among sites (Table 3.1) and (2) *C. jamaicense* leaf tissue is insensitive to the concentration of P, the limiting nutrient, in the pore water, while accumulating the non-limiting N when growing on high N sites; E. cellulosa does not appear to accumulate either nutrient in response to high concentrations in pore water (Figure 3.1, A-D). While the inability to accumulate phosphorus seems counterintuitive, it may be this conservative characteristic of the dominant Everglades marsh species that allows them to dominate on low-P sites, but leads to their competitive displacement under high P conditions. In an experimental setting, Newman et al. (1996) found that Typha domingensis responded to augmented P availability by increasing growth and leaf P, while *C. jamaicense* and *E. cellulosa* were largely unable to respond to fertilization.

Table 3.1: Mean nutrient conent of *C. jamaicense* and *E. cellulosa* leaves in four broad habitat types. Standard errors are enclosed in parentheses.

Species	Habitat	# of Sites	N (%)	P (%)	N:P (molar ratio)
C. jamaicense	Spikerush Marsh	9	0.72 (0.04)	0.023 (0.001)	69.5 (5.0)
	Sparse Sawgrass	13	0.68 (0.03)	0.024 (0.001)	65.2 (3.6)
	Tall Sawgrass	7	0.54 (0.03)	0.026 (0.001)	47.9 (5.4)
	Bayhead Forest	1	0.47 (--)	0.027 (--)	38.5 (--)
E. Cellulosa	Spikerush Marsh	13	0.77 (0.04)	0.038 (0.003)	48.7 (2.2)
	Sparse Sawgrass	11	0.73 (0.03)	0.037 (0.003)	44.9 (2.5)
	Tall Sawgrass	4	0.70 (0.05)	0.033 (0.002)	46.2 (1.8)

Table 3.2: Mean nutrient content of pore water in four broad habitat types. Standard errors are enclosed in parantheses.

Habitat Type	# of Sites	N (µg/L)	P (µg/L)	N:P (molar ratio)
Spikerush Marsh	12	4132 (522)	16.3 (2.9)	697.7 (112.0)
Sparse Sawgrass	13	3072 (324)	24.9 (4.3)	346.3 (58.5)
Tall Sawgrass	7	2543 (394)	30.9 (8.0)	269.0 (86.5)
Bayhead Forest	1	3191 (--)	30 (--)	235.3 (--)

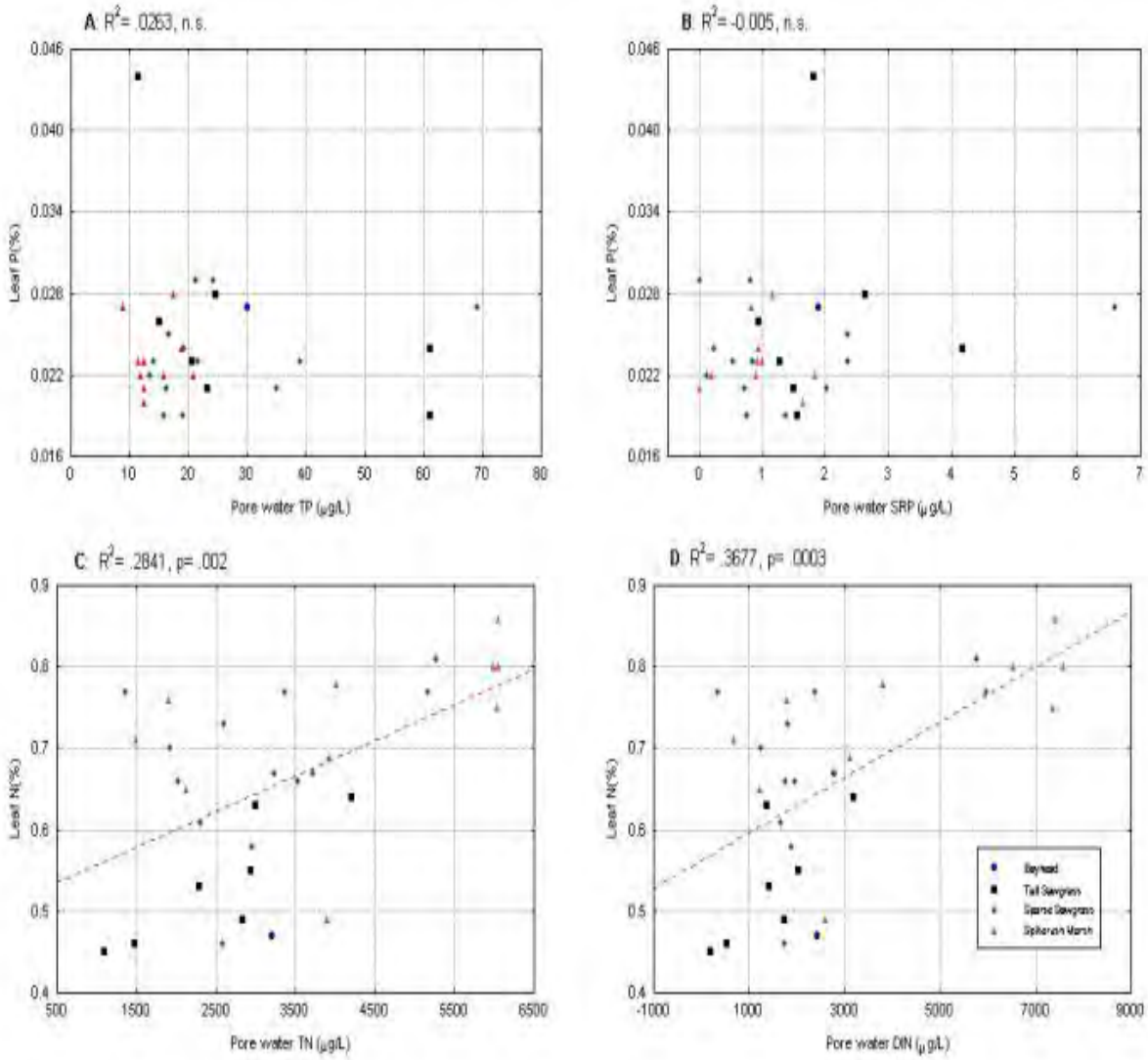


Figure 3.1: Scatterplots of nutrient concentrations of pore water and *C. jamaicense* leaves collected from the same sites in four habitat types. (A) Pore water DIN v. leaf N. (B) Pore water TN v. leaf N. (C) Pore water SRP v. leaf P. (D) Pore water TP v. leaf P.

Our results do differ in an intriguing way from those of Fourqurean et al. (1992), who found a positive association between pore water P and seagrass (Thalassia testudinum) leaf P in the phosphorus-limited Florida Bay estuary. Several factors may contribute to this discrepancy, including: (1) The nature of soils-primarily organic in Shark Slough and carbonate muds in Florida Bay. The contrast in physical characteristics and biological activity of these sediments present very different conditions for nutrient regeneration and recycling; and (2) The role of periphyton in Shark Slough and epiphytes on Florida Bay seagrass blades as alternative sinks/sources for nutrients. In Shark Slough, periphyton and macrophyte compete for light and nutrients, and their production generally appears to be inversely related across sites. These relationships deserve further investigation.

Section 4

Vegetation Maps of Shark Slough

Introduction:

Vegetation maps are important resource management tools with multidisciplinary applications. They are used by plant and community ecologists to monitor and document succession, disturbance, exotic species expansion, as well as changes in community structure and species extirpation / extinction. The use of vegetation maps for land use planning, forestry, agriculture, conservation, climatology, communications, investments and military applications has been well established for many years (Küchler, 1951).

In recent years, a number of vegetation maps of Everglades National Park and adjacent natural areas, in particular the Water Conservation Areas to the north (Rutchey & Vilcheck, 1994, Welch et al., 1995; Olmsted & Armentano, 1997), have been produced. However, crude vegetation maps of the area have existed since 1750 (Davis et al., 1994). In 1943 Davis created one of the most comprehensive vegetation maps of South Florida, extending from Florida Bay to well north of Lake Okeechobee (Davis et al., 1994). Since then, most vegetation maps have focused with greater detail on smaller areas (e.g., Olmsted & Armentano, 1997; Alexander & Crook, 1973 & 1975). One exception, however, is the vegetation map created by The Center for Remote Sensing and Mapping Science at The University of Georgia, which covers more than one million hectares of the Florida Everglades and adjacent areas (Welch et al., 1995).

In recent years, a number of vegetation maps of Everglades National Park and adjacent natural areas, in particular the Water Conservation Areas to the north (Rutchey & Vilcheck, 1994, Welch et al., 1995; Olmsted & Armentano, 1997), have been produced. However, crude vegetation maps of the area have existed since 1750 (Davis et al., 1994). In 1943 Davis created one of the most comprehensive vegetation maps of South Florida, extending from Florida Bay to well north of Lake Okeechobee (Davis et al., 1994). Since then, most vegetation maps have focused with greater detail on smaller areas (e.g., Olmsted & Armentano, 1997; Alexander & Crook, 1973 & 1975). One exception, however, is the vegetation map created by The Center for Remote Sensing and Mapping Science at The University of Georgia, which covers more than one million hectares of the Florida Everglades and adjacent areas (Welch et al., 1995).

With few exceptions (e.g., Olmsted & Armentano, 1997), most of the vegetation maps of Everglades National Park have failed to effectively integrate vegetation sampling and groundtruthing with remote sensing in creating realistic and useful vegetation maps. At the same time, few attempts have been made to remap areas previously mapped. The vegetation maps presented in this section bridge this gap by integrating vegetation data collected along transects as groundtruthing for interpretation of color infrared aerial photographs, in areas which had been mapped twenty years earlier (Olmsted and Armentano, 1997) (Appendix 6).

Methods:

Six transects, ranging in length from 4 to 12 km (Table 4.1), were established in Shark Slough (Figure 4.1). Five transects were oriented perpendicular to the apparent direction of water flow and in most cases bisected the Slough. The sixth and most southern transect, however, was oriented perpendicular to the coast (Figure 4.1).

Table 4.1: Location of transect map corners and length. Datum is WGS 84 in the UMT 17 co-ordinate system.

		Plot Corners							
Transect	**Length (km)**	**NW (x,y)**		**NE (x,y)**		**SE (x,y)**		**SW (x,y)**	
1	4.0	537865.58	2842587.69	541368.61	2840651.87	540930.68	2839685.56	537865.58	2841621.50
2	7.0	528364.36	2844232.62	534570.90	2840995.12	534152.44	2840016.62	527945.55	2843254.31
3	6.0	525300.09	2837622.05	530566.65	2833812.94	530035.84	2832919.26	524769.08	2836728.58
4	8.0	520081.43	2831929.44	527087.96	2828054.92	526649.20	2828089.23	519642.30	2830963.97
5	11.9	511705.16	2823000.82	519470.64	2813984.53	518783.01	2813265.58	511017.59	2822282.27
6	4.0	510575.64	2810709.45	511192.41	2809931.35	507751.24	2807700.81	507061.91	2808556.95

The vegetation sampling methodology, described in Section 1 and in Ross et al. (2000), involved nested sampling of species composition and structure in 10 x 10 meter plots distributed at 20-100 meter intervals along the six transects. From these data, we regrouped, renamed and created eleven distinct vegetation classes to best match those described by Olmsted and Armentano (1997, Appendix 6). Along with three other non-vegetation categories, these eleven vegetation cover classes were used in the preparation of the vegetation maps (Table 4.2, Figures 4.2-7). For all transects except Transect 6, vegetation cover/class was recorded at 5 meter intervals, and subsequently grouped into one of the 14 cover classes created for mapping. In essence, this survey became the groundtruthing data set, and was also used directly to test for temporal changes in landscape structure in Section 5.

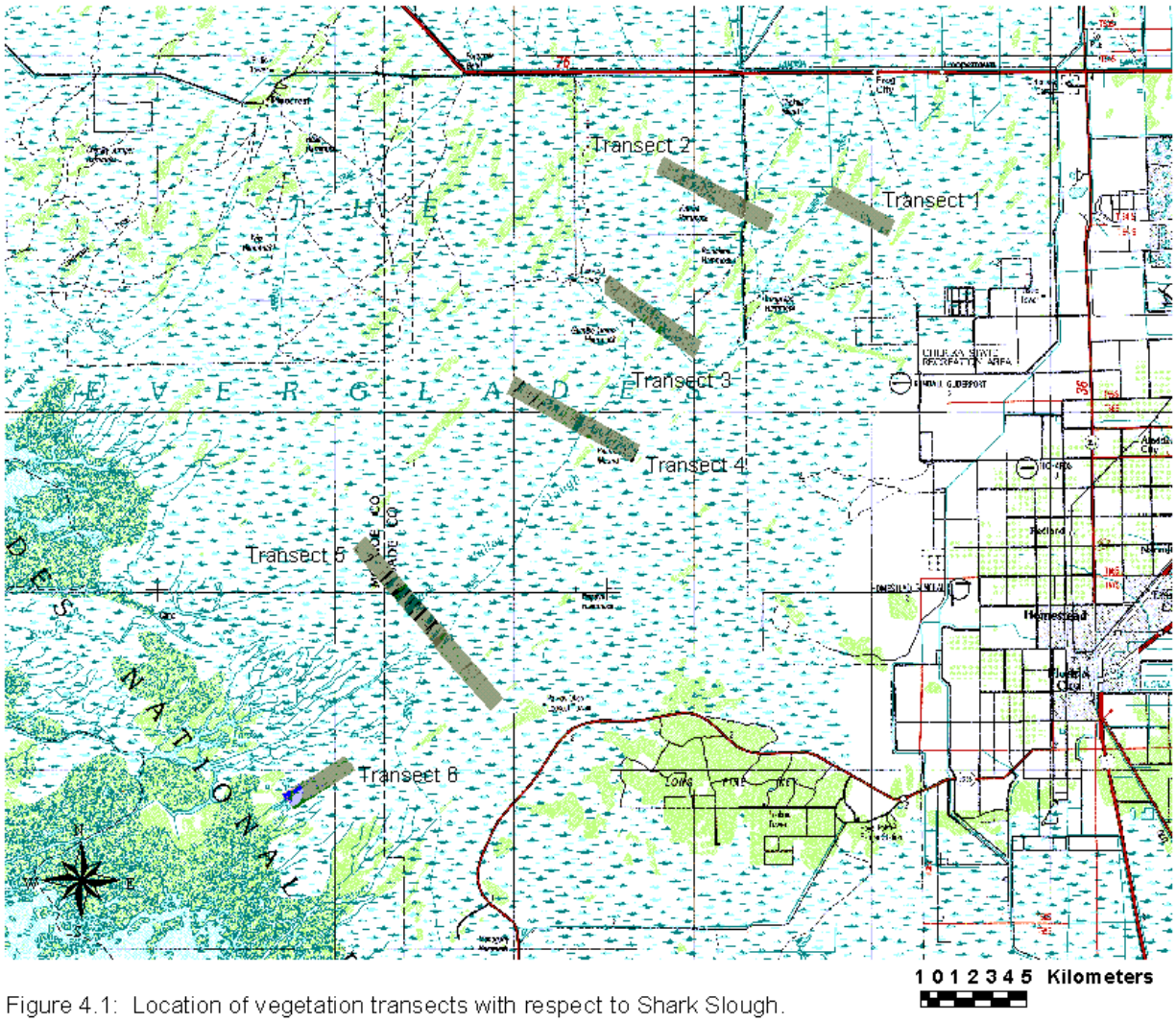


Figure 4.1: Location of vegetation transects with respect to Shark Slough.

Table 4.2 : Description of cover types used in Shark Slough.

Cover Types	Criteria
Dead sawgrass	Total live vegetation cover < 20% with substantial amounts of dead vegetation in particular *C. jamaicense*.
Tall sawgrass	Dominant species *C. jamaicense* with canopy heights ≥ 2 meters.
Sparse sawgrass	Dominant species *C. jamaicense* with canopy heights < 2 meters.
Graminoid-mangrove marsh	Dominant species *C. jamaicense*, with scattered *E. cellulosa* and *R. mangle*. Vegetative cover ≤ 10%, canopy heights < 1.5 meters, and periphyton cover > 60%.
Spikerush-Sawgrass Mosaic	Co-dominant species association of *C. jamaicense* and *E. cellulosa*.
Spikerush Marsh	Dominant species *E. cellulose*, *P. hemitomon*, or *P. geminatum*. Canopy heights ≤ 1.5 meters.
Bayheads	Woody vegetation with extended hydroperiods and dominant or co-dominant with *C. jamaicense*.
Tropical Hardwood Hammocks	Woody vegetation on topographical highs with closed canopies. Dominant species: *B. simaruba*, *M. foetidissimun*, *C. laevigata*, and *Ficus* spp.
Cattails	Dominant species *Typha domingensis* with live vegetation cover > 25 % and canopy heights ≥ 2 meters.
Exotics	Species not native to the South Florida landscape in particular *M. quinquenervia* and *Casuarina* spp.
Mangroves	Halophilic vegetation in particular *Rhizophara mangle*.
Water	Open areas within the marsh lacking vegetative cover.
Canal	Man-made structure designed to transport water.
Levee Roads	Man-made structure paralleling canals.

The vegetation maps were created by processing the 1994-96 color infrared digital orthophotos form the National Aerial Photography Program (NAPP) with Dynamo-GIS 1.0 in the field, and Arcview 3.2 in the office. The maps represent bands ranging from ca 4-12 km long by 1 km wide (Figure 4.2-7, Table 4.1). Community types were identified based on their signatures on the infrared photos, qualitative field observations, and species composition and structure data gathered between November 1998 and January 2000. Generally, features smaller than 15 m2 were excluded from the vegetation map. However, individual mangroves or groups of mangroves smaller than 15 m2 in Transect

6 were usually mapped, because of their potential use as a marker of marine encroachment.

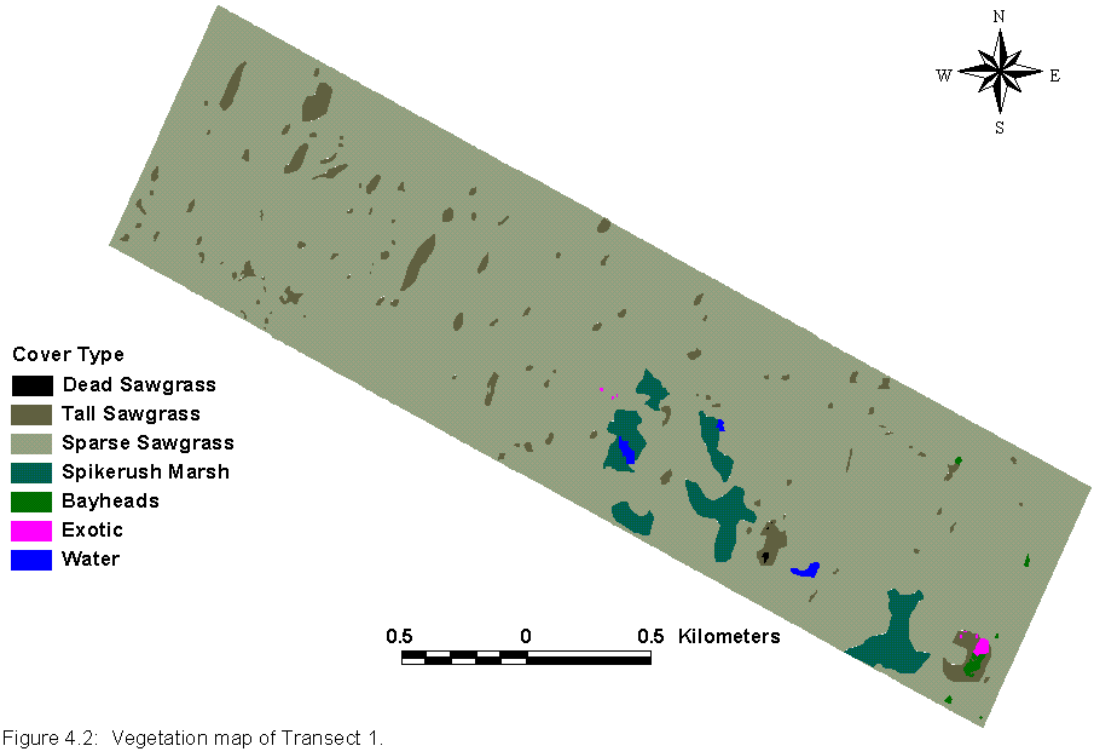


Figure 4.2: Vegetation map of Transect 1.

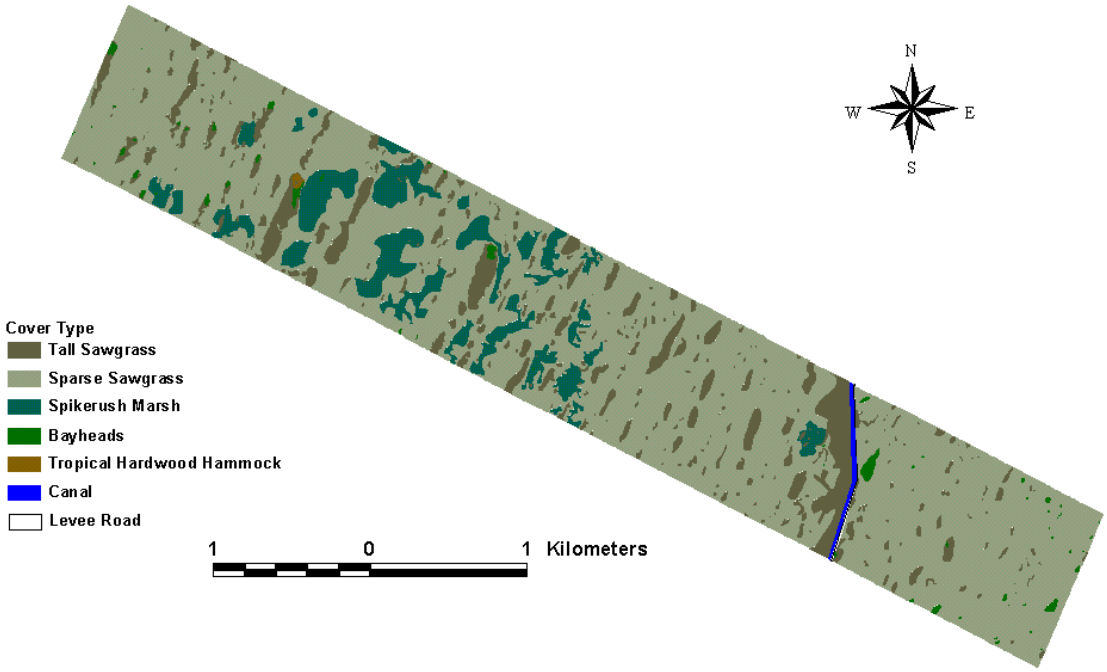


Figure 4.3: Vegetation map of Transect 2.

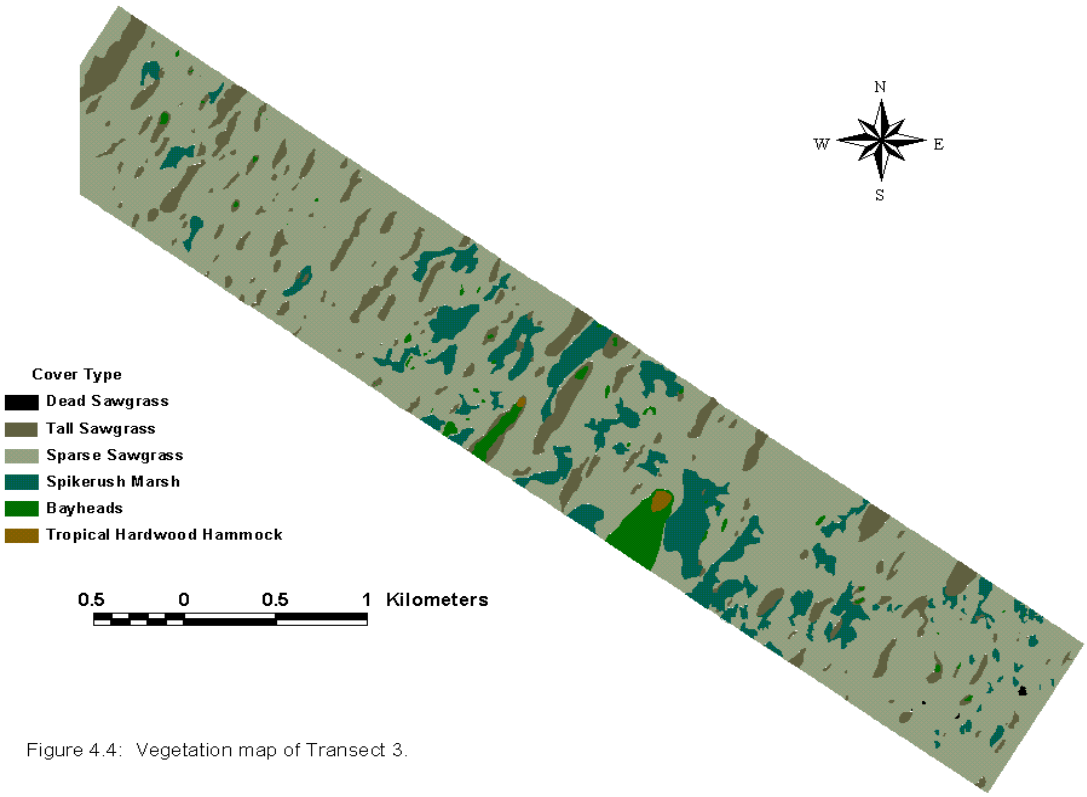


Figure 4.4: Vegetation map of Transect 3.

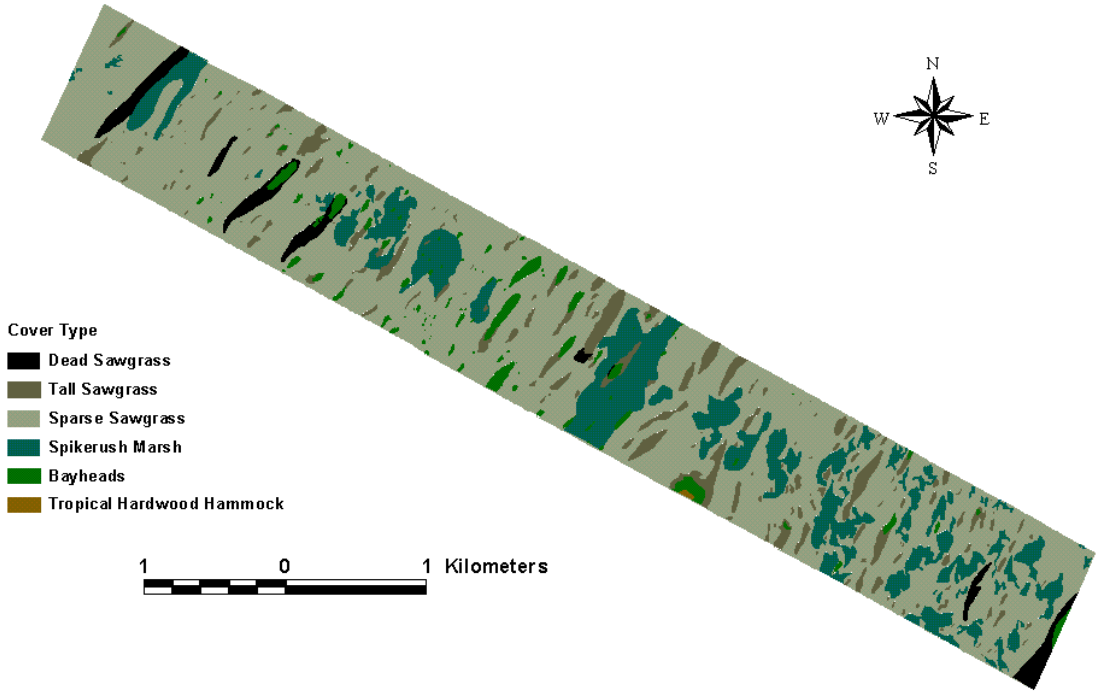


Figure 4.5: Vegetation map of Transect 4.

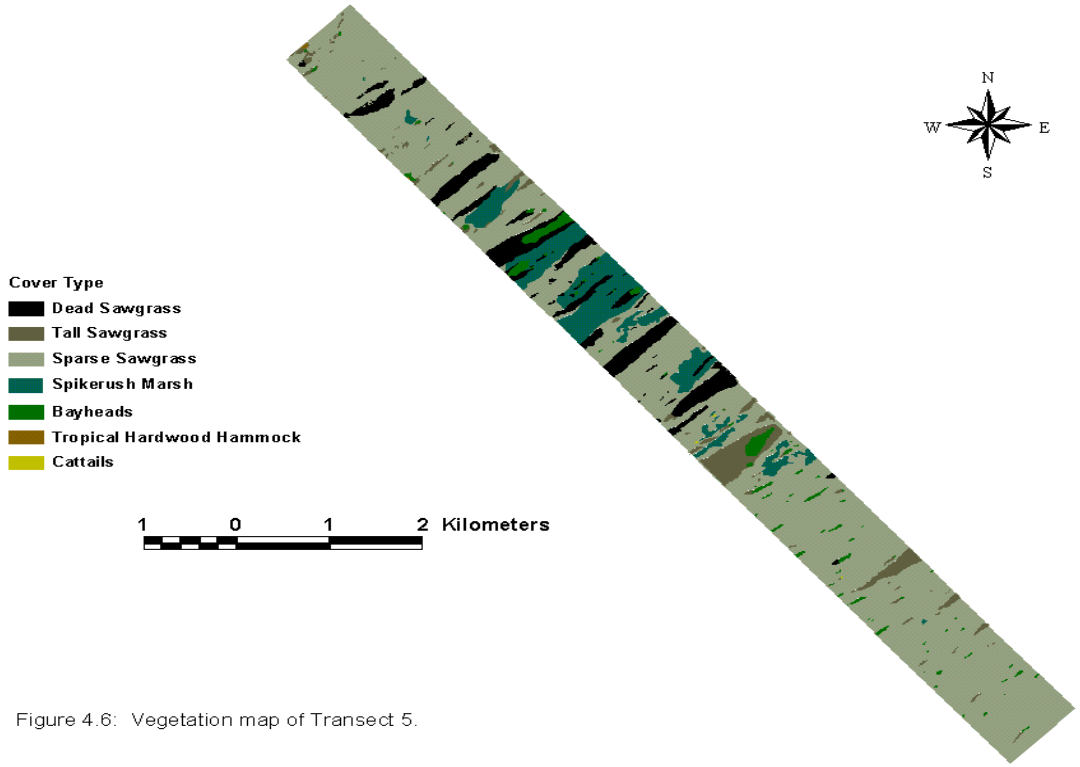


Figure 4.6: Vegetation map of Transect 5.

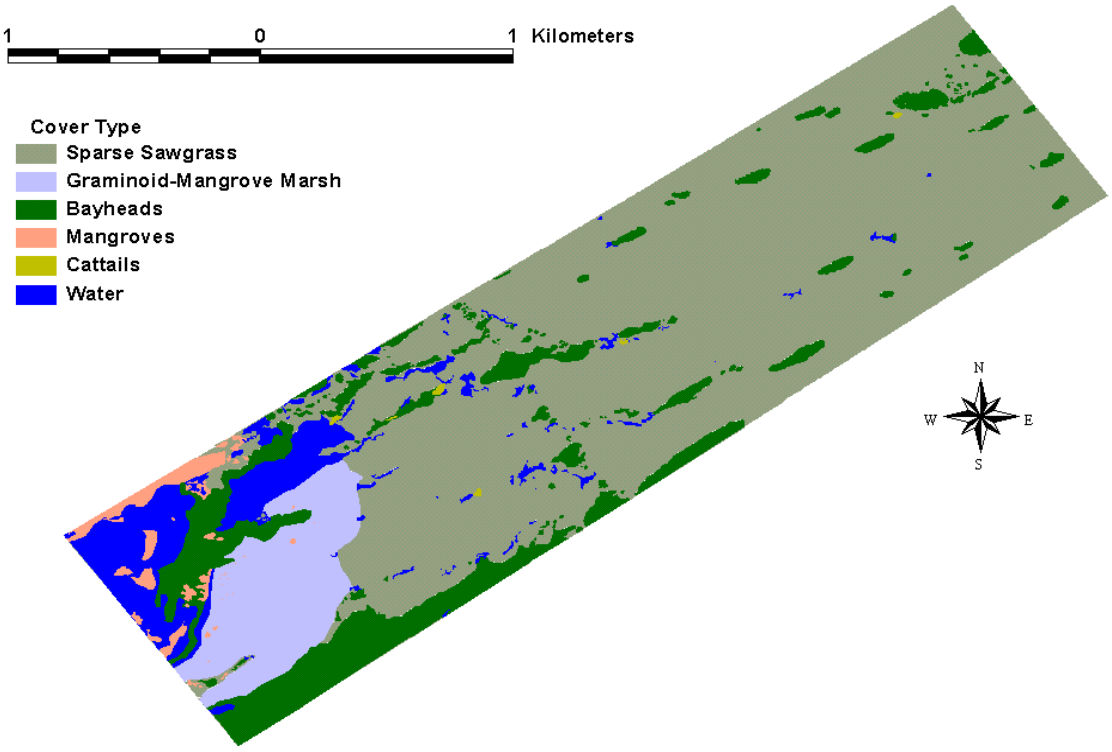


Figure 4.7: Vegetation map of Transect 6

Vegetation & Vegetation Maps:

The vegetation of Shark Slough is well documented (Gunderson, 1994; Davis et al., 1994; other references). In general, the Slough appears as a patch mosaic of physiographic units interconnected by strands of sawgrass (Cladium jamaicense), which in places exceeds two meters in height. Though dominated by sawgrass, these strands contain other aquatic species, e.g., Peltandra virginica, Eleocharis cellulosa, Crinum americanum, Bacopa caroliniana, Nymphea odorata, Utricularia purpurea, among others. Scattered throughout the landscape are bayheads ranging from 15 m2 to approximately 70 ha in size. These larger bayheads are usually associated with tropical hardwood hammocks or basins. The macrophyte composition of these forests tends to be more diverse, perhaps because of the wide range of hydrologic and light regimes present. Characteristic species include Magnolia virginiana, Myrica cerifera, Salix caroliniana, Persea borbonia, Ilex cassine, Chrysobalanus icaco, Cephalanthus occidentalis, and Annona glabra, to name but a few. Tropical hardwood hammocks are also a major component of the Slough's vegetation, though they are not as abundant as bayheads. Hammocks tend to form on limestone outcrops and have a shorter hydroperiod than bayhead forests. As a result, the species composition is strikingly different then that of the surrounding vegetation. Species commonly found within hammocks are Celtis laevigata, Bursera simaruba, Mastichodendron foetidissimum, Ficus aurea, F. citrifolia, Coccoloba diversifolia, Eugenia axillaris, Simarouba glauca, Psychotria nervosa, Chrysophyllum oliviforme, Trema micranthum, and Sabal palmetto. Non-native species such as Psidium guajava, Citrus spp., and Schinus terebinthefolius are sometimes present as well.

Transect 1:

Transect 1 is located in Northeast Shark Slough (Figure 4.1, Table 4.1). This area is bounded on the west by the L-67 Levee, on the north by U.S. Highway 41, and on the east by Krome Avenue. As a result, Northeast Shark Slough is mostly isolated from the rest of the Slough. Moreover, because of its proximity to urban areas, this section of the Slough, has experienced years of abuse by recreational airboat users and hunters, as well as water management practices geared towards flood control. Melaleuca quinquenervia and Casuarina spp. are major components in the landscape.

The vegetation map of Transect 1 (Figure 4.2) covers approximately 423 ha and consists of six different vegetation types: Dead Sawgrass; Tall Sawgrass; Sparse Sawgrass; Spikerush Marsh; Bayheads; and Exotics (Table 4.3). Sawgrass marsh is by far the dominant community type with 406 ha. Within this community type, Sparse Sawgrass accounts for 92.5% (392 ha) of the total area mapped. Tall Sawgrass (14 ha) and Spikerush Marsh (15.5 ha) combine for 7% of the total area mapped while the remaining cover classes, Dead Sawgrass (0.1 ha), Bayheads (0.7 ha), Exotics (0.4 ha), and Water (0.9 ha), account for the remaining 0.5%.

Figure 4.2 suggests that the vegetation of Northeast Shark Slough is relatively homogeneous and dominated by sparse sawgrass. This is generally the case. However, there are many Bayheads and Hardwood Hammocks, albeit degraded, scattered throughout the landscape. Though not well represented on the map, the Spikerush Marsh community is an important component as well. And, though they account for less than 0.01% of the area mapped, exotics, in the form of M. quinquenervia and Casuarina spp., are a significant element in Northeast Shark Slough, specifically towards the east and north.

Transect 2:

Transect 2 is located about 2 km northeast of Vulture Hammock in Northern Shark Slough and is crossed by the L-67 Levee near the point where the levee turns southwest for about one kilometer before turning back south again (Figure 4.1, Table 4.1). As a result, the area east of the levee-about one third of the total transect-is hydrologically isolated, and most closely resembles Transect 1 in water regime. This section also has the same land use history as Transect 1 or Northeastern Shark Slough (e.g., recreational airboat use, camping, and hunting). Furthermore, the western two km of Transect 2 occurs on a topographical high and thus tends to have shorter hydroperiod than the rest of the transect.

The vegetation map of Transect 2 (Figure 4.3) covers approximately 743 ha and consists of five different vegetation types: Tall Sawgrass, Sparse Sawgrass, Spikerush Marsh, Bayheads, and Hardwood Hammocks (Table 4.3). The sawgrass marsh community, Tall Sawgrass (89 ha) and Sparse Sawgrass (578 ha), accounts for nearly 90% (667 ha) of the area mapped (Table 4.3). The Spikerush Marsh community covers less than 10% (65 ha) of the area mapped, and Bayheads and Hardwood Hammocks account for less than 1%, i.e., 0.8% (5.8 ha) and 0.07% (0.5 ha), respectively (Table 4.3).

In contrast to the near homogeneity of the Transect 1 landscape (Figure 4.2), the map of Transect 2 (Figure 4.3) shows a highly diversified and structured marsh community. As mentioned earlier, the L-67 Levee (canal and road) effectively divides the transect into two distinct hydrological units. However, besides a region of Tall Sawgrass which parallels the L-67 Levee on the west side, there was no observable effect of this levee on the vegetation of Transect 2. Though rare, the exotic M. quinquenervia is present as isolated individuals 3 to 4 meters tall, usually in association with Bayheads and/or rock outcrops throughout the area.

Transect 3:

Transect 3 is located about 2 km north of Gumbo Limbo Hammock and 2 km east of the Shark Valley Lookout Tower (Figure 4.1, Table 4.1). The physiography and hydrology of the region are very similar to that of Transect 2, west of the L-67 Levee. This section was previously mapped in Olmsted & Armentano (1997) and corresponds to their North Transect (Appendix 6).

Table 4.3: Area and percentage cover for each cover type mapped in Shark Slough.

Area of Coverage (ha)

Cover Type	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6
Dead Sawgrass	0.1 (0.02%)		0.3 (0.05%)	25.4 (3.0%)	106.3 (9.0%)	
Tall Sawrass	14.0 (3.3%)	88.9 (12.0%)	68.3 (10.4%)	61.4 (7.2%)	59.4 (5.0%)	
Sparse Sawgrass	391.9 (92.5%)	578.5 (77.9%)	501.7 (76.0%)	593.9 (70.1%)	861.0 (73.0%)	296.1 (69.2%)
Sawgrass Total	**406.0 (95.8%)**	**667.4 (89.9%)**	**570.3 (86.5%)**	**680.7 (80.3%)**	**1026.7 (87.1%)**	**296.1 (69.2%)**
Graminoid-Mangrove Marsh						36.2 (8.5%)
Spikerush Marsh	15.5 (3.7%)	65.3 (8.8%)	73.9 (11.2%)	142.2 (16.8%)	123.6 (10.5%)	
Bayheads	0.7 (0.2%)	5.8 (0.8%)	14.7 (2.2%)	24.5 (2.9%)	28.1 (2.4%)	57.0 (13.3%)
Hardwood Hammock		0.5 (0.07%)	1.1 (0.2%)	0.4 (0.05%)	0.6 (0.05%)	
Cattails					0.2 (0.02%)	0.5 (0.1%)
Mangroves						6.8 (1.6%)
Exotics	0.4 (0.09%)					
Other Cover Types						
Canals		2.9 (0.4%)				
Levee Road		1.0 (0.1%)				
Water	0.9 (0.2%)					31.4 (7.3%)
Total Coverage	**423.5**	**742.9**	**660.0**	**847.8**	**1179.2**	**428.0**

The vegetation map of Transect 3 (Figure 4.4) covers an area of 660 ha consisting of six different vegetation communities: Dead Sawgrass, Tall Sawgrass, Sparse Sawgrass,

Spikerush Marsh, Bayheads, and Hardwood Hammocks (Table 4.3). Once again, the sawgrass marsh is the dominant community type (Table 4.3). This community type, consisting of Dead Sawgrass (0.3 ha), Tall Sawgrass (68.3 ha), and Sparse Sawgrass (501.7 ha), accounts for 86.5% of the total area mapped (Table 3.3). The remaining 13%, or so is divided between the Spikerush Marsh (11.2%), Bayheads (2.2%), and Hardwood Hammock (0.2%) plant communities (Table 4.3).

As with Transect 2 (Figure 4.3), the marsh community of Transect 3 is highly diversified and structured (Figure 4.4). Hardwood Hammocks and Bayheads are a major component of this region, though they are not well represented on the specific area we mapped (see North Transect, Appendix 6).

Transect 4:

Transect 4 is located just north of Panther Mound, almost in the center of Shark Slough (Figure 4.1, Table 4.1). Therefore, hydroperiods along this transect generally decrease with increasing distance from the center of the transect, notably towards the western end. Transect 4 was previously mapped in Olmsted & Armentano (1997) and corresponds to their Intermediate Transect (Appendix 6).

The vegetation map of Transect 4 (Figure 4.5) represents an area of approximately 847 ha. Its vegetation composition resembles that of Transect 3 (Table 4.3). The sawgrass marsh community is by far the dominant community type, with a total coverage of nearly 680 ha or 80.3% of the area mapped (Table 4.3). Sparse Sawgrass once again dominates the landscape with a total coverage of 594 ha (Table 4.3). As in Transects 2 and 3, Dead Sawgrass (25.4 ha) and Tall Sawgrass (61.4 ha) combine for about 10% of the total area mapped, 3 and 7.2 percent, respectively (Table 4.3). The Spikerush Marsh community covers about 142 ha or 16.8% of the total area mapped. Finally, Bayheads and Hardwood Hammocks account for less than 3.0% of the area mapped, 2.9 and 0.05 percent, respectively (Table 4.3).

The most striking feature on the Transect 4 vegetation map is the obvious increase in the amount of Dead Sawgrass compared to the previous three vegetation maps, 3.0% vs 0.02%, 0.0%, 0.05%, respectively (Table 4.3). Generally, the Dead Sawgrass community is located in the tails (downstream sections) of Bayheads, or in areas that until recently were Tall Sawgrass communities.

Transect 5:

Transect 5 is located about 1.5 km north of Rookery Branch. On the east, it extends to within 2.6 km of the Pay-hay-okee Lookout Tower in Everglades National Park (Figure 4.1, Table 4.1). At 12 km in length, Transect 5 is by far the largest section of Slough mapped in this report. The region was previously mapped in Olmsted & Armentano (1997) and corresponds to their South Transect (Appendix 6).

The vegetation map of Transect 5 (Figure 4.6) covers 1,179 ha of Shark Slough. Yet again, the dominant community type is sawgrass marsh, representing 1,030 ha, or 87% of the total area mapped (Table 4.3). Sparse Sawgrass accounts for nearly three-quarters (861 ha) of the sawgrass marsh community, followed by Dead Sawgrass (106.3 ha) and Tall Sawgrass (59.4 ha), 9.0 and 5.0 percent, respectively (Table 4.3). The Spikerush Marsh community accounts for nearly 11.0% (123.6 ha) of the marsh mapped. As in the previous maps, Bayheads and Hardwood Hammocks account for less than 3 percent of the area mapped, 2.4 and 0.05 percent, respectively (Table 4.3). Cattails are also present, but account for only 0.02% (0.2 ha) of the area mapped.

Though not mapped as a distinct community type, Taxodium distichum (Bald-Cypress) was commonly associated with many of the Bayheads in the southeastern 2 km of Transect 5. Furthermore, individual cypress stems, in dwarf form, were present in the sawgrass marsh community, as well. The presence of T. distichum in this segment of the transect is not at all surprising considering the proximity of this transect to cypress domes associated with the Pay-hay-okee Lookout Tower area of Everglades National Park. The most significant observations revealed by this map are: (1) there is an apparent lack of Hardwood Hammocks in this southern section of the Slough, especially considering the large area mapped, and (2) there is an overwhelming amount of Dead Sawgrass present in the area. As in Transect 4, the presence of Dead Sawgrass is associated with the tails of Bayheads or areas which until recently were Tall Sawgrass communities.

Transect 6:

Transect 6 is located approximately 7 km southeast of Tarpon Bay and 5 km southwest of Rookery Branch (Figure 4.1). Its location (Table 4.1) places it at the headwaters of the Watson River. Unlike the five transects described above, Transect 6 is oriented parallel to the presumed flow of water.

The vegetation map of Transect 6 (Figure 4.7) covers approximately 428 ha, and includes five distinct vegetative communities: Sparse Sawgrass; Graminoid-Mangrove Marsh (similar to Sawgrass-Spikerush-Mangrove Marsh; Meeder et al, 1996); Bayheads; Cattails; and Mangroves (Table 4.3). Not surprisingly, sawgrass is the dominant community type, with a total area of approximately 300 ha, or about 69% of the total area mapped (Table 4.3). Bayheads are next most extensive, with coverage of 57 ha, or 13% of the total area mapped (Table 4.3). The Graminoid-Mangrove Marsh, an ecotonal type in the southern section of Transect 6 (Figure 4.7), accounts for nearly 9% of the area mapped. This zone marks the transitional region between the upstream fresh water marsh and the marine influenced mangrove communities of Whitewater Bay. The remaining 9% is divided unevenly between the Cattail (0.1%) and Mangrove (1.6%) vegetation communities, and the open water (7.3%) cover type (Table 3.3).

Table 4.4: Mean percent cover (1 ± S.E.) for two cover types present on Transect 6. Values within row that include same superscript and are not bold faced do not differ at $\alpha = 0.05$, based on Tukey HSD. Zones represent regions along the transect: Zone 1— 0 to 1400 meters, Zone 2 – 1500 to 3000 meters; and Zone 3 – 3100 to 4000 meters.

Cover Type	Zone 1	Zone 2	Zone 3
Periphyton	28.03 ± 6.80[b]	34.54 ± 6.70[b]	**73.79 ± 6.54[a]**
Sawgrass			
Living	17.54 ± 3.29[a]	21.67 ± 3.21[a]	**7.00 ± 1.90[b]**
Dead	8.09 ± 3.41[b]	**25.40 ± 4.17[a]**	6.61 ± 2.15[b]
Total Cover	25.64 ± 4.68[b]	**47.07 ± 6.30[a]**	13.61 ± 3.94[b]
Maximum Height (cm)	172.33 ± 4.73[a]	152.42 ± 11.49[a]	**109.23 ± 14.42[b]**

Close examination of the NAPP photo and data revealed three distinct zones present within the mapping region (Figure 4.8). These zones are associated with variation in the periphyton and sawgrass components of the marsh community (Table 4.4). Zone 3 - aqua in color and mapped as Graminoid-Mangrove Marsh (Figure 4.7) - has a mean periphyton cover of 74%, much higher than either Zones 1 & 2, where periphyton covers an estimated 28% and 34% of the surface, respectively (Table 4.4). Moreover, live sawgrass in Zone 3 is lower in cover and shorter than in Zones 1 or 2 (Table 4.4). Furthermore, the data reveal that Zone 2 (Figure 4.8), an area appearing purple on the NAPP photograph when Bands 2 (Green) and 3 (Blue) are switched with each other, is significantly higher in total sawgrass cover and in the coverage of dead sawgrass than either of the adjacent zones (Table 4.4).

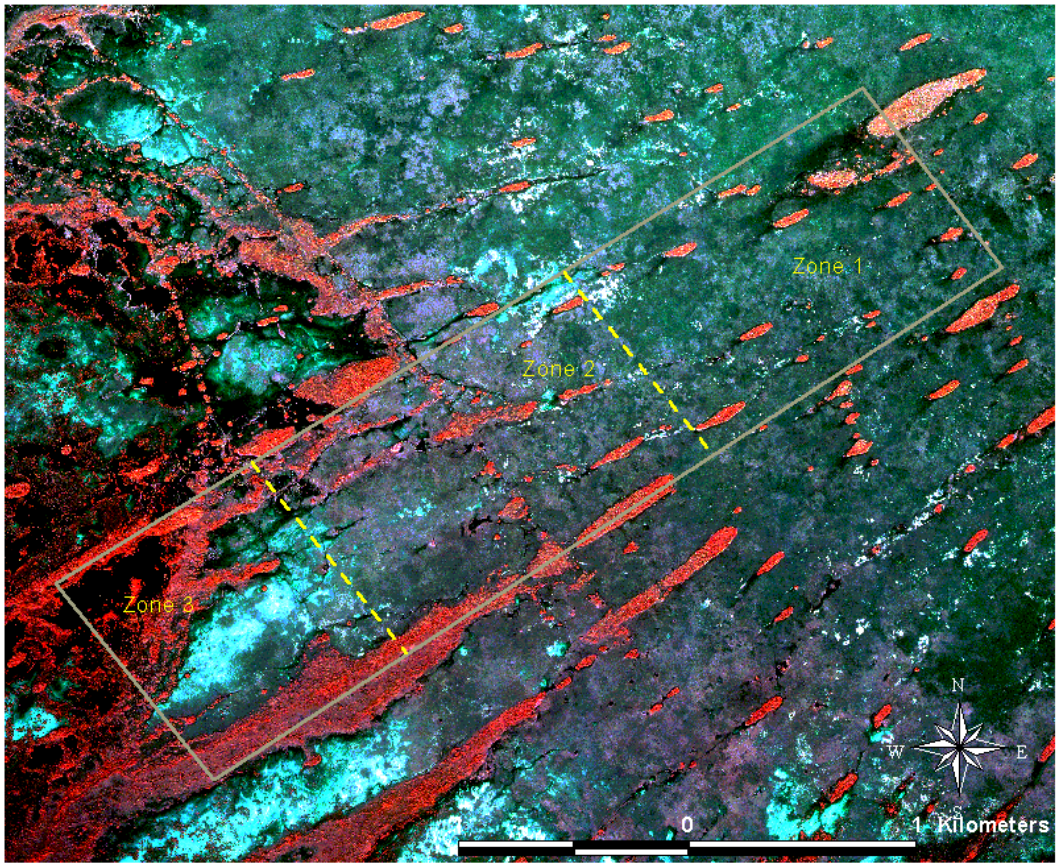


Figure 4.8: NAPP photo of Transect 6. Zones represent areas which differ in the amount of dead sawgrass cover, particularly Zone 2 - a purple band originating at the bottom right corner of the photo which crosses the transect between 1500 and 3000 meters.

Discussion:

General Vegetation Trends:

From the data collected and the maps created, several key observations and conclusions can be made about the general structure and composition of Shark Slough vegetation. For one, Sparse Sawgrass is by far the most abundant community type in Shark Slough. It represents three-quarters, 3,223 ha, of the entire area mapped, 4280 ha. As a result, the sawgrass marsh community exceeds all other plant communities combined by about six fold. The percentage of total sawgrass marsh cover decreased slightly from north to south (Table 4.3), while the coverage of Dead Sawgrass increased toward the south (Table 4.3). Generally, these areas of Dead Sawgrass are associated with regions of Tall Sawgrass and/or in the tails of Bayheads and Hardwood Hammocks. At this time the mechanism(s) responsible for sawgrass decadence are unknown, or even whether it is driven by water management or some natural cycle. However, we suspect that the current event is the result of some combination of the prolonged hydroperiods of the mid-1990's and a natural successional process within very dense, tall stands of sawgrass.

At 3.0% and 0.06% of the total area mapped, respectively, Bayheads and Hardwood Hammocks represent a small proportion of the Shark Slough landscape. From a floristic standpoint, however, they are a very significant component of the mosaic as a result of their high niche diversity.

Mangroves and other halophytes were restricted to the southern portions of the Slough, Transect 6 (Figure 4.7, Table 4.3). The encroachment of these species further north seems inevitable if nothing is done to increase fresh water flow and fire frequency in this area. At the larger scale, however, the main process affecting the future distribution of R. mangle et al. in Shark Slough is sea level rise. Thus, any strategy developed to retard the expansion of R. mangle, for instance, into northern sections of the Slough which ignores sea level rise will, in all likelihood, end up in failure.

Lastly, the distributions of exotics like M. quinquenervia, Casuarina spp., and S. terebinthefolius were mostly limited to Northeastern Shark Slough, Transect 1. However, M. quinquenervia is present as individual trees as far south as the tail of Panther Mound. Furthermore, S. terebinthefolius along with Citrus spp. are sometimes found in the Hardwood Hammock community, with the latter more common then the former. Furthermore, S. terebinthefolius is also common in Bayheads in the southern Slough near Rookery Branch and Transect 6.

Map Accuracy:

Because of the apparent sensitivity of marsh species composition to interannual variation in hydrology and other factors (see Section 1), the accuracy of our maps are a function of: photo resolution and quality; the environmental conditions at the time the photo was taken; the gap in time between the date the photo was taken and the date of vegetation sampling; and the environmental conditions at the time the data and observation were made. Another source of error inherent in these maps (and in all maps, for that matter) is the ability of the mapmaker and the mapping software and algorithm to distinguish between the communities being mapped. As a result, the maps illustrated in this document contain some inaccuracies (Table 4.5).

A major source of error in these maps was in discriminating among Sparse Sawgrass, Spikerush Marsh, and the Spikerush-Sawgrass Mosaic on the NAPP photos, both within and across transects (Table 4.5, Figure 4.9). Generally, however, most mapping errors resulted from: 1) difference in scale between the area mapped and the area observed in the field; 2) edge effects between adjacent communities, in particular near the interfaces between Bayheads, Tall Sawgrass and Dead Sawgrass types; and 3) the gap in time between the date the photo was taken and the date the data/observations were recorded (Table 4.5).

Table 4.5: Percentage of observed vs. mapped community types in Shark Slough based on Transects 1-5. The observed vegetation data are based on the 5 meter interval plot transects described in the methods section. See Table 4.2 for vegetation descriptions.

Observed Vegetation (5 meter interval point transect)	Mapped Vegetation (%)						
	Dead Sawgrass	Tall Sawgrass	Sparse Sawgrass	Spikerush Marsh	Bayheads	Cattails	Hardwood Hammock
Dead Sawgrass	62.1	17.6	17.8	18	0.7		
Tall Sawgrass		42.1	56.2	0.8	1.0		
Sparse Sawgrass	0.1	2.8	93.5	3.4	0.2		
Spikerush Marsh	0.1	0.4	45.0	54.5			
Bayheads	1.9	14.8	5.9	3.7	70.0		3.7
Cattails	7.7	23.1	38.5			30.8	
Spikerush-Sawgrass Mosaic	0.4	0.5	91.4	7.5	0.2		

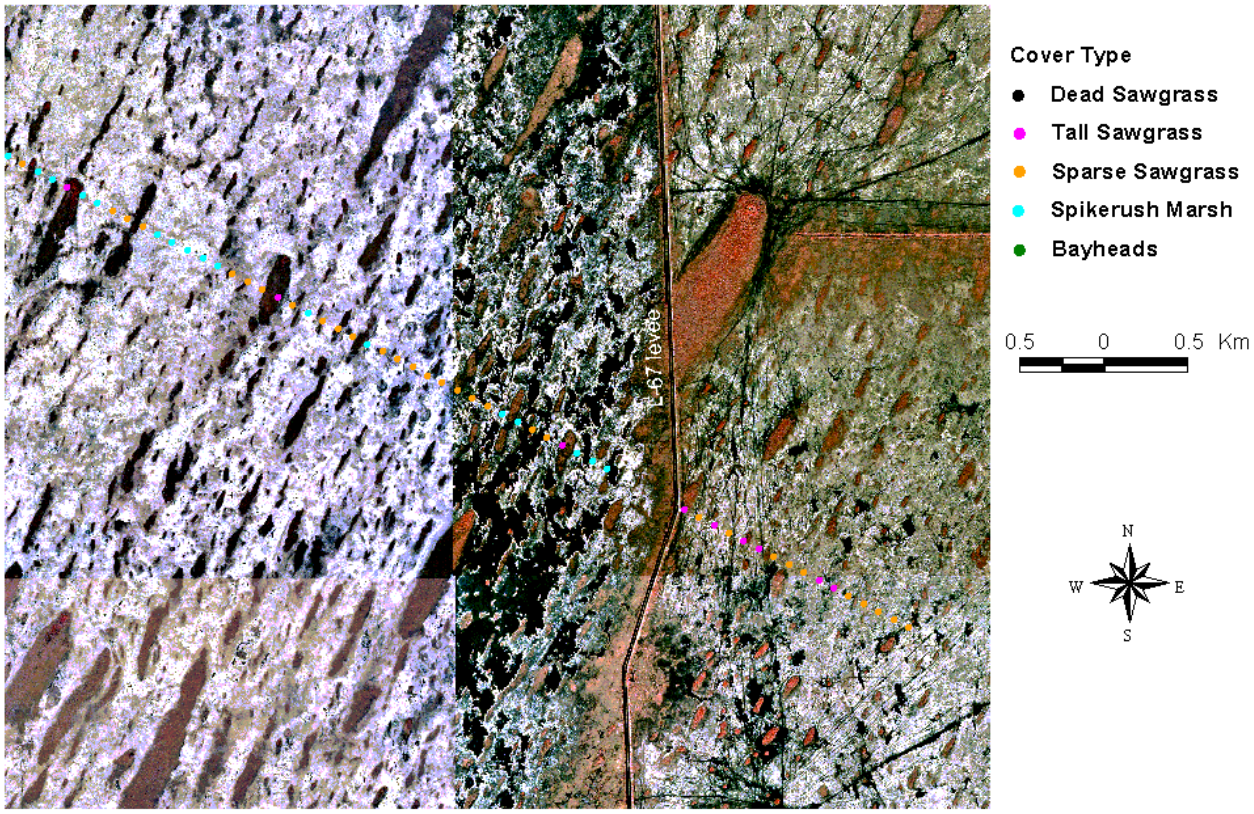


Figure 4.9: Mosaic of the four Chekika Island digital orthophoto quarter quads, with dominant cover type indicated at 100 meter intervals. Note differences in reflectivity between quarter quads, particularly with respect to cover type. The NE and SE quarter quads (right) were photographed in Dec. 1994 while the NW and SW quarter quads (left) were photographs in Jan. 96. Average water depth in 1994 was greater than in 1996.

For instance, scale, edge and temporal effects were all significant in the case of Dead Sawgrass, where about 18% of the area observed of this type in 2000 was mapped as either Tall Sawgrass or Bayheads based on appearance in the NAPP photos (Table 4.5). Since these three communities are usually associated with one another, determining where one community begins and the other ends is difficult, at best. Likewise, the five years gap between the photo and the data can lead to an underestimate of Dead Sawgrass coverage if the Tall Sawgrass has senesced during this time frame.

In most cases, the communities observed in the field matched well with those interpreted from the photos (Table 4.5). However, in the case of the Tall Sawgrass community, 56% of the points observed in this vegetation type were mapped as Sparse Sawgrass (Table 4.5). One likely explanation for this discrepancy is that hydrologic conditions at the time the NAPP photo was taken differed significantly from those during field observations, i.e., deeper water at the time the photo was taken may have masked the characteristic appearance of the Tall Sawgrass community with that of the Sparse Sawgrass community. Another possibility is that some of the Sparse Sawgrass communities shifted to Tall Sawgrass during the ca five-year interval. If this is true, this

shift in community types during a relatively short period of time suggest that the photos used were not current enough for the task.

Our original intent was to employ the same units previously used by Olmsted & Armentano (1997) in our map. However, with respect to their Spikerush-Sawgrass Mosaic, we were able to identify the community in the field but found it impossible to distinguish it from Sparse Sawgrass on the NAPP photos (Table 4.5, Figure 4.9). Thus, our maps lump the two community types.

In all likelihood, our maps underestimate the area covered by the Spikerush Marsh because 45% of the field-observed Spikerush Marsh community was mapped as Sparse Sawgrass (Table 3.5). Again, this discrepancy is attributed to the difficulty in discriminating between the two community types on the available photos (Figure 4.9).

Conclusion:

The maps presented are only a close approximation of the true vegetation and landscape pattern presently found in Shark Slough. Attempts to compare these maps with earlier vegetation maps (e.g., Olmsted and Armentano, 1997), or to describe the status or distribution of any particular community type, must acknowledge the problems outlined above, and expectations should be tempered accordingly. Nevertheless, we do believe the data and maps presented in this section are useful.

For example, the groundtruthing data are now a valuable historical account of the vegetation structure and composition of Shark Slough at the turn of the 21th century. These data augments and improves the existing vegetation database for Shark Slough. Furthermore, because of its nature, these data can easily be integrated into future ecological studies of Shark Slough. In addition, these maps and data have documented an episode of sawgrass mortality. As a result, a record now exists of a phenomenon that in all likelihood would have gone unnoticed or undocumented had this study not been conducted. Thus, these maps are a valuable resource for those land managers, ecologist, and naturalists who are interested in understanding and describing the process which drive the Tall Sawgrass community to a decadent state, and how it recovers.

Furthermore, our attempt to map the vegetation of Shark Slough calls attention to the problems associated with trying to combine vegetation data with aerial photographs taken several years earlier, especially in wetlands. We recommend that future mapping efforts attempt to minimize the gap between the time of data collection and the time the photo is taken. We realize, however, that this not always possible since NAPP photos are usually not available until two years after they were taken. A better solution, of course, is to establish a regular monitoring program at selected sites in which photographs are contracted locally, under optimal (dry) water conditions. Combined with a reasonably extensive field monitoring component at permanently marked and GPS-located points, it would be relatively simple to assess changes in the Everglades marsh landscape accurately and at minimal cost. For specific purposes in which local landscape structure is the subject of interest, and accuracy is at a premium, it may be useful and cost-effective

to delineate habitat units directly in the field, using the latest advances in real-time GIS/GPS technology.

Section 5

Temporal Changes in the Vegetation Structure of Shark Slough During the Last Two Decades

Introduction:

The vegetation and physiography of Shark Slough have been described by many observers during the last century or so (e.g., Willoughby, 1898; Small, 1923 & 1927; Harper 1927; Davis, 1943; Craighead, 1971; Gunderson, 1994; Davis et al., 1994). In general, the vegetation of the Slough consists of a mosaic of mixed-species patches of several more or less distinct types (Table 4.1), interwoven by monotypic stands of sawgrass (Cladium jamaicense) which in places exceeds two meters in height. The boundaries between these units are generally abrupt and are controlled by topography, hydrology, soil depth, and fire, to name a few (Davis, 1943; Craighead, 1971; Herndon et al., 1991). These boundaries can change through time (Herndon, unpublished manuscript), but controls on the rates of change are not well understood.

Early accounts of the Everglades marsh were descriptive and botanical in emphasis (Willoughby, 1898; Small 1923 &1927; Harper, 1927; Davis, 1943). More recent studies have focused on the physical factors driving changes in plant species composition, especially hydroperiod and fire (Craighead, 1971; Hofstetter, 1976; Gunderson, 1989 and 1994; Davis et al., 1994; Herndon et al., 1991 and unpublished manuscript). Many of these studies documented temporal changes in community structure and/or composition during the last four decades in Shark Slough (Kolipinski and Higer, 1969; Craighead, 1971; Hofstettter, 1976; Hofstetter and Pearson, 1976; Wade et al., 1980; Davis et al., 1994). In general, these studies called attention to the dynamic nature of the Slough and to the strong effects of hydrology on the vegetation.

In this section, we attempt to document plant community dynamics in Shark Slough during the last two decades, by comparing a 1982 vegetation map of Shark Slough (Olmsted and Armentano, 1997; see Appendix 6) with field data collected along three transects during 1999-2000.

Methods:

During November 1999 - January 2000, we characterized the marsh vegetation at 5-meter intervals along Transects 1-5 described in Sections 1 and 4 (Figure 1.1 & 4.1). Using the definitions enumerated in Olmsted and Armentano (1997) and presented in Table 5.1, we assigned each point to one of the following seven cover types: Dead Sawgrass, Tall Sawgrass, Sparse Sawgrass, Spikerush-Sawgrass Mosaic, Spikerush Marsh, Bayheads, and Cattails. Data collected from Transects 3, 4, and 5-which correspond to the same areas mapped in Olmsted and Armentano (1997) (Figure 1.1, Appendix 6)-were used to test for temporal changes in the landscape structure of Shark Slough during the last two decades.

We used Arc-View 3.1 to overlay the above data on each of the three vegetation maps presented in Olmsted and Armentano (1997) (Appendix 6). Then, using the Spatial Analysis utility in Arc-View 3.1, we compared the cover types determined in 1980 (Olmsted and Armentano, 1997) and in 2000 (our point assignments). The distance of overlap between the two surveys were ca. 6.4, 8.0 and 11.9 km for Transects 3, 4, and 5, or approximately 1,282, 1,601, and 2,376 paired observations, respectively.

Table 5.1: Description of cover types.

Cover Type	Criteria
Sawgrass	
Dead	Total live vegetation cover < 20% with substantial amounts of dead vegetation in particular *C. jamaicense*.
Tall	Dominant species *C. jamaicense* with canopy heights > 2 meters.
Sparse	Dominant species *C. jamaicense* with canopy heights < 2 meters.
Spikerush-Sawgrass Mosaic	Co-dominant species association of *C. jamaicense* and *E. cellulosa*.
Spikerush Marsh	Dominant species *E. cellulose*, *P. hemitomon*, or *P. geminatum*. Canopy heights < 1.5 meters.
Bayheads	Woody vegetation with extended hydroperiods and dominant or co-dominant with *C. jamaicense.*
Cattails	Dominant species *Typha domingensis* with live vegetation cover > 25 % and canopy heights > 2 meters.

Results:

Examination of the two data sets indicates that changes in the landscape structure of Shark Slough have occurred in the last 20 years (Table 5.2). The most obvious is the current abundance of Dead Sawgrass, a cover type not observed in the earlier survey. Furthermore, these data indicate that the Spikerush-Sawgrass Mosaic and Spikerush Marsh communities increased during the interval 1980-2000, while Sparse Sawgrass and especially Tall Sawgrass decreased in extent across the three transects (Table 5.2). Bayheads were more extensive in the 2000 survey; however, this apparent increase may be attributable to the sampling method, since this cover type represented a very small proportion of the entire transect length in both years (Table 5.2).

The marsh community we examined in 2000 was organized along a latitudinal gradient. Whereas greatest temporal changes were generally observed in the

southernmost transect (Transect 5), the changes cited above were observed to varying degree in all transects (Table 5.2). The amount of Dead Sawgrass and Spikerush-Sawgrass Mosaic increased from Transect 3 to Transect 5-from north to south and from highest elevation to lowest-while Tall Sawgrass and Sparse Sawgrass communities decreased across the same range. Unlike the other types, the spatial distribution of Spikerush Marsh in Shark Slough was relatively uniform in 2000, despite an increase in abundance across all transects during the previous two decades.

Table 5.2: Percentage of mapped (1981), observed (2000) and change (% Δ) in the vegetation community of Shark Slough determined by the dominant vegetation cover associated with an array of points evenly spaced at 5-meter intervals along three transects.

	Transect 3			**Transect 4**			**Transect 5**		
Vegetation Type	1981	2000	% Δ	1981	2000	% Δ	1981	2000	% Δ
	(% of Transect)			(% of Transect)			(% of Transect)		
Dead Sawgrass									
Tall Sawgrass	0.0	2.6	---	0.0	6.4	---	0.0	12.4	---
Sparse Sawgrass	18.1	12.1	-33.1	16.1	4.2	-73.9	18.0	2.7	-85.0
Spikerush-Sawgrass Mosaic	49.0	40.0	-18.4	41.3	19.6	-52.5	55.3	16.7	-69.8
Spikerush Marsh	12.7	16.0	+25.9	15.4	35.9	+133.0	12.6	46.2	+266.7
Bayheads	18.5	27.1	+46.5	22.5	28.0	+24.4	11.9	17.5	+47.1
Cattails	1.7	2.2	+29.4	4.0	5.9	+47.5	2.2	4.2	+90.9
	0.0	0.0	0.0	0.7	0.1	-85.7	0.0	0.3	+30.0

Discussion:

With several interruptions (1971-1979 and 1989-1992), mean surface water levels in Shark Slough have exhibited a general increase since the mid-1960's (Figure 5.1). Based on what is currently known about the hydrologic regime that characterizes different Shark Slough plant communities (e.g., Ross et al., 2000; Olmsted and Armentano 1997;

Gunderson 1989); Herndon, unpublished document), one would predict that persistently high water levels might lead to the replacement of shorter hydroperiod sawgrass marsh by long hydroperiod types such as Spikerush Marsh. In fact, this is what the data summarized in Table 5.2 indicates, i.e., Spikerush Marsh and Spikerush-Sawgrass Mosaic increased in all three transects, primarily at the expense of the two major sawgrass types. However, with data limited to two vegetation surveys separated by 20 years, it is not possible to determine when and over how long a period these changes in landscape pattern took place, or even whether hydrologic variability was the primary driving force behind it.

Hofstetter (1976) made the following observations about the sawgrass marshes of Everglades National Park in the early 1970's, following several years of high water: 1) a decrease in the overall coverage of sawgrass marsh; 2) a dieoff or decrease in vigor in the Tall Sawgrass community, which left behind areas of open marsh and Dead Sawgrass; and 3) direct replacement of some Sawgrass communities by other aquatic macrophytes. Hofstetter's first two observations could be accurately applied to the condition of the sawgrass marsh in Shark Slough today, following a series of wet years. Wade et al. (1980) reported a general recovery from the sawgrass decline described by Hofstetter (1976). Wade's study followed a period in which the yearly mean surface water elevation was below the 30-year average (Figure 5.1). Aerial photo interpretation by Davis et al. (1994) also indicated a general increase in sawgrass and decrease in spikerush marsh over the greater Everglades during the 1969-1985, a period which included the low water years 1971-1979.

Based on the literature discussed above, we postulate (a) that the present vegetation structure in Shark Slough is a result of the 1993-1999 period of prolonged hydroperiods, (b) that hydrology is the main physical factor affecting this community, and (c) the discrepancies in results among studies are due to interannual or interdecadal variation in the hydrologic regime of Shark Slough, and rapid response of vegetation to it. We base these hypotheses on the observation that every reported increase in the relative abundance of sawgrass in the Slough coincided with or closely followed periods of below-average water level (e.g., Wade et al., 1980; Davis et al., 1994; Olmsted & Armentano, 1997). Conversely, every increase in the relative abundance of Spikerush Marsh coincided with or followed periods when annual mean surface water elevation was high (e.g., Hofstetter, 1976 and this study). Based on the hydrograph presented in Figure 5.1, it is quite likely that the dominance of sawgrass among the plant communities of Shark Slough has changed markedly several times during the 1980-2000 period considered in this study.

Finally, our finding that a structural change occurred in Shark Slough during the last two decades assumes that the maps presented in Olmsted and Armentano (1997) are an actual representation of the vegetation structure of Shark Slough during the period that the photo was taken (1971) and the groundtruthing conducted (1981). Although there is no way of verifying the accuracy and precision of these maps, the detail in landform and the diversity of vegetation groups identified (Appendix 6) argue that these maps provide reasonable representations of Shark Slough during the 70's. If this is the case, then our assumption is valid and our methods and results are upheld.

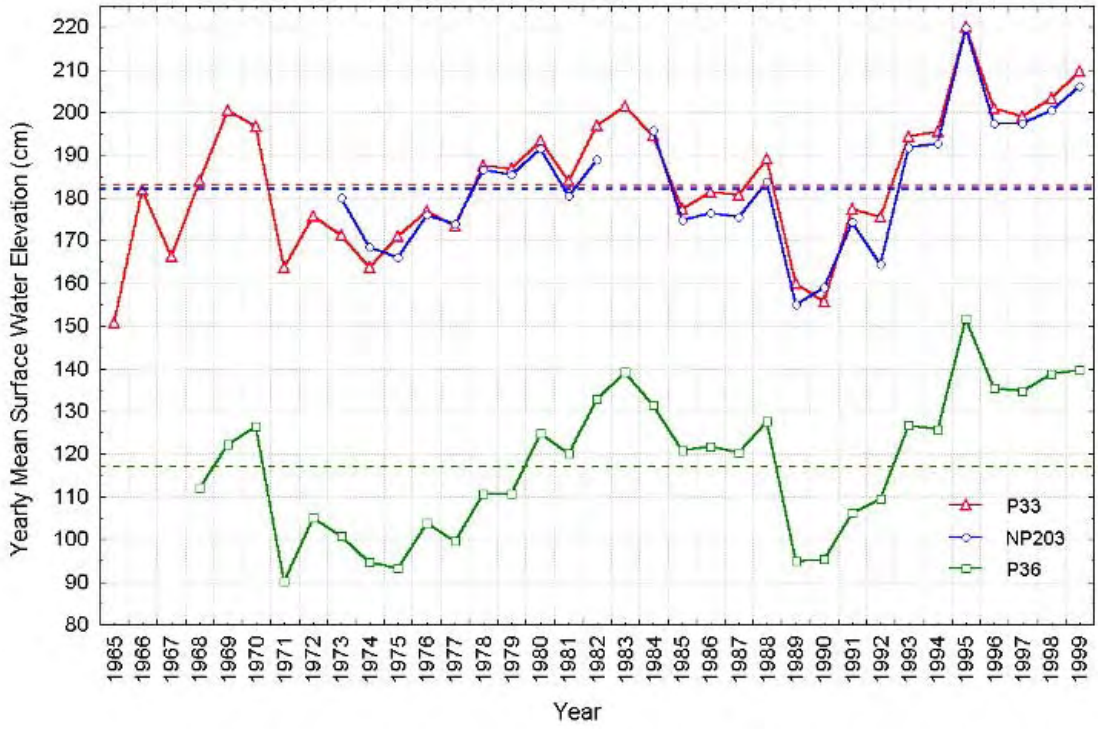


Figure 5.1: Hydrograph of yearly mean surface water elevation at three hydrostations within Shark Slough. Dash lines represents 34 year mean.

Conclusion:

During the last two decades the structural composition of Shark Slough has changed, at least once and possibly twice, in response to fluctuations in the hydrological regime. In general, during extended periods of below average yearly mean surface water elevations the structural composition of Slough tends to change to a Sawgrass dominated marsh. In contrast, if the yearly mean surface water elevations are above average during extended period of time, the structural composition of Slough tends to change to a Spikerush dominated marsh. This relationship between hydrology and changes in the Sawgrass/Spikerush marsh communities of Shark Slough is important because it aids in the understanding of how communities change through time. It is also an important management tool, because it allows managers the ability to plan ahead and make ecologically sound water management decisions knowing in advance what the effects will be on the marsh communities of Shark Slough. This hydrology:vegetation relationship demonstrates how closely bonded the hydrophilic communities of the Slough are to one another and to the physical environment, particularly hydrology.

Section 6

Landscape Structure in Shark Slough

Introduction:

In Section 1 we examined the interrelationships of hydrology and soils with Shark Slough vegetation. In Sections 4 and 5 we summarized geographic variation in the relative abundance of marsh cover types today, and compared them to patterns evident in a similar study concluded in 1980. In this section, we describe the vegetation briefly from a landscape perspective, one that asserts that the Everglades landscape has emergent properties that are not entirely expressed by the characteristics of its constituent local ecosystems.

Methods:

The data consist of a field survey of the identity and extent of habitat patches intercepted by five transects distributed from north to south in the ENP portions of Shark Slough (Figure 1.1). The transects ranged in length from 4-12 km, and were oriented perpendicular to the apparent direction of water flow, which is generally to the southwest. In November - December 2000 we drove an airboat along the transect, noting which of the seven habitat types defined in Table 4.2 best described a five meter-wide band surrounding the transect. The position of every cover type transition was determined by differential GPS to the nearest five meters.

Data analysis focused on the size structure of patches within the habitat mosaic, especially in variation among cover types or regions (as defined in Section 1). It is important to recognize that the orientation of the transects meant that, to the extent that habitat units were aligned parallel to the flow of water, our measurements reflected their shortest dimension. Though anisotropy (directionality) in landscape features was not addressed in this study, the shape, size and orientation of Everglades tree islands has been a subject of recent research attention (Brandt et al. 2000).

In order to describe structural diversity in the Shark Slough landscape, we calculated a patchiness index (P) that incorporates both the number of habitat patches and the structural contrast among them (Romme 1982):

$$P_j=((\sum D_i)/N_j)*100 \text{ for } i=1 \text{ through } N_j$$

In the above equation, Nj is the number of boundaries between adjacent 5-meter intervals along Transect j, and Di is the dissimilarity value for the ith boundary. In order to calculate Di, we first ranked the seven cover types in order of decreasing canopy height and vegetative cover, based on data described in Section 1. The rankings were: Bayhead, 1; Cattails and Tall Sawgrass, 2; Sparse Sawgrass, 3; Sawgrass-Spikerush Mosaic, 4; Spikerush Marsh and Dead Sawgrass, 5. Di was then calculated as the absolute value of the difference in rankings between adjacent intervals. Di values were

therefore zero for boundaries within a habitat patch, but were positive for boundaries at the interface of two patches. For each region, in addition to the patchiness index P, we also reported the number of patches per kilometer of transect, and mean inter-patch dissimilarity ($D_{x\text{-bar}}$).

Another structureal aspect is landscape diversity, which may be summarized by applying the Shannon-Wiener index (H') to the relative abundance of habitat or cover types within a landscape (Romme 1982). This well-known index is calculated as:

$$H' = \sum p_I * \ln(p_I)$$

where pI is the proportional coverage of Type i in the landscape (Pielou 1975). In the current application, pI values were based on proportions of points along all transects within a region.

Results:

Landscape diversity (H') was much lower in Northeast Shark Slough (NESS) than in the other three regions (Table 6.1). This was a result of a low evenness among cover types in NESS (Table 4.3), because the richness component of diversity was equal in the four regions (seven cover types present in each).

Table 6.1: Landscape diversity matrics in four regions of Shark Slough. Calculations of P and H` are described in ext.

Region	**Transect Length (km)**	**Patch Density (#/km)**	**Mean Contrast Among Patches ($D_{x\text{-bar}}$)**	**Patch Index (P)**	**Landscape Diversity (H')**
Northeast	5.47	30.7	1.40	21.6	0.96
Northern	10.94	39.9	1.39	27.4	1.50
Central	8.29	35.1	1.32	22.7	1.56
Southern	12.24	32.4	1.18	19.0	1.46

Regional patterns in patch size structure are illustrated in Figure 5.1. Patches 50 meters across or smaller accounted for 50-70% of total marsh area in each region, and the largest uninterrupted patches were less than 250 meters wide. Small patches were most characteristic of Northern Shark Slough (NSS), and large patches were most prevalent in NESS.

Not surprisingly, the above differences in landscape structure were reflected in the patchiness statistics (Table 6.1). NSS was characterized by the highest patch density (~40/km) and P index of the four regions. Patch density was lowest in NESS (~30/km), but, because of low contrast among patches, Southern Shark Slough exhibited the lowest P. Central Shark Slough was intermediate in both patchiness measures.

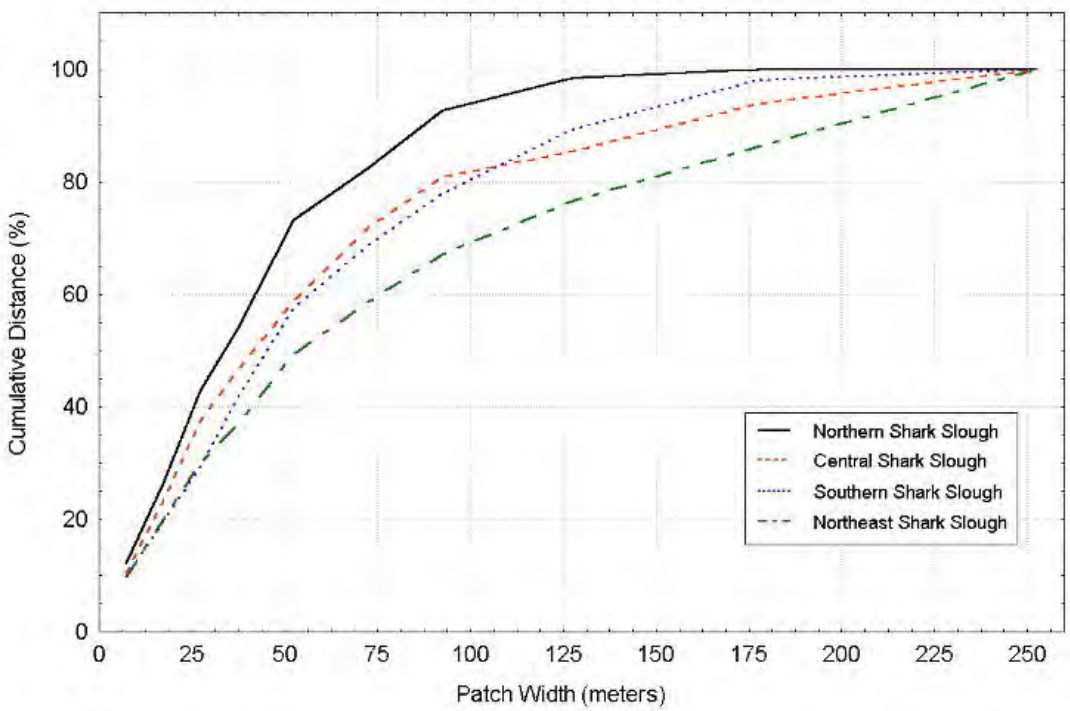


Figure 6.1: Cummulative distance in increasing patch widths in four regions of Shark Slough, expressed as % of transect length.

Shark Slough cover types did not differ greatly in patch size distribution (Figure 6.2). There was no obvious relationship between the total abundance of a cover type in the Slough and its patch size distribution. For instance, among the less widely distributed cover types, Cattails and Tall Sawgrass were predominantly found in small patches, and Bayheads and Dead Sawgrass were found in large patches. To some extent, the latter may an artifact of limited sampling in these restricted types, where one or two large patches could constitute a large percentage of their total coverage.

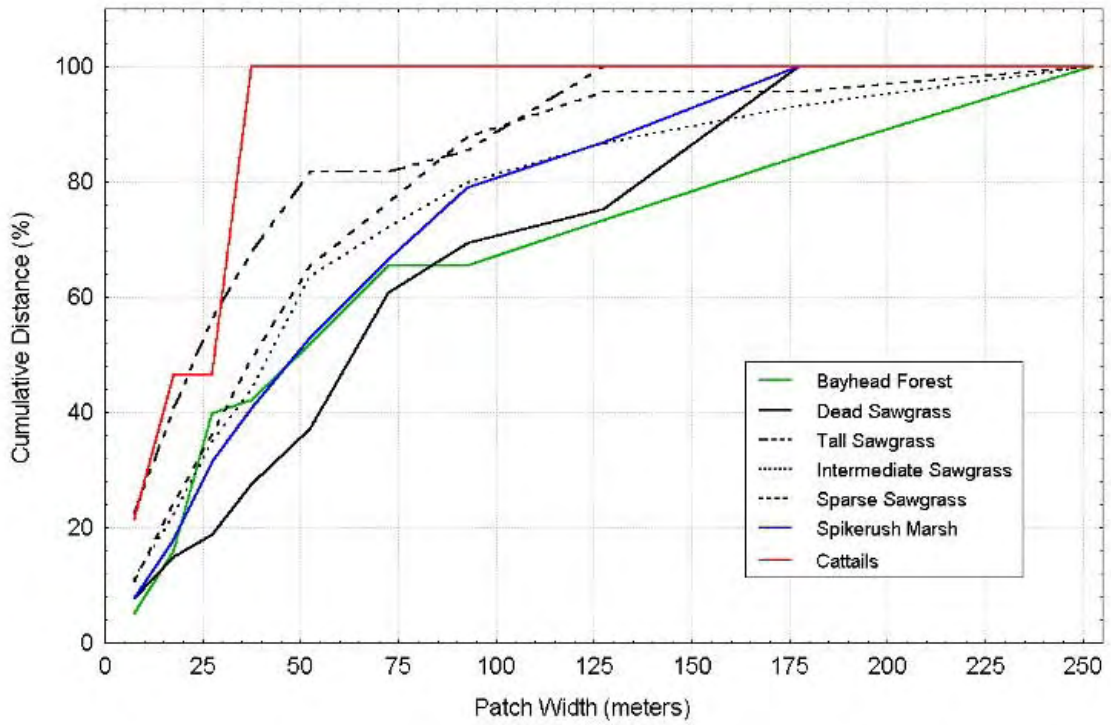


Figure 6.2: Cummulative distance in increasing patch widths in seven vegetation types in Shark Slough, expressed as % of transect length.

Discussion:

Habitat diversity and patch structure are fundamental landscape-scale features of the Florida Everglades. Descriptions of the Everglades landscape are common in literary works and naturalists' accounts, but quantitative analyses are nowhere to be found in the scientific literature. For this reason, our initial attempts to describe the Shark Slough landscape cannot be confidently placed in historical context, nor in relation to other South Florida wetlands. However, these data do provide a sense of the Shark Slough habitat mosaic on the ground, i.e., one characterized by a substantial diversity of cover types, arranged predominantly in small (< 50 meters across) structural and compositional units, separated from place to place by extensive areas of uniform vegetation. Only after understanding the structure of this landscape in detail can we begin to think critically about the forces that create and maintain it.

The landscape indices calculated in our study are strongly scale-dependent. By characterizing plant cover at 5-meter intervals, and by dividing marsh vegetation into seven cover types, our sampling provided a very fine-textured view of the Shark Slough landscape, akin to what one would experience traversing the area on foot, canoe, or airboat. A coarser-textured view, e.g., based on aerial photos would result in very different estimates of landscape diversity or patchiness. For instance, based on 1:40,000 NAPP images, maps produced by the University of Georgia (Welch et al. 1995; Madden

et al. 1999) distinguished 3-5 cover types, with patch density of 2-5 patches/km, in Northern, Central, and Southern Shark Slough. On the basis of 1:16,600 aerial photos, Olmsted and Armentano (1997) mapped Shark Slough vegetation in much greater detail. However, detailed as they were, their maps identified only 8-11 patches/km in the above regions, where our field observations yielded patch densities of 33-37 patches/km.

Following Romme (1982), we used the familiar Shannon-Wiener H' to index landscape diversity. Since cover types are not as unambiguous as species, use of this index is especially sensitive to the scale effects discussed above. Nevertheless, H' may be useful in monitoring temporal changes or in describing spatial variation within a broad study area. H' depends on both richness and evenness, but in Shark Slough inter-regional differences were related to the evenness component of diversity. Four of the cover types (Cattails, Dead Sawgrass, Tall Sawgrass, and Bayheads) were always minor elements whose abundance probably did not affect H' greatly. The relatively low landscape diversity observed in Northeast Shark Slough (Table 6.1) is the result of a predominance in that region of Sparse Sawgrass over the other two major marsh cover types, Spikerush Marsh and Sawgrass-Spikerush Mosaic. NESS was once near the center of Shark Slough, but sheet flow through the area was interrupted with the construction of Tamiami Trail, and has never been adequately reestablished. The possible role of sheet flow in maintaining a mixture of marsh types and therefore high landscape diversity is an open question.

H' indexes the number and relative abundance of community types, but does not address how these types are distributed in the marsh. To express this spatial component of diversity, we again borrowed an index previously applied by Romme (1982) to the forest mosaic in Yellowstone National Park. The patchiness index P is highest when the landscape is dissected into many small structural or compositional units, and when adjacent units contrast sharply with one another. Within the wetlands of our study area, and at the scale on which we were focusing, the factors that promote dissection and contrast may not be identical. What are those factors?

As in other south Florida wetlands, vegetation pattern in Shark Slough appears to be driven by the combination of hydrology and disturbance (Section 1; Herndon et al. 1991); Duever 1986; Egler 1952). One may think of the process hierarchically, with hydrology eliciting the background pattern, and disturbance events/locations overlaid in a random or ordered fashion on the landscape. By this scheme, vegetation responds determinately to small variations in hydroperiod and water depth, created by modest differences in surface topography within an anastamosing drainage network. In general, vegetation stature in the Slough increases as water level and hydroperiod decrease. Superimposed on this background, major or minor disturbances (fire, freeze, animal activity, etc.) leave their mark; however, unless the underlying topography is altered, or climate change or water management actions intervene, the initial equilibrium is gradually approached following disturbance.

As suggested earlier, hydrology and disturbance may affect "patchiness" differently. Because of the strong correlation between hydrology and vegetation detailed in Section 1

(e.g., Figures 1.4-1.6), a highly dissected vegetation pattern should result from high spatial variation in surface elevation and hydrology. However, under the same conditions, contrast between adjacent units is expected to be low, due to spatial autocorrelation in the driving physical variables. The effects of disturbance are more complex. Frequent small disturbances should contribute to landscape dissection, but a disturbance regime dominated by widespread events might lead to a relatively homogeneous vegetation matrix. Moreover, disturbance may result in high contrast between neighboring units, depending on the type of disturbance and its location within the surrounding landscape.

Data summarized in Table 6.1 illustrates the highly dissected nature of the Shark Slough marsh, with 30-40 patches crossed per kilometer of transect. However, adjacent units tend not to be too dissimilar in structure (mean dissimilarity ($D_{x\text{-}bar}$), 1.18-1.40; Table 6.1). Based on the above discussion, this combination may indicate a landscape in which the primary control on vegetation is hydrologic, and disturbance plays a secondary (but critical) role. One disturbance whose influence may be detected in the Shark Slough landscape is the recent sawgrass dieoff episode that was described in Sections 1, 4 and 5 of this report. Since sawgrass dieoff takes place almost exclusively in Tall Sawgrass, it is possible to compare current patch density and contrast to that of a hypothetical pre-dieoff landscape in which Tall Sawgrass occupies current Dead Sawgrass patches. Dieoff had the following effects:

NESS: Increased patch density by 2%, Increased patch contrast by 4%
NSS: Increased patch density by 6%, Increased patch contrast by 6%
CSS: Patch density unchanged, patch contrast increased by 14%
SSS: Patch density unchanged, patch contrast decreased by 2%

The persistence of the dieoff-related increase in patchiness (in all regions except Southern Shark Slough), of course, depend on the rate and trajectory of succession in the affected areas, which are unknown at present.

Conclusions:

If one asks the average nature tourist, weeks after returning home from a trip to the Everglades, to recount the properties of the ecosystem that left the most lasting impression, his/her list is apt to include at least one item associated with the wetland landscape, e.g., grass, water, trees, sky, and more grass. More than in most ecosystems, the landscape level is central to human perceptions of the Everglades. Furthermore, landscape-level feedbacks on other important ecosystem attributes, for instance wildlife population dynamics and surface water flow patterns, are also likely. Nevertheless, though we are making great efforts to restore the Everglades, few attempts have been made to describe this important level in the organizational hierarchy quantitatively. In the research discussed above, we applied several well-known metrics to identifying cover types distributed along a series of transects. The results of these preliminary analyses have been instructive, especially with respect to the small size of patches that dominate the landscape.

Acknowledgements:

We would like to thank the following people for their logistical and administrative support: Tom Armentano, David Jones, and Ruth Franklin from the South Florida Natural Resources Center at Everglades National Park; the rangers from the Tamiami and Chekika Ranger Stations; and Andy Gottlieb and Darcy Stockman of FIU.

Literature Cited:

Alexander, T.R. and Crook, A.G. 1973. Recent and long-tern vegetation changes and patterns in South Florida: part I: preliminary report. South Florida Environmental Project. University of Miami, Coral Gables, FL. 224 pp.

Alexander, T.R. and Crook, A.G. 1975. Recent and long-term vegetation changes and patterns in South Florida. In: P.J. Gleason, (ed.). Environments of South Florida: present and past. 61-72 pp. Miami Geol. Soc. Mem. 2.

Arabas, K.B. 2000. Spatial and temporal relationships among fire frequency, vegetation, and soil depth in an eastern North American sperpentine barren. Journal of the Torrey Botanical Society 127 (1): 51 -65.

Bedford, B. L., M. R. Walbridge, and A. Aldous. 1999. Patterns in nutrient availability and plant diversity of temperate North American wetlands. Ecology 80(7): 21651-2169.

Brandt, L.A., Portier, K.M., and Kitchens, W.M. 2000. Patterns of change in tree islands in Arthur R. Marshall Loxahatchee National Wildlife refuge from 1950 to 1991. Wetlands 20(1):1-14.

Busch, D.E., Loftus, W.F., and Bass, O.L. Jr. 1998. Long-term hydrologic effects on marsh plant community structure in the southern Everglades. Wetlands 18(2):230-241.

Carter, V., Reel, J.T., Rybicki, N.B., Ruhl, H.A., Gammon, P.T., and Lee, J.K. 1999. Vegetative resistance to flow in South Florida: summary of vegetation sampling at Sites NESRS3 and P33, Shark River Slough, November, 1996. U. S. Department of the Interior, U. S. Geological Survey Open File Report OFR-99-218.

Craft, C.B. and Richardson, C.J. 1993. Peat accretion and N, P, and organic C accumulation in nutrient-enriched and unenriched everglades peatlands. Ecological Applications 3 (3): 446 - 458.

Craft, C.B. and Richardson, C.J. 1997. Relationships between soil nutrients and plant species composition in Everglades peatlands. Journal of Environmental Quality 26 (1): 224 - 232.

Craft, C.B., Seneca, E.D., and Broome, S.W. 1993. Vertical accretion in microtidal regularly and irregularly flooded estuarine marshes. Estuarine, Coastal and Shelf Science 37(4):371-386.

Craighead, F.C. Sr. 1971. The trees of south Florida, Vol. 1: the natural environments and their succession. University of Miami, Coral Gables, Florida, USA.

Curnutt, J.L., Mayer, A.L., Brooks, T.M., Manne, L., Bass, O.L. Jr., Fleming, D.M., Nott, M.P., and Pimm, S.L. 1998. Population dynamics of the endangered Cape Sable seaside-sparrow. Animal Conservation 1:11-21.

Daoust, R.J., and Childers, D.L. 1998. Quantifying aboveground biomass and estimating net aboveground primary production for wetland macrophytes using a non-destructive phenometric technique. Aquatic Botany 62:115-133.

Davis, J.H. 1943. The natural features of southern Florida, especially the vegetation, and the Everglades. Florida Department of Conservation, Geological Bulletin No. 25: 1-311.

Davis, S.M. 1991. Growth, decomposition, and nutrient retention of Cladium jamaicense Crantz and Typha domingensis Pers. in the Florida Everglades. Aquatic Botany 40(3): 203-224.

Davis, S.M., Gunderson, L.H., Park, W.A., Richardson, J.R., and Matson, J.E. 1994. Landscape dimension, composition, and function in a changing Everglades ecosystem. In: Davis, S.M. and Ogden, J. (eds.), Everglades: the ecosystem and its restoration. pp 419-444. St. Lucie Press, Delray Beach, Florida, USA.

Day, J.W. Jr., Rybczyk, J., Scarton, F., Rismondo, A., Are, D., and Cecconi, G. 1999. Soil accretionary dynamics, sea-level rise and the survival of wetlands in Venice Lagoon: a field and modelling approach. Estuarine, Coastal and Shelf Science 49(5): 607-628.

Dolan, T.J., Hermann, A.J., Bayley, S.E., and Zoltek, J. Jr. 1984. Evapotranspiration of a Florida, USA, freshwater wetland. Journal of Hydrology 74: 355-371.

Doren, R.F., Armentano, T.V., Whiteaker, L.D., and Jones, R.D. 1997. Marsh vegetation patterns and soil phosphorus gradients in the Everglades ecosystem. Aquatic Botany 56(2): 145-163.

Duever, M.J., Carlson, J. E., Meeder, J. F., Dueverm L.C., Gunderson, L.H., Riopelle, L.A., Alexander, T.R., Myers, R.L., and Spangler, D.P. 1986. The Big Cypress National Preserve. National Audubon Society, New York, New York, USA.

Egler, F.E., 1952. Southeast saline Everglades, Florida and its management. Vegetatio 3: 213-265.
EPA, 1983. Methods of chemical analysis of water and wastes. USEPA, Cincinnati, OH

Fourqurean, J. W., J. C. Zieman, and G. V. N. Powell. 1992. Relationships between porewater nutrients and seagrasses in a subtropical carbonate environment. Marine Biology 114: 57-65.

Fourqurean, J.W. and Robblee, M.B. 1999. Florida Bay: a history of recent ecological changes. Estuaries 22: 345-357.

Froehlich, D.J. 1973. The rock reefs of the Everglades of south Florida. M.S. thesis, University of Miami, Miami, Florida, USA.

Jayachandran, K., K.G. Shetty, M. Nair, and R.D. Jones. 2001. Microbial transformation of nitrogen in Everglades peat soils. (Manuscript in preparation).

German, E.R. 2000. Regional evaluation of evapotranspiration in the Everglades. USGA Water-Resources Investigations Report 00-4217. Tallahassee, Florida.

Godfrey, R.K. and Wooten, J.W. 1981. Aquatic and wetland plants of southeastern United States: dicotyledons. University of Georgia Press, Athens, USA. 933 pp.

Gunderson, L.H. 1989. Historical hydropatterns in wetland communities in Everglades, National Park. In: Sharits, R.R. and Gibbons, J.W. (eds.),
Freshwater wetlands and wildlife. pp 1099-1111. CONF-8603101, DOE Symposium Series No. 61.

Gunderson, L.H.. 1994. Vegetation of the Everglades: determinants of community composition. In: Davis, S.M. and Ogden, J. (eds.), Everglades: the ecosystem and its restoration. pp 323-340. St. Lucie Press, Delray Beach, Florida, USA.

Gunderson, L. H. and J. R. Stenberg. Unpublished manuscript. Pan evaporation and community evapotranspiration from two wetland sites in Everglades National Park..

Harper, R.M. 1927. Natural resources of southern Florida. Fla. Geol. Surv., 18th Ann. Rept., Tallahassee, FL. pp.25-206.

Herndon, A., Gunderson, L., and Stenberg, J. 1991. Sawgrass (Cladium jamaicense) survivaal in a regime of fire and flooding. Wetlands 11: 17-27.

Herndon, A., Stenberg, J. R., and Gunderson, L. Unpublished manuscript. Relationships between sawgrass and spikerush in hydric habitats.

Hofstetter, R. H. 1976. Current status of vegetation and possible indications of vegetational trends in the Everglades: part 1. an evaluation of the current status of sawgrass in the Everglades. Research Agreement No. 18-492. U.S.D.A. Forest Service.

Hofstetter, R.H., and Parsons, F. 1976. the ecology of sawgrass in the Everglades of southern Florida. In: Proc. First Conf. On Scientific Research in the National Parks, vol. 1. pp. 165-170. New Orleans, LA, USA.

Hüchler, A.W. 1951. The relation between classifying and mapping vegetation. Ecology 32(2): 275-283.

Koerselman, W. S. and A. R. M. Meuleman. 1996. The vegetation N:P ratio: a new tool to detect the nature of nutrient limitation. Journal of Applied Ecology 33: 1441-1450.

Kolipinski, M. C. and A. L. Higer. 1969. Some aspects of the effects of quantity and quality of water on biological communities in Everglades National Park. Open File Report, U.S. Geological Survey, Tallahassee, FL.

Legendre, P., Vaudor, A., and Casgrain, P. 1996-99. The R Package 4.0. Departement de sciences biologiques, Universite de Montreal. Montreal, Canda.

Leighty, R.G. and Henderson, J.R. 1958. Soil survey (detailed-reconnaissance) of Dade County, Florida. Series 1947, No. 4. USDA Soil Conservation Service, Washington, DC, USA.

Light, S.S. and Dineen, J.W. 1994. Water control in the Everglades: a historical perspective. In: Davis, S.M. and Ogden, J.C. (eds.), Everglades: the ecosystem and its restoration. pp. 47-84. St. Lucie Press, Boca Raton, Florida, USA.

Loveless, C.M. 1959. A study of the vegetation in the Florida Everglades. Ecology 40:1-9.

Madden, M., Jones, D., and Vilchek, L. 1999. Photointerpretation key for the Everglades vegetation classification system. Photogrammetric Engineering & remote Sensing. 65(2): 171-177.

McCally, D. 1999. The Everglades: an environmental history. University Press of Florida, Gainesville, Florida, USA.

McCune, B. and Mefford, M.J. 1999. PC-ORD. Multivariate analysis of ecological data, Version 4. MjM Software Design, Gleneden Beach, Oregon, USA.

McClung, G., and W.T. Frankenberger, Jr. 1985. Soil nitrogen transformations as affected by salinity. Soil Science 139:405-411.

McLean, E.O. 1982. Soil pH and lime requirement. pp. 199-224. In A.L. Page et al. (ed.) Methods of Soil Analysis, Part 2, American Society of Agronomy, Madison, WI

Meeder, J. F., M. S. Ross, G. Telesnicki, P. L. Ruiz, and J. P. Sah. 1996. Vegetation analysis in the C-111/Taylor Slough basin. Final Report to the South Florida Water Management District, Contract C-4244. West Palm Beach, FL.

Newman, S., J. B. Grace, and J. W. Koebel. 1996. Effects of nutrients and hydroperiod on Typha, Cladium, and Eleocharis: implications for Everglades restoration. Ecological Applications 6(3): 774-783.

Ogden, J.C. 1994. A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem conditions in the southern Everglades. In: Davis, S.M. and Ogden, J.C. (eds.), Everglades: the ecosystem and its restoration. pp. 533-570. St. Lucie Press, Boca Raton, Florida, USA.

O'Hare, N.K. and Dalrymple, G.H. 1997. Wildlife in southern Everglades wetlands invaded by melaleuca (Melaleuca quinquenervia). Bulletin of the Florida Museum of Natural History 41(1): 1-68.

Olmsted, I. and Armentano, T.V. 1997. Vegetation of Shark Slough, Everglades National Park. SFNRC Technical Report 97-001. South Florida Natural Resource Center, Everglades National Park, Homestead, Florida, USA.

Paul, E.A., and F.E. Clark. 1996. Ammonification and nitrification. pp. 182-199. In Soil Microbiology and Biochemistry. Academic Press, San Diego, CA.

Pielou, E. 1975. Ecological diversity. Wiley, New York, USA.

Powell, G.V.N., Bjork, R.D., Ogden, J.C., Paul, R.T., Powell, A.H., and Robertson, W.B. Jr. 1989. Population trends in some Florida Bay wading birds. Wilson Bulletin 101(3): 436-457.

Rejmankova, E., Pope, K.O., Post, R., and Maltby, E. 1996. Herbaceous wetlands of the Yucatan Peninsula: communities at extreme ends of environmental gradients. Int. Revue ges. Hydrobiol. 81: 223-252.

Rhoades, J.D. 1996. Salinity: Electrical conductivity and total dissolved solids. pp. 417-435. In D.L. Sparks et al. (ed.) Methods of Soil Analysis, Part 3, American Society of Agronomy, Madison, WI.

Romme, W.H. 1982. Fire and landscape diversity in subalpine forests of Yellostone National Park. Ecological Monographs 52(2):199-221.

Ross, M.S., Ruiz, P.L., Reed, D.L., Jayachandran, K., Sah, J.P., and Lewin, M.T. 2000. Assessment of marsh vegetation responses to hydrological restoration in Shark Slough, Everglades National Park. Annual Report

Rutchey, K., and Vilcheck, L. 1994. Development of an Everglades vegetation map using a SPOT image and the global positioning system. Photogrammetric Engineering & Remote Sensing 60(6): 767-775.

Schmitz, D.C., and Brown, T.C. 1994. An assessment of invasive non-indigenous species in Florida's public lands. Technical Report No. TSS-94-100. Florida Department of Environmental Protection. Tallahassee, Florida, USA.

Small, J.K. 1923. Green deserts and dead gardens. A record of exploration in florida in the spring of 1921. Jour. N.Y. bot. Gard. 24:193-247.

Small, J.K. 1927. Among floral aborigines: a record of exploration in Florida in the winter of 1922. Jour. N.Y. Bot. Gard. 28:1-20, 25-40.

Solorzano, L., and J.H. Sharp. 1980. Determination of total dissolved phosphorus and particulate phosphorus in natural waters. Limnology and Oceanography 25:754-758.

USACOE. 1994. Central and Southern Florida Project Comprehensive Review Study. U. S. Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, USA.

Welch, R., Remillard, M., Doren, R.F. 1995. GIS database development for South Florida's national parks and preserves. Photogrammetric Engineering & remote Sensing. 61(11): 1371-1381.

Van Lent, T., Snow, R.W., and James, F.E. 1999. An examination of the Modified Water Deliveries Project, the C-111 Project, and the Experimental Water Deliveries Project: hydrologic analyses and effects on endangered species. South Florida Natural Resources Center, Everglades National Park, Homestead Florida, USA.

Wade, D.D., Ewel, J.J., and Hofstetter, R. 1980. Fire in South Florida ecosystems. General Technical Report SE-17, SE Forest Experiment Station, Forest Service, USDA, Asheville, North Carolina, USA.

Walters, C., Gunderson, L. and Holling, C.S. 1992. Experimental policies for water management in the Everglades. Ecological Applications 2(2): 189-202.

Williams, K., Ewel, K.C., Stumpf, R.P., Putz, F.E., and Workman, T.W. 1999. Sea-level rise and coastal forest retreat on the west coast of Florida, USA. Ecology 80(6): 2045-2063.

Willoughby, H. L. 1898. Across the Everglades, A Canoe Journey of Exploration, J. M. Dent and Co., London.

Wu, Y., Sklar, F.H., Gopu, K., and Rutchey, K. 1996. Fire simulations in the Everglades landscape using parallel programming. Ecological Modeling 93: 113-124.

Wu, Y., Sklar, F.H., and Rutchey, K. 1997. Analysis and simulations of fragmentation patterns in the Everglades. Ecological Applications 7(1): 268-276.

Appendix 1

The Hydrologic Regime of Bayheads in Shark Slough

Hydrologic parameters for 11 bayhead forest (BF) or bayhead swamp (BS) sites in the 1990's. Data for driest year of record (1990 for Transects 2-4; 1991 for Transect 5), wettest year of record (1995 for all transects), and average of all years of record are listed separately. Parameters: Hydroperiod (estimated number of days inundated); 30-day Maximum Flooding (average water depth during deepest continuously inundated 30-day period); and Mean Depth of Flooding (annual mean over all days in which water was above the surface). *= *never flooded for 30 days continuously*.

		Hydroperiod (days)			30-Day Maximum (cm)			Average Flooding Depth (cm)		
Vegetation	Site	Dry	Wet	All	Dry	Wet	All	Dry	Wet	All
BS	2-6360	2	365	255	*	68	38	1	45	30
BS	3-1200	23	365	268	*	62	40	1	43	24
BS	4-1400	172	365	324	16	78	55	11	59	36
BS	4-4340	0	365	235	*	56	34	*	36	24
BS	4-6340	0	365	220	*	52	27	*	32	21
BS	5-2320	162	365	287	*	62	34	8	36	20
BF	2-6340	0	365	215	*	61	32	*	38	26
BF	2-6400	0	365	245	*	66	37	*	44	29
BF	4-4000	0	365	193	*	46	25	*	27	18
BF	4-4500	0	343	169	*	41	21	*	23	14
BF	4-6360	0	365	206	*	48	27	*	29	19

Appendix 2

Description of Shark Slough Soils

Transect 1, meter 900 (sparse sawgrass):

Soil Description:

- 0”-3” – Dark organic 10YR3/1, with broken shells and abundant roots.
- 3”-6” – Marl (2.5YR6/2) strongly mixed with organic, with abundant roots.
- 6”-9” – Black organic layer (10YR2/1) with many fine dead roots.

Transect 1, meter 1500 (spikerush marsh):

Vegetation:*Sagittaria lancifolia, Eleocharis cellulosa, Utricularia purpurea,* & *Potamogeton illinoensis*

Conductivity:0.5 mS/cm/s.

Soil Description:

- 0”-3” – Marl suffused with small shells (10YR6/1 to 10YR7/1), overlain by broken-up periphyton floc (color mix of 10YR7/1 and 10YR3/1). Marl includes mixture of fine live and dead roots, spotted with accumulations of organic material. In places, marl is up to 5” in depth, with weak blocky structure.

In spots closer to sawgrass edge, we found the following profile:

- 0”-3” – 10YR7/1 marl.
- 3”-6” – black peat.
- 6”-8” – 2.5YR5/2 marl.
- 8”-10” – black organic.

Transect 1, meter 3500 (tall sawgrass):

Soil Depth: 64 cm

Conductivity: 0.5 mS/cm/s.

Soil Description:

- 0”-5” – Black non-fibrous organic, 10YR2/1, abundant roots.

- 5”-14” – Gray (10YR7/1) marl, silt loam texture; abundant roots and rhizomes; frequent shells, especially in contact with organic horizon below.

- 14”-22” – Black organic horizon (10YR 2/1), non-fibrous, with dead roots.

- 22”-28” – Slightly redder organic (10YR2/2).

Transect 2, meter 500 (sparse sawgrass):

Vegetation: *Cladium jamaicense* & *Eleocharis cellulosa.*

Soil depth: 112 cm

Conductivity: 0.5 mS/cm/s.

Soil Description:

- 0”-15” – Decomposed organic (10YR3/1); frequent live and dead roots; no shells. Sampled from top 10”.

- 15”-30” – Decomposed organic, as above but with occasional shell material. Sampled from 15”-25”.

- 30”-39” – Organic (10YR2/2), as above except for color.

Transect 2, meter 1100 (tall sawgrass):

Vegetation: *Cladium jamaicense*, >2.2 meters tall.

Soil depth: 177 cm

Conductivity: 0.4 mS/cm/s.

Soil Description:

- 0”-70” – Entire profile uniformly non-fibrous organic, brown (10YR3/2) in color. Live roots in first 10”. Some broad-leaved plant material at 40”-50”. Rock broken at limestone interface with soil profile.Collected soils from 0”-10”, 20”-30”, 40”-50”, and 60”-70”.

Transect 2, meter 1200 (spikerush marsh):

Vegetation: *Panicum hemitomon, Eleocharis cellulosa, Utricularia purpurea,* & *Paspalidium geminatum*

Soil Depth, 108 cm.

Soil Description:

- Color and soil materials similar to T2-1100.

Transect 2, meter 2300 (spikerush marsh):

Soil Depth: 81 cm.

Soil Description:

- 0”-20” – Organic layer (10YR3/2) with abundant live roots in upper section. Sampled 0”-10” (S1) and 10”-20” (S2) separately.

- 20”-32” – Organic stratum slightly darker (10YR3/1) than above.

Transect 2, meter 2600 (spikerush marsh):

Vegetation: *Utriculariapurpurea* and *U. foliosa, Eleocharis cellulosa, Cladium jamaicense* &

periphyton.

Soil Depth: 86 cm.

Soil Description:

- 0”-15” – Organic soil (10YR3/1) with abundant plant material, live (top) and dead roots. Sampled from 0”-9” (S1) and 9”-15” (S2).

- 15”-30” – Organic (10YR3/2) layer with abundant plant material, including leaves. Sampled from 15”-25” (S3).

- 30”-34” – Marl (10YR5/1), with silt loam texture. Frequent shells.

Vulture Hammock (tropical hardwood hammock):

Vegetation: *Bursera simarouba, Mastichodendron foetidissimum, Celtis laevigata, Eugenia axillaris,* &

Chrysophylum oliviforme.

Soil Depth: 53 cm.

Soil Description:

- 0”-7” – Dark (10YR3/1) silt loam with medium and fine roots. Quartz particles visible in sun. (S1)

- 7”-21” – Marl (10YR4/1 – 10YR5/1) with broken, rounded rock pieces; some thin shell-like fragments.

Transect 2, meter 5600 (tall sawgrass):

Soil Depth: 57 cm.

Soil Description:

- 0”-22” – Organic soil (10YR3/1) throughout profile. Live roots confined to upper 3”. No shells. Collected in 2 layers: 0”-10” (S1) and 10”-22” (S2)

Transect 2, meter 5900 (sparse sawgrass):

Vegetation: *Cladium jamaicense* (<1.5 m tall*), Eleocharis cellulosa,* & *Utricularia foliosa*.

Conductivity: 0.3 mS/cm/s.

Soil Depth: 10 cm.

- 0”-4” – Non-fibrous organic (10YR3/1) on limestone, with floc layer on top. Frequent roots, no shells. Bare limestone may exceed 50% of surface. (S1)

Transect 3, meter 300 (spikerush marsh):

Vegetation: *Eleocharis cellulosa, Nymphaea odorata*. Sampled near edge of sawgrass.

Conductivity: 0.5 mS/cm/s.

Soil depth: 53 cm

Soil Description:

- 0”-14” – Non-fibrous organic 10YR3/2; very abundant shells; abundant live and dead roots. Sampled from top 10”.

- 14”-20” – Organic 10YR3/1, with abundant shells.

Transect 3, meter 400 (tall sawgrass):

Vegetation: *Cladium jamaicense* >2.5 meter height

Conductivity: 0.5 mS/cm/s.

Soil Depth: 33 cm

Soil Description:

- 0”-12” – Organic 10YR3/1; no shells. Greasy feel toward bottom of core may indicate increase in silty minerals. Yellow spots of decomposed carbonate rock at base of profile.

Transect 3, meter 5500 (spikerush marsh):

Vegetation: *Paspalidium geminatum*, *Eleocharis cellusosa*, & *Cladium jamaicense*.

Conductivity, 0.4 mS/cm/s.

Soil Depth: 91 cm

Soil Description:

- 0”-22” – Non-fibrous organic 10YR3/3; no shells; thick rhizomatous layer at top. Sampled from upper 10”
- 22”-25” – Marl (10YR7/1); well mixed with organic material and shells.
- 25”-35” – Non-fibrous organic (10YR3/1); shells toward upper boundary only.

Transect 3, meter 5600 (tall sawgrass):

Vegetation: *Cladium jamaicense* ~2 meters tall

Soil depth: 83 cm

Soil Descripton:

- 0”-20” (S1) – Organic 10YR3/2; abundant fine roots, lots of rhizomes; no shells.
- 20”-25” (S2) – Marl (10YR7/1) with streaks of dark (10YR3/1) organic; common fine roots; abundant shells.
- 25”-32” (S3) – Organic (10YR3/2); abundant dead roots; small round shells.

Transect 4, meter 200 (sparse sawgrass):

Vegetation: *Cladium jamaicense*, *Peltandra virginica*, & periphyton.

Soil Depth: 36 cm

- 0”-8” – Organic layer (10YR3/1) with root material, few shells (S1).

- 8”-14” – Organic layer (10YR3/2), with thin layer of marl (10YR5/1) at 8”-9”; shells associated with marl, otherwise there are none (S2)

Transect 4, meter 1340 (spikerush marsh):

Vegetation: predominantly *Eleocharis cellulosa* & *Panicum hemitomon*

Soil Depth: 65 cm (but varies considerably)

Soil Description:

- 0”-23” – Organic material 10YR3/1 throughout the profile; in bottom 1”, this is mixed with 10YR7/1 calcareous mud, probably rubbed off rock, with a few large shells. Sampled at 0”-9” (S1) and 16”-25” (S2).

Transect 4, meter 2900 (spikerush marsh):

Vegetation: *Panicum hemitomon*, *Elecharis cellulosa*, & *Nymphaea odorata*

Soil Depth: 84 cm

- 0”-20” – Organic 10YR3/2, with live roots largely confined to upper 4”, dead roots present throughout.Sample is from upper 10” (S1)

- 20”-27” – Peaty marl (relatively even mixture of 10YR3/2 and 10YR5/1), with many shells and rock fragments; at 20”-22”, there is a more pure marl layer with less organic (S2)

Transect 4, meter 4000 (bayhead):

Vegetation: *Chrysobalanus icaco*, *Myrica cerifera*, *Persea borbonia*, *Cepalanthus occidentalis*.

Soil Depth: 143 cm.

- 0”-43” – Organic material, 10YR3/1, composed primarily of dead roots. No woody tissues at all throughout core. Sampled at 0”-10” (S1) and 24”-37” (S2).

- 43”-51” – Organic material of slightly browner color (10YR3/2) than above. Shells, some small clams, in bottom 1”, with decomposing rock or marl. (S3)

Transect 4, meter 5300 (sparse sawgrass):

Vegetation: *Cladium jamaicense*, & *Eleocharis cellulosa*

Conductivity: 0.4 mS/cm/s

Soil Depth: 59 cm

Soil Description:

- 0”-23” – Organic soil, 10YR3/2, with live and dead roots. Sampled in 2 layers: 0”-9” (S1) and 15”-23” (S2).

Transect 4, meter 7400 (spikerush marsh):

Vegetation: *Eleocharis cellulosa, Bacopa caroliniana, &Panicum hemitomon*

Soil Depth: 50 cm

Soil Description:

- 0”-3” – Relatively even mixture of 10 YR3/2 organic and 10YR5/1 marl; very abundant shells; live and dead roots (S1).

- 3”-22” – Greyish marl (10YR5/1 – 10YR6/1), of silt loam texture; many shells; live and dead roots(S2).

Transect 4, meter 7500 (tall sawgrass):

Soil Depth: 58 cm

Soil Description:

- 0”-4” – Organic layer (10YR3/2) with abundant roots and rhizomes, very little shell material (S1)

- 4”-20” – Marl (10YR 4/1 – 10YR5/1), silt loam in texture. Many small shells, and with spots of 10YR3/2 organic matter. Roots often within organic matter spots. (S2)

- 20”-23” – Marl of same color as above, but finer in texture (silty clay loam). Fewer shells. (S3)

Transect 5, meter 100 (sparse sawgrass):

Soil Depth: 38 cm

Soil Description:

- 0”-4” – Marl (10YR6/2), silt loam in texture; many shells; roots evident; inclusions of 10YR3/2 organic matter (S1)

- 4”-15” – Primarily organic layer (10YR3/1), but with spots of marl, and many shells. (S2)
- 15”-20” – Organic (10YR3/1) with no evidence of marl; shells present as above (S3)

Transect 5, meter 1500 (sparse sawgrass):

Conductivity: 0.5 mS/cm/s

Soil Depth: 59 cm

- 0”-10” – Organic layer (10YR3/2) of loose consistency, with few shells, and live roots mostly in upper 3” (S1)

- 10”-20” – Organic as above.However, thin layer of 10YR3/1 at 15”-17” has abundant shells (S2)

- 20”-24” – Organic layer of similar color (10YR3/2) but firmer consistency than higher in the profile (S3)

Transect 5, meter 4200 (sparse sawgrass):

Vegetation: *Cladium jamaicense* about 1.9 m tall

Soil Depth: 40 cm

Soil Description:

- 0”-3” – Marl (10YR5/1) with many shells, roots, and a good mixture of 10YR3/1 organic matter (S1)

- 3”-13” – Organic layer (10YR2/1) with some shells, especially near top of stratum. Base of profile features 10YR6/2 broken limestone with yellowish cast, some shells. (S2)

Transect 5, meter 4600 (spikerush marsh):

Vegetation: *Eleocharis cellulosa* & *Panicum hemitomon*

Conductivity: 0.5 mS/cm/s

Soil Depth: 43 cm

Soil Description:

- 0”-9” – Organic layer (10YR3/2) with few shells. At 2”, there is a thin (1/2”) layer of 10YR6/1 marl, with many shells (S1)

- 9”-18” – Darker organic (10YR2/1), mostly dead but some live roots. Bottom 3-4” with abundant shells, but few above. (S2)

Transect 5, meter 9000 (spikerush marsh):

Vegetation: *Eleocharis cellulosa* & *Paspalidium geminatum*.

Soil Depth: 36 cm; soil depth very patchy, ranging from 0-100 cm

Soil Description:

Sample A:

- 0”-8” – Organic material (10YR3/1), including live and dead roots; no shells (S1)
- 8”-11” – Marl (10YR5/1), with inclusions of organics (10YR3/1) and shells (S2)

Sample B (2’ from Sample A, appears to be more typical of site):

- 0”-3” – Marl (10YR5/1), with inclusions of organics (10YR3/1) and shells (S3)
- 3”-10” – Organic layer (10YR3/2), with dead roots and assorted plant material, including sawgrass leaves. (S4)

Transect 5, meter 10800 (dead sawgrass):

Vegetation: Scattered *Cladium jamaicense*, *Cephalanthus occidentalis*, & *Peltandra virginica*

Soil Depth: 108 cm

Soil Description:

- 0”-36” – Blackish (10YR2/1) organic soil, abundant dead roots, live roots nr surface; no shells; sawgrass remains apparent, especially below. Sampled at 0”-11” (S1) and 32”-36” (S2).

- 36”-41” – Mixture of marl (10YR4/1), organics (10YR2/1), shells. Marl prevails in 36”-38” layer, organics below (S3).

Transect 5, meter 11500 (sparse sawgrass):

Vegetation: *Cladium jamaicense*, *Eleocharis cellulosa*, & periphyton

Conductivity: 0.3 mS/cm/s

Soil Depth: 39 cm

Soil Description:

- **0”-2” – Marl (10YR5/1) with spots of lighter marl (10YR7/1) and organic matter (10YR3/1); silt loam in texture; few shells, very few roots (S1).**

- 2”-11” – Organic layer (10YR3/2) with roots and rhizomes, few shells (S2).

Transect 6, meter 0 (sparse sawgrass):

Vegetation: *Cladium jamaicense* is 2 meters or so in height

Soil Depth: 115 cm

Soil Description:

- 0”-4” – Gray marl (10YR6/1) of silt loam texture; roots and rhizomes (S1)
- 4”-21” – Organic material (10YR3/2) (S2)

- 21”-25” – Mixture of organic material (10YR3/1) with large shells; reminiscent of shell layer in T5-1500 (S3)

- 25”-33” – Gray marl (10YR6/1), with spots of organic matter; some shells (S4)
- 33”-41” – Organic layer (10YR3/2), blackening downward; occasional shells (S5)
- 41”-53” – Black organic (10YR2/1); greasy feel is evidence of some marl present (S6)

Transect 6, meter 2300 (sparse sawgrass):

Vegetation: *Cladium jamaicense* nearly as high as above.

Soil Depth: 135 cm

Soil Description:

- 0”-9” – Organic material (10YR3/2), roots live above 3”, mostly dead below; few shells (S1)
- 9”-34” – Organic layer with same color as above, but with shells present; dead roots (S2)

- 34”-40” – Dark silt loam marl (10YR4/1); inclusions of 10YR2/1 organics; shells. Bottom 3” of stratum has thin layer of organic, then marl again at base (S3)

- 40”-46” – Organic material (10YR3/1) (S4)

Transect 6, meter 4000:

Vegetation: *Cladium jamaicense* mostly about 60 cm tall, very open; thick periphyton mat; red mangrove

encroaching from the side.

Soil Depth: 110 cm

Soil Description:

- 0”-8” – Gray marl (10YR7/2 – 10YR6/2), mixed with 10YR3/2 organics; shells present (S1)

- 8”-20” – Organic material (10YR3/2) mixed with marl (10YR5/3); organic predominant by about 70:30 (S2).

- 20”-26” – Yellowish (10YR6/3) marl, with organic inclusions (10YR3/2); big shells; dead sawgrass rhizomes present; strong sulfur smell(S3)

- 26”-35” – Organic layer (10YR3/2), with shells (S4)
- 35”-45” – Marl layer (10YR5/3), but mixed with 10YR3/2 organics; many shells (S5)
- 45”-51” – Black (10YR2/1) organic layer; large shells (S6)

P38 A, (intermediate sawgrass):

Vegetation:*Cladium jamaicense*

Soil Depth: 19”

Soil Description:

- 0”-6” – Peaty marl with shells and coarse roots (10YR6/2).

- 6”-14” – Peat with some marl and shells with small fine roots (10YR3/1).

- 14”-19” – Peat with shells and fine roots (10YR3/1).

P38 B, (spikerush marsh):

Vegetation:*Eleocharis cellulosa*, *Sagittaria latifolia*, *Rhynchospora tracyi*, *Oxypolis filiformis*, and *Cladium jamaicense*.

Soil Depth:26”

Soil Description:

- 0”-8” – Marl with shells and living fine roots along with plant detritus (10YR7/2).
- 8”-14” – Marl with shells and thick roots (10YR6/2).
- 14”-26” – Marly-peat with small shell fragments (10YR3/2).

Appendix 3

Selected Physicochemical Properties of Shark Slough Soils: Transects 1-6

Transect 1

Site	Depth (inches)	pH	Bulk Density (g dry wt cm^3)	Percent			Total P
				Organic Matter	Total C	Total N	$\mu g\ g^{-1}$ dry wt
3500	0 - 5	7.14	0.623	5.89	13.46	0.24	108.65
3500	5 - 14	7.82	0.392	9.06	15.76	0.31	134.30
3500	19 - 22	7.36	0.127	79.57	48.52	2.55	203.20
1500	0 - 3	7.35	0.140	69.61	40.90	2.90	388.80
900	0 - 3	7.82	0.397	25.69	14.12	0.97	146.20
900	3 - 6	7.46	0.387	19.20	18.51	0.86	268.80
900	6 - 8.5	7.32	0.352	24.35	20.63	1.13	277.40

Transect 2

Site	Depth (inches)	pH	Bulk Density (g dry wt cm^3)	Percent			Total P
				Organic Matter	Total C	Total N	$\mu g\ g^{-1}$ dry wt
5900	0 - 4	7.10	0.310	31.75	16.21	1.46	205.20
5600	0 – 10	6.86	0.222	60.54	32.02	2.18	540.15
5600	10 – 22	6.61	0.244	58.22	32.33	2.17	622.00
V Ham	0 – 7	8.14	0.690	19.61	9.62	0.88	785.40
V Ham	7 – 21	7.60	1.249	6.93	8.74	0.12	403.20
2600	0 – 9	7.12	0.116	85.56	49.63	3.66	106.95
2600	15 – 25	7.17	0.917	87.82	52.1	3.18	255.00
2600	30 – 34	7.07	0.098	5.21	13.48	0.20	331.50
2300	0 – 10	6.65	0.115	85.83	47.97	3.64	295.20
2300	10 – 20	6.84	0.124	87.06	49.09	3.46	232.00
2300	20 – 32	6.83	0.163	78.66	46.93	2.50	248.50
1200	0 - 10	7.02	0.134	84.37	49.04	2.84	352.00
1100	0 – 10	6.52	0.128	86.23	47.05	3.31	107.10
1100	20 – 30	6.83	0.122	88.03	54.06	2.89	154.80
1100	40 – 50	6.91	0.082	91.15	52.88	3.25	234.90
500	0 – 10	6.90	0.105	85.94	50.06	3.43	104.55
500	15 –25	7.49	0.123	87.70	51.76	3.12	104.55
500	30 - 39	7.46	0.100	89.05	53.62	3.19	83.60

Transect 3

Site	Depth (inches)	pH	Bulk Density (g dry wt cm^3)	Percent			Total P
				Organic Matter	Total C	Total N	$\mu g\ g^{-1}$ dry wt
5600	0 – 20	6.85	0.098	89.72	48.89	3.82	325.80
5600	20 – 25	7.68	0.485	8.95	15.95	0.32	39.60
5600	25 – 32	7.39	0.124	74.41	43.66	2.37	264.25
5500	0 – 10	6.73	0.097	89.01	48.64	3.82	271.95
5500	22 –25	7.49	0.146	17.47	19.90	0.63	75.60
5500	25 –35	7.45	0.290	67.61	40.33	2.28	184.00
400	0 – 12	6.58	0.163	78.32	41.71	2.80	498.00
300	0 – 10	7.31	0.128	73.66	43.86	3.05	218.75
300	14 - 20	7.13	0.198	41.07	23.44	1.52	206.70

Transect 4

Site	Depth (inches)	pH	Bulk Density (g dry wt cm^3)	Percent			Total P
				Organic Matter	Total C	Total N	$\mu g\ g^{-1}$ dry wt
7500	0 – 4	7.29	0.146	63.64	35.69	3.07	429.75
7500	4 – 20	7.66	0.769	6.39	14.39	0.34	101.20
7500	20 – 23	7.68	0.917	4.09	13.20	0.17	108.30
7400	0 – 3	7.61	0.345	29.08	22.56	1.57	220.40
7400	3 – 22	8.03	0.849	3.84	13.24	0.20	79.80
5300	0 – 9	6.83	0.097	88.92	49.73	4.16	238.05
5300	15 – 23	7.29	0.149	66.59	40.90	2.38	335.40
4000	0 –10	6.31	0.158	86.21	47.28	3.50	613.80
4000	24 – 37	6.91	0.151	83.38	50.99	2.44	129.05
4000	43 –51	6.49	0.118	87.97	52.58	3.13	258.30
2900	0 – 10	6.69	0.131	84.73	49.95	3.46	324.30
2900	20 – 27	6.83	0.470	11.72	16.55	0.36	133.65
1340	0 – 9	7.04	0.120	82.06	47.37	3.20	427.50
1340	16 – 25	7.42	0.121	71.38	42.17	2.74	272.00
200	0 – 8	7.37	0.157	66.67	38.27	2.75	264.50
200	8 -14	7.26	0.154	66.77	39.23	2.85	313.50

Transect 5

Site	Depth (inches)	pH	Bulk Density (g dry wt cm^3)	Percent			Total P
				Organic Matter	Total C	Total N	$\mu g\ g^{-1}$ dry wt
11500	0 – 2	7.57	0.273	27.25	21.93	1.42	305.45
11500	2 – 11	7.55	0.178	65.09	37.62	3.48	589.60
10800	0 – 11	6.98	0.154	82.41	46.55	3.42	385.95
10800	32 –36	7.49	0.138	79.29	48.06	3.07	401.80
10800	36 – 41	7.67	0.204	28.48	24.10	1.09	400.00
9000	0 – 8 (A)	7.83	0.225	49.04	26.91	2.13	359.55
9000	8 – 11 (A)	7.38	0.615	6.76	14.01	0.28	83.20
9000	0 – 3 (B)	7.57	0.258	42.58	27.89	1.99	277.20
9000	3 – 10 (B)	7.72	0.200	54.05	29.06	2.36	350.00
4600	0 – 9	7.40	0.094	84.23	48.02	3.77	310.20
4600	9 –18	7.12	0.145	72.61	43.34	2.54	133.40
4200	0 – 3	7.65	0.262	30.22	24.09	1.47	290.45
4200	3 –13	7.69	0.133	69.89	42.04	2.96	243.00
1500	0 – 10	7.07	0.112	87.12	49.51	4.01	227.55
1500	10 – 20	7.68	0.156	55.28	33.69	2.08	233.70
1500	20 – 24	7.57	0.134	69.06	39.90	2.65	216.60
100	0 – 4	7.57	0.352	16.94	18.29	0.86	150.35
100	4 – 15	7.18	0.207	47.80	29.61	2.23	440.75
100	15 -20	7.54	0.240	35.27	24.46	1.87	334.25

Transect 6

Site	Depth (inches)	pH	Bulk Density (g dry wt cm^3)	Percent			Total P
				Organic Matter	Total C	Total N	$\mu g\ g^{-1}$ dry wt
4000	0 – 8	7.58	0.390	11.43	16.68	0.62	79.50
4000	8 – 20	7.61	0.154	39.07	28.96	1.67	89.30
4000	20 –26	7.72	0.317	13.81	18.15	0.67	41.65
4000	26 –35	7.47	0.128	56.89	37.53	2.44	159.75
4000	35- 45	7.83	0.233	26.24	23.50	1.17	107.10
4000	45 – 51	7.66	0.126	61.05	36.80	2.68	342.35
2300	0 – 9	7.34	0.093	87.60	49.04	4.16	372.40
2300	9 – 34	7.36	0.099	75.45	45.50	3.60	173.95
2300	34 – 40	7.54	0.169	38.74	30.38	1.64	118.00
2300	40 – 46	7.51	0.133	67.02	37.84	2.34	241.80
0	0 – 4	7.64	0.257	21.91	20.89	1.08	159.90
0	4 – 21	7.48	0.117	85.61	48.87	4.02	218.75
0	21 – 25	7.63	0.152	41.16	31.35	1.98	93.10
0	25 –33	7.49	0.405	11.20	17.35	0.48	48.60
0	33 –41	7.60	0.126	68.00	41.86	2.71	158.62
0	41 – 53	7.43	0.152	45.37	25.81	1.70	353

Appendix 4

Pore Water Chemistry

Transect 1

Unfiltered Samples						Filtered Samples				
Site	pH	EC mS/cm	TOC mg L^{-1}	TN mg L^{-1}	TP µg L^{-1}	DOC mg L^{-1}	NO_2-N µg L^{-1}	NO_3-N µg L^{-1}	NH_4-N µg L^{-1}	SRP µg L^{-1}
3500	7.98	0.94	41.06	2.996	61.01	21.21	6.90	35.53	1320.60	1.55
1500	8.07	0.68	19.78	1.897	12.39	17.30	6.40	53.02	1727.72	1.64
900	0.69	0.69	31.08	3.221	13.97	17.33	7.04	58.48	2708.07	2.35

Transect 2

Unfiltered Samples						Filtered Samples				
Site	pH	EC mS/cm	TOC mg L^{-1}	TN mg L^{-1}	TP µg L^{-1}	DOC mg L^{-1}	NO_2-N µg L^{-1}	NO_3-N µg L^{-1}	NH_4-N µg L^{-1}	SRP µg L^{-1}
5900	8.01	0.73	-	2.015	21.62	13.60	4.69	29.39	1706.92	0.53
5600	7.95	0.52	70.78	1.467	24.45	19.94	9.16	50.97	467.20	2.63
2600	7.81	0.87	159.80	6.043	12.30	37.83	6.90	30.76	7368.68	0.91
2300	7.87	0.69	107.00	3.890	17.41	40.73	14.77	66.04	2496.89	1.15
1200	7.78	0.86	44.08	5.987	11.34	28.96	8.19	90.78	7468.20	0.99
1100	7.75	0.51	45.10	2.285	20.63	24.64	6.90	43.53	1346.31	1.27
500	7.76	0.59	137.30	2.573	34.93	30.14	8.70	21.52	1701.16	2.01
400	7.80	1.07	61.63	5.156	16.10	37.28	5.94	23.38	5928.73	0.71

Transect 3

	Unfiltered Samples					Filtered Samples				
Site	pH	EC mS/cm	TOC mg L^{-1}	TN mg L^{-1}	TP µg L^{-1}	DOC mg L^{-1}	NO_2-N µg L^{-1}	NO_3-N µg L^{-1}	NH_4-N µg L^{-1}	SRP µg L^{-1}
5600	7.86	0.88	80.18	4.19	14.87	46.46	8.88	39.00	3137.16	0.93
5500	7.88	0.77	68.81	6.046	11.77	33.96	8.47	47.56	6466.42	0.89
3000	7.85	0.75	51.65	6.033	18.80	20.90	8.19	40.18	7298.17	0.93
400	7.96	0.58	25.16	1.086	23.07	23.13	8.14	66.23	98.56	1.49
300	7.90	0.79	48.44	2.127	8.76	20.65	4.74	38.32	1164.54	0.83

Transect 4

	Unfiltered Samples					Filtered Samples				
Site	pH	EC mS/cm	TOC mg L^{-1}	TN mg L^{-1}	TP µg L^{-1}	DOC mg L^{-1}	NO_2-N µg L^{-1}	NO_3-N µg L^{-1}	NH_4-N µg L^{-1}	SRP µg L^{-1}
7500	7.63	0.33	133.60	2.939	11.46	13.16	5.02	20.90	1995.45	1.80
5300	7.97	0.59	29.22	5.256	15.67	27.34	7.87	19.53	5724.87	1.36
4000	7.35	0.43	27.23	3.191	29.98	23.96	9.57	11.66	2405.64	1.89
2900	7.45	0.59	53.92	3.921	15.73	21.18	5.66	27.47	3066.67	0.19
1340	7.76	0.73	33.17	5.436	11.46	19.09	6.79	41.85	4428.61	0.81
200	7.87	0.91	94.41	3.721	18.89	25.20	3.59	2.11	2751.86	0.74

Transect 5

	Unfiltered Samples					Filtered Samples				
Site	pH	EC mS/cm	TOC mg L^{-1}	TN mg L^{-1}	TP µg L^{-1}	DOC mg L^{-1}	NO_2-N µg L^{-1}	NO_3-N µg L^{-1}	NH_4-N µg L^{-1}	SRP µg L^{-1}
11500	7.76	0.71	95.86	2.295	13.47	20.33	4.28	16.62	1638.16	0.12
10800	7.72	0.35	183.30	2.832	60.98	13.04	8.70	31.51	1691.86	4.18
9600	7.89	0.66	21.93	2.237	45.53	17.41	8.33	48.24	1039.94	1.11
4600	8.01	0.91	29.25	4.485	9.57	17.28	5.29	16.82	3217.39	-
4200	8.05	0.85	45.79	3.357	21.06	21.63	4.55	13.33	2351.22	0.81
1500	8.01	0.75	36.43	3.523	38.93	9.320	5.89	17.73	1937.49	0.84
100	7.91	0.79	119.70	1.356	19.20	18.88	6.49	56.37	264.96	0.22

Transect 6 and P38A & B

	Unfiltered Samples					Filtered Samples				
Site	pH	EC mS/cm	TOC mg L^{-1}	TN mg L^{-1}	TP µg L^{-1}	DOC mg L^{-1}	NO_2-N µg L^{-1}	NO_3-N µg L^{-1}	NH_4-N µg L^{-1}	SRP µg L^{-1}
4000	7.97	1.36	158.40	4.002	12.33	17.40	7.41	31.94	3761.07	0
2300	8.12	1.05	220.60	2.597	69.06	20.21	14.72	26.42	1755.78	6.60
0	7.79	0.65	149.30	2.942	16.48	15.85	5.94	34.17	1842.47	2.35
P38A	7.98	0.52	116.50	1.919	24.13	6.885	5.66	30.57	1190.95	0
P38B	8.01	0.48	146.30	1.485	20.84	6.853	3.82	16.31	646.36	1.83

Appendix 5

Plant Nutrient Content of *Cladium jamaicense* and *Eleocharis cellulose*

Cladium jamaicense

Transect	Location	Percent			μg g^{-1}		
		TC	TN	TP	TC	TN	TP
T1	3500	45.86	0.63	0.019	458600	6314	189.97
T1	1500	46.32	0.76	0.020	463206	7618	199.57
T1	900	45.82	0.67	0.023	458212	6678	226.60
T2	5900	45.65	0.66	0.023	456544	6627	232.64
T2	5600	45.32	0.46	0.028	453165	4553	280.37
T2	2600	45.98	0.86	0.023	459762	8551	229.93
T2	2300	45.54	0.49	0.028	455398	4933	275.95
T2	1200	45.69	0.80	0.023	456867	7970	228.84
T2	1100	45.70	0.53	0.023	456995	5256	233.31
T2	500	46.07	0.46	0.021	460690	4596	212.74
T2	400	46.11	0.77	0.021	461132	7717	212.77
T3	5600	45.44	0.64	0.026	454441	6367	258.64
T3	5500	45.58	0.80	0.022	455815	8019	216.89
T3	3000	45.70	0.75	0.024	456960	7478	244.34
T3	400	45.55	0.45	0.021	455199	4473	212.84
T3	300	45.49	0.65	0.027	454858	6556	271.75
T4	7500	44.71	0.55	0.044	447062	5501	442.95
T4	5300	45.76	0.81	0.019	457587	8071	192.76
T4	4000	45.56	0.47	0.027	455626	4656	265.69
T4	2900	45.25	0.69	0.022	452484	6928	221.18
T4	200	45.38	0.67	0.019	453835	6692	184.81
T5	11500	46.06	0.61	0.022	460693	6089	216.53
T5	10800	45.67	0.49	0.024	456695	4949	241.74
T5	4200	45.55	0.77	0.029	455502	7709	287.67
T5	1500	44.81	0.66	0.023	448147	6617	228.62
T5	100	45.58	0.77	0.024	455806	7667	244.13
T6	4000	45.54	0.78	0.021	455364	7773	213.14
T6	2300	45.31	0.73	0.027	453060	7265	265.96
T6	0	45.39	0.58	0.025	453923	5751	244.89
P38	A	45.36	0.70	0.029	453582	7012	288.83
P38	B	44.66	0.71	0.022	446625	7059	218.95

Eleocharis cellulosa

Transect	Location	Percent			μg g^{-1}		
		TC	TN	TP	TC	TN	TP
T1	3500	40.63	0.69	0.032	406261	6940	321.61
T1	1500	39.65	1.15	0.055	396492	11509	550.96
T1	900	41.27	0.87	0.034	412671	8716	340.40
T2	5900	40.85	0.78	0.040	408489	7793	399.42
T2	5600	42.16	0.81	0.040	421568	8094	401.30
T2	2600	37.21	0.71	0.037	372147	7097	369.84
T2	2300	40.53	0.72	0.035	405349	7202	348.23
T2	1200	40.95	0.63	0.026	409492	6335	263.62
T2	500	40.08	0.67	0.030	400820	6709	301.93
T2	400	40.73	0.59	0.029	407299	5874	288.25
T3	5600	40.73	0.73	0.032	407337	7332	323.17
T3	5500	41.11	0.77	0.028	411102	7681	281.17
T3	3000	40.86	0.67	0.029	408570	6702	291.69
T3	400	40.35	0.55	0.029	403526	5544	292.12
T3	300	40.56	0.61	0.041	405595	6147	407.48
T4	7400	41.13	0.77	0.030	411296	7656	302.71
T4	5300	40.50	0.75	0.029	404991	7533	285.93
T4	2900	41.53	0.80	0.044	415319	7957	438.84
T4	1340	40.43	0.88	0.053	404290	8805	526.79
T4	200	40.16	0.62	0.042	401629	6163	414.93
T5	11500	40.95	0.70	0.039	409498	7022	390.35
T5	9000	40.80	0.61	0.023	407986	6081	228.57
T5	4600	40.85	0.89	0.047	408522	8862	468.02
T5	4200	40.70	0.71	0.035	406975	7103	347.26
T5	1500	40.28	0.76	0.035	402822	7629	350.52
T5	100	40.98	0.77	0.036	409837	7744	360.52
T6	4000	40.34	0.76	0.028	403416	7599	275.95
P38	A	40.63	0.83	0.060	406322	8286	592.39
P38	B	41.37	0.80	0.035	413743	7954	348.

Appendix 6

Vegetation Map of Shark Slough, 1982
adapated from Figure 1 in Olmsted and Armentano, 1997

Vegetation Description:

Tropical Hardwood Hammocks: Mixed stands of tropical hardwoods with relatively closed canopies, including *Bursera simaruba, Eugenia axillaries, Sabal palmetto, Mastichodendrom foetidissimum, Myrsinefloridana*, and *Celtis laevigata* (an important temperate species), shrubs and vines.

Bayheads: Dense stands of temperate hardwoods with closed canopies, dominated by *Magnolia virginiana* and *Persea borbonia*. Other temperate species, *Salix caroliniana, Ilex cassine*, and *Myrica cerifera*, and other tropical species, *Chrysobalanus icaco*, also occur.

Bayhead Swamp-Forest: Mixed stands of bayhead species often with *Annona glabra* and *Cephalanthus occidentalis* as well. The canopy is very open. *Cladium, Typha*, and aquatic plants like *Sagittaria, Peltandra, Pontederia*, and *Utricularia* are often found in this community.

Willowheads: Stands of *Salixcaroliniana* growing on deep muck deposits. *Cladium, Typha*, and aquatic plants are usually present.

Sawgrass Marsh: Large, often sparsely vegetated expanses, dominated by *Cladium jamaicense*, that is 1-1.5 m in height. *Eleocharis, Rhynchospora, Panicum* and herbs like *Justicia, Bacopa, Gerardia* and *Utricularia* also occur.

Tall Sawgrass: Stands of tall (>2 m) *Cladium jamaicense*, usually very dense and monotypic or with a few vines and aquatic species. Communities usually form long strands or surround bayhead swamp-forests and form their "tails".

Tall Sawgrass with Shrubs: Tall *Cladium jamaicense* strands with scattered bayhead species like *Annona, Cephalanthus, Salix* or *Myrica*, that have invaded following a fire or a change in hydroperiod or water level.

Typha: Stands of *Typhadomingensis*, mixed with sawgrass and aquatic plants.

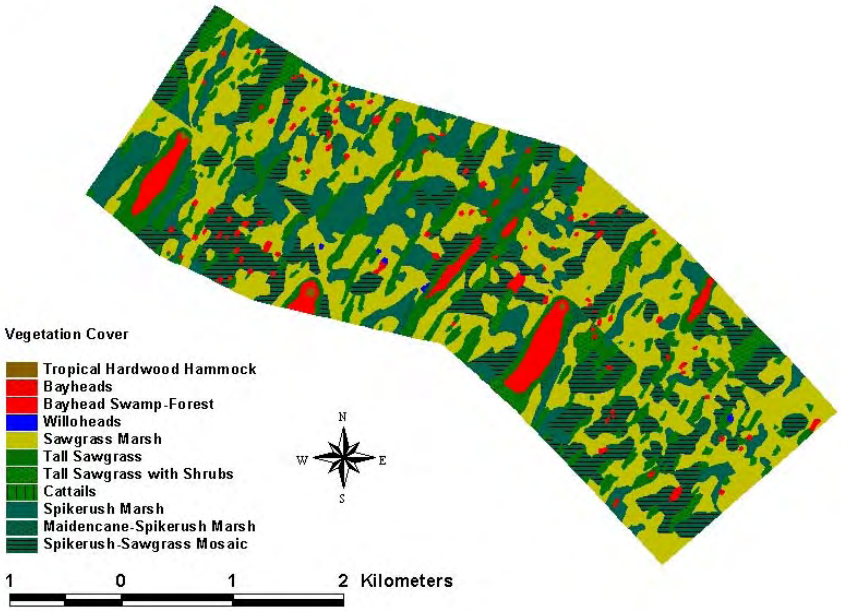
Spikerush Marsh: Large, sparsely vegetated areas, dominated by *Eleocharis cellulosa* with *Paspalidium, Rhynchospora, Panicum, Nymphea, Sagettaria, Pontederia*, and *Utricularia* as associates.

Maidencane-Spikerush Marsh: Similar to the spikerush marsh, but though *Elocharis* is

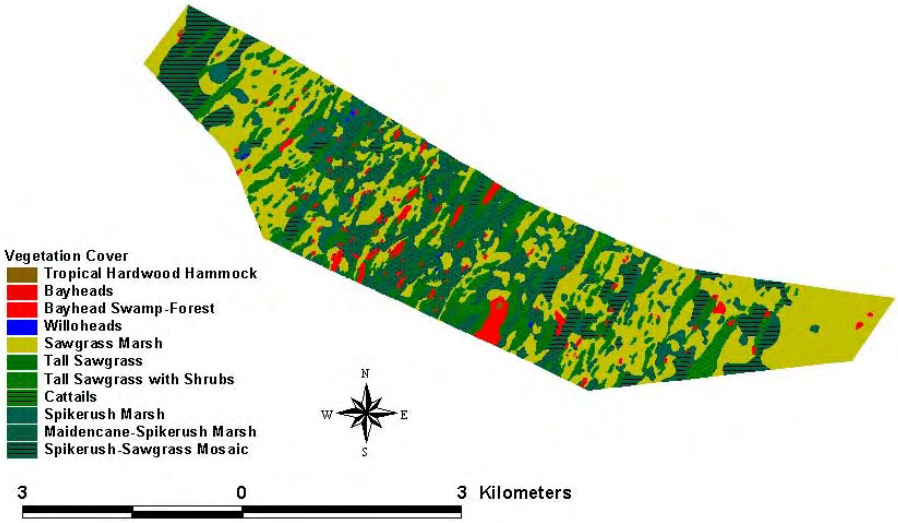
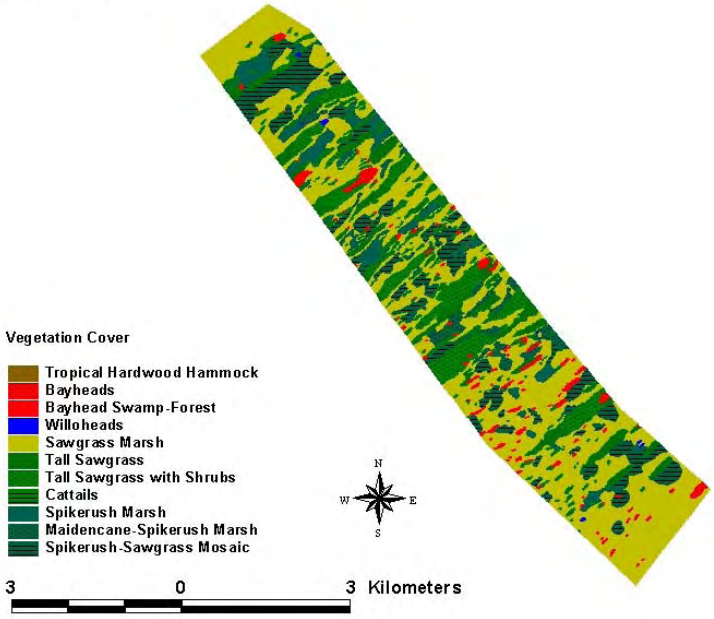
always present, *Panicum hemitomon* is dominant.

Spikerush-Sawgrass Mosaic: Mixed small patches of both communities with signatures different from those for the individual community, because of variation of periphyton reflectance.

North Transect



Intermediate Transect:



South Transect: