Landscape Pattern–Marl Prairie/Slough Gradient; patterns and trends in Shark Slough marshes and associated marl prairies

(Cooperative Agreement #: W912HZ-14-2-0023)

Year 5 Report

(2014-2019)

Submitted to

Ms. Sherry Whitaker

U.S. Army Engineer Research and Development Center (U.S. Army - ERDC)

3909 Halls Ferry Road, Vicksburg, MS 39081-6199

Email: Sherry.L.Whitaker@usace.army.mil

Jay P. Sah, Michael S. Ross, Carlos Pulido, Susana Stoffella Rosario Vidales

Southeast Environmental Research Center

Florida International University

Miami, FL 33186

September 30, 2020

Authors' Affiliation

Jay P. Sah, Ph.D. – *Research Associate Professor*
Institute of Environment
Florida International University
11200 SW 8th Street, Miami, FL 33199
Tel. (305) 348-1658
sahj@fiu.edu

Michael S. Ross, Ph.D. – *Professor*
Department of Earth & Environment/Institute of Environment
Florida International University
11200 SW 8th Street, Miami, FL 33199
Tel. (305) 348-1420
rossm@fiu.edu

Susana Stoffella, M.S. – *Research Analyst*
Institute of Environment
Florida International University
11200 SW 8th Street, Miami, FL 33199
Tel. (305) 348-0493
stoffell@fiu.edu

Carlos Pulido – *Grad Student/Graduate Research Assistant*
Department of Earth & Environment/Institute of Environment
Florida International University
11200 SW 8th Street, Miami, FL 33199
Tel. (305) 348-0177
cpuli002@fiu.edu

Rosario Vidales – *Grad Student/Graduate Research Assistant*
Department of Earth & Environment/Institute of Environment
Florida International University
11200 SW 8th Street, Miami, FL 33199
Tel. (305) 348-0177
rvidales@fiu.edu

Cover photo: Spikerush dominated wet prairie (a transitional community between ridge & slough) in Shark River Slough on Transect M2

Table of Contents

General Background

The Water Resources Development Act (WRDA) of 2000 authorized the Comprehensive Everglades Restoration Plan (CERP) as a framework for modifications and operational changes to the Central and Southern Florida Project needed to restore the South Florida ecosystems. Provisions within WRDA 2000 provide for specific authorization for an adaptive assessment and monitoring program. A CERP Monitoring and Assessment Plan (MAP; RECOVER 2004, 2006, 2009) has been developed as the primary tool to assess the system-wide performance of the CERP by the Restoration Coordination and Verification (RECOVER) program. The MAP presents the monitoring and supporting research needed to measure the responses of the South Florida ecosystem to CERP implementation. In the Everglades, marsh vegetation in both marl prairie and ridge and slough landscapes is sensitive to large-scale restoration activities associated with the CERP. More specifically, changes in hydrologic regimes at both local and landscape scales are likely to affect vegetation composition in the transition zone between these two landscapes, resulting in a shift in boundary between plant communities. In order to track these dynamics, Florida International University (Dr. Michael Ross, PI and Dr. Jay Sah, Co-PI) undertook a study of vegetation structure and composition in relation to physical and biological processes along the marl prairie-slough (MP-S) gradient beginning in 2005. Since the Fall of 2014 (Cooperative Agreement # W912HZ-14-2-0023), the study has been led by Dr. Jay Sah, while Dr. Michael Ross is also actively involved as the Co-PI in the study.

Vegetation monitoring transects in the Shark Slough basin, funded by US Army Corps of Engineers (USACE) under RECOVER-MAP, capture the full range of marl prairie and slough plant communities, and address Performance Measure (PM):GE-15 (Landscape Pattern–Marl Prairie/Slough gradient), by "…detecting spatio-temporal change in vegetation structure and composition in response to natural and restoration-induced hydrologic changes...". Monitoring of vegetation along the marl prairie/slough gradients addresses a working hypothesis that '*Spatial patterning and topographic relief of ridges and sloughs are directly related to the volume, timing and distribution of sheet flow and related water depth patterns*', identified in the hypothesis cluster "Landscape Patterns of Ridge and Slough Peatlands and Adjacent Marl Prairies in Relation to Sheet Flow, Water Depth Patterns and Eutrophication" (RECOVER 2009). The study also addresses the hypothesis that, '*Resumption of historical flow and related patterns of hydroperiod, water depth, and fire with the implementation of CERP will cause a noticeable change in plant community composition and structure along the gradient and in the transition zone between marl prairie and peat-dominated ridge and sloughs*'.

The primary objective of the study is to assess the impact of Everglades restoration activities on plant communities along the marl prairie-slough gradient, and to detect any shift in position and attributes of boundaries between those communities. The study is conducted on six transects that extend across Shark River Slough (SRS) into adjacent marl prairies. Shark Slough portions of the transects overlap transects that were established and surveyed under different sponsorship in 1998-2000, providing the prospect of assessing long-term temporal change in vegetation in those areas.

The specific objectives if the study are:

1) To characterize recent vegetation composition along the marl prairie-slough gradient,
2) To identifying boundaries between different vegetation types, and
3) To assess changes in vegetation structure and composition to changes in hydrology resulting from CERP restoration projects.

Initiated in 2005 as an expansion on Shark Slough study transects that had been established and surveyed in 1998-2000 with funding from DOI's Critical Ecosystems Study Initiative (CESI), this study covers the project period, from Sept 17, 2014 and Sept 16, 2019. The results for individual years of this cycle were reported in Sah et al. (2017a, b, c, and 2018). This document summarizes results for all five MP-S gradient transects (M1-M5) from this 5-year cycle (2014-2019), and updates the findings in relation to the study done in 1999/2000, and during the previous project cycles (2005-2009, 2009-2014) of this ongoing study. The report now also includes the summary of the vegetation composition along Transect M6, which has been established and surveyed for the first time in the spring of 2019.

1. Introduction

In the Everglades, plant communities arranged along environmental gradients are expressions of ecosystem processes associated with underlying physico-chemical drivers that vary in space and time. Hence, determining the responses to spatio-temporal changes in key environmental drivers of plant assemblages along gradients, and the boundaries between them, is important for conservation and ecosystem restoration. The landscape in both Shark River and Taylor Slough basins of the Everglades includes long hydroperiod sloughs, flanked by short hydroperiod marl prairies. Particularly in the Shark River Slough (SRS) basin, vegetation structure and composition change gradually along an elevation and water depth gradient, from short-hydroperiod marl prairies to ridge and slough, which are characteristic features of the landscape of central SRS (Olmsted and Loope 1984; Olmsted and Armentano1997; Ross et al. 2003;).

Hydrology is one of the major drivers of species differences between marl prairie and ridge-and slough landscapes. Hence, alterations in hydrologic conditions usually cause a shift in vegetation structure and composition within each landscape; extreme changes can even lead to dominance of hydric vegetation in marl prairie (Nott et al. 1998) or various levels of degradation of landforms in the ridge and slough (R&S) landscape (Watts et al. 2010). In the past century, changes in the amount and flow patterns of water, resulting from the construction and operation of a series of canals, levees and water structures (Light and Dineen1994, McVoy et al. 2011), have altered the proportions of prairie and slough vegetation in the region. Furthermore, changes in water management associated with the ongoing Comprehensive Everglades Restoration Plan (CERP 2000) are likely to affect vegetation composition in the transition zone between these ecosystems, resulting in a shift in the boundary between marl prairie and slough communities. It is therefore important to understand how restoration impacts the dynamics of prairie and slough landscapes and the boundaries between the two.

Along the marl prairie-slough gradient, vegetation in the marl prairie portion of the gradient is likely to respond to hydrologic changes more rapidly than vegetation in the slough portion. Armentano et al. (2006) also argued that the transition from one vegetation type to another (e.g., prairie to marsh) in response to hydrology may take place in as little as 3 to 4 years. However, while vegetation within ridge and slough landscape can change in four years (Zweig and Kitchens 2008), the transition from marsh to prairie vegetation may take longer (Armentano et al. 2006, Sah et al. 2014). In the southern Everglades, recent water management efforts have been directed towards ameliorating the adverse effects caused of previous water management activities. In this respect, a series of water detention ponds have been brought into operation along the eastern boundary of the park to mitigate the wet-season water reversals that were prevalent in this region due to the loss of water from the rocky glades to the canal (Van Lent et al. 1999). In contrast, strategic regulation of water deliveries through the S-12 structures along US 41 has been in place since 2002 to reverse the damage that was caused by the extended wet conditions that resulted from both high water deliveries and rains in the mid-to-late -1990s.

These modifications in water management activities, along with those planned or being carried out under Central Everglades Planning Project (CEPP), Modified Water Deliveries (MWD) Project, and Combined Opertioans Plan (COP), including construction and operation of Tamiami Bridges, have affected, and are likely to influence water conditions within the Park (USACE 2014, USFWS 2016, USACE 2020). As outlined in CEPP and COP, restoration activities are expected to increase water deliveries from WCA 3A to ENP through NESRS (USACE 2014, 2020). Under the preferred plan (ALTQ+) identified in COP, water delivery into ENP (both northeast and western SRS combined) is projected to increase by 25%, and the delivery into NESRS is projected to increase by approximately 162,000 acre-feet per year on average (USACE 2020). Similarly, during the process of revisions to the 2005 Interim Goals and Targets for CERP, out of four simulations, 2032PACR simulation projects the flow into NESRS to increase by a total of 528,000 acre-feet per year (RECOVER 2020). Changes in water conditions within the Park are likely to result in changes in vegetation communities in SRS and marl prairies on both sides of the slough.

In 2005, we initiated a long-term study of vegetation dynamics in relation to changes in underlying environmental drivers, especially hydrology, along the marl prairie – slough (MP-S) gradient. The broader goal of the study is to assess the impact of Everglades restoration activities on plant communities along the gradient, and to detect any shift in position and attributes of boundaries between those communities. The study is now conducted on six transects (M1 to M6) that extend across SRS into adjacent marl prairies. Shark Slough portions of four transects (M1-M4) overlap transects that were established and surveyed under different sponsorship in 1998-2000 (hereafter 1999 study), providing the prospect of assessing long-term temporal change in vegetation in those areas.

In this study, our specific objectives were, i) to characterize recent vegetation composition along the marl prairie-slough gradient, and ii) to assess changes in vegetation in both the Shark Slough and marl prairie portions of the transects over a twenty-year period (1999-2019). We hypothesized that variation in vegetation composition along the MP-S gradient is mainly driven by hydrology, i.e. duration and depth of flooding. We also hypothesized that Shark River Slough vegetation follows the temporal trend in hydrologic regimes, and over the last nineteen years has changed in species composition toward assemblages more indicative of relatively dry conditions. In addition, in compliance with the differential water management goals on both sides of SRS, we hypothesized that marl prairie vegetation follows a spatially differentiated temporal trend in hydrologic regimes. Over the thirteen years (2006-2019) period, vegetation in the eastern portion of the marl prairies has changed toward a wetter character, while vegetation in the western marl prairies has shifted toward a drier type.

2. Methods

2.1 Study Sites

Sites surveyed over five years (2014-2019) were mostly the part of the ongoing long-term vegetation monitoring program along MP-S gradient in the southern Everglades. The study design includes six transects (M1 to M6), varying in length from 3.4 km to 35.8 km. Five (M1-M5) of these six transects were established in 2005, when systematic survey along MP-S gradient began. Four transects (M1-M4) extend across SRS to adjacent short-hydroperiod marl prairie habitat (**Figure 1**). M1, located in NESRS, extends to the marl prairie only to the east of the slough. M2 originally covered an area restricted to the Shark River Slough (SRS), extending on both sides of L-67S canal. But in 2015, this transect was extended further east by 5 km (hereafter, named as M2E), thereby covering prairie vegetation along the eastern boundary of the ENP and transitional zone between marl prairie in NESRS and R&S landscape in SRS. Transect M5 covers an area between fresh and brackish water ecosystems in the southeastern corner of SRS, extending to the east into freshwater marl prairies located on both sides of the main Park road. Transect M6, established in spring 2019, extends from Main Park Road, southwest of Pa-Hay-Okee, to the edge of SRS (**Figure 1**).

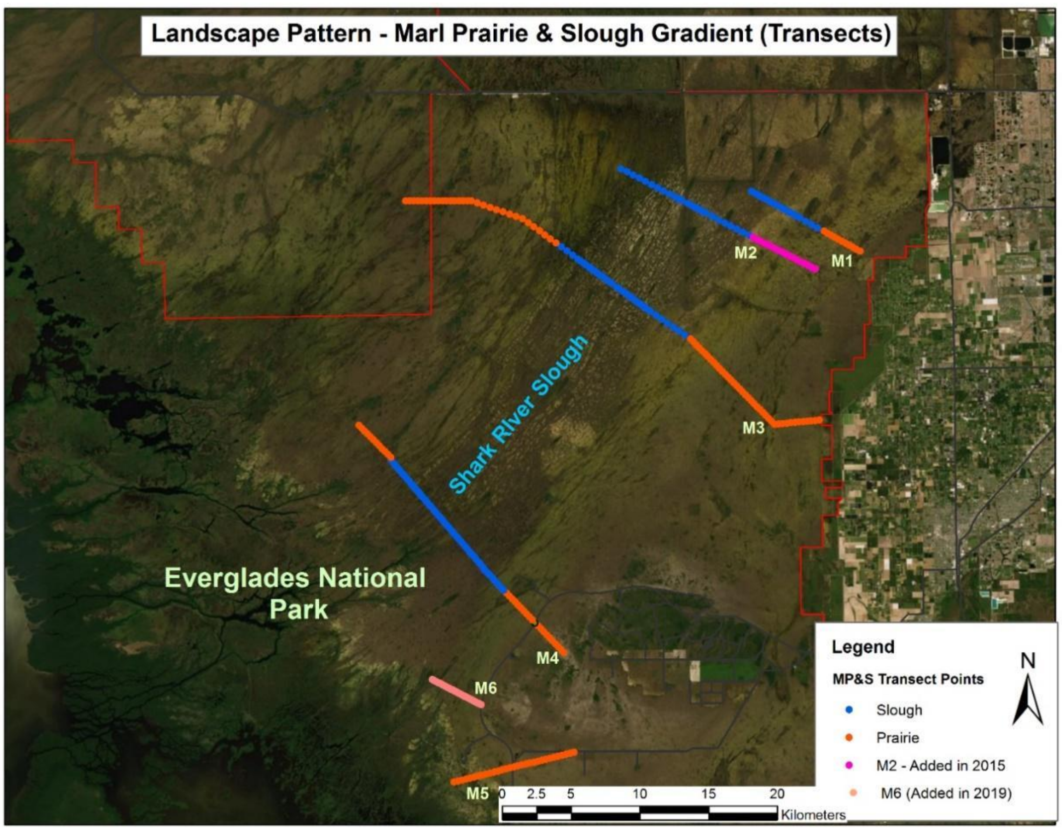

Figure 1: Location map of Marl prairie-Slough Gradient Study plots on Transects M1-M6.

On Transects M1-M4, the vegetation survey plots are at 200 to 500 m intervals. In the marl prairie section of the transects, the plots are at 300 m intervals, and in the SRS portion of the transects, the plot density varies between 2 to 4 plots per km (200-500 m intervals). In Transect M5, the vegetation survey plots are at 300 m intervals all along the transect. In contrast, in Transect M6, the plots are at 100 m intervals to capture fine-scale gradual change in vegetation and soil characteristics along MP-S gradient within a short distance.

Table 1 summarizes the years and numbers of sites surveyed on Transects M1-M6 over 14 years (2005-2019). The slough portion of these transects was surveyed in the wet season (July to November), accessing the sites by airboat or helicopter. Marl prairie portions of the transects were surveyed in the dry season (Jan to May) and were accessed by helicopter for drop off and pickup, and on foot for vegetation survey. In 2016, however, the dry season survey on Transect M3 continued through June 13th, primarily due to unusually highwater levels in early dry season, and partly due to the unavailability of helicopters caused by high demand during a squeezed period of survey in late spring by various research groups. Likewise, in 2019, the dry season survey on transect M6 continued through June 15th, due to the late arrival of the permit.

Table 1: Sites survey on MAP transects M1-M6 between 2005 and 2019.

Transect	Sampling Event	Sites Surveyed			
		Prairie sites		Slough sites	
		Year	No. of Sites	Year	Number of Sites
M1	E1	2006	11	2005	20
	E2	2009	11	2008	20
	E3	2012	11	2011	20
	E4	2015	11	2014	20
	E5	2019	11	2018	20
M2 & M2E	E1			2005	25
	E2			2008	26
	E3			2011	25
	E4	2015	18	2014	25
	E5	2019	18	2018	25
M3	E1	2007	72	2006	37
	E2	2010	72	2009	37
	E3	2013	72	2012	37
	E4	2016	71	2015	37
M4	E1	2008	32	2007	55
	E2	2011	32	2010	55
	E3	2014	32	2013	55
	E4	2017	30	2016	50
M5	E1	2008	31		
	E2	2011	31		
	E3	2014	31		
	E4	2018	31		
M6	E5	2019	34		

2.2 Vegetation survey

Vegetation was surveyed in a nested-plot design that allowed for efficient sampling of the range of plant growth forms (herbs, shrubs and trees) present along the transects (Ross et al. 2005; Sah et al. 2013). Vegetation plots were sampled at every 200-500 m intervals. Higher intensity sampling occurred in areas accessible by airboat, and was based on the contention that increased sampling intensity would enable us to make a more meaningful comparison of current vegetation with that present on the same transects in 1999 (Ross et al. 2001; Ross et al. 2003). At each survey site, a PVC tube marked the SE corner of a 10x10m tree plot. Nested within each tree plot, a 5x5m herb/shrub plot was laid out, leaving a 1-m buffer strip along the southern and eastern border of the tree plot. In the 10x10m tree plots, we measured the DBH and crown length and width of any woody individual ≥ 5cm DBH, and then calculated species cover assuming horizontally flattened elliptical crown form. Within each 5x5m herb/shrub plot, we estimated the cover class of each species of shrub (woody stems>1m height and <5cm DBH) and woody vines, using the following categories: <1%, 1-4%, 4-16%, 16-33%, 33-66%, and >66%. We estimated the cover percent of herb layer species (all herbs, and woody plants <1m height) in five 1-m^2 subplots located at the four corners (NE, NW, SE and SW) and the center (CN) of the 5x5m plot. Species present in the 5x5m plot but not found in any of the 1m^2 subplots was assigned a mean cover of 0.01%. In addition, a suite of structural parameters was recorded in a 0.25m^2 quadrat in the SW corner of each of the five subplots. Structural measurements included the following attributes: 1) The height and species of the tallest plant in the plot; 2) Canopy height, i.e., the tallest vegetation present within a cylinder of ~5cm width, measured at 4 points in each 0.25m^2 quadrat; 3) Total vegetative cover, in %, and 4) Live vegetation percent cover, expressed as a % of total cover.

2.3 Water depth measurements

Field water depths in combination with EDEN (Everglades Depth Estimation Network, http://sofia.usgs.gov/eden) water surface elevation data serve as the basis for calculation of ground elevation and estimation of hydrologic conditions at each site. Water depth was measured at each site along a transect, whether marl prairie or slough. We measured water depths at the PVC, the marker of the plot, and in the center of five vegetation sub-plots in a 5x5m plot. At the marl prairie sites of four transects (M1, M3-M5), water depths were measured in the Fall of 2008. Likewise, water depths on Transect M2E were measured in Spring 2016, when the water level was unusually high, and the area had up to 30 cm of standing water. On the most recently established transect, M6, the water depths were measured in August 2019.

2.4 Soil and plant analysis

In 2015-2016, soil and plant samples were collected from 15 sites on Transect M3. At each site, three 0.25 m^2 subplots were randomly selected by throwing a quadrat within the plot area for soil and vegetation biomass sampling. In each of three selected subplots, one soil core of 10 cm length was collected using 5.7 cm diameter core tube. At one site, M3-11400, soil samples were collected only in two sub-plots, as other plots are very rocky and there was not enough soil to be collected. Soil samples were placed in Ziploc bags, labelled, and brought to the lab at FIU, where they were placed in the refrigerator until further analysis. Each core's compaction and length were measured in the field and recorded.

The net weight of wet soil samples was obtained. Samples were oven-dried at 80˚C for 48 hours or until a constant weight was achieved. For each sample, dry weight and volume were obtained, and the sample bulk density was calculated following Blake and Hartge (1986). We removed extraneous macro materials, including roots and rocks. Samples were then ground to pass a 2-mm sieve. Later, 2-3 mg dry samples were obtained and enclosed in tin (Sn) capsules, and then delivered to the SERC Nutrient Analysis Lab at FIU for total nitrogen (TN) and total carbon (TC) Analysis. Another 2-3 g of dry sample were obtained and transferred to small screw cap glass vials (7 mL), and then delivered to FIU Freshwater Biochemistry Lab for total phosphorus (TP) and other analysis. Soils were also analyzed for phosphatase and glucosidase enzyme activity. Subsamples of soils for such analysis were also delivered to the FIU Freshwater Biogeochemistry Lab.

For each sample of subplot vegetation, extraneous material such as periphyton and excess soil was removed. Plant material from each subplot was separated by species and was transferred to a paper bag of known weight. Plant material was dried in an oven at 70°C for three days or until constant weight. The dry weight of each species by subplot was obtained to determine biomass.

Soil nutrient analysis

Measured soil parameters were soil bulk density and pH; total C, N, and P (TC, TN and TP); ash content, inorganic carbon (IC, based on ash %C), total organic carbon (TOC), soil enzyme activities (e.g. phosphatase and glucosidase activity), and total extractable phosphorus and carbon. Soil pH was determined in 1:1 (w/v) soil:water suspension using a pH meter. TC and TN were measured on a dry weight basis using a CHN analyzer (Perkin Elmer, Inc, Wellesley, Massachusetts, USA), and TP was determined colorimetrically following the method of EPA365.1 after ashing-acid digestion (Solorzano and Sharp 1980). Total inorganic carbon (IC) was determined in ash (residual after combustion at 500^{o} C) and scaled as percent IC to total dry weight. Then, total organic carbon (TOC) was determined by difference (TC - IC).

The remineralization of elements in soils is a function of liberating exoenzymes, therefore, soil enzyme (e.g. phosphatase and glucosidase) activity was determined using methylumbelliferyl substrates (MUF) on a slurry created from the soil (Sinsabaugh et al. 1997). Enzyme activity was determined from the difference between the amounts of fluorescent substrate liberated during incubation time from the time zero. The µmole MUF-substrate liberated g^{-1} dry weight soil h^{-1} was determined by comparison to standard curves generated using known concentrations of MUF. Bioavailable P was assayed via a serial extraction procedure that involved analysis for water soluble P (WSP) and sodium bicarbonate-extracted phosphorus ($NaHCO_3$-P) (Wright and Reddy 2001a). Likewise, sodium bicarbonate-extracted total organic carbon ($NaHCO_3$-TOC) was also determined. In addition, as a measure of microbial respiration, CO_2 production in soil was determined following slightly modified methods of Amador and Jones (1993). In this method, samples were loaded in vials and purged with $C0_2$-free air. Samples were then incubated in the dark at 25°C for 72 to 96 hours and analyzed on a gas chromatograph for $C0_2$.

Carbon isotope ($\delta^{13}C$) analysis

Plant biomass samples were collected from 0.25x0.25 m^2 quadrat within the same 1x1m^2 sub-plots in which soil samples were collected. Plant samples were then separated by species, oven dried at 70° C for 72 hrs, and weighed to calculate the above ground plant biomass. Plant samples for four major species, sawgrass (*Cladium jamaicense*), muhly grass (*Muhlenbergia capillaris* ssp. *filipes*), spikerush (*Eleocharis cellulosa*) and beakrush (*Rhynchospora tracyi*), were sub-sampled. Sawgrass was present in most plots along the gradient, whereas muhly grass was restricted to the marl prairie portion of the gradient. Beakrush was common in the marl prairie and transition zones, while spikerush was common in the transition zone and the ridge & slough portion of the gradient. The subsamples of these species were ground in a coffee-grinder. After each use, the coffee grinder was washed and dried to avoid contamination. The powdered samples were then sieved with a mesh (# 10 sieve), weighed, and placed into 20 mL scintillation glass vials for further analysis.

For isotope analysis, sub-samples of soil were treated with 1N hydrochloric acid (HCL) for one hour to remove carbonate, rinsed thoroughly with distilled water thoroughly, and filtered using suction filtration. The residues were then air-dried, powdered and sieved. Leaf and soil samples were then packed in individual tin capsules that were rolled into small balls. Each ball was then placed into an automated elemental analyzer connected to a continuous flow isotope ratio mass spectrometer (EA-IRMS). The stable carbon isotope ratio in plants and SOM was reported as:

$$\delta^{13}C\ (\text{‰}) = \left(\frac{\left(\frac{^{13}C}{^{12}C}\right)_{sample}}{\left(\frac{^{13}C}{^{12}C}\right)_{standard}} - 1 \right) * 1000\ (\text{‰})$$

2.5 Data Analysis

2.5.1 Hydroperiod and annual mean water depth

We used field water depth-derived elevation and EDEN water surface elevation data to estimate the hydrologic conditions at each survey site. We calculated the ground elevation of each plot using mean water depth for the plot and EDEN estimates of water surface elevation at the plot center during the same survey date. Daily water levels for each plot were estimated based on ground elevation and the time series data of water surface elevation extracted from EDEN database. The hydroperiod (the number of days per year when a location had water depth >0cm) and mean annual water depth were calculated for each plot. We then averaged hydroperiod and mean annual water depth for the four water years (May1st–April 30th) prior to each survey to examine vegetation response to hydrologic changes.

2.5.2 Fire frequency and time since last fire

A fire geodatabase, covering the period 1948 to 2012 (Smith III et al. 2015), was obtained from Everglades National Park (ENP). The shape files for 2013-2019 fires were also obtained from the Park, and later added to the geodatabase. The database contains shape files of fires with other attributes such as type of fire (Natural, RX, incendiary, etc.), date of incidence, etc. The data were used to calculate fire frequency and time since the last fire (TSLF) for vegetation-monitoring sites on transects M1-M6 using ArcGIS 10.5.

2.5.3 Vegetation classification and ordination

We summarized species data by calculating the importance value (IV) of each species present in herb and shrub layers in each plot. We calculated species' importance value as IV = (relative cover + relative frequency)/2. Species that did not occur in any of five subplots but occurred within the 5 x 5m^2 plot were assigned a frequency of species occurrence as 4%. The assumption was that, had all 25 1 x 1 m^2 subplots within a plot been surveyed, the species would have occurred in at least one subplot. Vegetation types at all sites that were surveyed along the five transects between 2005 and 2008 had already been defined using a hierarchical agglomerative cluster analysis (Sah et al. 2013). In the analysis, Bray-Curtis dissimilarity was used as the distance measure, and relatedness among groups and/or individual sites was calculated with the flexible beta method (McCune and Grace 2002). Non-metric multidimensional scaling ordination (NMDS) was done to analyze the shift in species composition using trajectory analysis (see below sub-section 2.5.5)

2.5.4 Biomass estimation

For the sites in the marl prairie portion of the gradient, vegetation structural measurements were summarized for each plot, and mean canopy height and total vegetative cover were used to estimate above ground plant biomass, using the allometric equation developed by Sah et al. (2007) for marl prairie vegetation within CSSS habitat. The equation for calculating biomass was as follows:

$$\sqrt{Biomass} = 6.708 + 15.607 * \text{arcsine} \sqrt{\frac{Cover}{100}} + 0.095 * \text{Ht}$$

where, Biomass = Total plant biomass (g/m^2), Cover = Crown cover (%), and Ht = Mean crown height (cm).

2.5.5 Vegetation response to hydrology – Trajectory analysis

At both marl prairie and slough sites on Transects M1-M5, changes in vegetation composition since 1999 survey were analyzed using trajectory analysis (Minchin et al. 2005; Sah et al. 2014), an ordination-based technique designed to test hypotheses about rates and directions of community change. In the NMDS ordination performed for trajectory analysis for slough sites, we included vegetation data for prairie as well as R&S sites that were collected between 1999 and 2019. Prairies sites were included to cover the full range of hydrologic conditions on the transects. In the NMDS ordination, the hydrology vector represented by mean annual water depth was defined through a vector fitting technique in DECODA (Kantvilas and Minchin 1989; Minchin 1998; Sah et al. 2014). To quantify the degree and rate of change in vegetation composition along the reference vector, two statistics, delta (Δ) and slope were calculated (Minchin et al. 2005). Delta, which measures the total amount of change in the target direction, was calculated as the difference between the projected score at the final and initial time steps. Slope measures the mean rate of change in community composition along the target vector. The statistical significance of both delta (Δ) and slope was tested using Monte Carlo simulations, with 1,000 permutations of the IVI values of species among surveys within each trajectory; the NMDS ordination and calculation of trajectory statistics were repeated on each permuted data matrix.

2.5.6 Weighted averaging and Vegetation-inferred hydroperiod

Vegetation change analysis in the marl prairie portion of the gradient also included calculation of vegetation-inferred hydroperiod, i.e., the hydroperiod for a site indicated from its vegetation composition using a weighted averaging partial least-square (WA-PLS) regression model. The training-data set with which we developed the WA-PLS regression model was the species cover data, instead of IVI used in trajectory analysis, plus hydroperiod estimates from 291 plots on six topographically-surveyed transects within the Cape Sable seaside sparrow habitat (Ross et al. 2006). In developing the WA-PLS models, species cover values were fourth square root transformed, which down-weights the influence of very dominant species. Mean hydroperiod was calculated across different time-periods (i.e., years preceding vegetation survey). The performance of the models was judged by the improvement in R^2 value and RMSEP (root mean square error of prediction). RMSEP was estimated by a leave-one-out (jackknife) cross-validation procedure, in which a model is developed from all samples except one, and consequently applied to predict the hydroperiod of the left-out point based on its vegetation. We used the C_2 program of Juggins (2003) to develop the WA-PLS model.

Finally, the best WA-PLS model was applied to the calibration data set, here the MP-S gradient data that included vegetation data at 198 sites on Transects M1, M2E, and M3-M6. The predicted hydroperiods for those sites were termed 'vegetation-inferred hydroperiod'. A change in vegetation-inferred hydroperiod between successive survey dates reflects the amount and direction of change in vegetation, expressed in units of days (0-365) along a gradient in hydroperiod.

3. Results

3.1 Hydrologic pattern (1999-2019)

In the slough portion of transects (M1-M4), the hydroperiod and mean annual water depth averaged over four years prior to vegetation survey varied over the 1998-2018 period. In the four years preceding the 1999 (E0) vegetation survey, mean hydroperiod on all four transects were >360 days (**Figure 2**), and mean (± SD) annual water depths were 38.0 ± 6.8, 45.4 ± 7.7, 42.8 ± 10.3 cm and 42.2 ± 5.3 cm on transects M1, M2, M3 and M4, respectively (**Figure 3**). At the slough sites on those transects, mean hydroperiod and annual water depth were lower during three subsequent surveys (2005-2007 (E1), 2008-2010 (E2) and 2011-2013 (E3)). However, for the 2014-2016 (E4) survey, sites in the slough were wetter than for the previous three surveys. During the 2014-2016 survey period, four-year average hydroperiod at the slough sites on M1, M2, M3, and M4 were 315, 337, 338 and 355 days (**Figure 2**), and annual mean annual water depths were 26, 36, 32 and 38 cm (**Figure 3**), respectively.

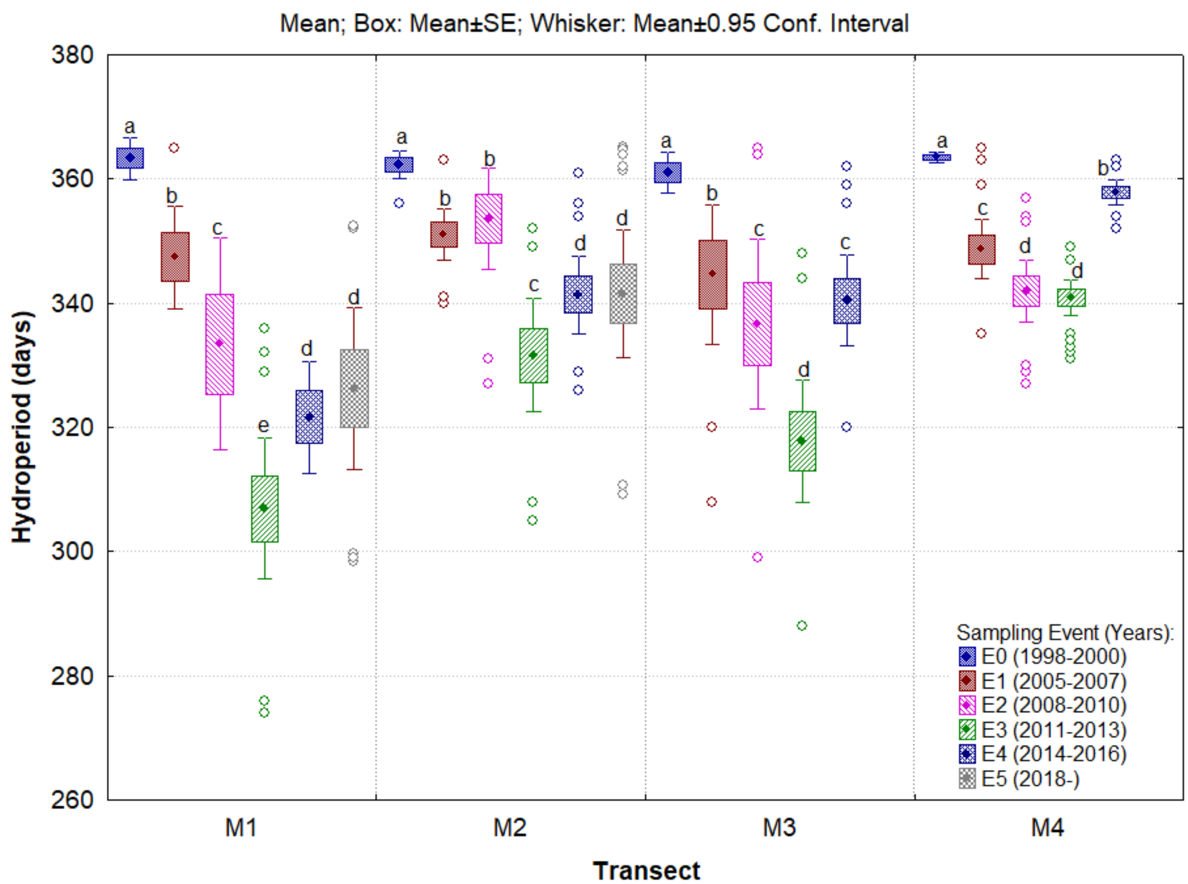

Figure 2: Box Plots showing hydroperiod averaged over four years prior to vegetation survey in the Shark River Slough portions of MAP transects M1, M2, M3 and M4. Different letters represent significant (pairwise t-test; p < 0.05) difference in 4-year average hydroperiod among surveys on individual transects.

On transects M1 and M2, the wetting trend observed after E3 continued through E5 (2018). On slough sites of these two transects, four-year average hydroperiods were 326 and 341 days (**Figure 2**), and annual mean (± SD) water depths were 33.0 ± 6.9 and 41.2 ± 7.2 cm (**Figure 3**). Nonetheless, both hydroperiod and mean annual water depth associated with the E4 and E5 surveys were lower than in the late 1990s. The hydroperiod was 22-42 days shorter and mean water depth 6-12 cm less than in the years prior to the 1999 survey.

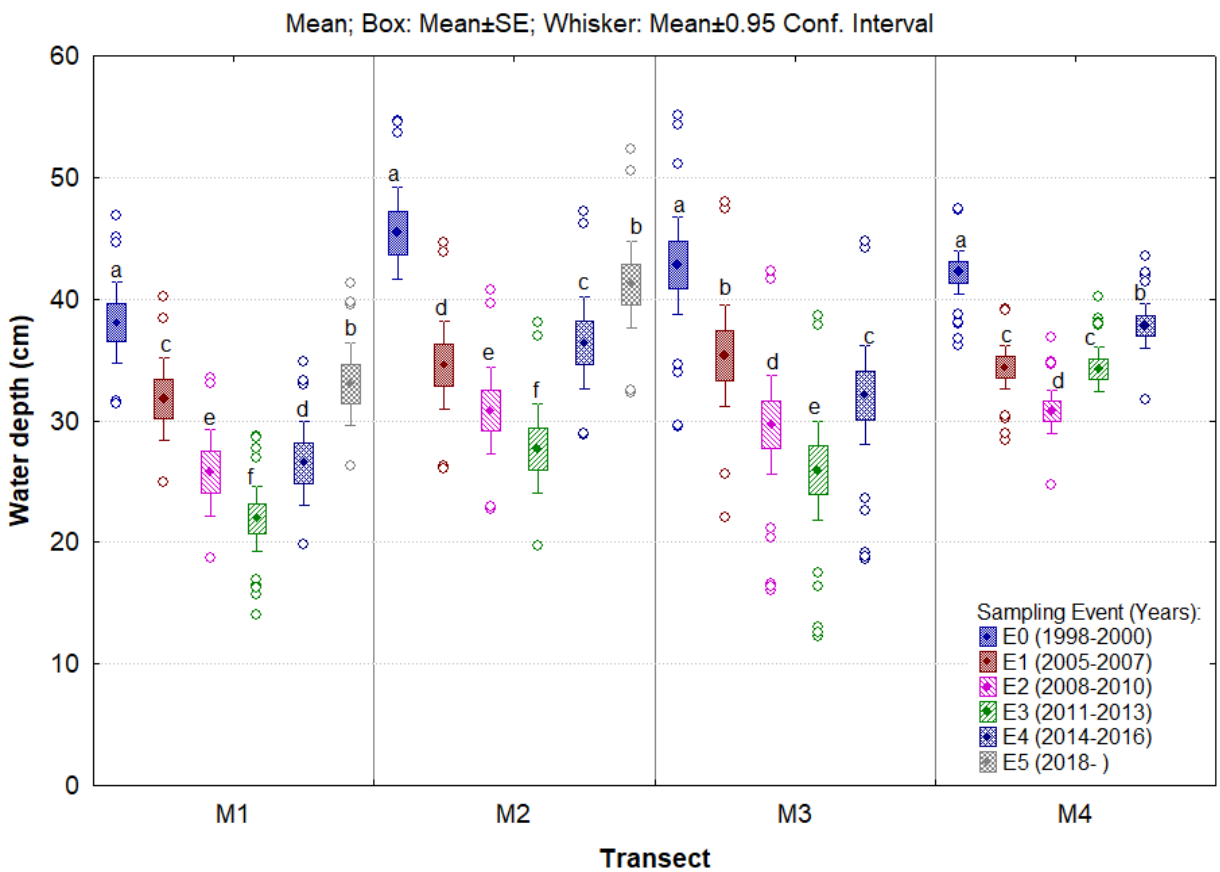

Figure 3: Box Plots showing annual mean water depth (WD) averaged over four years prior to vegetation survey in the Shark River Slough portions of MAP transects M1, M2, M3 and M4. Different letters represent significant (pairwise t-test; $p < 0.05$) difference in 4-year average water depth among surveys on individual transects.

Water conditions in the marl prairie portion of transect M1 varied among different surveys. Mean hydroperiod, averaged over four years before the E2 survey was 220 days, i.e. 69 days shorter than in the years before E1 (**Figure 4a**). However, the hydrologic conditions in subsequent years, i.e. after the E2, became wetter, and the wetting trend continued until the most recent (2019) survey, E5, when the mean hydroperiod was 58 days longer than in the years before E2 (2009). A similar trend was observed on the Transect M2E which has been surveyed only twice, in 2015 and 2019. On this transect, the mean (±SD) hydroperiod was 309 ± 45 days in 2019, i.e. 19 days longer than during the 2015 survey (**Figure 4a**).

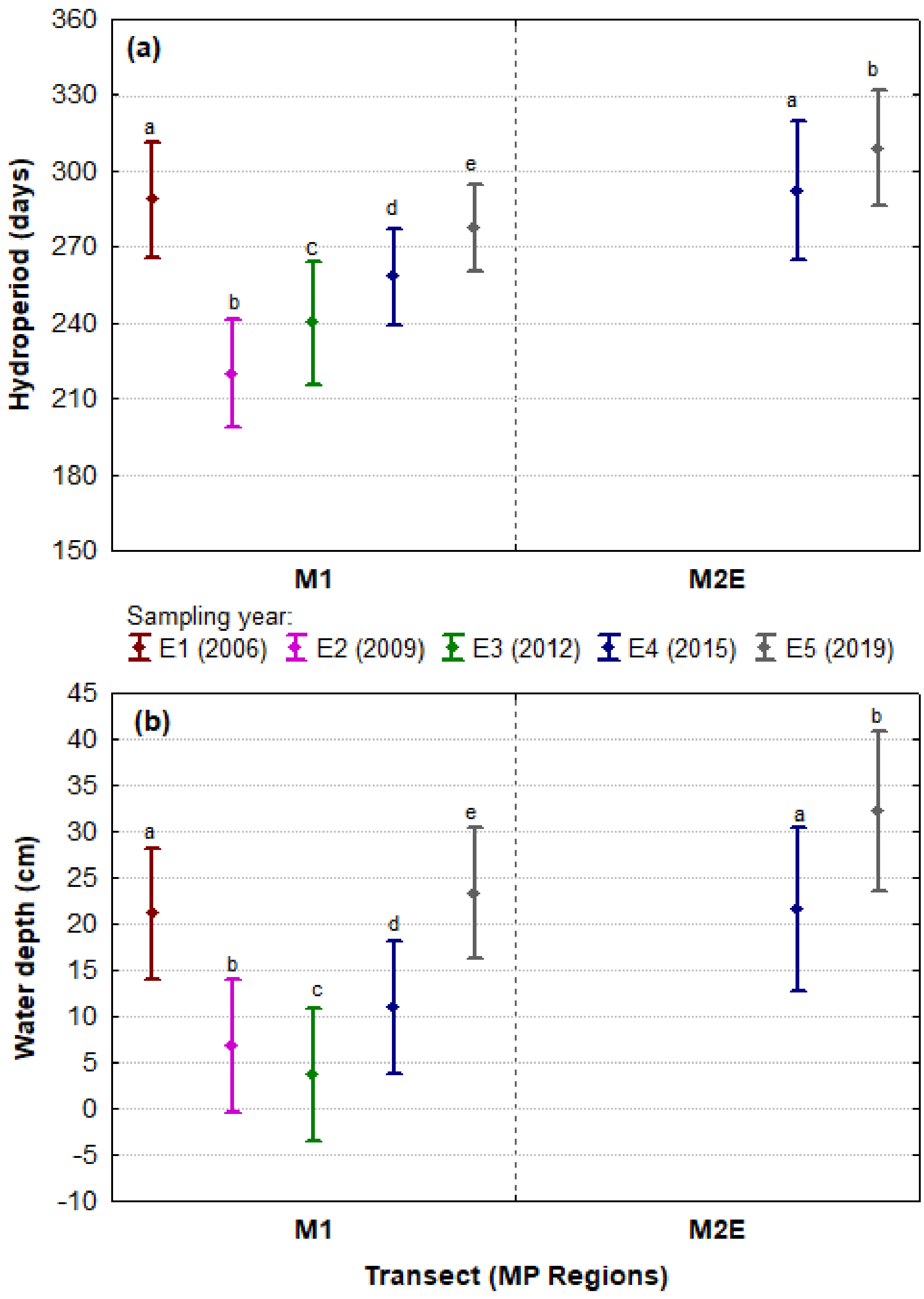

Figure 4: Mean (±95% CI) (a) hydroperiod, (b) annual mean water depth averaged over four years prior to vegetation survey in the marl prairie portions of MAP transects M1and M2E. Different letters represent significant (pairwise t-test; $p < 0.05$) difference in 4-average hydroperiod and annual mean water depth among surveys on individual transects.

On Transect M1, the 4-year average annual mean water level during the 2019 (E5) survey was 23.3 ± 10.5 cm, which was higher than all the previous surveys (**Figure 4b**). Likewise, in 2019, the Transect M2E had an annual mean water depth of 31.2 ± 17.2 cm, i.e. 11 cm higher than during 2015 survey (**Figure 4b**). In general, hydroperiod and annual mean water depth are in tandem with each other. But on the marl prairie portion of Transect M1, the 4-year average annual mean water level was lowest during E3, not during E2, as was observed for hydroperiod (**Figure 4b)**. However, both the hydroperiod and mean annual water level before the 2015 (E4) and 2019 (E5) surveys were higher than E2 and E3. The differences in hydrologic conditions between surveys, and the discrepancy between hydroperiod and annual mean water level were mostly due to extreme events. While the prolonged dry period between 2006 and 2008, i.e. the period before the 2nd census (E2), saw water levels dip far below the ground level, in the spring of 2011, i.e. just before the 3rd survey (E3), the water level was the lowest in last two decades (**Figure 5**). Moreover, on both M2E and the marl prairie portion of M1, the wetter condition during the 2019 survey than the previous surveys was expected, as these transects are in the NESRS region, where water delivery from the WCAs to the Park were enhanced during the 2016 emergency operations (Abtew & Ciuca, 2017) and due to the Increment Field Tests that began in October 2015 and continued through 2019 (USACE, 2020a).

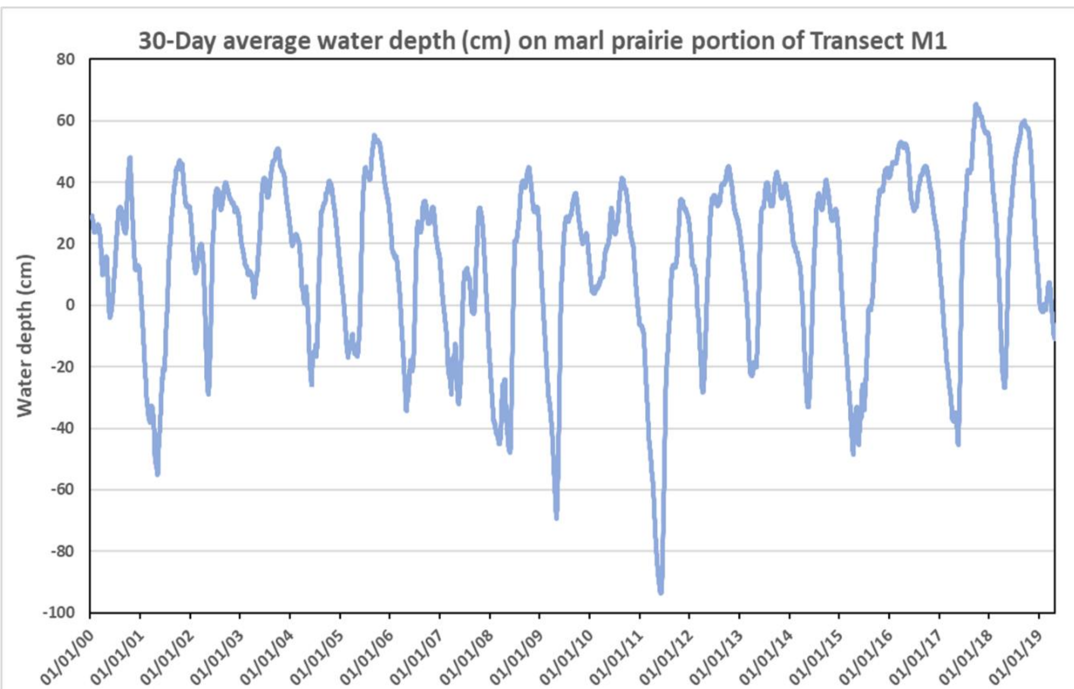

Figure 5: 30-day average mean annual water depth on the marl prairie portion of the transect M1.

The hydrologic conditions on transects M3, M4 and M5 are described only until E4 (2016-2018), as these transects are still to be surveyed the 5th time. Transects M3 and M4 are unique, as the hydrologic conditions in the marl prairie portion of these two transects differ between eastern and western sections, i.e. east and west sides of SRS. On transect M3, when averaged over all surveys, water conditions were wetter in the eastern than western prairies. However, in the prairies on both sides of the slough, it was much drier during E2 than E1. In contrast, an increasing trend in both four-year average hydroperiod and mean annual water depth was observed during the next two surveys, E3 and E4 (**Figure 6a, b**). On both sides of the slough, the four-year average hydroperiod was the highest during the last survey year, 2016 (**Figure 6a**), but the mean annual water depth was the highest in 2016 only at the eastern (M3E) sites (**Figure 6b**). It is important to note that, at the western prairie (M3W) sites, despite unusually high-water conditions in the spring of 2016, the four-year mean annual water depth associated with the 2016survey was still significantly lower (paired t-test: $n = 31$, $p < 0.001$) than during 2007 (E1) survey (**Figure 6b**). In 2016, the four-year average hydroperiod in eastern and western prairies were 260 ± 41 days and 226 ± 59 days, respectively. Likewise, the mean annual water depths were 9.3 ± 13.3 cm and 2.2 ± 10.4 cm, respectively. The difference in water level between M3E and M3W was very distinct in the dry season, when the water level at the western sites went far below the ground (**Figure 7**), primarily due to different seasonal closure schedules of the S-12s between Nov 15 and July 15.

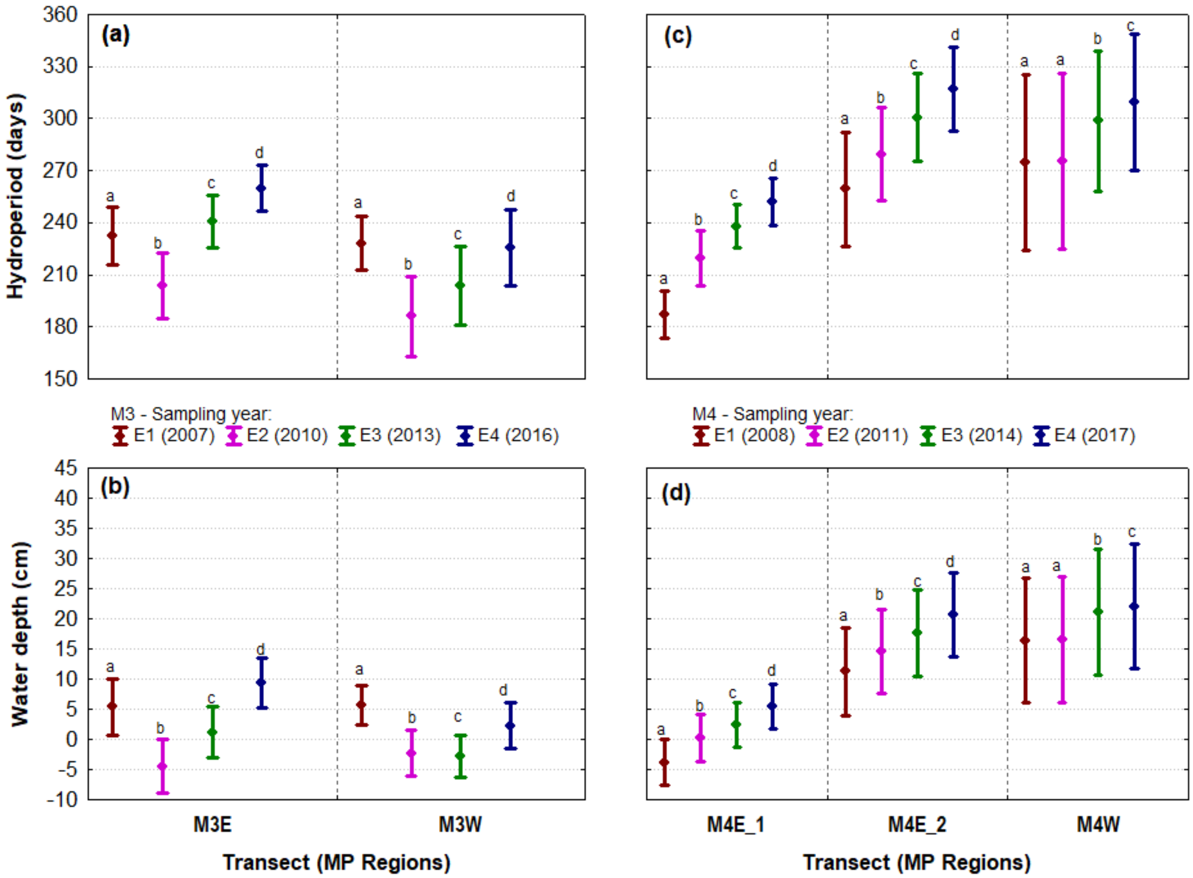

Figure 6: Mean (±95% CI) (a & C) hydroperiod and (b & d) annual mean water depth averaged over four years prior to vegetation survey in the marl prairie portions of MAP transects M3 (a, b) and M4 (c, d). Both transects M3 & M4 are separated into east (M3E, M4E) and west (M3W, M4W) based on location of sites on both sides of Shark River Slough. M4E is further separated into M4E_1 and M4E_2, based on the east and west side of the Main Park road. Different letters represent significant (pairwise t-test; $p < 0.05$) difference in hydroperiod and mean water depth among surveys on individual transects or a section of the transects. Marl prairie portions of the transects M3 and M4 were last (E4) surveyed in 2016 and 2017, respectively.

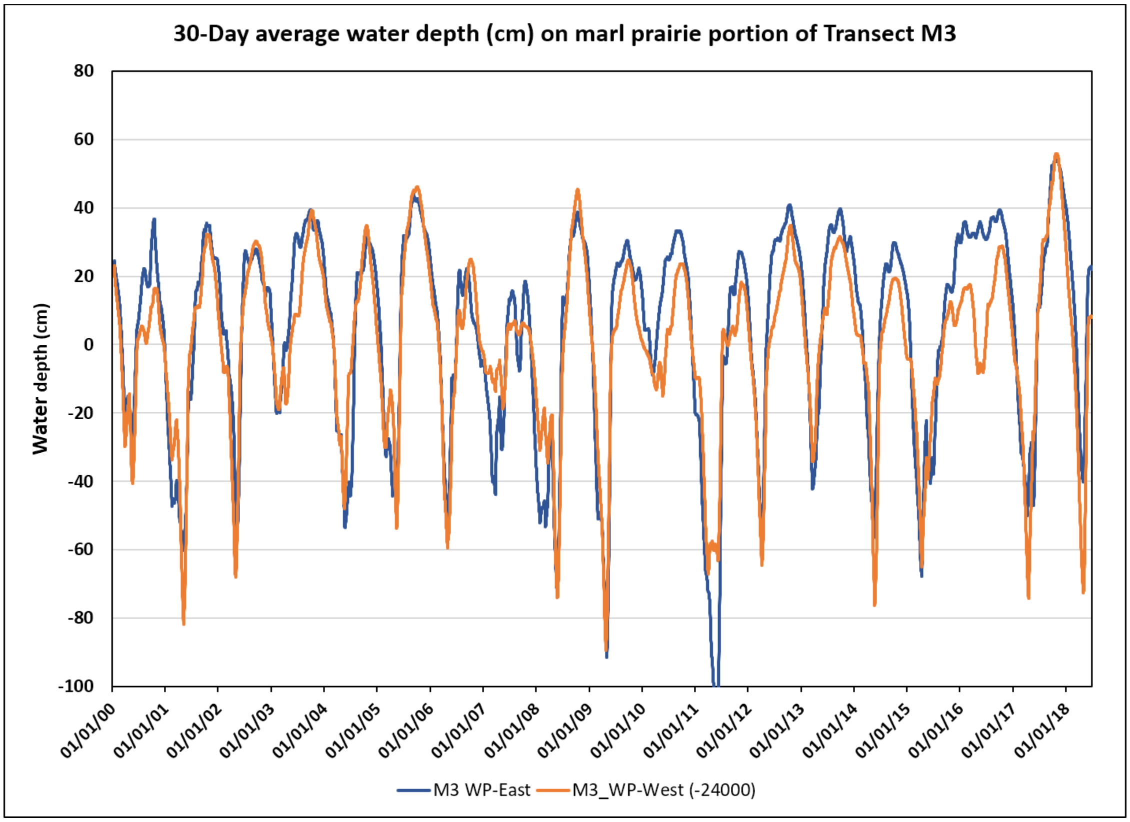

Figure 7. 30-day average mean annual water depth on marl prairie portions of the transect M3. Transect M3 is separated into east (M3E) and west (M3W) based on location of sites on both sides of the Shark River Slough.

Along transect 4, the hydrologic conditions in the marl prairie portion also differed between eastern and western sectors (**Figure 6c, d**). In this region of the marl prairie landscape, the Main Park Road also affects the hydrologic conditions. The sites to the southeast of the road (M4E_1) were much drier than the sites in the northwestern portion (M4E_2) of marl prairie, as the daily mean water level at eastern sites were consistently lower than the sites west of the Main Park Road (**Figure 8**). The difference in water level is especially distinct in dry season, when the water level at eastern sites go far below the ground, while the sites between the Park road and the slough had water level higher than eastern sites, but lower than the sites west of SRS.

On transect M4, in the prairies on both sides of the slough, it was drier during E1 than any other survey. In all three portions of the prairies of this transect, both the four-year average hydroperiod and mean annual water depth increased during the next three surveys. The increase in water depth across the four surveys was less in the western prairies (~5 cm) than in the eastern prairies (~10 cm) (**Figure 6d**). In 2017, the four-year average hydroperiod in M4E_1, M4E_2 and M4W portions of this transect were 252 (± 16), 317 (± 34) and 309 (± 62) days, respectively (**Figure 6c**). Likewise, the mean annual water depths were 5.4 (± 4.4), 20.6 (± 9.8) and 22.0 (± 16.3) cm, respectively (**Figure 6d**).

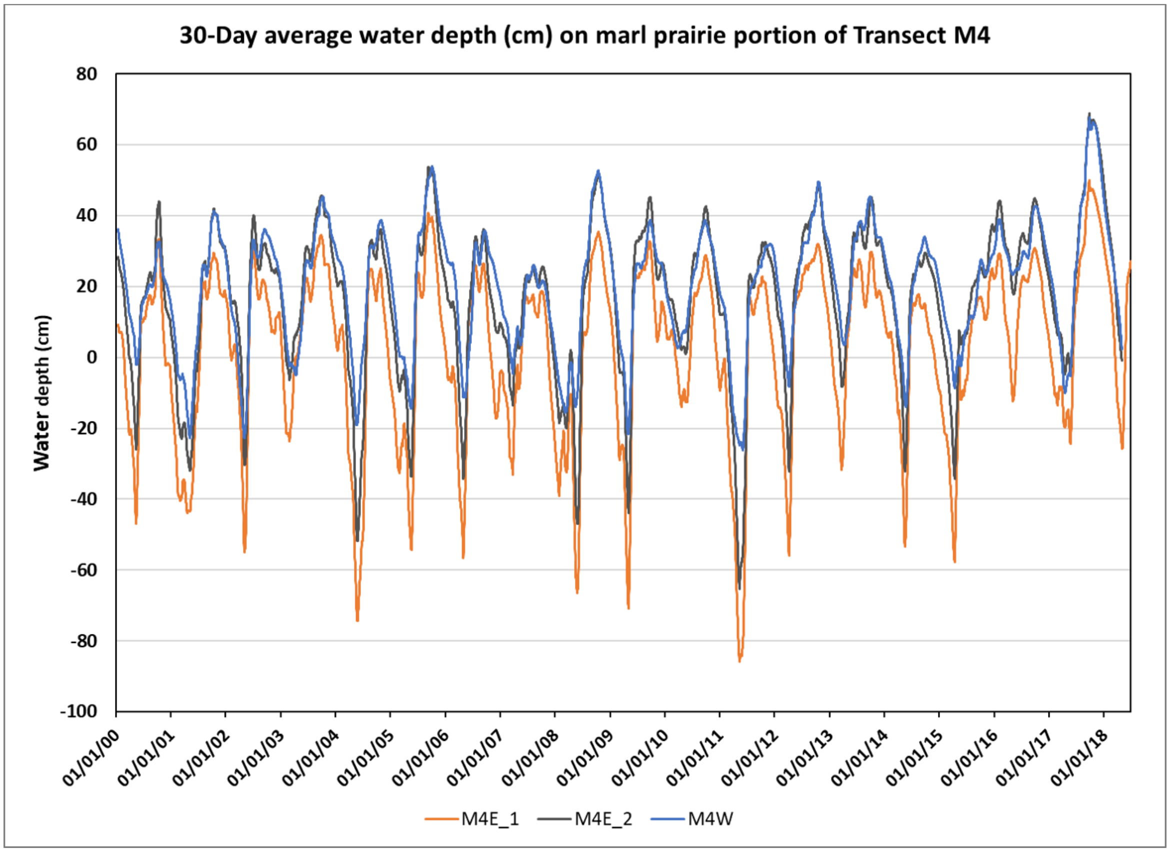

Figure 8. 30-day average mean and annual water depth on marl prairie portions of the transect M4. Transect M4 is separated into east (M4E) and west (M4W) based on location of sites on both sides of the Shark River Slough. The eastern marl prairie sites are further separated into east (M4E_1) and west (M4E_2) of the Park road.

Transect M5 had an increasing trend in four-year average hydroperiod and mean annual water depth during E1 to E4 surveys (**Figure 9a, b**), with the lowest average hydroperiod and mean annual water depth for E1, and the highest for E4. However, there were consistently wetter conditions at sites west of the Main Park Road than at eastern sites (**Figure 10**). Between 2008 and 2018, the four-year average hydroperiod increased from 250 days to 311 days and from 195 to 265 days on the western (M5W) and eastern (M5E) portions of the transect, respectively. In 2008, mean annual water depth was 6.4 (± 4.6) cm in the western portion of the transect, and -3.2 (± 4.3) cm in the eastern portion, whereas in 2018, the mean water depths were 14.6 (± 4.4) cm and 5.9 (± 4.2) cm in the western and eastern portions, respectively.

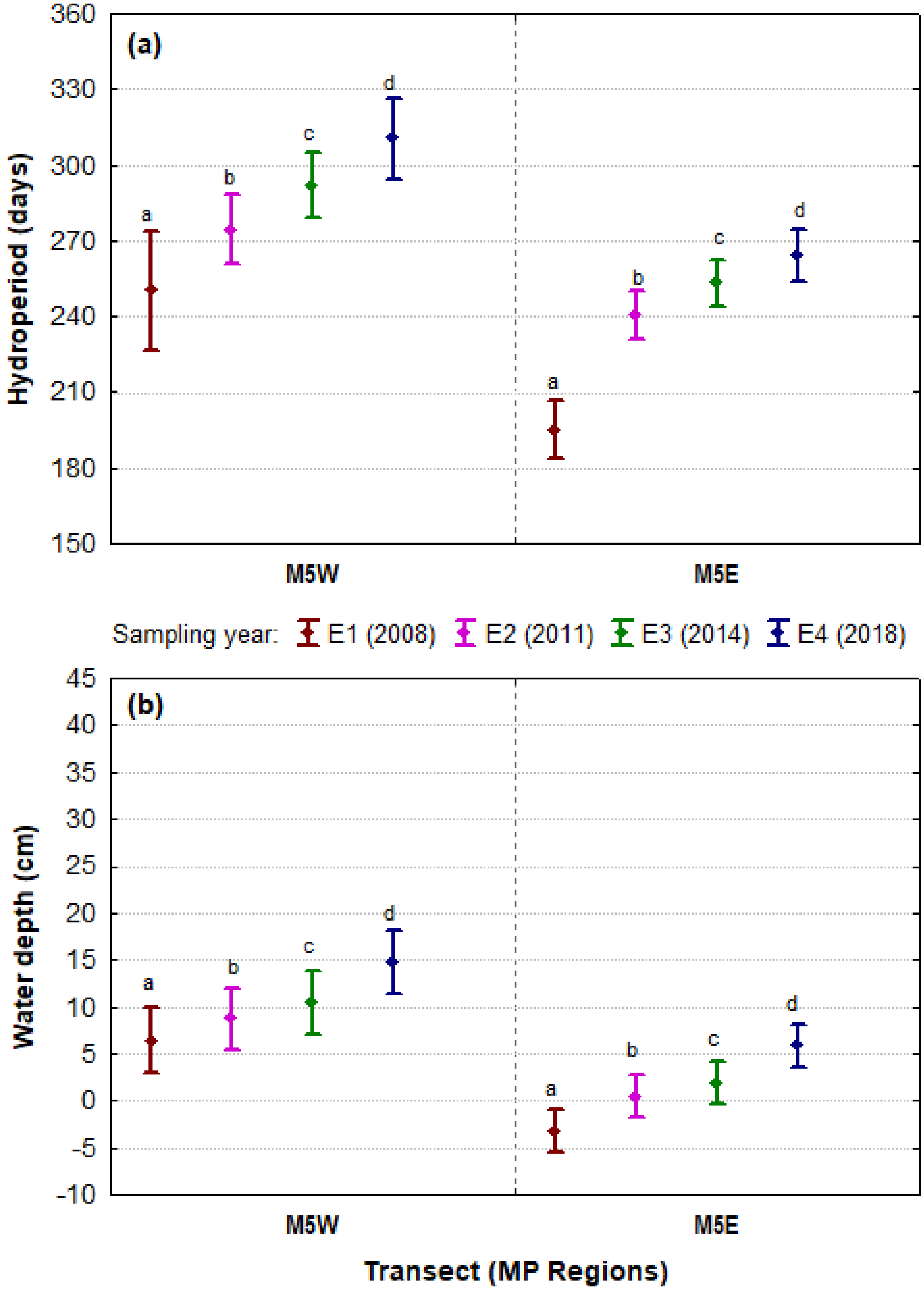

Figure 9: Mean (±95% CI) (a) Hydroperiod and (b) annual mean water depth averaged over four years prior to vegetation survey in the marl prairie portions of MAP transects M5. The transect M5 is separated into east (M5E) and west (M5W)) based on location of sites on both sides of the Main Park road. Different letters represent significant (pairwise t-test; $p < 0.05$) difference in hydroperiod and mean water depth among surveys on a section of the transect. The transect was last (E4) surveyed in spring 2018.

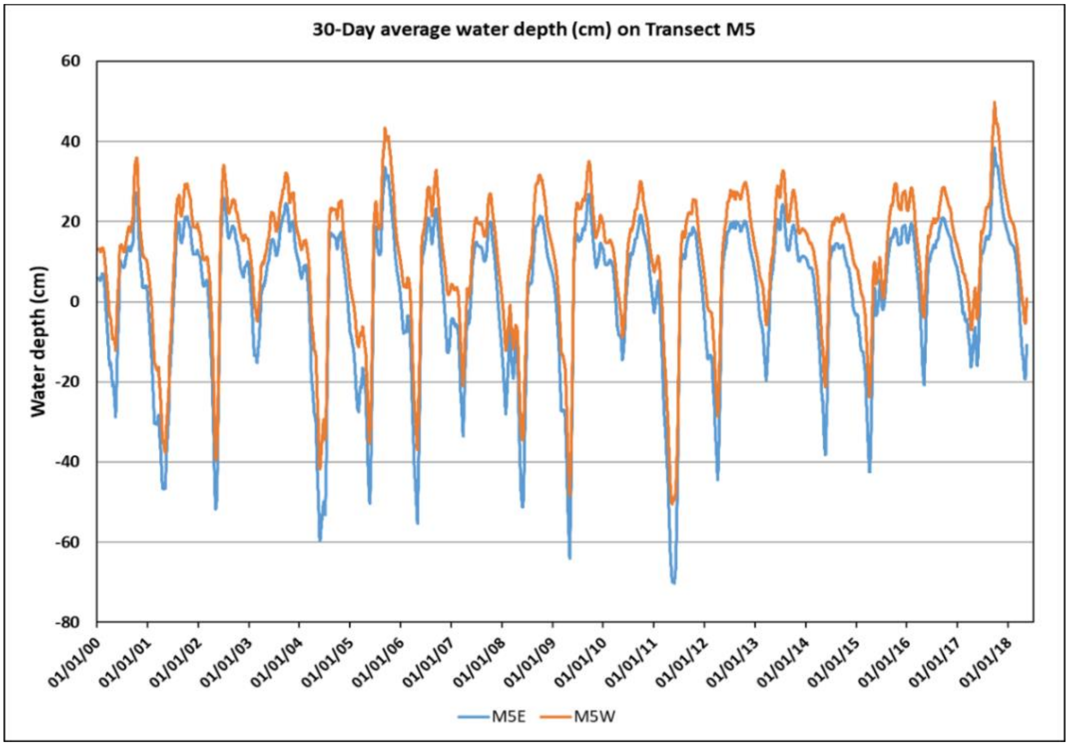

Figure 10. 30-day average mean annual water depth on eastern and western portions of the transect M5. The transect M5 is separated into M5E and M5W based on the sites east and west of the Park road.

On the recently established transect, M6, hydrologic conditions showed less variation. In contrast to other transects where the plots are located every 200-500m, on transect M6, survey was done at 100 m intervals to capture fine-scale changes in vegetation and soil characteristics over short distances. On this transect, mean 4-year average hydroperiod ranged between 273 and 365 days (**Figure 11**), and annual mean water depth ranged between 9.8 and 50.1 cm (**Figure 12**). In general, while the majority of sites remained inundated during most part of a year (Mean hydroperiod = 355 days: Coefficient of variation (CV) = 6.5%), the water depth varied greatly among sites (Mean water depth = 35.9 cm; CV = 32.0%).

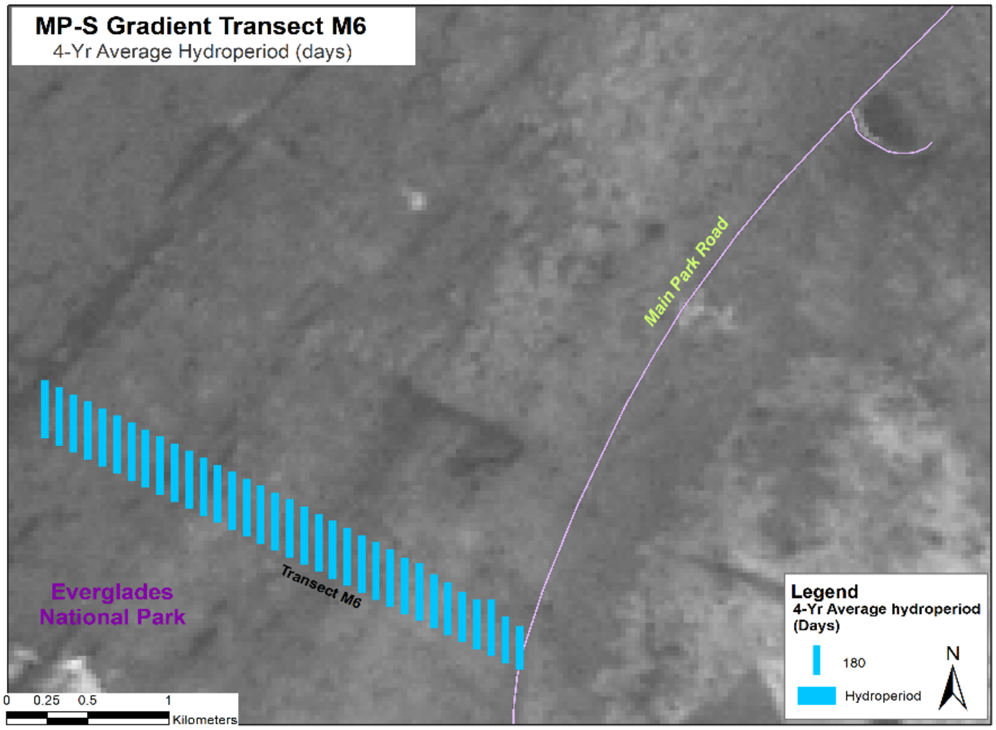

Figure 11: Mean hydroperiod averaged over four years prior to vegetation survey on MAP Transect M6

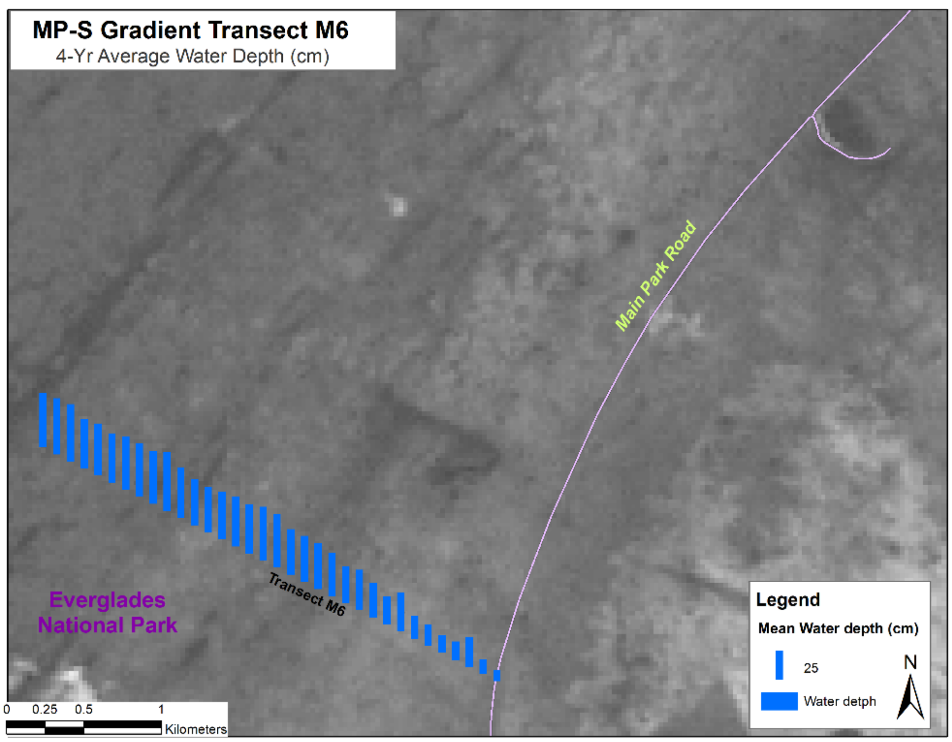

Figure 12: Mean water depth averaged over four years prior to vegetation survey on MAP Transect M6

3.2 Fire frequency and time since last fire

Historically, sites on the MP-S gradient transects have burned frequently**.** However, between 1990 and 2005, the period that included E0 vegetation survey (1999/2000) at the slough sites, there were few fires within the area. Burned plots included only two sites burned on M2E in 1990, and several on M4, where four burned in 1999 and four in 2003. After 2005, when vegetation monitoring began at regular intervals on the transects, fire frequency increased. Both prairie and slough sites on four transects (M1, M2, M3 & M4) burned due to either prescribed burns (Rx), human-caused fire or wildfires (**Table 2**). In contrast, sites on transect M5 and M6 did not burn during this period.

Table 2: Vegetation survey sites burned over the study period (2005-2019). The fire attributes were obtained from the Fire database of Everglades National Park.

Fire Name	Year	M1	M2	M2E	M3	M4	M5	M6
Between 1990 and 2005		0	0	2	0	8	0	0
L67 Rx	2005	0	1	0	0	0	0	0
Airboat	2006	18	4	6	7	0	0	0
U Road Rx	2007	0	0	10	0	0	0	0
Coptic	2007	1	0	0	0	0	0	0
West L67 WFU	2007	0	1	0	0	0	0	0
Mustang Corner	2008	11	1	9	44	0	0	0
Shark Valley Tram Rx	2009	0	0	0	1	0	0	0
ROG NE Rx	2012	0	12	0	31	0	0	0
EE 1 Rx	2012	18	13	0	0	0	0	0
ROG NW Rx	2014	0	0	0	11	0	0	0
Branch	2015	0	0	0	0	1	0	0
Dog Wood	2015	0	0	0	2	0	0	0
ROG West wui	2017	0	0	0	3	0	0	0
Cane Mill Hammock	2018	0	0	0	0	1	0	0
ROG NE	2018	0	12	0	24	0	0	0
Western Pines	2018	0	0	0	0	10	0	0
ROG East	2019	0	0	0	0	12	0	0

The fire-frequency on these transects over 72 years (1948-2019) for which fire data were available from ENP records is summarized in **Figure 13**. Fire frequency was as high as 1.25 fires per decade, and northern transects (M1-M3) burned more often than southern ones (M4-M6) where fire frequency was as low as 0.1 fires per decade. An exception was the eastern portion (east of Main Park Road) of Transect M4, where some sites had fire frequency similar to the marl prairie portion of the northern transects. In general, on four transects (M1-M4) that include both prairie and slough sites, the fire frequency was higher in the marl prairie sites than the slough portion of the transects. The time elapsed between the burned-year and vegetation survey, defined as time since last fire (TSLF), have affected vegetation composition observed at the burned sites.

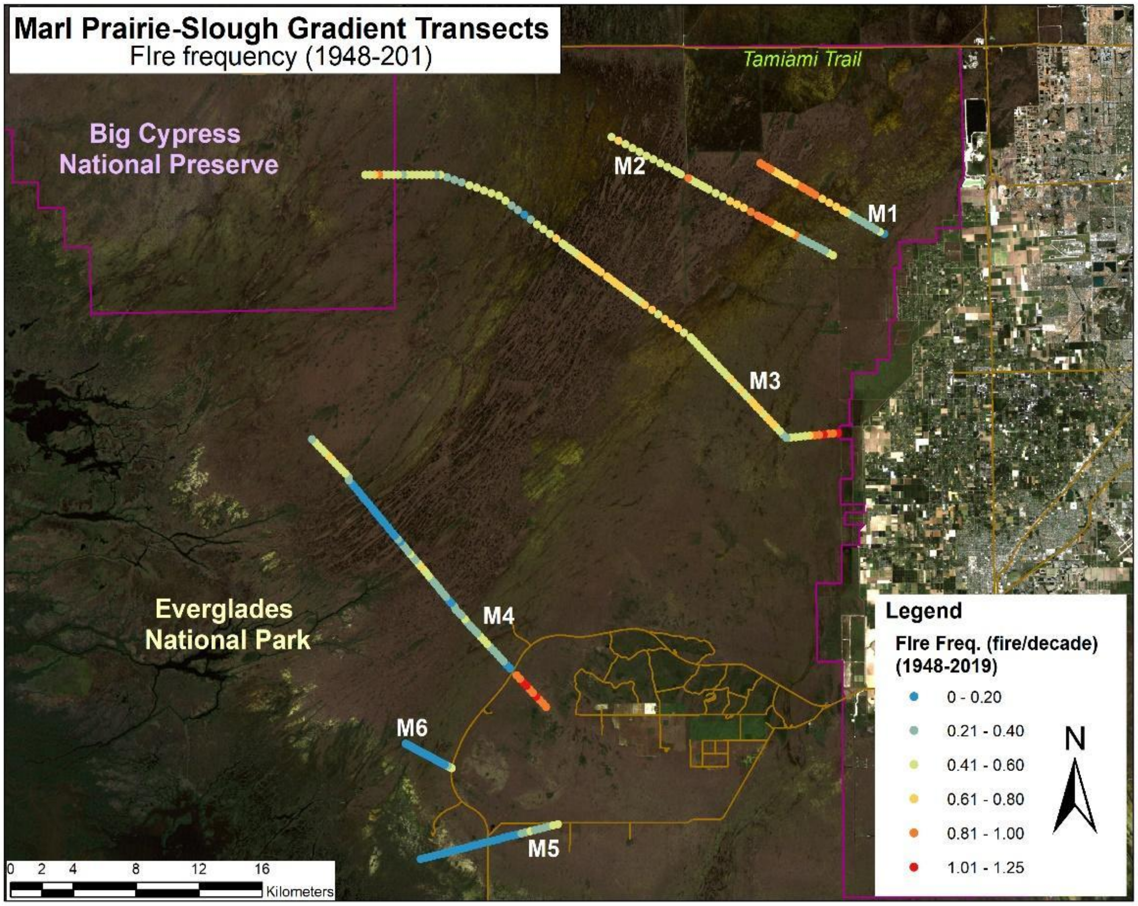

Figure 13: Fire frequency (number of fires/decade) at the vegetation survey sites on Transect M1-M5. Fire frequency was calculated over 72 years (1948-2019) for which the fire shape files were available in Everglades National Park Fire database.

3.3 Soil and plant characteristics

3.3.1 Soil Characteristics

Surface soil characteristics varied along the MP-S gradient represented by transects M3 and M6. However, variation in soil characteristics on M6 is less distinct than M3. In general, soil bulk density (BD) showed a decreasing trend from marl prairie to slough portions of the transects (**Figure 14**). The mean (±) bulk density ranged between 0.076 (± 0.009) g cm^{-3} and 0.547 (± 0.043) g cm^{-3} on M3 and between 0.084 (± 0.028) g cm^{-3} and 0.424 (± 0.118) g cm^{-3} on M6 (Appendix 1). Variability in soil bulk density was much less on M6 (CV = 35.8%) than M3 (CV = 69.3%).

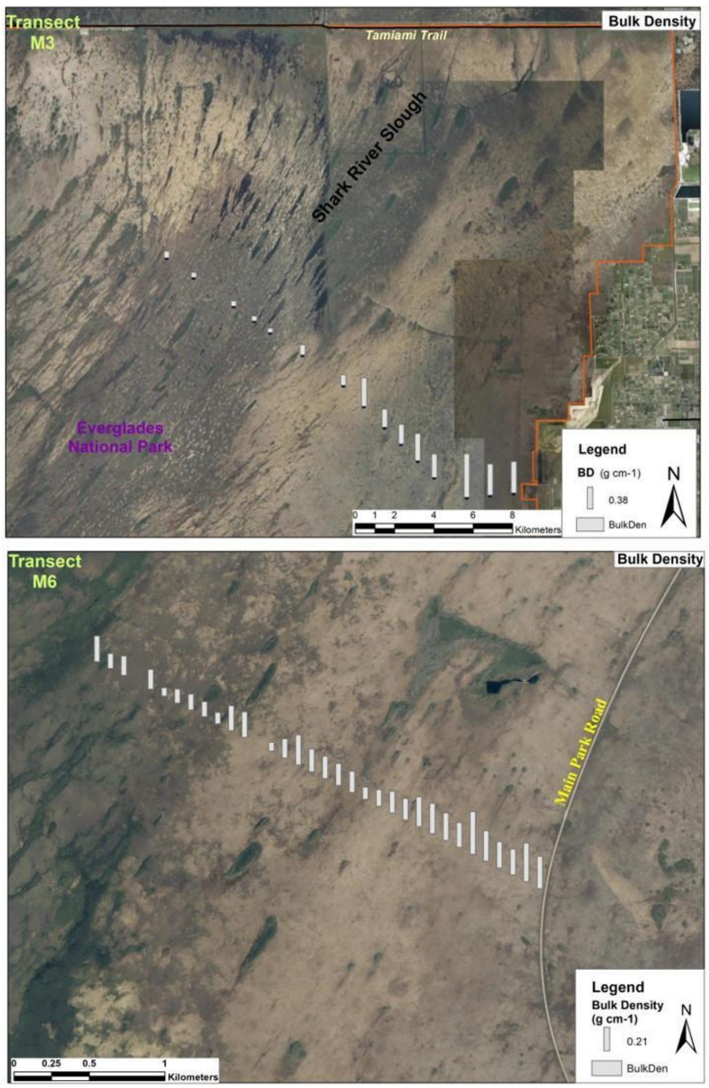

Figure 14: Soil bulk density at sites along marl prairie-slough gradient on Transects M3 & M6.

Along the MP-S gradient, both total carbon (TC) and organic carbon (OC) were lowest at marl prairie sites and showed an increasing trend toward the sloughs (**Figure 15**). On M3, the mean TC content ranged from 138.1 ± 15.4 mg g^{-1} at a prairie site near the ENP boundary to 444.1 ± 15.1 mg g^{-1} at a site (M3-18300) in the slough portion of the transect. The mean OC ranged from 22.7 ± 5.58 mg g^{-1} to 404.0 ± 13.2 mg g^{-1}. The ranges in the amount of TC and OC on M6 were relatively narrow; the soil total carbon (TC) ranged between 173.3 ± 9.5 mg g^{-1} and 376.5 ± 57.3 mg g^{-1} and organic carbon (OC) between 56.3 ± 7.8 and 267.9 ± 48.0 mg g^{-1}.

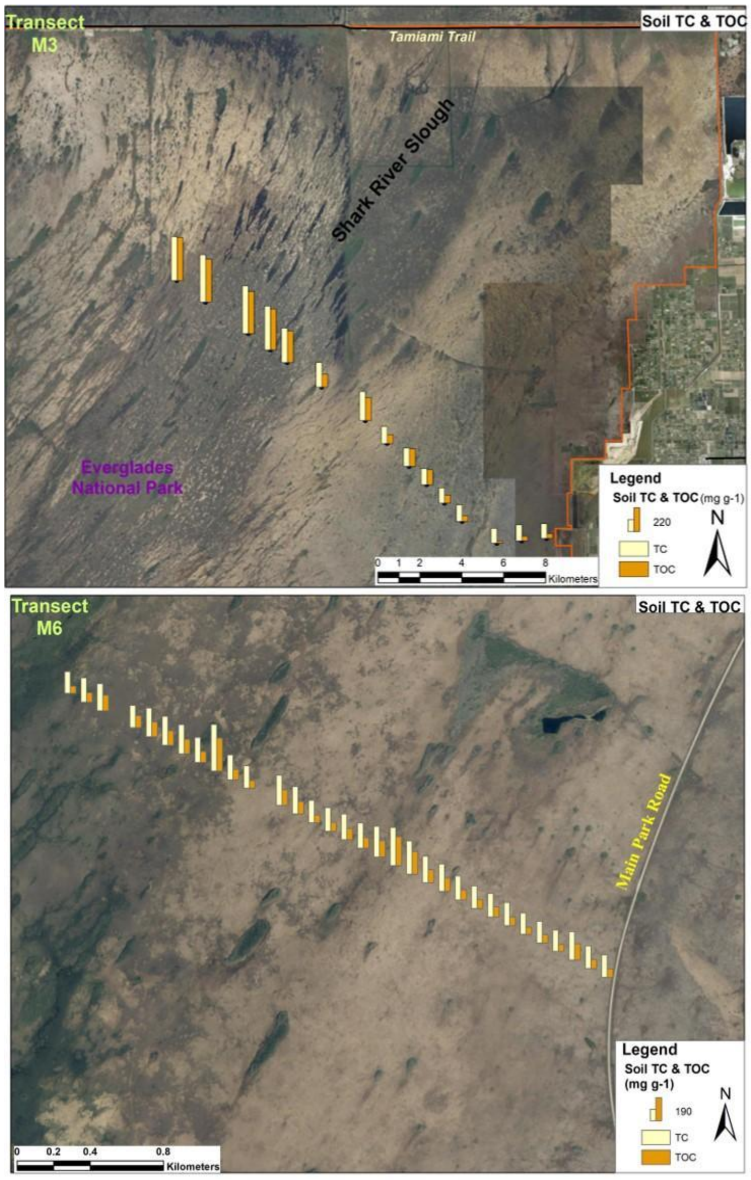

Figure 15: Soil (a) total carbon (TC) and organic carbon (OC) content at sites along marl prairie-slough gradient on Transects M3 and M6.

Similar to the trend observed for TC and OC, soil total nitrogen (TN) also showed an increasing trend (on a dry weight basis) from marl prairie to slough (**Figure 16**). On M3, mean (± SD) soil TN ranged between 2.8 ± 0.99 mg g^{-1} and 32.5 ± 0.43 mg g^{-1} with CV (coefficient of variation) of 64% (Appendix 1). In contrast, variability in soil TN on M6 was relatively low (CV = 35.1%). Unlike TC, OC and TN, soil total phosphorus (TP) did not show a strong trend along the MP-S gradient. However, in general, prairie sites had lower soil phosphorus than sites in ridge and slough (**Figure 16**), but the variability was very high in the transition zone, between M3-07300 and M3-12000 **(**Appendix 1**)**. On M3, mean (± SD) TP ranged between 100.5 ± 20.9 $\mu g\ g^{-1}$ and 367.4 ± 25.1 $\mu g\ g^{-1}$, while on M6, it varied from 85.2 ± 20.1 $\mu g\ g^{-1}$ to 418.8 ± 139.2 $\mu g\ g^{-1}$. Overall variation in soil TP on M3 (CV = 31.8%) was lower than on M6 (CV = 42.7%).

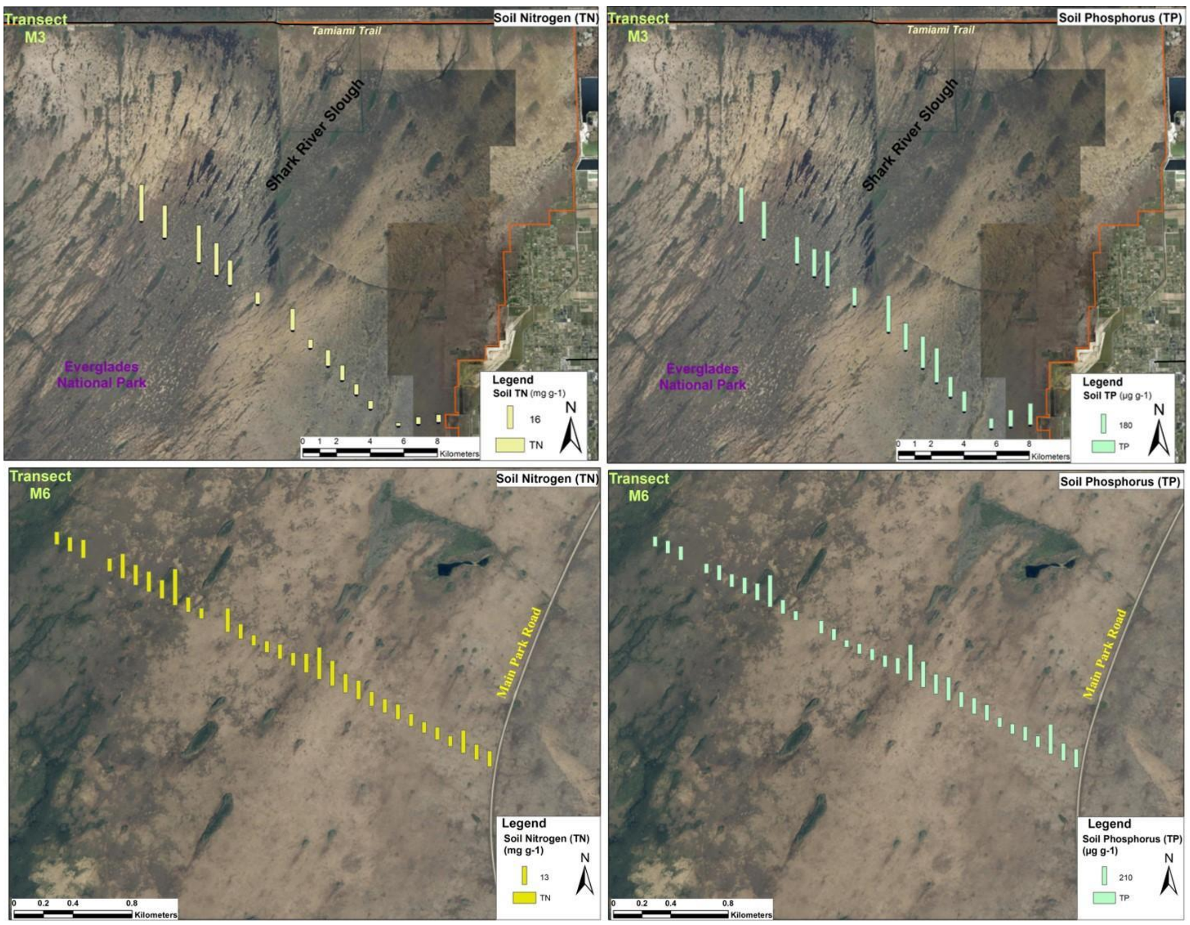

Figure 16: Soil total nitrogen (TN) and total phosphorus (TP) content at sites along marl prairie-slough gradient on Transects M3 and M6.

Along the MP-S gradient, TC, OC and TN, were strongly and positively correlated ($r > 0.70$; $p = 0.001$) with both hydroperiod and mean annual water depth, when the latter were averaged over 16 years prior to our sample collection (**Figure 17a-f**). Soil TP also increased with the two hydrologic variables, though the correlations were not significant (**Figure 17g, h**). Unlike TC, OC, TN and TP, soil IC decreased with site wetness, though the relationship was weak.

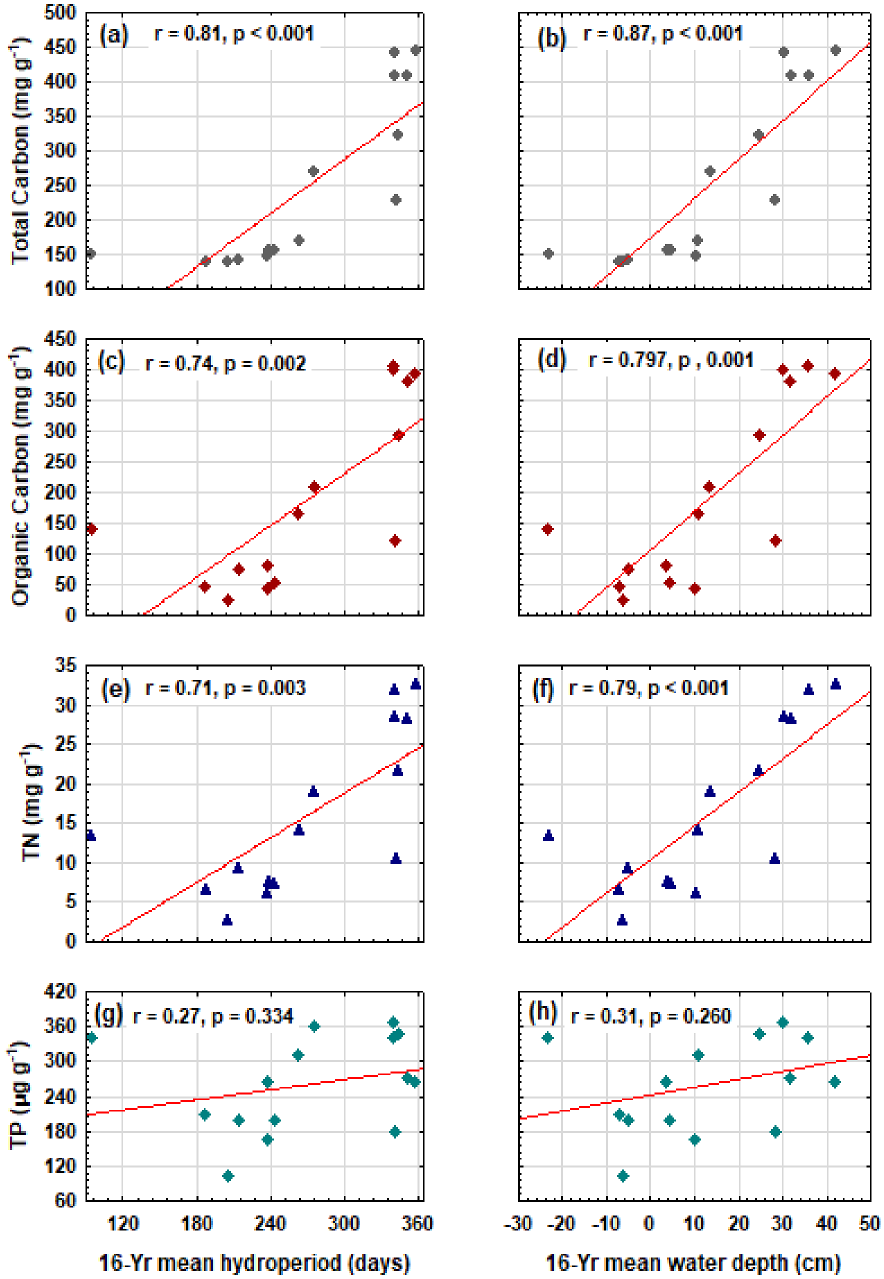

Figure 17: Relationships between hydrologic variables and soil TC, OC, TN and TP at the sites along marl prairie-slough gradient on the transect M3.

In this study, physicochemical measurements that included enzyme (phosphatase and glucosidase) activities and microbial biomass were also determined. Additionally, bioavailable P was assayed via a serial extraction procedure that involved analysis for water soluble P (WSP) and NaHCO3-P. Mean (± SD) methylumbelliferyl-glucosidase (MUF-C) ranged between 0.007 ± 0.003 and 0.583 ± 0.533 µ mole hr^{-1}, and the values were higher at the slough sites than at marl prairies sites (**Figure 18a**). However, mean methylumbelliferyl-phosphatase (MUF-P) did not show a significant (Nonparametric, M-W Test: $p = 0.395$) difference between slough and prairie sites. In contrast, both soil microbial biomass carbon (biomass-C) and phosphorus (biomass-P) showed an increasing trend along marl prairie-slough gradient (**Figure 18c, d**). Along the gradient, mean (± SD) microbial biomass-C increased by several orders of magnitude, ranging from 35.6 to 14069.6 µg g^{-1} (dry weight). Mean microbial biomass-P ranged between 1.13 µg g^{-1} and 68.01 µg g^{-1}. The increase in MUF-C (glucosidase enzyme activity) and both microbial biomass C and P values along the MP-S gradient were similar to the trend observed in organic TC, OC and TN, and they were positively correlated with 16-year average hydroperiod and annual water depth. Nonetheless, the increasing trend in water-soluble phosphorus (WSP) and labile phosphorus (LP) along the MP-S gradient was not so strong (**Figure 18e, f**).

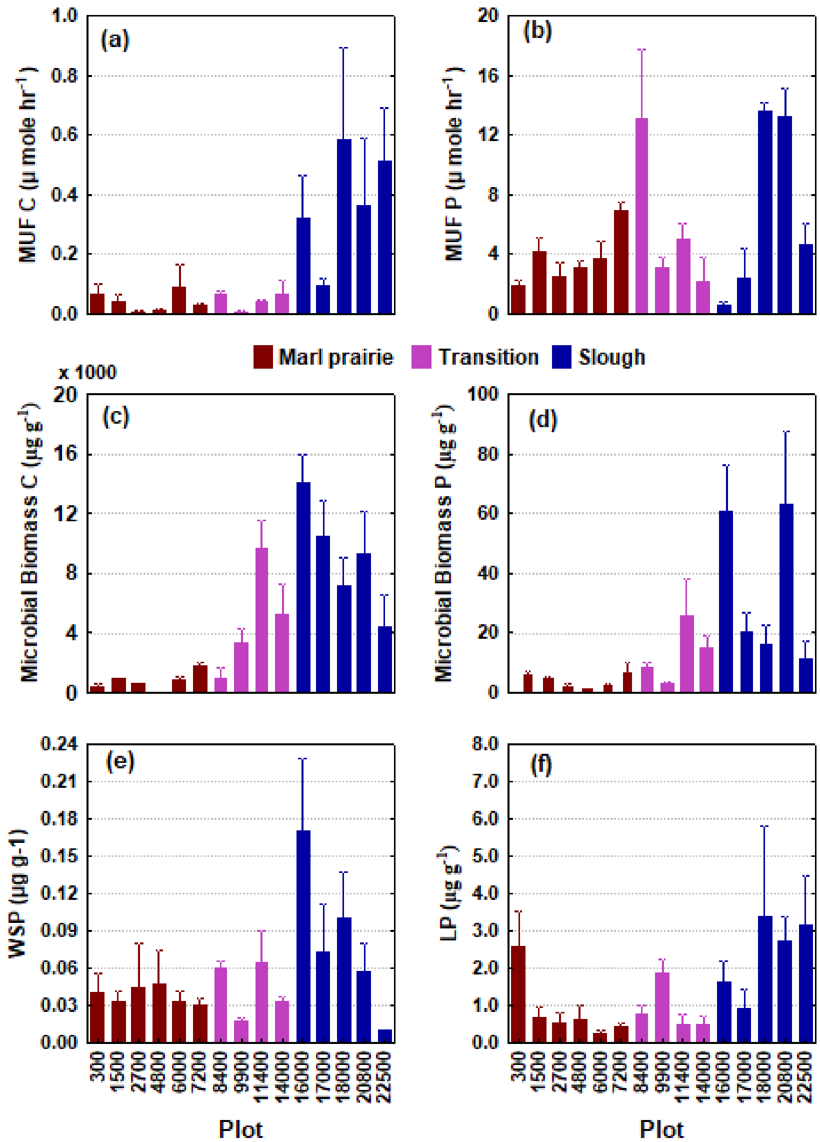

Figure 18: Soil characteristics at sites along marl prairie-slough gradient on Transect M3. (a) Methylumbelliferylglucosidase (MUF-C, µ mole hr^{-1}) (b) Methylumbelliferyl-phosphatase (MUF-P, µ mole hr^{-1}), (c) Soil microbial biomass carbon (biomass-C, µg g^{-1}), (d) Soil microbial biomass phosphorus (biomass-P, µg g^{-1}), (e) Water soluble phosphorus (WSP, µg g^{-1}), and (f) Labile phosphorus (LP).

3.3.2 Carbon isotopic signature of Soil Organic Matter and Plants

In the Everglades, spatial variation in vegetation composition along marl prairie-slough gradient correlates with changes in the relative abundance of C_4 and C_3 species. Among 152 species recorded on five transects (M1-M5) during the E1 (2005-2008) survey, we identified 11.8% of species as C_4 (Appendix 3). On these transects, C4:C3 ratio (cover value log-transformed) was negatively correlated with 4-year hydrology (**Figure 19**). Variability in relative proportion of C_4 and C_3 species in short hydroperiod (<240 days) marl prairie sites was much higher than the slough sites (hydroperiod > 300 days) which were primarily dominated by C_3 species.

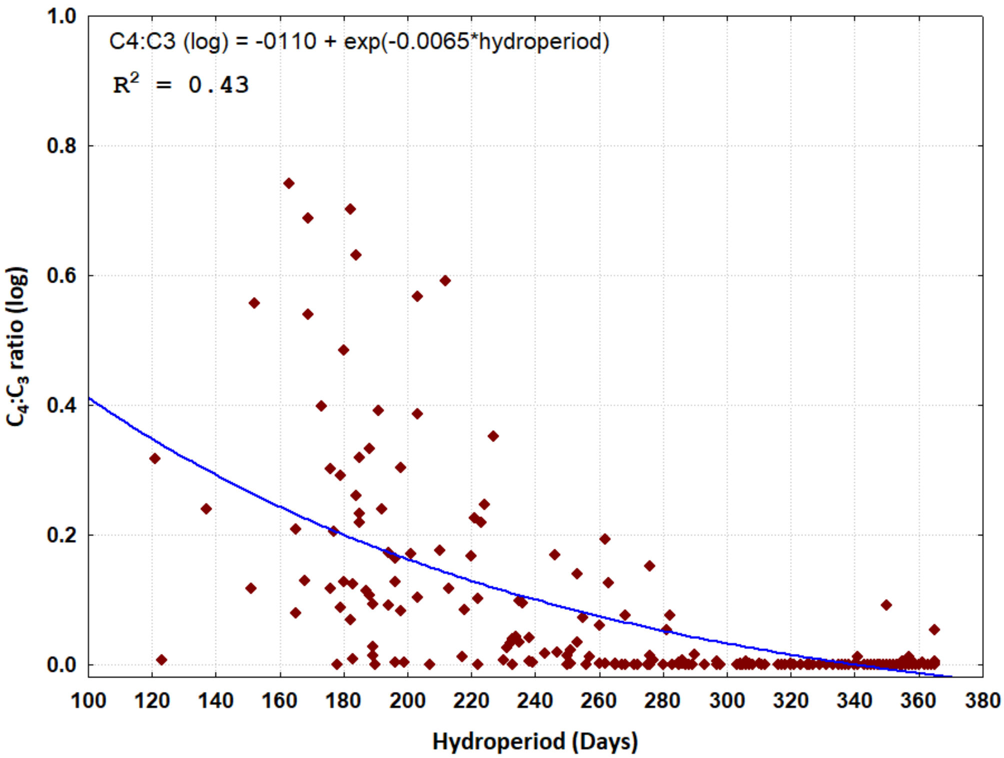

Figure 19: C4:C3 plants ratios along hydrologic gradient on five transects (M1-M5) surveyed between 2005 and 2008.

Surface soils along the MP-S gradient varied in Carbon-13 ($\delta^{13}C$) and Nitrogen-15 ($\delta^{15}N$) values. The $\delta^{13}C$ values in surface soil organic matter (SOM) were more negative in sloughs than in marl prairies, and had significant negative correlation ($r = -0.88$, $p < 0.001$) with both 16-year average hydroperiod and mean annual water depth (**Figure 20a, b**). The mean $\delta^{13}C$ values in SOM ranged from -23.0 ± 1.22‰ at a marl prairie site to -27.9 ± 0.50‰ at a site within the R&S landscape. The mean $\delta^{15}N$ values ranged between 2.34 ± 0.09‰ and 4.32 ± 0.17‰, and the values were significantly (Nonparametric Mann-Whitney Test: $p < 0.001$) lower at the slough sites than marl prairie sites. The $\delta^{15}N$ values were negatively correlated ($r = -0.66$, $p < 0.01$) with wetness of the sites (**Figure 20c, d**).

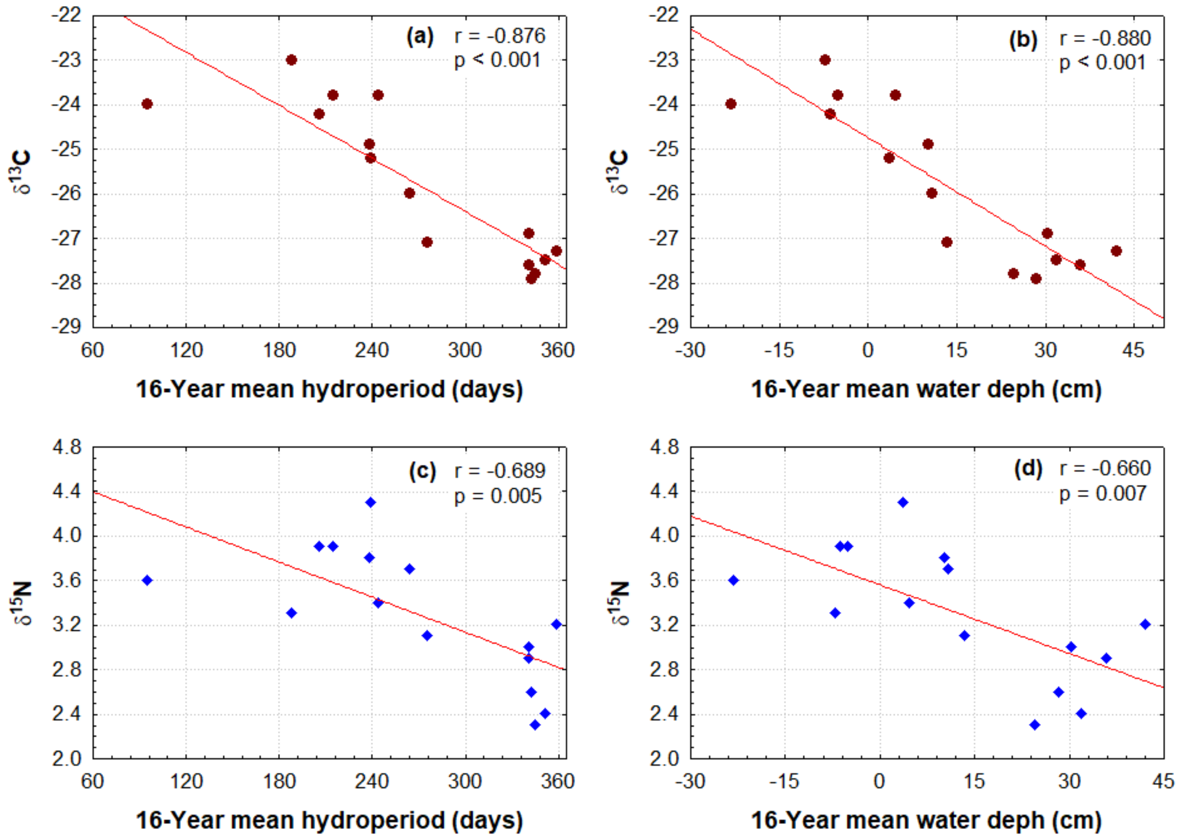

Figure 20: Relationships between hydrologic variables (hydroperiod and mean annual water depth) and soil δ13C and δ15N values along marl prairie-slough gradient on Transect M3.

Plants along the MP-S gradient also varied in δ^{13}C values. The mean δ^{13}C values in plant matter ranged from -20.5 ± 3.53‰ to -27.52 ± 0.11‰. Values significantly decreased with increasing hydroperiod (r= -0.82, p=0.0002) and mean average water depth (r= -0.81, p= 0.0003) (**Figure 21**). δ^{13}C values in the easternmost portion of the marl prairie and the slough sites of transect M3 had a narrower confidence interval compared to plots in the transitional zone (**Figure 22**). Such variation in δ^{13}C values of plants was mainly due to variability in plant composition, as C_4 plants with higher δ^{13}C values were dominant at the shorter hydroperiod portion of the transect. For instance, among the four major plant species, *Muhlenbergia capillaris* (C_4) was mostly limited to marl prairie plots (meter 300-6000) while *Rhynchospora traycii* (C_3) was present in marl prairie but also maintained relatively high biomass in transition zone. In contrast, *Cladium jamaicense* (C_3) was present throughout the gradient, whereas *Eleocharis cellulosa* (C_3) was present mainly on the ridge and slough sites (meter 16000-22500) (**Figure 23**).

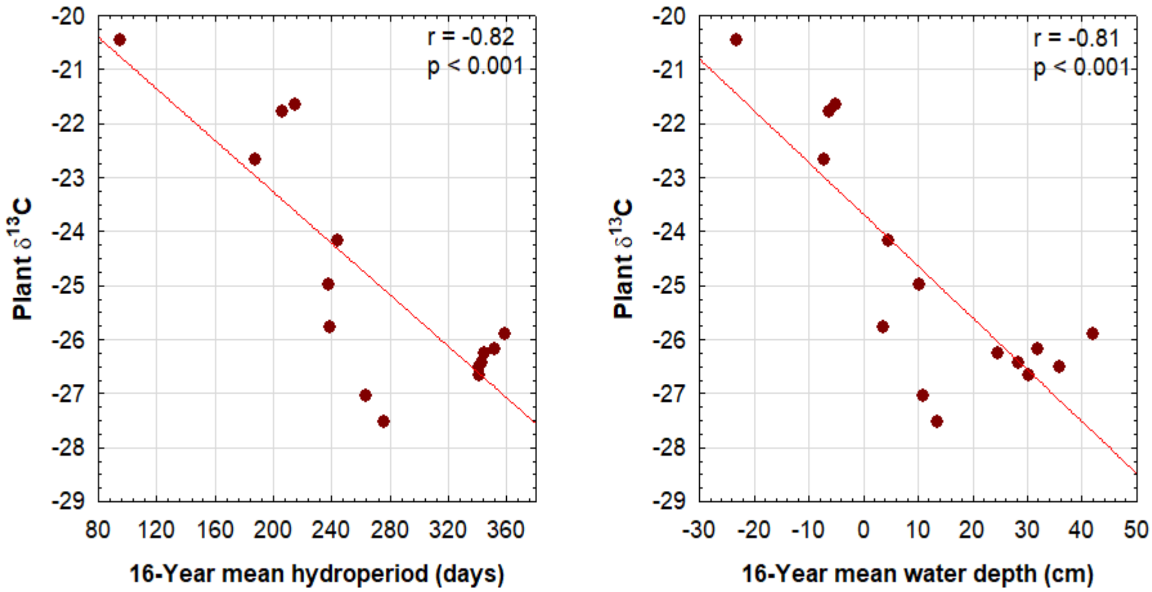

Figure 21: Relationships between hydrologic variables (hydroperiod and mean annual water depth) and plant δ13C values along marl prairie-slough gradient on Transect M3.

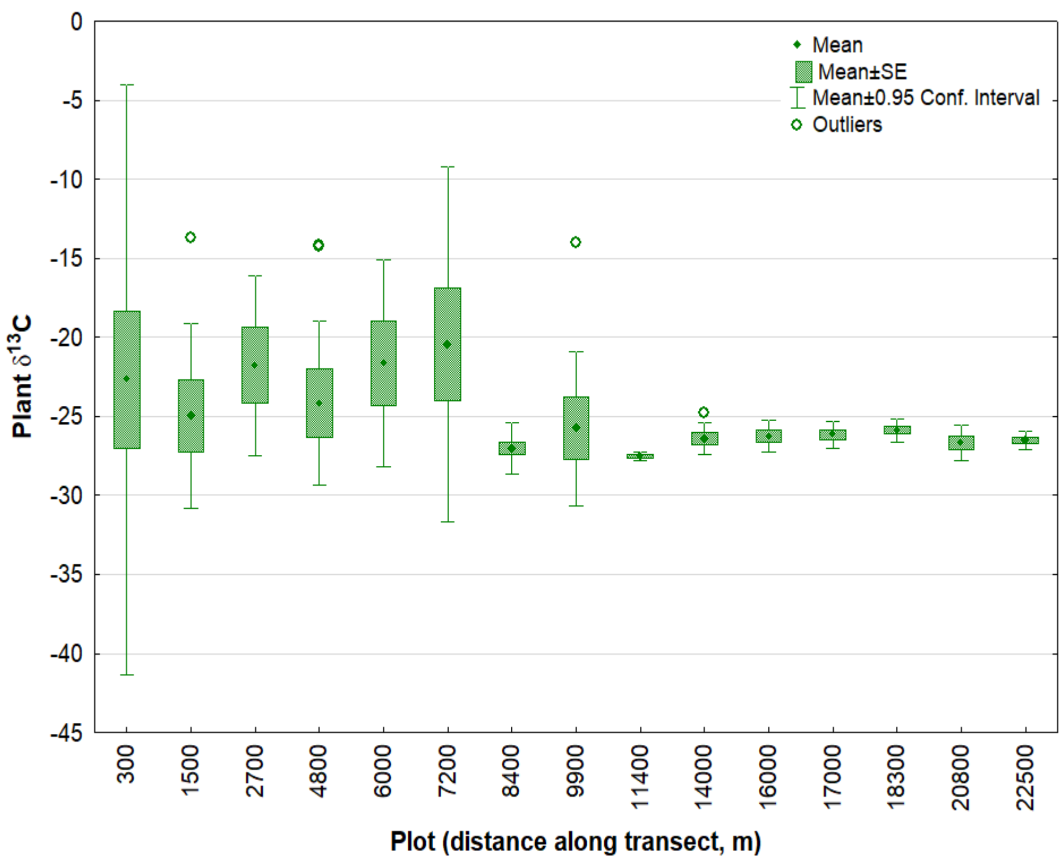

Figure 22. Average δ13C values of plants collected from fifteen sites along marl prairie-slough gradient on transect M3. Five eastern sites are in marl prairie (meter 300-600), five in transition (meter 7200-14000), and five sites in the ridge and slough portion (meter 16000-22500) of the Transect M3.

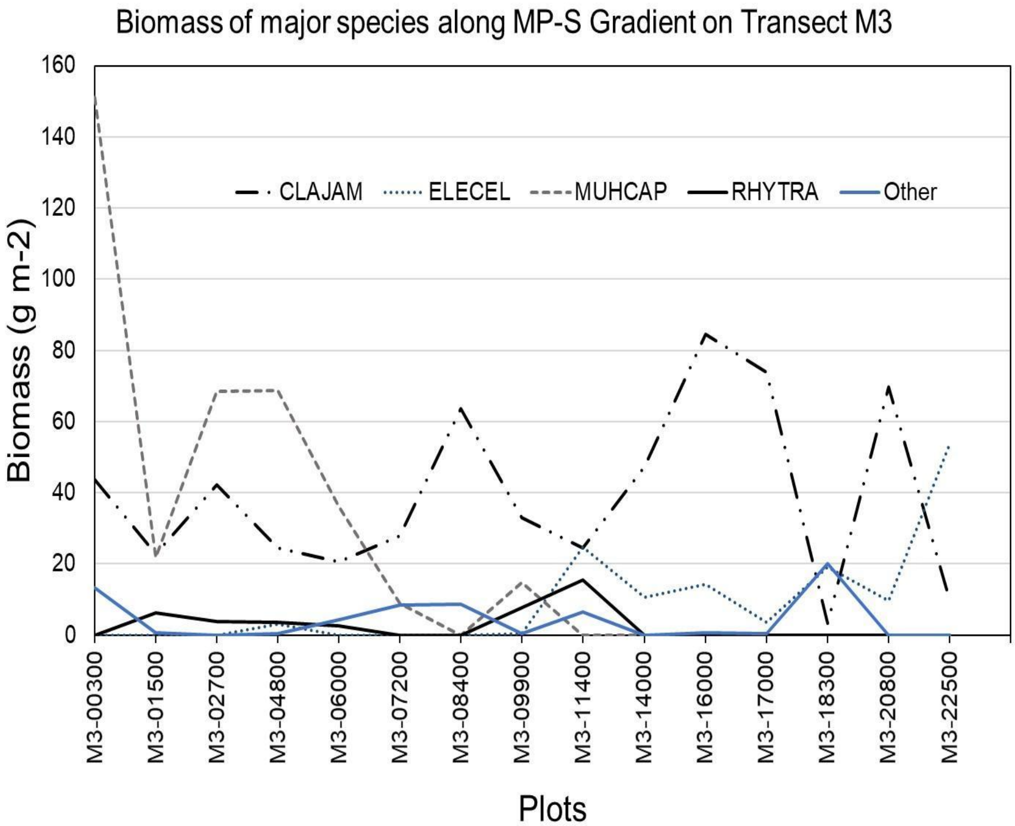

Figure 23. Average measured biomass (g m^{-2}) of selected species, *Cladium jamaicense* (CLAJAM), *Eleocharis cellulosa* (ELECEL), *Muhlenbergia capillaris* (MUHCAP), and *Rhynchospora tracyi* (RHYTRA) at fifteen sites along the marl prairie-slough gradient on transect M3.

3.4 Vegetation characteristics on Transect M6

Transect M6 was surveyed for the first time in 2019. The spatial distribution of vegetation types along it follows the general pattern observed for the rest of the transects (M1-M5) along MP-S gradient (Sah et al. 2015). While Sawgrass Mixed and Sawgrass Prairie types were dominant within the marl prairie landscape that predominates within a few hundred meters of the Park road, long-hydroperiod Marsh vegetation types (Sawgrass, Spikerush Maidencane and Sawgrass Spikerush Marsh) were common at the rest of the transect sites. However, the extent of marl prairie was reduced compared to the other transects (M1-M5) with only one site representing each of the two marl prairie types present (**Figure 24**). The most dominant vegetation types in the slough portion were Sawgrass and Spikerush Maidencane Marsh. Unlike the transition zones of transects M1, M2, M3 and M4, where the vegetation composition was of mixed types, i.e. species composition at those sites were dominated by sawgrass, but also included a number of species that were characteristic in both Prairie and Marsh vegetation groups, the transition zone in M6 was entirely represented by the Sawgrass Mixed Marsh type. Red mangroves were present at one site in the western extreme of transect M6, resembling a section of transect M5 where the freshwater marsh transitioned into brackish water vegetation.

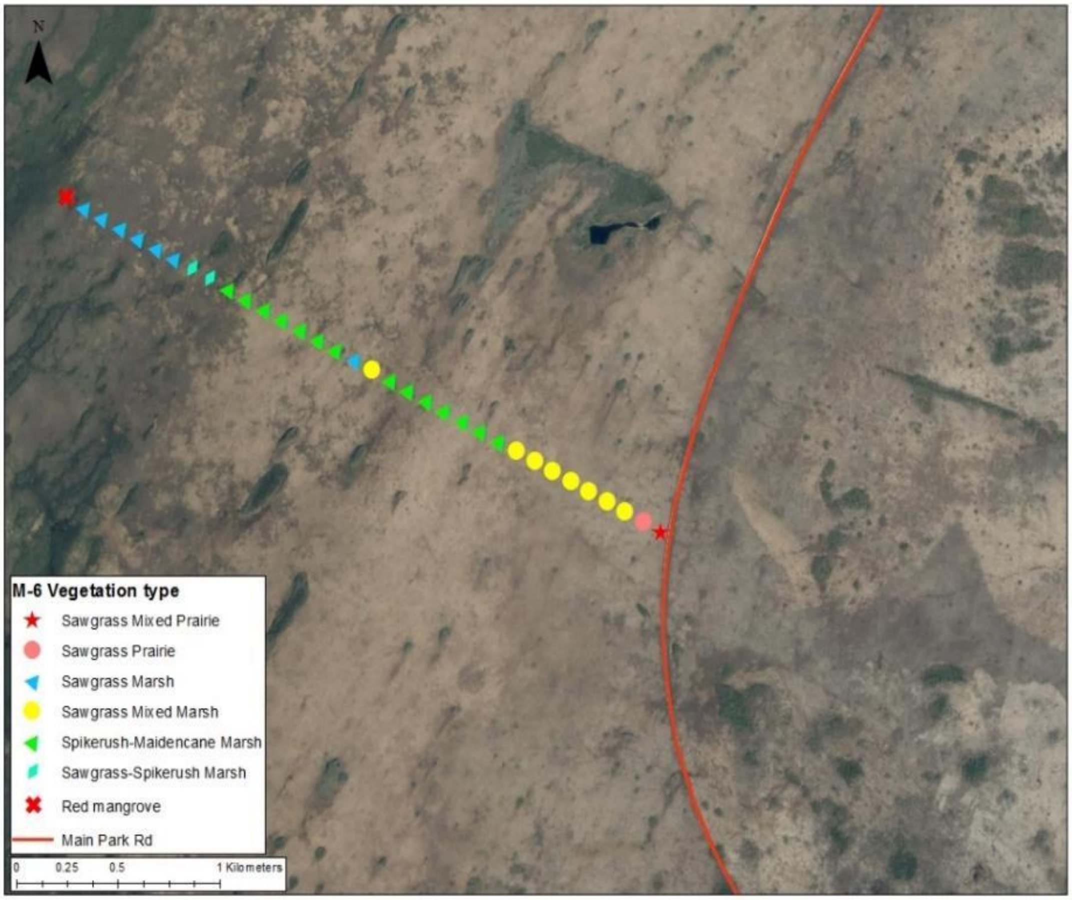

Figure 24: Vegetation types at sites on Transect M6.

Along MP-S gradient on M6, the general pattern of spatial distribution described above was also depicted in the NMDS ordination (**Figure 25**). Annual mean water depth and several soil characteristics, including soil depth, bulk density, TN, TP and N:P ratio were significantly correlated with the ordination configuration (**Table 3).** In the NMDS ordination space, the two sites corresponding to Sawgrass Mixed and Sawgrass Prairie types were placed on the left, representing the dry end of the hydrologic gradient while the sites with Sawgrass Marsh, Spikerush-Sawgrass Marsh, Sawgrass-Maidencane Marsh vegetation and Red Mangrove were towards the wetter end of the gradient. The Sawgrass Mixed Marsh occupied an intermediate position. The characteristic species of drier marl prairie sites included muhly grass (*Muhlenbergia capillaris* ssp. *filipes*), little bluestem (*Schizachyrium rhizomatum*), and Elliott's lovegrass (*Eragrostis elliottii*). On the other hand, *Cladium jamaicense* characterized the Sawgrass Marsh. Likewise, spikerush (*Eleocharis cellulosa*), bladderwort (*Utricularia* sp.), arrowhead (*Sagittaria lancifolia*) and maidencane (*Panicum hemitomon)* are associated with the Spikerush-Sawgrass Marsh and Sawgrass-Maidencaine Marsh. The total cover was highest in Sawgrass Marsh while the species richness in Sawgrass Mixed Marsh and Sawgrass Maidencane Marsh was higher than other vegetation types (**Figure 25**).

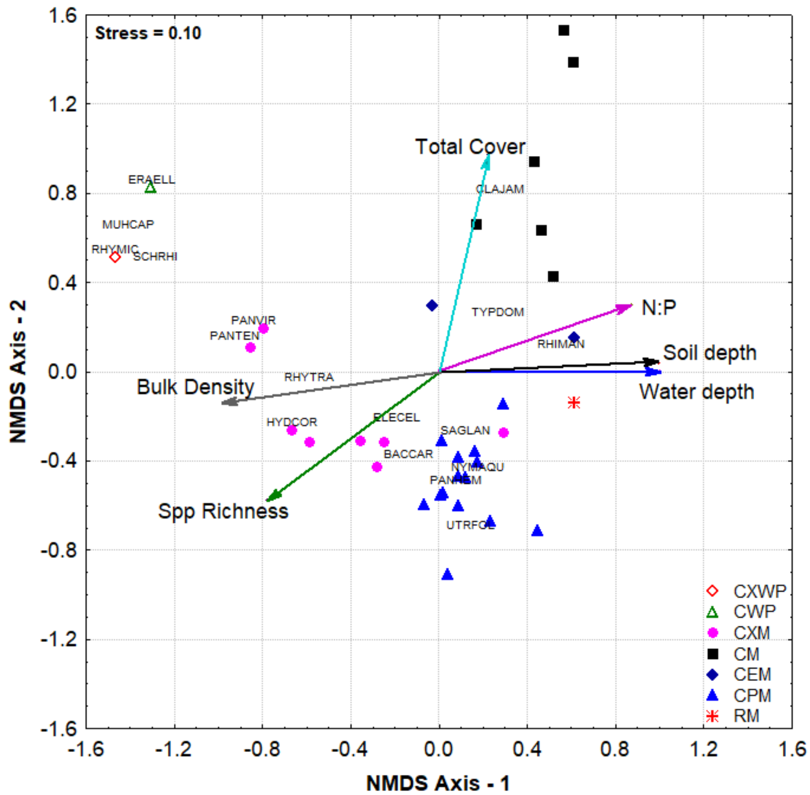

Figure 25: Tri-plots (site scores, species scores and fitted vectors) of non-metric multidimensional scaling (NMDS) 3-D Ordination (Axis-1 and 2). Vegetation types: CXWP = Sawgrass mixed wet prairie, CWP = sawgrass wet prairie, CXM = Sawgrass mixed marsh, CM = Sawgrass marsh, CEM = Sawgrass-Spikerush marsh, CPM = Sawgrass-Maidencane marsh, and RM = Red mangrove. Species Codes are as per in Appendix 3.

Table 3: Correlation (r) and statistical significance of fitted community (total cover, species richness and Shannon diversity) and environmental (hydrology and soil characteristics) vectors with species importance value (IV)-based 3-dimensional ordination configuration.

Variable	N	r	p
Soil depth (cm)	34	0.654	0.001
Hydroperiod (days)	34	0.928	0.000
Water depth (cm)	34	0.915	0.000
Soil Bulk density (BD) (g cm^{-1})	32	0.610	0.002
Total Carbon (TC) (mg g^{-1})	32	0.394	0.057
Organic Carbon (OC) (mg g^{-1})	32	0.340	0.224
Total Phosphorus (TP) (µg cm^{-1})	32	0.701	0.000
Total Nitrogen (TN) (µg cm^{-1})	32	0.672	0.001
N:P Ratio	32	0.512	0.009
Species Richness	34	0.932	0.000
Total Cover (%)	34	0.609	0.004
Shannon Diversity	34	0.827	0.000

3.5 Shark River Slough vegetation change (1999-2018)

Between 1999 and 2018, marsh vegetation on all four transects (M1-M4) showed a shift in relative abundance of species that was indicative of sensitivity to hydrologic change. However, the direction and rate of vegetation change was not uniform throughout the study. Trajectory analysis results revealed that in the slough portion of M1 and M2 surveyed at 3 to 6-year intervals, species composition tracked the trend in hydrologic changes, and continued to shift towards drier vegetation types until 2011 (E3) (**Figures 26, 27**), but between 2011 (E3) and 2018 (E5), species composition shifted in the opposite direction, i.e. toward wetter vegetation types. Such a change in vegetation composition from dry to wet type in recent years, especially between 2014 (E4) and 2018 (E5), was much more distinct on transect M1 than M2. Moreover, the results revealed that over 20 years, only a few sites (17.6% and 33.3% on M1 and M2, respectively) were significantly displaced along the hydrologic vectors in ordination space (Appendix 2), suggesting that at the majority of sites on those two transects, species composition in 2018 was similar to those in 1999.

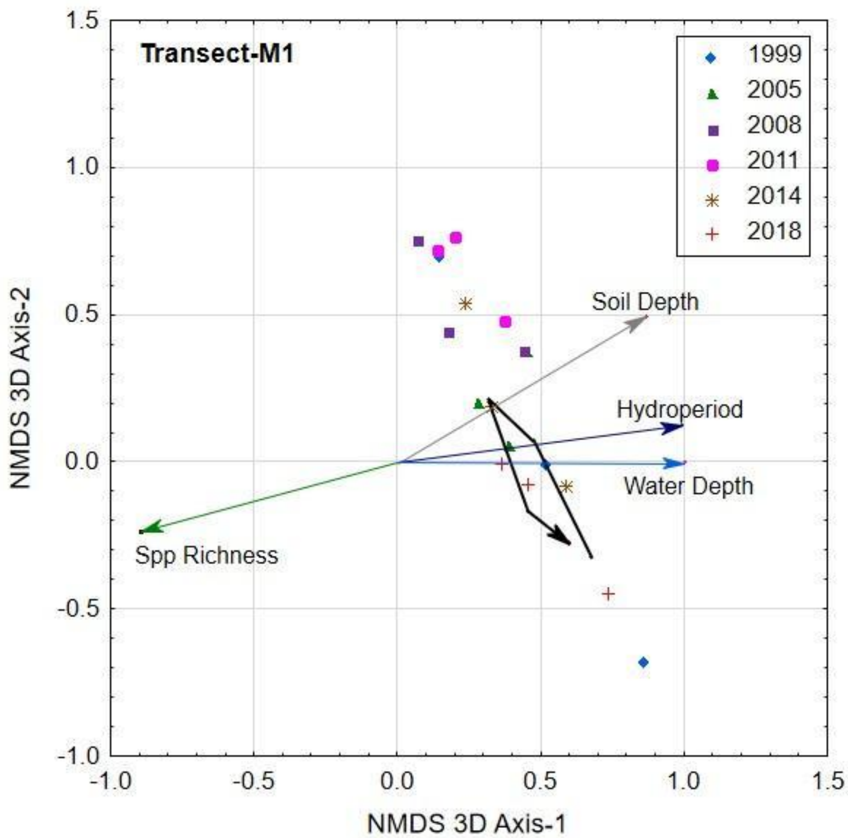

Figure 26: : NMDS ordination bi-plots of site scores, the environmental vectors fitted in the ordination space, and the trajectory of centroid. The ordination is based on species abundance data collected five times between 1999 and 2018 in the Shark Slough portion of the Transect M1. Only the sites that showed significant ($p \leq 0.1$) displacement (delta, Δ) and rate of change (slope) in species composition, along the hydrology gradient over 20 years are shown. Initial point and the end of the trajectory represent the 1999 and 2018 survey, respectively.

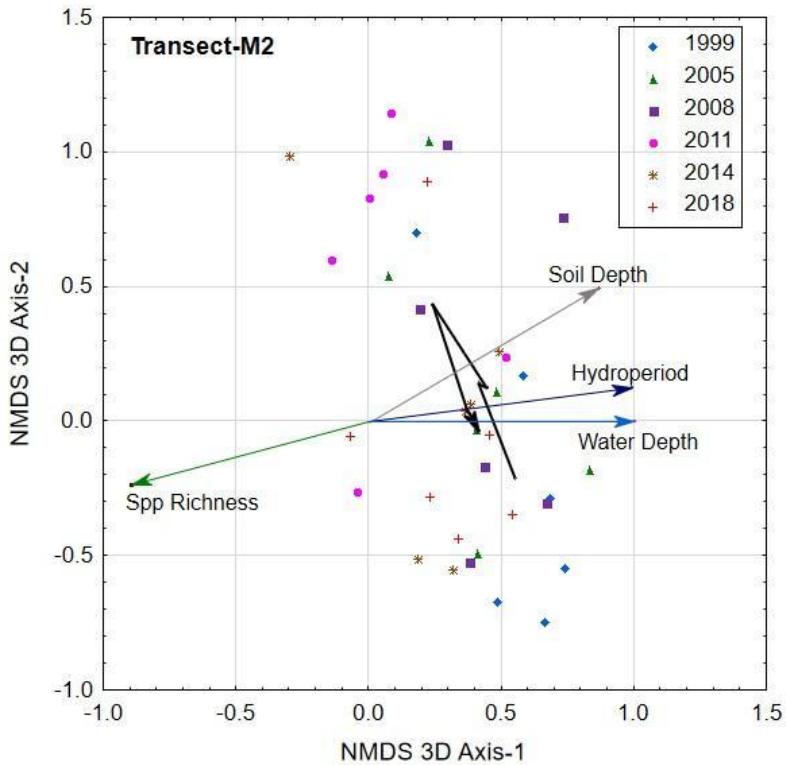

Figure 27: NMDS ordination bi-plots of site scores, the environmental vectors fitted in the ordination space, and the trajectory of centroid. The ordination is based on species abundance data collected in the Shark Slough portion of the Transect M2. Only the sites that showed significant ($p \leq 0.1$) displacement (delta, Δ) and/or rate of change (slope) in species composition along the hydrology gradient over 20 years are shown. Initial point and the end of the trajectory represent the 1999 and 2018 survey, respectively.

In the slough portion of transect M3 in central SRS, the direction of vegetation shift was similar to that observed on M1 and M2 through E2 (2009) (**Figure 28**). However, during the next two surveys, its vegetation trajectory was opposite in direction to those observed on M1 and M2; between 2009 (E2) and 2012 (E3), the vegetation on M3 slough sites shifted towards a wetter type, whereas between 2012 and 2015 (E4) the sites showed a drying trend. In contrast, in the slough portion of M4 that is in southern SRS, the direction of vegetation shift toward a drier type lasted only until 2007 (E1). During the subsequent survey, i.e. between 2007 and 2010 (E2), there was a shift toward vegetation characteristic of wetter environments, and the trend roughly continued through the 2016 (E3) survey (**Figure 29**).

The percentage of sites that showed a drying or wetting trend in vegetation varied among transects. When summarized over the survey period (1999-2018), most of the sites on M1 and M2 had either shifted back to wetter vegetation similar to those in 1999, while during the E4 (2014-2016) survey almost 50% sites on M3 still hosted vegetation of drier character than in 1999 (**Figure 28**). Transect M4 differed from all other transects. Between E1 (2007) and E2 (2010), vegetation composition at many sites shifted significantly towards wetter types, and a similar trend was observed between E3 (2013) and E4 (2016) (**Figure 29**).

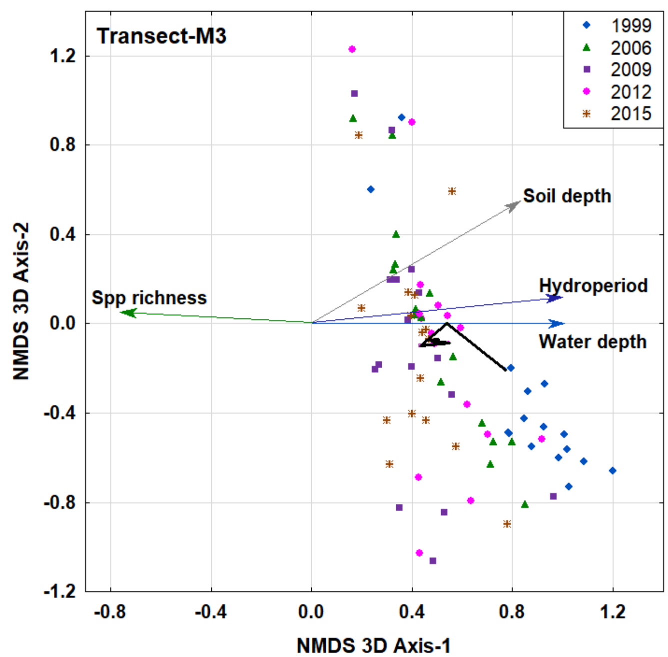

Figure 28: NMDS ordination bi-plots of site scores, the environmental vectors fitted in the ordination space, and the trajectory of centroid. The ordination is based on species abundance data collected in the Shark Slough portion of the Transect M3. Only the sites that showed significant ($p \leq 0.1$) displacement (delta, Δ) and/or rate of change (slope) in species composition along the hydrology gradient are shown. Initial point and the end of the trajectory represent the 1999 and 2015 survey, respectively.

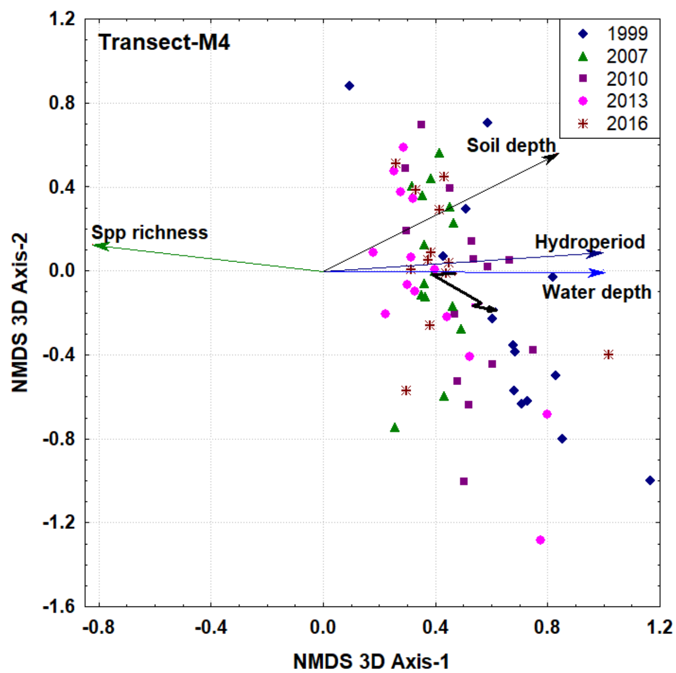

Figure 29: NMDS ordination bi-plots of site scores, the environmental vectors fitted in the ordination space, and the trajectory of centroid. The ordination is based on species abundance data collected in the Shark Slough portion of the Transect M4. Only the sites that showed significant ($p \leq 0.1$) displacement (delta, Δ) and/or rate of change (slope) in species composition along the hydrology gradient are shown. Initial point and the end of the trajectory represent the 1999 and 2016 survey, respectively.

Species richness

Species richness at the SRS sites varied greatly among transects, as well as between years on individual transects. Across all the six surveys since 1999, transect M3 had higher mean species richness than any other transect. Two transects, M1 and M2, were surveyed five times since the systematic monitoring began in 2005. Between these two transects, M2 had significantly (pairwise t-test; $p = 0.024$) lower species richness during the E5 (2018) survey than E4 (2014), whereas a change in richness on M1 between those two surveys was not significant (**Figure 30**).

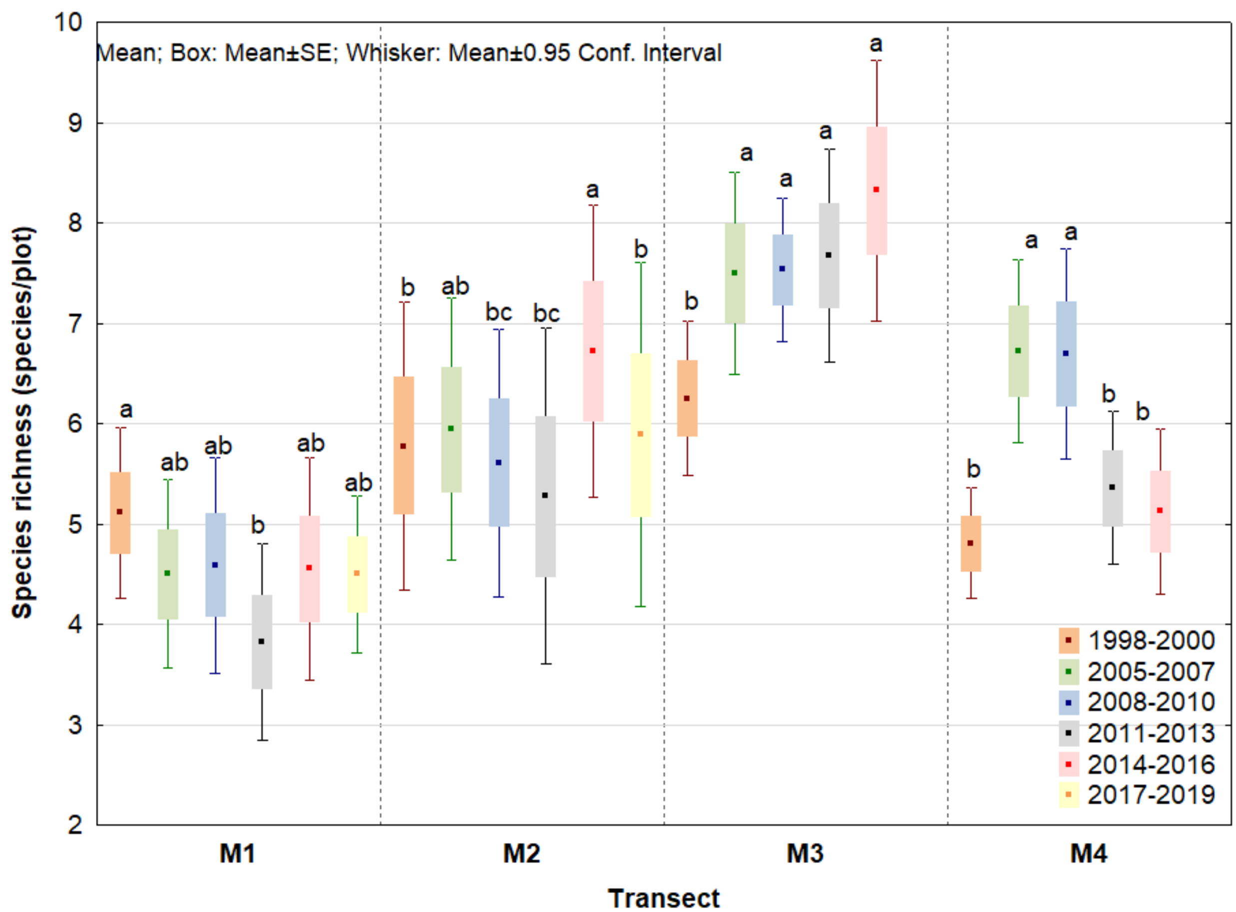

Figure 30: Plant species richness (species/plot) at the sites in slough portion of the transects M1, M2, M3 and M4. Different letters represent significant (pairwise t-test; $p < 0.05$) difference in species richness between different surveys on individual transects.

Between E0 (1999) and E4 (2014-2016), when slough portions on all four transects were surveyed, significant changes in species richness and relative abundance of some major species accompanied the trajectories described above. Mean species richness on Transect M1 in 2011 (E3) was significantly lower than during any other surveys, but there were no differences in species richness among the other surveys (**Figure 30**). In the slough portion of M2, mean species richness in 2014 (E4) was significantly higher than any previous survey except 2005 (E1).

During E4, mean species richness at the M3 sites was also higher than in other surveys, but the inter-period difference was only significant with E0. In contrast, species richness at the M4 marsh sites in 2016 (E4) was similar to 2013 (E3), but lower than both 2007 (E1) and 2010 (E2) surveys. Nevertheless, the species richness on this transect in 2016 (E4) was similar to 1999 (E0) survey (**Figure 30**).

Change in major species cover

When averaged over all four transects, the total plant cover at slough sites did not change much. However, the relative abundance (Importance Value, IV) of some of the most abundant species (Mean IV >2.0) did change significantly (**Figure 31**). It is important to note that the mean importance value of major species for 2018 (E5) is based on only two transects, M1 and M2. The drier conditions during E1-E3 (2005-2013) surveys than in E0 (1999) resulted in an increase in relative abundance of sawgrass (*Cladium jamaicense*) and spikerush (*Eleocharis cellulosa*) and a decrease in abundance of bladderworts (*Utricularia* spp.) over those years (**Figure 31**). However, during the 2014-2016 (E4) survey, as well as in 2018 (E5) the opposite trend was observed. The relative abundance of sawgrass did not differ between E3 and E4 surveys, whereas IV of sawgrass was significantly lower during E5 (2018) than both E3 and E4 surveys (**Figure 31a**).

The mean abundance of spikerush significantly increased (Paired t-test; $p = 0.28$) from 17.2% in E3 to 19.7% in the E4 survey, but then again decreased in the next four years (**Figure 31b**). In contrast, between E3 and E4, the IV of eastern purple bladderwort (*Utricularia purpurea*) also had increased by more than 50%, from 9.6% to 14.8%, and the trend continued for the next four years. Its IV increased more than 100% between E4 and E5 (**Figure 31c**). Interestingly, mean relative abundance of the other species of bladderwort (*Utricularia foliosa*) did not change significantly during the same period (**Figure 31d**). As in previous surveys, changes in the relative abundance of lemon bacopa (*Bacopa caroliniana)* was not significant (**Figure 31e**), while the relative abundance of maidencane (*Panicum hemitomon*) was less in E3, E4 and E5 than in E1 and E2 (**Figure 31f**).

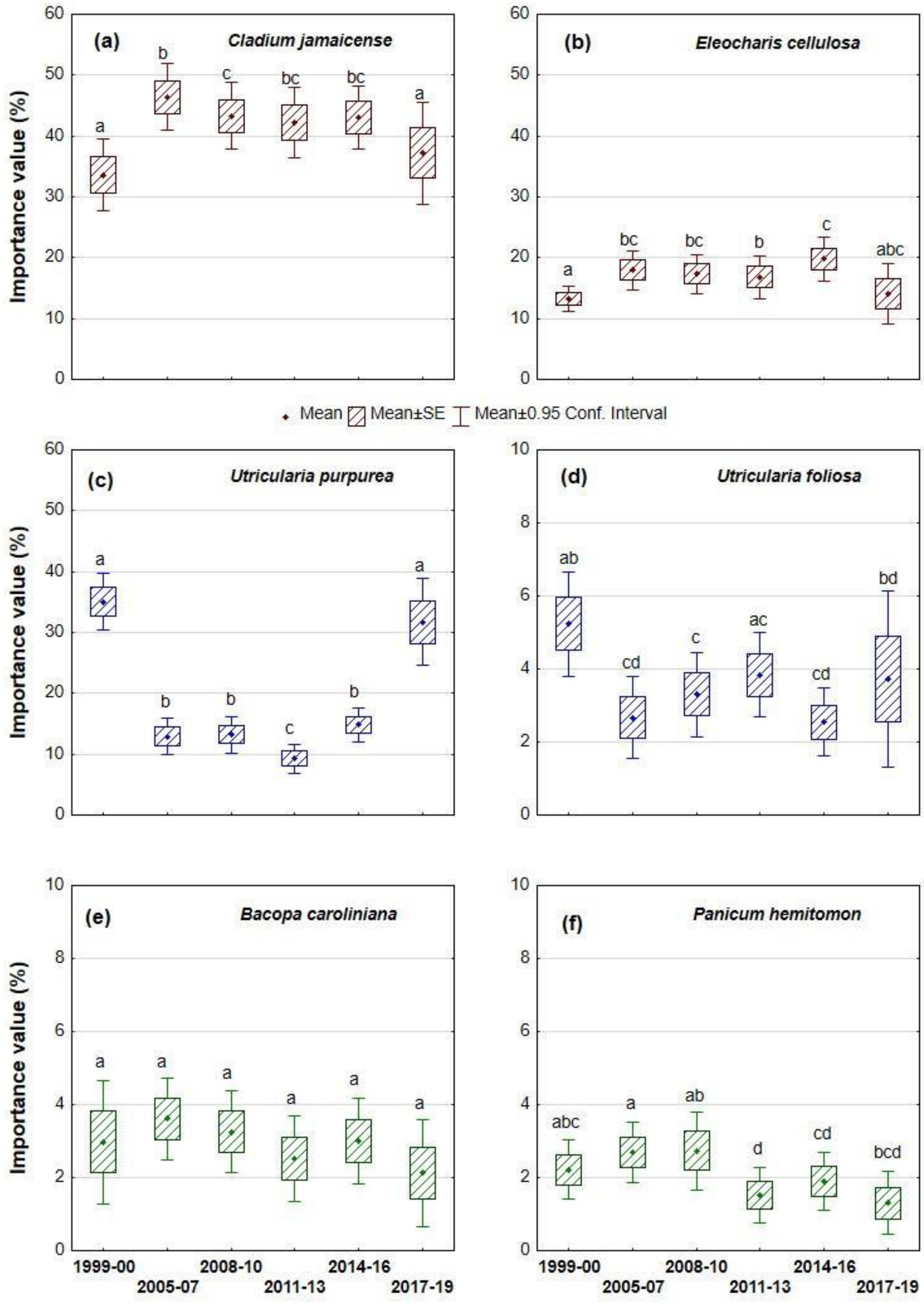

Figure 31: Box-plots of major species' importance value (IV) in the slough portion of transects, averaged across all four (M1-M4) transects for each survey. Different letters represent significant (pairwise t-test; $p < 0.05$) differences in species cover between different surveys.

3.6 Vegetation change in Marl Prairie (2006-2019)

In contrast to the vegetation change pattern observed in slough portion of the transect M1, trajectory analysis revealed that between 2006 (E1) and 2015 (E4) surveys, species composition on prairie portion of this transect continued to shift toward a drier type (**Figure 32**). However, after 2015, the trend in vegetation shift switched toward a wetter type. Over 13 years (2006-2019), while 54.5% of prairie sites had still drier vegetation in 2019 (E5) than 2006 (E1), between last two surveys (E4 and E5), 90% of sites showed an increase in vegetation-inferred hydroperiod (**Figure 33**), suggesting that the hydrologic conditions in this region in last four years i.e. between 2015 and 2019 had become wetter than before. When averaged over all the sites, the mean inferred hydroperiod increased from 230 (± 48) days in 2015 to 247 (± 54) days in 2019. However, the mean inferred hydroperiod was still 17 days shorter in 2019 than in 2006, when these sites were surveyed for the first time. The continued drying trend of some sites on M1 observed until 2012 (E3) had resulted in a significant (t-test, $p<0.05$) increase in importance value (IV) of muhly grass (*Muhlenbergia capillaris* ssp. *filipes*), and *Centella asiatica* (Appendix 3). But the recent shift toward wetter conditions resulted in a significant decrease in abundance of those species, but an increase in abundance of sawgrass and other hydric species. For instance, between 2015 and 2019, the mean IV of sawgrass (*Cladium jamaicense*) increased from 27.7% to 32.5% and the IV of spikerush (*Eleocharis cellulosa*) increased from 7.1% to 15.4%.

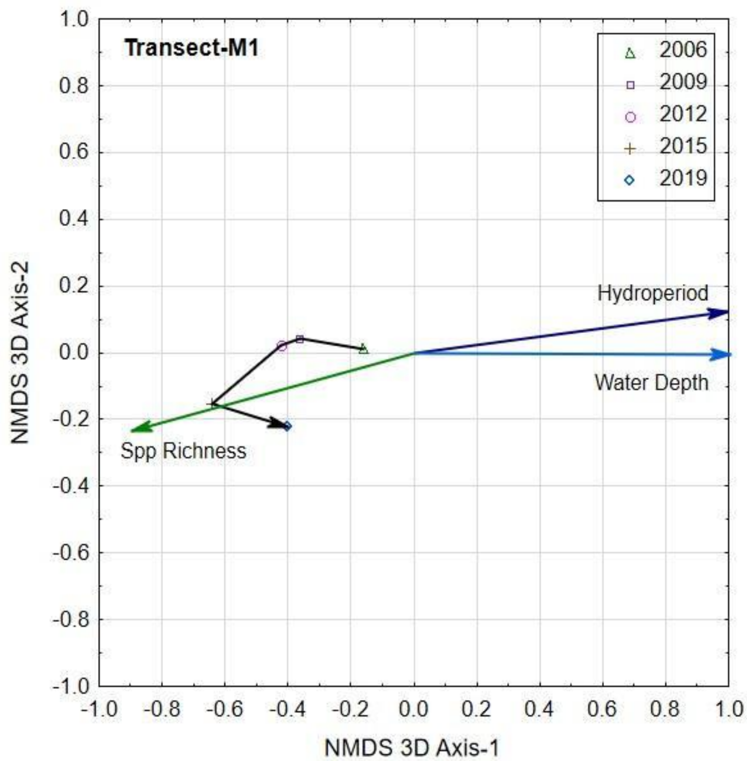

Figure 32: NMDS ordination bi-plots of the trajectory of centroid and the environmental vectors fitted in the ordination space. The ordination is based on species abundance data collected four times between 2006 and 2019 in the prairie portion of the Transect M1. Initial point and the end of the trajectory represent the 2006 and 2019 survey, respectively.

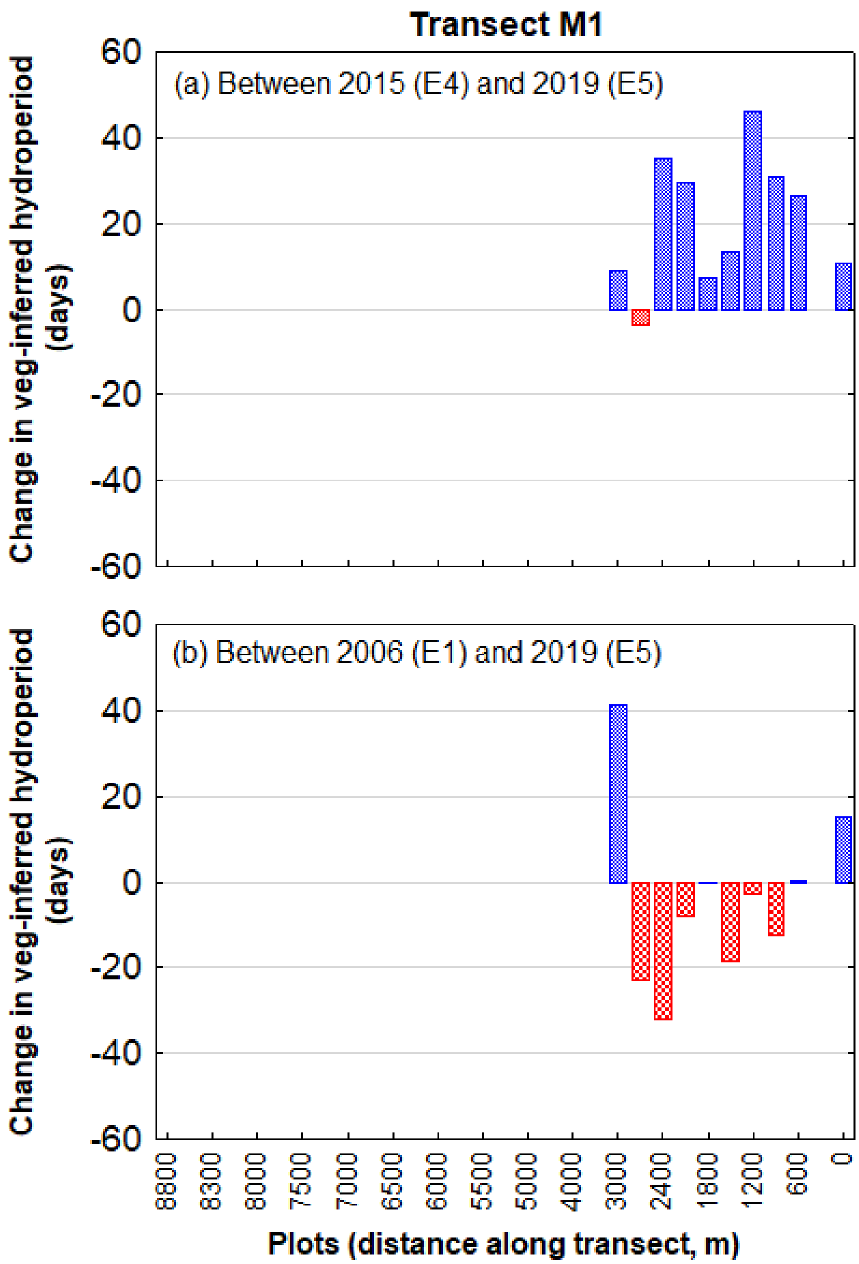

Figure 33: Change in vegetation-inferred hydroperiod between different surveys at the vegetation monitoring plots on the marl prairie portion of the Transect M1.

In concurrence with the vegetation trend observed on the prairie portion of M1, vegetation composition on the transect M2E also shifted towards wetter type in four years, 2015-2019 (**Figure 34**). During that period, the mean vegetation inferred hydroperiod increased from 282 (±80) to 296 (±76) days. Here, it is important to note that while both transects, M1 and M2E, are within NESRS, M2E was surveyed only twice, in 2015 and 2019, and thus trajectory analysis was not done on the data from this transect.

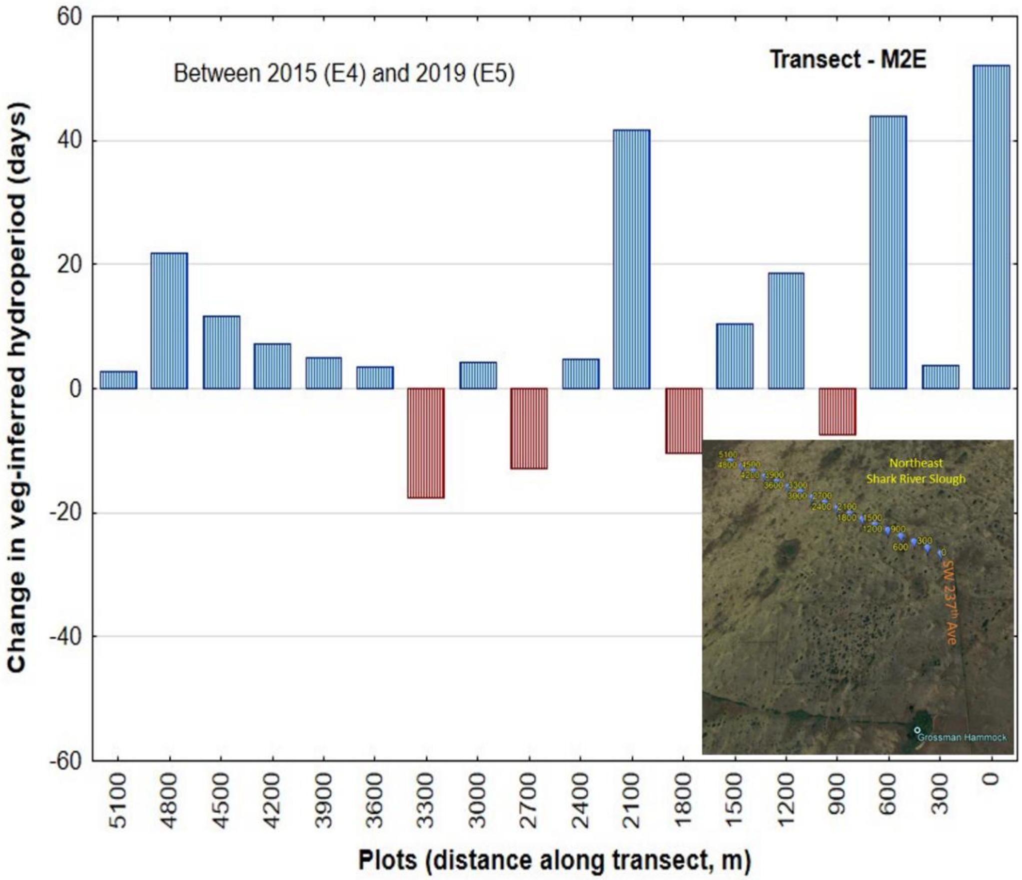

Figure 34: Change in vegetation-inferred hydroperiod between different surveys at the vegetation monitoring plots on the marl prairie portion of the Transect M2E.

On M3, where marl prairie sites were surveyed on both sides of SRS, the vegetation change pattern differed between eastern and western prairies. While species composition in western prairies shifted towards a drier type, as evidenced in an increase in the abundance of *Schizachyrium rhizomatum*, the direction of change in vegetation composition in the eastern prairie sites on this transect showed a mixed pattern (Appendix 3). Several sites at the distal portions of the transect, especially those close to the eastern Park boundary, and the sites close to the slough, exhibited an increase in inferred-hydroperiod, suggesting that species composition at these sites shifted toward a wetter type between 2007 and 2016 (**Figure 35**). However, between the last two surveys, E3 (2013) and E4 (2016), the magnitude of change toward wetter vegetation type along the eastern boundary of ENP was relatively less. Surprisingly, in recent years, the abundance of representatives of both prairie and hydric species were observed to increase on this section of the transect. Mean relative abundance of both sawgrass (*Cladium jamaicense*) and muhly grass (*Muhlenbergia capillaris* ssp. *filipes*) doubled in three years, from 2013 and 2016. The relative abundance of these species in 2016 was similar to the values in 2007.

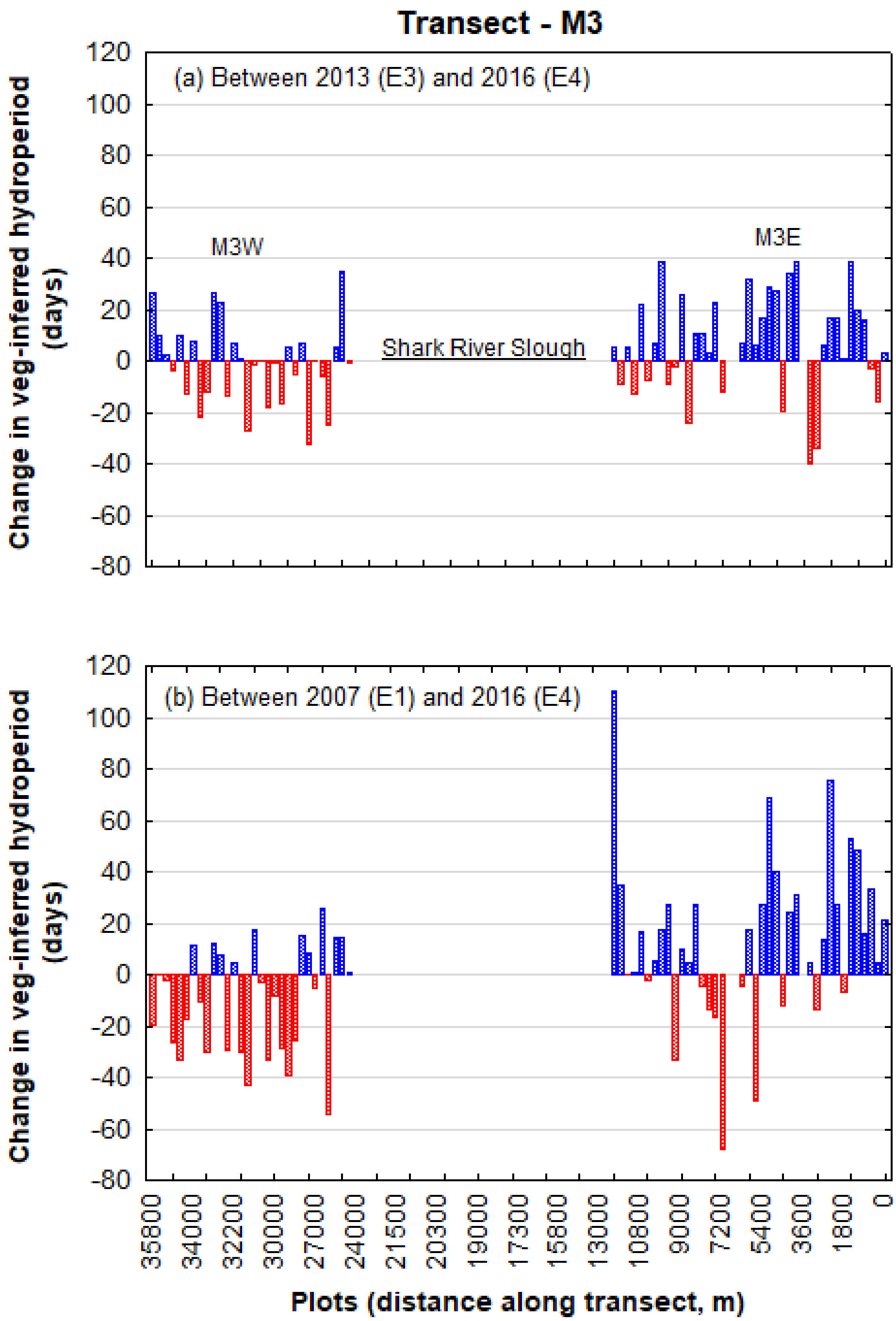

Figure 35: Change in vegetation-inferred hydroperiod between different surveys at the vegetation monitoring plots on the marl prairie portion of the Transect M3.

On M4, which also has marl prairie sites located on both sides of SRS, there was little compositional change during the three years between 2014 (E3) and 2017 (E4). During this period, vegetation composition at a majority of sites showed a drying trend (**Figure 36**). However, this shift in vegetation composition differed from the long-term trend observed on this transect, especially on the eastern portion of the transect. Over the ten years between 2007 (E1) and 2017 (E4), eastern and western prairies showed different patterns. Vegetation at the sites to the west of SRS (M4W sites) shifted towards drier type, whereas vegetation at the eastern portion of the transect (M4E), especially west of the main Park road (sites at >3000 m from the beginning of the transect), shifted towards wetter type.

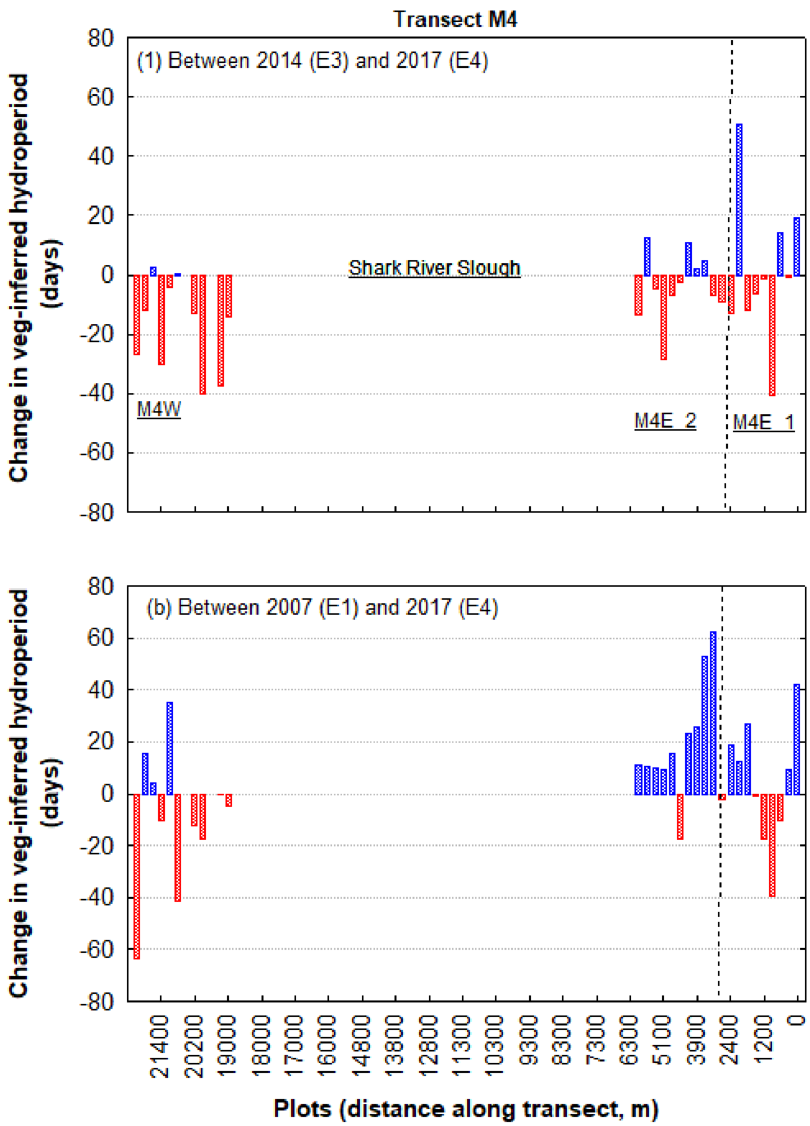

Figure 36: Change in vegetation-inferred hydroperiod between different surveys at the vegetation monitoring plots on the marl prairie portion of the Transect M4. Vertical dashed line is the location of Main Park Road separating eastern marl prairie of Transect M4 into M4E_1 and M4E_2.

Transect M5, which consists mainly of marl prairie sites, is divided into section M5W (west of the Park road) and M5E (east of the Park road), and M5W is wetter than M5E (**Figure 9**). In general, both the short term (2014-2018) and long term (2008-2018) trend in vegetation inferred hydroperiod along the transect showed that vegetation in these areas have shifted towards a wetter character (**Figure 37**). However, between 2014 (E3) and 2018 (E4), 67% of western sites exhibited either minimal change or showed a shift in vegetation composition towards a drier type, a trend also revealed by the trajectory analysis results (**Figure 38**). Over the 10-year period (between E1 and E4), there was a marked increase in abundance of species indicative of wet conditions. Such changes were more uniform at sites on the eastern portion of the transect (plot 4500-9000) (Appendix 3). In contrast, on the eastern section of the transect, the mean cover of muhly grass (*Muhlenbergia capillaris* var. *filipes*) and bluestem (*Schizachyrium rhizomatum*) decreased from 15% to 7.6%, and from 13.2% to 8.5%, respectively.

The westernmost part of the transect M5 runs into an area which transitions from freshwater marsh to mangroves. The first 900 m of the transect from the west are classified as mangroves. On the first 3,300 m of western portion of the transect, there was an increase in both frequency and cover of mangroves in 10 years. For instance, the mean importance value (IV) of red mangrove increased from 0.75% to 3.85% over the study period (Appendix 3).

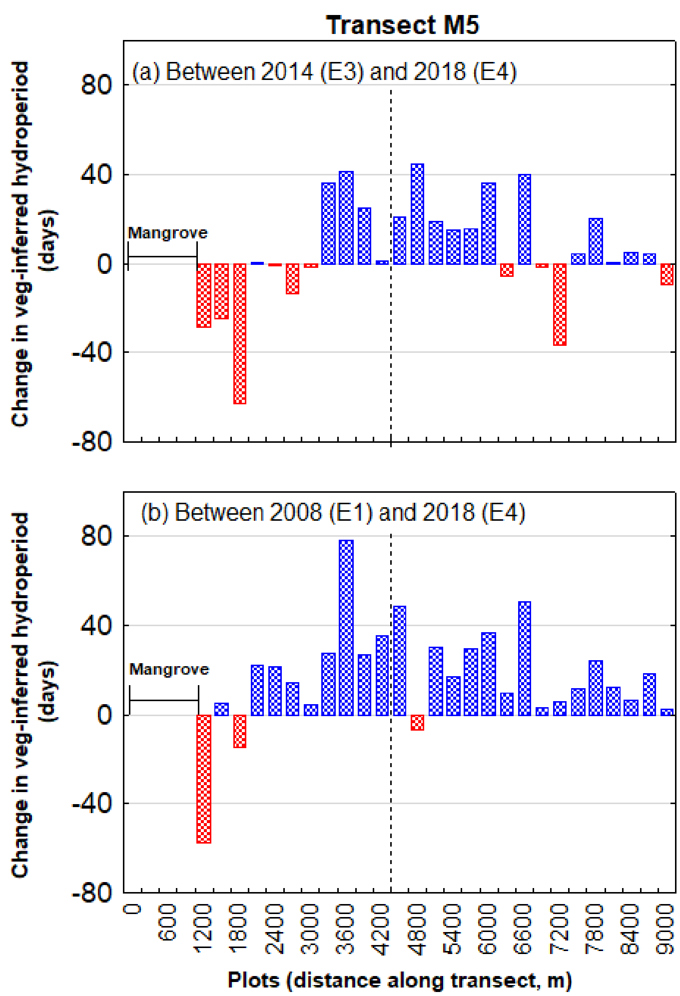

Figure 37: Change in vegetation-inferred hydroperiod between different surveys at the vegetation monitoring plots on the marl prairie Transect M5 both west (0-4200) and east (4500-9000) of the road (separated by dotted line).

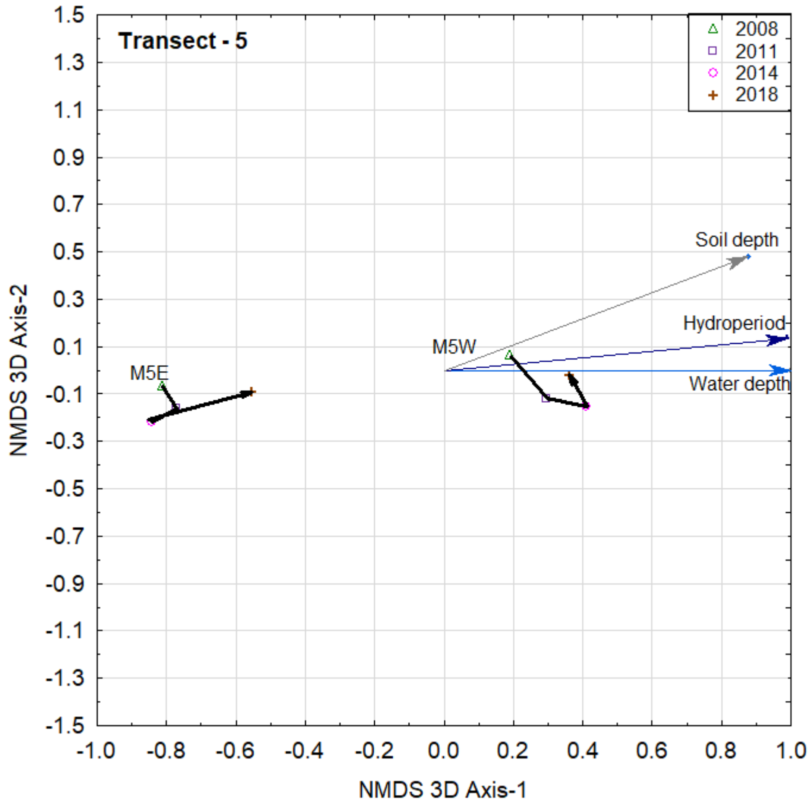

Figure 38: NMDS ordination bi-plots of the trajectory of centroid and the environmental vectors fitted in the ordination space for transect M5. The ordination is based on species abundance data collected four times between 2008 and 2018 in the prairie portion of the Transect M5. Initial point and the end of the trajectory represent the 2008 and 2018 survey, respectively

Species richness in marl prairies

The shift in vegetation composition observed over 14 years in the marl prairie portion of the transect M1 resulted in changes in species richness. On M1, mean species richness showed an increasing trend until E4 (2014) (**Figure 39**), as a drying trend was observed over 13 years in NESRS where the transect is located. However, in the next four years, the species richness decreased, and it was significantly (Pairwise t-test, p = 0.03) lower in 2019 (E5) than in 2015 (E4). Likewise, on M2E, mean species richness decreased over 4 years from 9.4 (± 7.9) species/plot in 2015 to 8.4 (5.6) species/plot in 2019, though the difference was not statistically significant (Pairwise t-test, p=0.175) (**Figure 39**).

The other three transects (M3-M5) had been surveyed only four times until 2018. The change pattern in species richness on M3 differed between eastern and western portions of the transect. On the eastern portion of M3, species richness was significantly lower during E4 (2016) than E3 (2013) (**Figure 39**). In contrast, on its western portion, M3W, species richness was significantly higher during the E4 survey than any previous year, mainly owing to the drying trend in that area. On M4, species richness was almost the same over the decade (2007-2017), except in the M4E_2 portion of the transect (east of main Park road). Here the sites were much wetter in recent years. At the sites in M4E_2, species richness was significantly lower during the E3 and E4 surveys than during the previous two surveys (**Figure 40**). On M5, species richness did not vary much across survey years. However, between E1 and E4 surveys, there was a small decrease in species richness (**Figure 40)**. Such a decrease in richness was significant (Pairwise t-test: df = 15, p = 0.003) in the eastern portion of the transect, corresponding with the increase in wetness of the sites in that area.

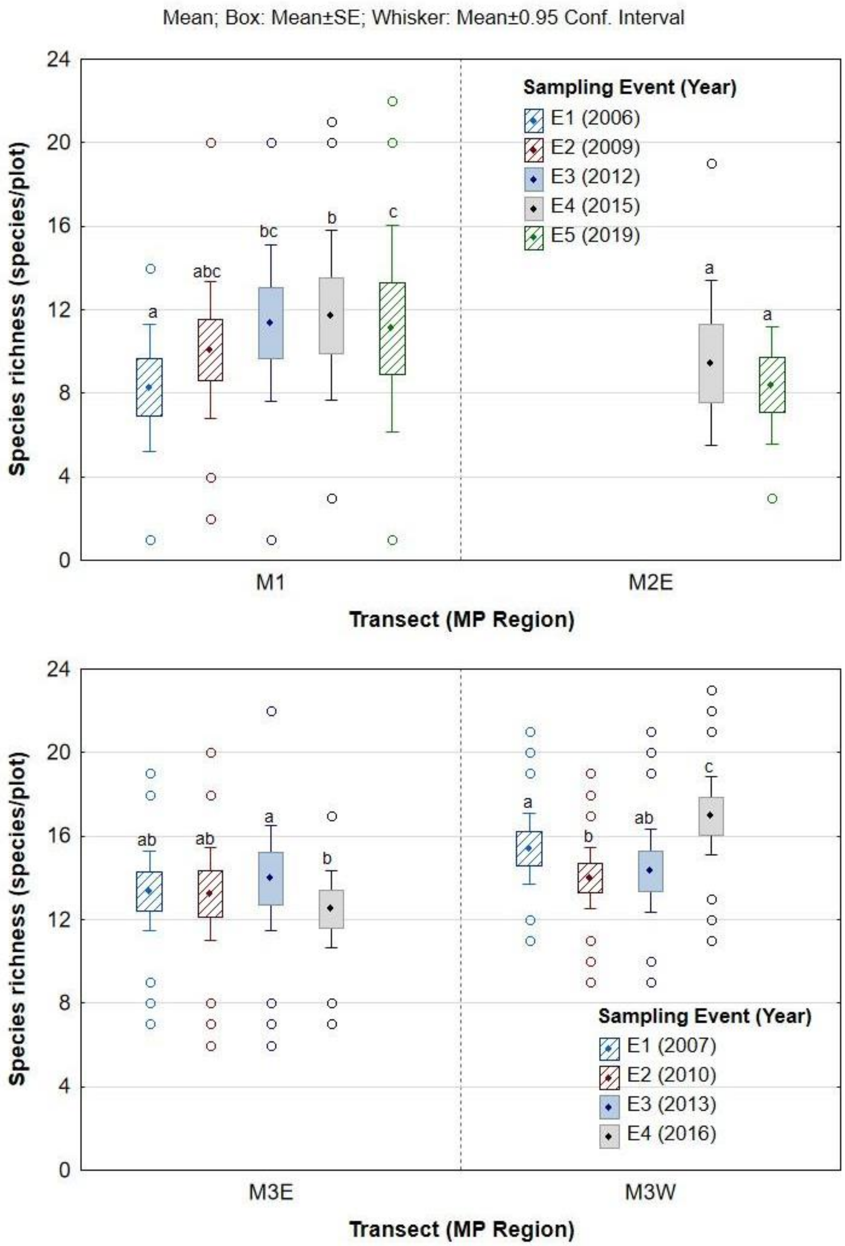

Figure 39. Plant species richness (species/plot) at the sites in the marl prairie portion of the transects M1, M2E and M3. Transect M3 extends within the marl prairies on both sides (M3E and M3W) of Shark River Slough. Different letters represent significant (pairwise t-test; p < 0.05) difference in species richness between surveys on individual transects or sections of a transect.

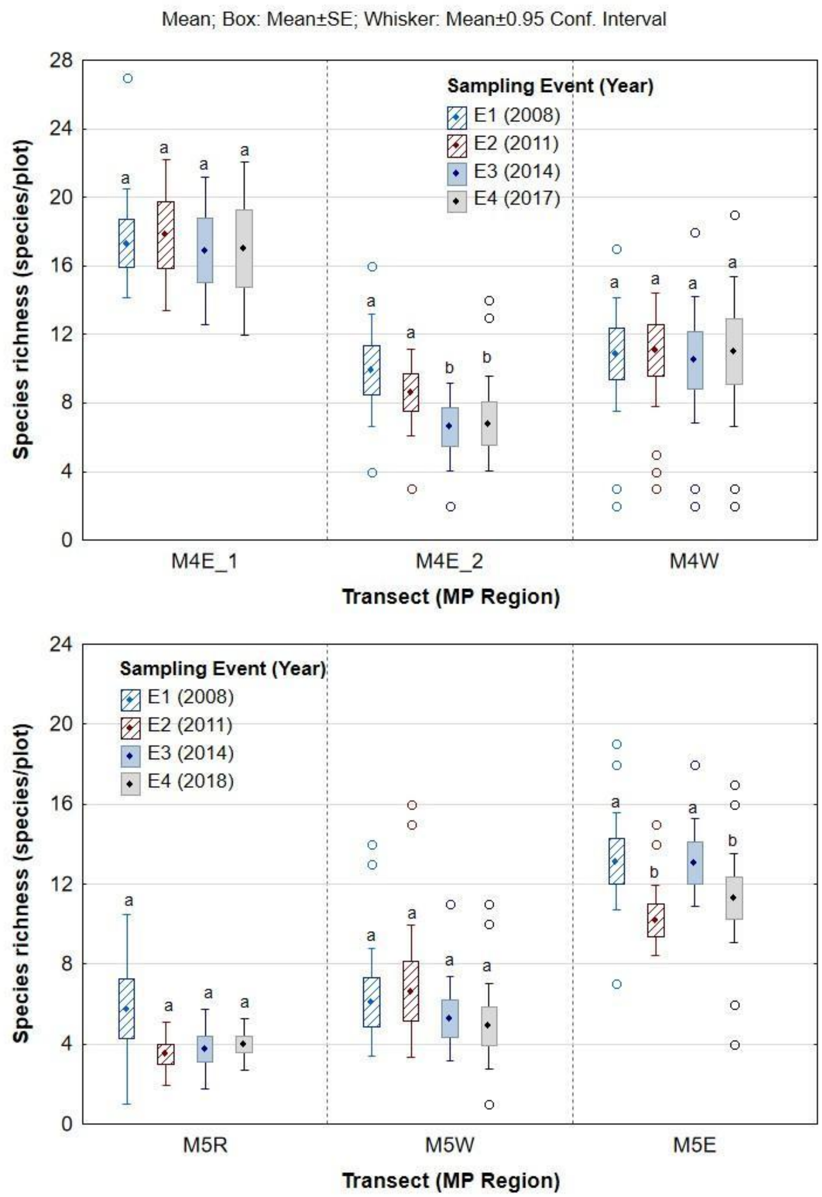

Figure 40. Plant species richness (species/plot) at the sites in marl prairie portion of the transects M4 and M5. Transect M4 extends within the marl prairies on both sides (M4E and M4W) of Shark River Slough. Moreover, M4E and Transect M5 are intersected by Main Park Road. Different letters represent significant (pairwise t-test; $p < 0.05$) difference in species richness between surveys on individual transects or sections of a transect.

Change in aboveground plant biomass

Over 13 years (2006-2019), mean aboveground plant biomass did not change much on M1 (**Figure 41**). Though, the biomass was slightly less during the 2019 (E5) survey than the 4th (E4) survey in 2016. Between the E4 (2015) and the E5 (2019) surveys, a similar trend was observed on M2E. During the E4 and E5, mean (± SD) plant biomass on M1 was 692 ± 711 g m^{-1} and 542 ± 364 g m^{-1}, whereas the biomass on M2E was 455 ± 247 g m^{-1} and 396 ± 158 g m^{-1}, respectively. On M3, aboveground plant biomass significantly changed over the study period (2008-2016) during which the sites were surveyed four times (E1-E4), and the transect is still to be surveyed a 5th time. On the eastern portion of M3 (M3E), where all but three plots burned in the Mustang Fire of 2008, plant biomass during the E2 survey, two years after the fire, was only half of what it was during E1. Mean (± SD) biomass during E1 and E2 was 783 ± 341 g m^{-1} and 403 ± 197 g m^{-1}, respectively. In this portion of M3, biomass recovered in three years, but by the time of E3, it was still only two-thirds of the initial biomass. In next three years, biomass increased slightly, but the mean biomass during the E4 survey (541 ± 273 g m^{-1}) was not significantly different (pairwise t-test; df = 39, p = 0.428) from the biomass during E3 (521 ± 267 g m^{-1}). In contrast, in western marl prairie (M3W), biomass showed an increasing trend during the first three surveys (E1-E3), but the biomass decreased between the E3 (2013) and the E4 (2016) surveys.

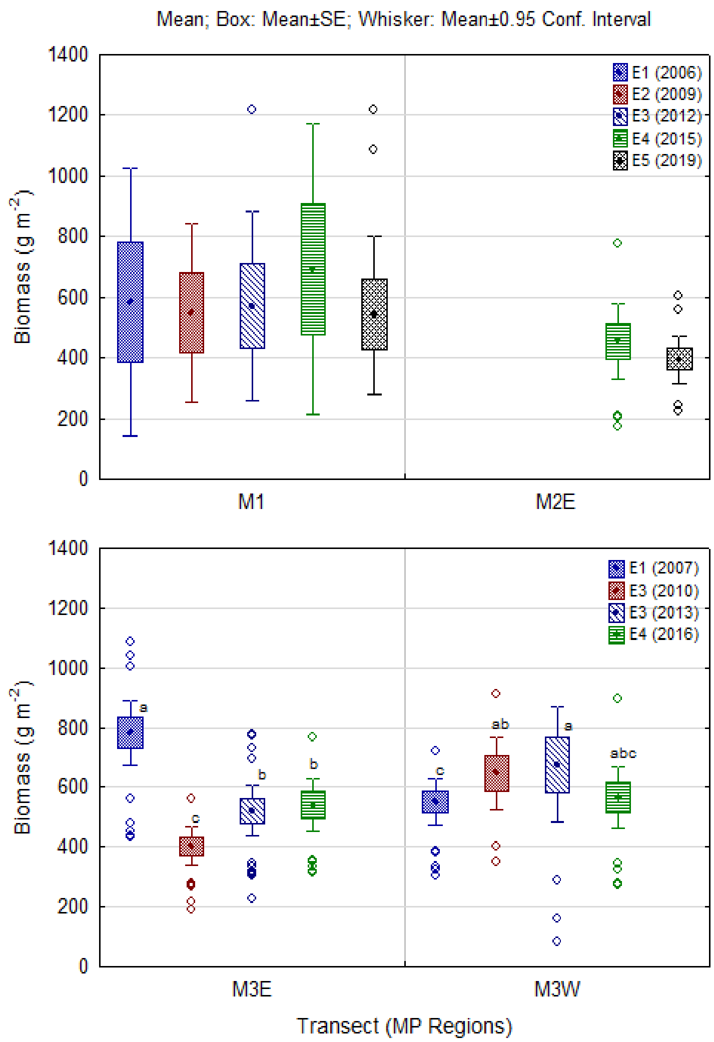

Figure 41: Above ground plant biomass (g m^{-2}) at the sites in the marl prairie portion of the transects M1, M2E and M3. M3 extends within the marl prairies on both sides of Shark River Slough. Different letters represent significant (pairwise t-test; p < 0.05) difference in aboveground biomass between surveys on individual transects or sections of a transect.

Biomass on transect M4 was more or less the same during the first three surveys (E1-E3). However, biomass during the 2017 (E4) survey varied spatially and across compartments (**Figure 42**). For instance, at the eastern sites, but west of the main park road (M4E_2), where hydrologic conditions during the 2017 (E4) survey were wetter than in previous survey years, aboveground biomass in 2017 (E4) was significantly (Paired t-test: $p < 0.001$) less than in 2007 (E1) and 2010 (E2). In contrast, at the sites on the western portion of the transect (M4W), aboveground biomass was significantly higher in E4 than the first two surveys, i.e., E1 and E2. In general, mean (± SD) aboveground biomass at sites west of Shark River Slough was 2-3 times higher than biomass in the eastern prairies. In 2017, the mean (± SD) aboveground biomass was 1,560 ± 604 g m^{-1}, 432 ± 145 g m^{-1} and 557 ± 176 g m^{-1} on M4E_1, M4E_2 and MW portions of the transect M4, respectively.

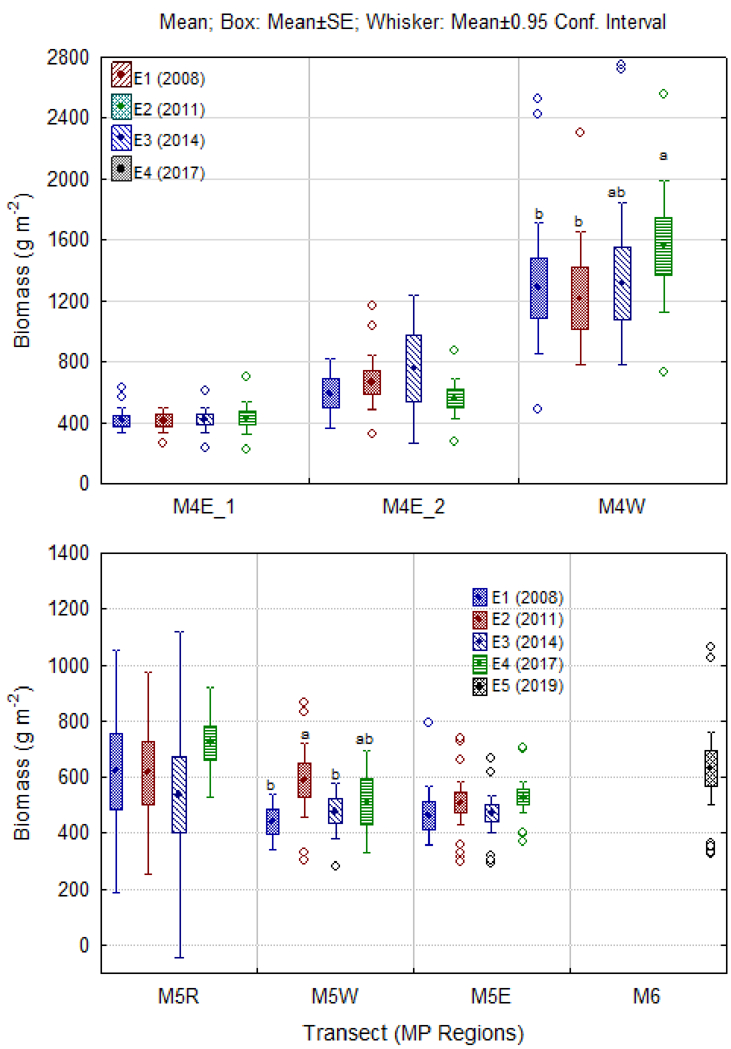

Figure 42: Above ground plant biomass (g m^{-2}) at the sites in the marl prairie portion of the transects M4, M5 and M6. M4 extends within the marl prairies on both sides of Shark River Slough, whereas both M4 and M5 extend both sides of the Main Park Road. Different letters represent significant (pairwise t-test; $p < 0.05$) difference in aboveground biomass between surveys on individual transects or sections of a transect.

Biomass on transect M5 remained almost the same throughout the four surveys. The western portion of the transect, M5W, had a slight increase in biomass during the 2011 (E2) survey. However, biomass during the most recent survey, E4 (2018) was not significantly different ((Paired t-test: $P > 0.05$) from the biomass in E1 or E2. In 2018, the mean (± SD) aboveground biomass was 724 ± 122 g m^{-1}, 512 ± 274 g m^{-1} and 528 ± 106 g m^{-1} on M5R, M5W and M5E portions of transect M5, respectively.

The transect M6, which was established and first-time surveyed in 2019, had the mean above ground biomass of 631 ± 371 g m^{-1}. On this transect, biomass value ranged between 324 g m^{-1} and 1,728 g m^{-1} in sawgrass marsh.

4. Discussion & Conclusion

In the Greater Everglades, the relationship between hydrologic regime and vegetation distribution is dynamic. Along the marl prairie-slough gradient, vegetation shift on individual transects was influenced by year-to-year variation in water conditions, possibly caused by both rainfall and water management activities. For instance, while water level was above the thirty-year average during the mid-to-late 1990s, and continuously for three years prior to the 2005 survey in northern SRS, water level was at or below the 30-year benchmark during the next four years. Moreover, in subsequent years, including the 2011 and 2014 drought, mean annual water level varied greatly. However, in recent years (2015-2019), water level was mostly above the 30-year benchmark.

Periodic fluctuations in annual mean water level were reflected in the four-year average hydroperiods and water levels that we used to examine the vegetation responses to the short-term changes in hydrologic regimes. At the slough sites along two (M1 and M2) of four transects, the 4-year average mean water depths before E4 (2014-2018) and E5 (2018-2019) surveys were higher than the previous two (E3 and E2) surveys (**Figure 3**). The mean water depth at the sites on the Transect M4 followed the same trend. In concurrence with the observed hydrologic shift, vegetation composition in slough portions of M1, M2 and M4 also shifted toward a more hydric type. In contrast, between E3 and E4 surveys, vegetation change on M3 was towards a drier type. Since not all transects were surveyed in the same year, the annual variation in water conditions might have also affected the magnitude and direction of vegetation change on these transects. For instance, conditions in 2014, the year before the 2015 survey on Transect M3, were very dry, which might have caused an aberrant shift in vegetation at slough sites on M3 compared to other transects. In general, the sensitivity of vegetation to short-term variation in hydrologic conditions observed in this study supports earlier findings that in Everglades prairies and marshes, discernible change in species composition can occur in periods as short as 3-4 years (Armentano et al. 2006; Zweig and Kitchens 2008; Gann and Richards 2015; Sah et al. 2014).

In the Everglades, the relative abundance of sawgrass and other hydric species such as spikerush, bladderwort and water lily are considered indicators of water conditions in the ridge and slough landscape (Ross et al. 2003; Zweig and Kitchens 2008; Gann and Richards 2015; Ross et al. 2016). In this study, mean sawgrass abundance (Importance Value, IV) showed an increasing trend until the 2010 survey, whereas the species' IV when averaged over slough sites on all four transects decreased in the next eight years. In contrast, the mean importance value of bladderworts showed an opposite trend. While during the E4 (2014-2017) survey on all four transects, sawgrass abundance was still much higher and that of bladderwort was significantly lower than during the 1999 survey. During the E5 (2018) survey, when only two transects (M1 and M2) were surveyed, IV of these two species were not statistically different from those in 1999, suggesting that vegetation composition at M1 and M2 in 2018 was very similar to the composition in 1999. The short-term changes in sawgrass cover observed during the last two decades in SRS support the longer-term dynamics, described for the post-drainage era in the Everglades by Bernhardt and Willard (2009). Other researchers have also reported an expansion of sawgrass and other emergent species, such as spikerush, in the R&S landscape, primarily due to decreases in water level (Busch et al., 1998; Zweig and Kitchens, 2008, 2009; Nungesser 2011) and flow velocity (Larsen et al. 2011). Such expansion may occur within 3-4 years, especially when a minimum water level is maintained beneath the peat surface of the sloughs for three consecutive dry seasons (Zweig and Kitchens 2009). While the extensive expansion of sawgrass could be a step towards succession toward woody vegetation, especially when it occurs on elevated ground that experiences prolonged dry conditions, the extended wet seasons that occur intermittently would reverse the process. In the slough portions of the study transects, both 4-year average hydroperiod and mean annual water depth before E4 and E5 surveys were higher than before E3. Results suggest that an increase of even 5-10 cm mean annual water depth in SRS can rapidly shift the vegetation toward one more characteristic of slough, as was evidenced in overall decrease in sawgrass and increase in bladderworts in recent years (2014-2018).

The deviation in trajectories of vegetation shift observed in the slough portion of transects is also affected by fire. Several slough sites on transects M1-M3 burned between 2006 and 2012. The Mustang Corner fire that occurred in May 2008, following almost two years of drought, ignited at a time when water level was 65 cm below the surface (Ruiz et al. 2013), and may have consumed significant amounts of peat on the SRS portion of transect M1. The vegetation at five burned sites on M1, where the mean cover was 32% in 1999, was very sparse (cover 11.2%) and consisted mostly of hydric species during 2011 survey. However, over the next three years, vegetation cover recovered, and mean species richness increased. Fire-induced elevation loss may also have contributed to an increase in mean annual water depth and compositional shift toward wetter vegetation at several locations on this transect. In comparison to dry season fire, wet season fire seems to have less impact on vegetation cover. All 18 slough sites on M1, and 25 sites on M2 were burned in two different prescribed fires in 2012 **(Table 2)**, but the mean total cover in 2014, two and half years after fire, was already 65% of preburn cover. Twelve of the 25 sites on M2 burned again in March 2018, 6 months before the E5 survey. Even though those sites burned during the dry season, 6 months after fire, only half of the 12 sites showed significantly reduced vegetation cover. At the other half of the sites, mean vegetation cover was about 90% of the cover recorded in 2014, suggesting that it was a patchy burn, possibly because there was about 30 cm of standing water at the sites during the fire. In March, 2018, the same fire burned 65 % slough sites on M3, but the impact of this fire on vegetation has not yet been assessed.

Short-hydroperiod marl prairies in the Everglades are flooded annually for varying periods, while remaining dry for extended portions of the year. Generally, in seasonally-flooded ecosystems similar to the Everglades marl prairies, differences in optimum flooding tolerances of species present in the vegetation mosaic form the basis for variation in vegetation composition (Ross et al. 2006). Hence, the change in vegetation-inferred hydroperiod on the prairie portion of M1, M3, M4, and M5 reflects the amount and direction of change in vegetation (Armentano et al. 2006). During the first three surveys of this study, the observed vegetation shift on M1 toward a drier type was not a surprise, especially considering that most years after the E1 survey in spring 2006 were relatively dry. However, this trend reversed after E4 (2015), and vegetation shifted back towards a wetter type. A similar trend was observed on M2E, which is further south of M1, but still within NESRS. In recent years, the wetting trend on those transects was primarily because the NESRS region received more water delivery from the WCAs during the 2016 emergency operations (Abtew & Ciuca, 2017), and also due to implementation of the MOD Water Delivery Project components, including the Increment (Increment 1, 1.1, 1.2 and 2) Field Tests. The Increment Field Tests that began in October 2015 and continued through 2019 delivered 343,400 and 450,000 acre-feet of water in 2018 and 2019, respectively (USACE, 2020). The trend of increased water deliveries to NESRS from Increment 2 is assumed to continue until the Combined Operations Plan (COP) is implemented. Moreover, under the preferred plan (ALTQ+) identified in COP, water delivery into ENP (both northeast and western SRS combined) is projected to increase by 25%, and the delivery into NESRS by approximately 162,000 acre-feet per year on average (USACE 2020a). These potential changes in water conditions within the NESRS region are likely to result in changes in vegetation communities in the area. In 2019, while the majority of the M1 prairie sites had a vegetation composition that was still drier than in 2005, they were relatively wet (Mean vegetation inferred hydroperiod = 247 days) and possibly transitioning to marl marsh vegetation types. Likewise, the vegetation at most M2E sites is already more hydric (Mean inferred hydroperd = 296 days) than a typical marl wet prairie (Inferred hydroperiod = 120-240 days) type (Ross et al. 2006), and with the trend of increased water deliveries, vegetation at these sites is likely continue to transition to the much wetter marsh vegetation types.

Management-driven water conditions were also responsible for the discrepancy in vegetation change patterns observed in the eastern and western prairies on M3, and to some extent on M4. Water conditions in the prairies west of SRS are influenced by the regulatory schedules for the S-12 structures along Tamiami Trail, implemented under the operational objectives of Interim Structural and Operation Plan (ISOP)/Interim Operational Plan (IOP). In concurrence with management efforts to regulate water deliveries from the S-12 structures, a consistently low water level has been maintained at water recorder NP-205. This has caused the vegetation composition to shift toward a drier type in recent years. However, such a shift towards drier vegetation was less prominent during the E4 (2016) survey, primarily because of the unusually high-water conditions in the spring of 2016. These conditions were brought on by high rainfall due to the very strong El Niño, which necessitated the 2016 Temporary Emergency Deviation operated by USACE. The four-year average water depth during E4 survey also was about 5 cm higher than during the previous two surveys. The effect of spring 2016 flooding will likely be intensified, and the drying trend will be reversed if the water conditions in subsequent years continue to be high. In the past, dry season flooding followed by years of high-water conditions have also caused significant change in habitat conditions. For instance, the management-driven spring season flooding of 1993, followed by high rains in subsequent years, caused short-hydroperiod wet prairie vegetation to change to long-hydroperiod sawgrass marsh that was less suitable habitat for Cape Sable seaside sparrow (CSSS) (Nott et al. 1998). However, under the current water management goal of moving water from west to east, these conditions are unlikely to persist. Recent modeling carried out using Regional Simulation Model (RSM) tool to evaluate the potential impact of Everglades Restoration Transition Plan (ERTP) has suggested that marl prairies northeast of current CSSS habitat will be relatively dry (USACE 2011, 2014; USFWS 2016), which will potentially result in a major change in vegetation composition in the transition zone. Thus, periodic vegetation surveys in the region are important to determine the vegetation responses to the potential changes in hydrologic conditions.

Management-driven water condition has also been a driver of the vegetation shift observed on the eastern portion of transect M3. In this region, water pump structures at S332B and S332C deliver water from the L31N canal into a series of interconnected detention ponds. These ponds have a large fixed-crest weir on the western levee that allows water from the pond to enter ENP marl prairies. In addition, water may also enter ENP through subsurface flow. The purpose of operating pump stations along the L-31N canal includes lowering canal and groundwater levels, but creating a continuous hydraulic ridge to control seepage back to the canal while protecting the marl prairie (sparrow habitat) from further deterioration (USACE 2006). Pumping through S332B and S332C serves the management goal of re-hydrating the marl prairies of the Rocky Glades. In addition, increased water deliveries in NESRS during the Increment Field Tests have augmented the wetting trend, especially in the transition zone where the influence of retention ponds is probably minimal. Thus, a shift in vegetation towards wetter types indicates that the management goal is being achieved, at least in part. However, regular monitoring is essential to detect a signal that inputs of water from the ponds continue to cause a shift in vegetation from marl-dominated wet prairie to marsh types.

In addition to a positive outcome of the operations of water pumps and detention ponds along the eastern border of the Park, the impact of such management efforts on prairie vegetation needs to be interpreted cautiously, because water flow from detention ponds towards prairies in the Park may have adverse consequences as well. For instance, periphyton near inflow structures had elevated phosphorus in comparison to adjacent marl prairie sites to the west, suggesting an increase in P-loading due to long-term exposure of the canal-side sites to seepage (Gaiser et al.

2008; 2014). Sah et al. (2014) also concluded that vegetation in the upper Taylor Slough basin followed a significant trajectory along the vector representing the phosphorus gradient, possibly due to the influence of seepage water from the detention ponds. In this study, while soil TC, OC and TN increased along marl prairie-slough gradient as expected, soil phosphorus at the site nearest to (300m) the detention pond levee was higher than at several sites 1200-2400 m from the levee. In areas of lower P enrichment, physicochemical measurements that include "bioavailable" P as estimated through fractionation schemes, enzyme (glucosidase, MUF-C and phosphatase, MUF-P) activities and microbial biomass have been used to characterize P-limitation (Wright and Reddy, 2001a, b). In this study, while we observed an increase in MUF-C and microbial biomass-C and P along the marl prairie-slough gradient, the highest values of MUF-C, microbial biomass-P and labile-P were observed in soils at a site near the levee, suggesting an increase in soil P at that site. If water from the detention ponds continues to influence vegetation in the adjacent prairies, the water quality issue may need to be addressed so that the affected marl prairies do not shift to another stable state more adapted to P-enriched soil (Hagerthey et al. 2008).

Contrary to management-induced changes in water conditions followed by a shift in vegetation composition observed on Transect M3, the hydrologic changes together with the vegetation shift on southern transect M4 are more likely rain-driven. In the prairie portion of these transects, vegetation was first time surveyed in the spring of 2008, an extremely dry year, and similar conditions had prevailed during the previous two years. Subsequently, water conditions varied, though the mean annual water level was above the 30-year average for five of the next eight years, probably causing vegetation on this transect to shift toward a wetter type. However, differences in direction and magnitude of vegetation shift observed between M4E_1 and M4E_2, eastern and western sides of the main park road, respectively, were obvious. A shift in vegetation toward wetter types at most sites northwest of the road, but not the southeastern portion, suggests that the main Park road acts as the barrier to the natural flow of the water from north to south, resulting in an impounding effect in that region. In fact, mean hydroperiod, averaged over four years, was 60 days longer and mean annual water depth was 15 cm higher at the M4E_2 than the M4E_1. A similar trend was observed along the transect M5, where M5W sites were wetter than the M5E. On transect M5, mean hydroperiod, averaged over four years was 46 days longer and mean annual water depth was 9 cm higher at the M5W sites than M5E sites. A number of culverts are placed along the road to facilitate the natural flow of water. However, while the culverts along the east-west road in the pinelands allow the water to flow southward, in the area south of Pa-hay-Okee there is a predominant westward flow of water (Stewart et al. 2002). This might be the reason why 94% of sites on the newly established transect M6 experienced hydroperiods >330 days and supported marsh vegetation types. Only two sites, both within 200 m from the Main Park Road, had the prairie vegetation types (**Figure 26**). One intended benefit of this difference in water conditions on both sides of the Main Park Road is that the CSSS habitat in sub-population B, particularly southeast of the Park road, is relatively unaffected by increasing wetness observed along the western and southwestern portions of sub-populations B and E (Sah et al., 2019).

Despite the prevalence of more naturally driven hydrologic conditions, an influence of water management activities on the western section of the transect M4, cannot be ruled out. In the western part of the prairie west of Shark River Slough, relatively high-water level persisted in the mid- to late 2000s, mainly because the hydrologic conditions in this area are influenced by flows through the culvert and bridges on Tamiami Trail and the Loop Road (Kotun et al. 2009). However, the current water management goal of moving water from west to east seems to reverse the trend to some extent. Moreover, sea level rise (SLR) also might have an impact on the southwestern portion of the marl prairie. This seems to be the case on transect M5, which at its western end transitions from freshwater to mangroves; a portion of the transect is primarily dominated by red mangrove (*Rhizophora mangle*). Over ten years (2008-2018), the mean frequency and cover of red mangrove has increased in the western portion of M5, suggesting the increasing influence of sea-level driven saltwater intrusion in that area.

Along MP-S gradients, changes in hydrologic and fire regimes are likely to also affect the soil characteristics. We have not been regularly monitoring the changes in soil characteristics, however, we have examined the variation in some soil characteristics along the gradients. Our study suggests that there is a great variation in soil TC, TN, TP and N:P ratio along the gradient, and the extent of variation is strongly correlated with the steepness of the hydrologic gradient. On the transect M3, where mean hydroperiod ranged between 90 and 360 days, coefficient of variation (CV) of the soil characteristics was almost twice as high as that of soils on transect M6, where 94% of sites had the mean hydroperiod >330 days. The soil characteristics described for sites on transects M3 and M6 during the present study will serve as the baseline data to determine any changes in those characteristics over time.

The distribution of C_3 and C_4 plants varies along hydrologic gradients, and in general, C_3 species increase in importance as wetness increases (Mozeto et al. 1996; Kotze and O'Connor 2000). In this study, we also observed a decrease in C_4 abundance with an increase in wetness. Moreover, a significant negative relationship of soil organic matter and plant $\delta^{13}C$ values with hydroperiod and water depths observed along MP-S gradient supports the geochemical theories that the isotopic composition of soil organic matter is related to plant type, productivity or isotopic composition (Kelly et al. 1998). These carbon isotope trends could indicate decreased $\delta^{13}C$ discrimination by plants with decreased water availability or values for plant $\delta^{13}C$ ratio could also be indicative of the proportion of C_3 or C_4 plants present, with C_3 plants having values of -32 to -22‰ and C_4 plants from -17 to -9‰ (Boutton et al. 1998). Along the hydrologic gradient on the M3 transect, C_4 plants are abundant in the eastern portion of the transect, which has a relatively short hydroperiod. In concurrence with a decrease in C4:C3 ratio along the MP-S gradient, the mean value of both plant and soil $\delta^{13}C$ decreased with an increase in wetness. It should be noted that there was small variation in $\delta^{13}C$ values (small standard error and narrow confidence interval) in ridge and slough area (M3-16000 to M3-22500), where mostly C_3 plants were present. In contrast, in eastern MP and transitional portions of the M3 transect, variation is high due to the presence of varied proportions of C_3 and C_4 plants. The relationship between species composition and soil organic characteristics along the gradient suggests that the species traits, such as C_4/C_3 ratio, and their relative abundance can possibly be used as indicators of soil organic matter turnover rates in this area.

In summary, regional differences in hydrologic regimes resulting from alternative management strategies have caused variation in species composition across the landscapes, and have also brought on temporal change in vegetation composition in Shark River Slough and adjacent marl prairies. The occurrence of these changes coincided with changes in hydrologic regimes during the past two decades. Recent increase in wetness together with the vegetation shift toward more hydric type at both the slough and eastern marl prairie sites of study transects suggest that restoration activities aimed at increased water delivery to the Park, especially in the NESRS region, are on the track of achieving restoration goals. Our results provide feedback for the adaptive management of Everglades wetland ecosystems along the marl prairie-slough gradient.

Acknowledgements

We would like to acknowledge the assistance in field and lab (during the period between 2005 and 2019) provided by the following members of our lab: Pablo Ruiz, Dr. Rachel King, Dave L. Reed, David Jones, Nilesh Timilsina, Mike Kline, Brooke Shamblin, Nate Colbert, Lawrence Lopez, Diana Rodriguez, Allison Lambert, Suresh Subedi, Danielle Crisostomo, Jesus Blanco, Junnio Freixa, Alex Martinez, Allison Jirout, Josue Sandoval and Santiago Castaneda. The project received financial support from the Department of Interior’s Critical Ecosystems Study Initiative (CESI), Everglades National Park (1998-2000) and the RECOVER working group within the Comprehensive Everglades Restoration Plan (CERP). The support from the RECOVER working group was provided through US Army Corps of Engineers (U.S. Army Engineer Research and Development Center) (Period 2014-2015: Cooperative Agreement # W912HZ-14-2-0023).

References

Abtew, W. and V. Ciuca (2017) South Florida Hydrology and Water Management. *In: 2017 South Florida Environmental Report Volume 1*. South Florida Water Management District (SFWMD), West Palm Beach, Florida.

Amador, J. A. and R. D. Jones (1993) Nutrient limitations on microbial respiration in peat soils with different total phosphorus content. Soil Biology and Biochemistry **5**: 793-801.

Armentano, T. V., J. P. Sah, M. S. Ross, D. T. Jones, H. C. Cooley and C. S. Smith (2006) Rapid responses of vegetation to hydrological changes in Taylor Slough, Everglades National Park, Florida, USA. Hydrobiologia **569**: 293-309.

Bernhardt, C. E. and D. A. Willard (2009) Response of the Everglades' ridge and slough landscape to climate variability and 20th century water-management. Ecological Applications **19**: 1723–1738.

Blake, G. R. and K. H. Hartge (1986) Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis, Part 1. American Society of Agronomy, Monograph **9**: 363–375.

Boutton, T.W., S. R. Archer, A. J. Midwood, S. F. Zitzer, R. Bol (1998) δ13C values of soil organic carbon and their use in documenting vegetation change in a subtropical savanna ecosystem. Geoderma **82**: 5-41.

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

CERP (2000) Comprehensive Everglades Restoration Plan. U.S. Army Corps of Engineer (USACE) and South Florida Water Management District (SFWMD), Florida, USA.

EDEN (Everglades Depth Estimation Network) (2008) South Florida Information Access (Sofia). http://sofia.usgs.gov/eden.

Gaiser E. E., R. M. Price, L. J. Scinto and J. C. Trexler (2008) Phosphorus retention and sub-surface movement through the S-332 detention basins on the eastern boundary of Everglades National Park. Year 3 Final Report to Everglades National Park, Homestead, FL, USA.

Gaiser, E. E., P. Sullivan, F. A. C. Tobias, A. J. Bramburger and J. C. Trexler (2014) Boundary effects on benthic microbial phosphorus concentrations and diatom beta diversity in a hydrologically-modified, nutrient-limited wetland. Wetlands **34** (Suppl 1): S55-S64.

Gann, D. and J. Richards (2015) Quantitative comparison of plant community: hydrology using large-extent, long-term data. Wetlands **35**: 81-93.

Hagerthey, S. E., S. Newman, K. Rutchey, E. P. Smith and J. Godin (2008) Multiple regime shifts in a subtropical peatland: community-specific thresholds to eutrophication. Ecological Monographs **78**: 547-565.

Juggins. S. (2003) C2 User guide. Software for ecological and palaeoecological data analysis and visualization. University of Newcastle, Newcastle upon Tyne, UK. 69pp.

Kantvilas, G. and P. R. Minchin (1989) An analysis of epiphytic lichen communities in Tasmanian cool temperate rainforest. Vegetatio **84**: 99-112.

Kelly, E.F., S.W. Blecker, C.M. Yonker, C.G. Olson, E.E. Wohl, L.C. Todd (1998) Stable isotope composition of soil organic matter and phytoliths as paleoenvironmental indicators. Geoderma, **82**: 59-81.

Kotun, K. Sonenshein, R., and DiFrenna, V. (2009). Analysis of flow across Tamiami Trail: An historical perspective. South Florida Natural Resources Center, Everglades National Park, Homestead, Florida. Technical Report (Unpublished Report).

Kotze, D. C. and T. G. O'Connor (2000) Vegetation variation within and maoung palustrine wetlands along an altitudinal gradient in KwaZulu-Natal, South Africa. Plant Ecology **146**: 77-96.

Larsen, L., N. Aumen, C. Bernhardt, V. Engel, et al. (2011) Recent and historic drivers of landscape change in the Everglades ridge, slough and tree island mosaic. Critical Reviews in Environmental Science and Technology **41**: 344-381.

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

McCune, B. and J. B. Grace (2002) Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR, USA.

McVoy C. W., W. P. Said, J. Obeysekera, J. A. VanArman and T. W. Dreschel (2011) Landscapes and Hydrology of the Pre-drainage Everglades. University Press of Florida, Gainesville, FL, USA.

Minchin, P. R. (1998) DECODA: Database for Ecological Community Data. Anutech Pty. Ltd., Canberra, Australia.

Minchin, P. R., M. Folk and D. Gordon (2005) Trajectory Analysis: A New Tool for the Assessment of Success in Community Restoration. Meeting Abstract, Ecological Society of America 90th Annual Meeting, Montreal, Quebec, August 7-12, 2005.

Mozeto, A. A., F. M. DE B. Nogueira, M. H. A. DE O. E. Souza, and R. L. Victoria (1996) C3 and C4 grasses distribution along soil moisture gradient in surrounding areas of the Lobo Dam, São Paulo, Brazil. Annals of the Brazilian Academy of Sciences **68** (1): 113-121.

Nungesser, M. K. (2011) Reading the landscape: temporal and spatial changes in a patterned peatland. Wetlands Ecology and Management **19**: 475-493.

Nott, M. P., O. L. Bass Jr., D. M. Fleming, S. E. Killeffer, N. Fraley, L. Manne, J. L. Curnutt, T. M. Brooks, R. Powell and S. L. Pimm (1998) Water levels, rapid vegetational changes, and the endangered Cape Sable seaside sparrow. Animal Conservation **1**: 23-32.

Olmsted, I. C., and L. L. Loope (1984) Plant communities of Everglades National Park. In: P.J. Gleason, (Ed). Environments of South Florida: Present and Past II. pp. 167-184. Miami Geological Society, Coral Gables.

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

RECOVER (2009) CERP Monitoring and Assessment Plan (MAP) – Revised 2009. Restoration Coordination and Verification. U. S. Army Corps of Engineers, Jacksonville, Florida, USA, and South Florida Water Management District, West Palm Beach, Florida, USA.

RECOVER. (2020) The Recover Team's Recommendations for Interim Goals and Interim Targets for the Comprehensive Everglades Restoration Plan. US Army Corps of Engineers, Jacksonville District, Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL. https://pdfs.semanticscholar.org/b545/b09e4581c654f936945ea769f9a285465c5b.pdf

Ross, M. S., P. L. Ruiz, D. L. Reed, K. Jayachandran, J. P. Sah, and M. T. Lewin. (2001). Assessment of marsh vegetation responses to hydrological restoration in Shark Slough, Everglades National Park. Final Report submitted to Everglades National Park, Homestead, FL, USA. 70 pp.

Ross, M. S., D. L. Reed, J. P. Sah, P. L. Ruiz, and M. T. Lewin (2003) Vegetation:environment relationships and water management in Shark Slough, Everglades National Park. Wetland Ecology and Management **11**: 291-303.

Ross, M. S., P. L. Ruiz, J. P. Sah, S. Stoffella, N. Timilsina, and E. Hanan (2005) Marl Prairie/Slough Gradients: Pattern and trends in Shark Slough and adjacent marl prairies. 1st Annual Report 2005.

Ross, M. S., J. P. Sah, P. L. Ruiz, D. T. Jones, H. C. Cooley, R. Travieso, J. R. Snyder, D. Hagyari (2006) Effect of Hydrology Restoration on the Habitat of the Cape Sable Seaside Sparrow. Report to Everglades National Park, Homestead, FL, USA. 50 pp.

Ross, M. S., J. B. Heffernan, J. P. Sah, P. L. Ruiz, A. A. Spitzig, E. Isherwood and J. Blanco. (2016). Everglades Ridge, Slough, and Tree Island Mosaics. Annual Report submitted to US Army Engineer Research and Development Center. Cooperative Agreement #: W912HZ-10-2-0030. Modification # P00004. Year 5 Report (2010-2015): 2016. 98 pp.

Ruiz, P. L., J. P. Sah, M. S. Ross and A. A. Spitzig (2013) Tree island response to fire and flooding in the short-hydroperiod marl prairie grasslands of the Florida Everglades. Fire Ecology **9** (1): 38 – 54.

Sah, J. P., M. S. Ross, J. R. Snyder, P. L. Ruiz, D. T. Jones, R. Travieso, S. Stoffella, N. Timilsina, E. Hanan and H. Cooley (2007) Effect of Hydrologic Restoration on the Habitat of the Cape Sable seaside sparrow. 2005-2006. Year-4 Final Report submitted to U. S. Army Corps of Engineers, Jacksonville, FL, USA. March 2007. 49 pp.

Sah, J. P., M. S. Ross, S. Saha, P. Minchin and J. Sadle (2014) Trajectories of vegetation response to water management in Taylor Slough, Everglades National Park, Florida. Wetlands (**Suppl 1**): S65-S79.

Sah, J. P., M. S. Ross and P. L. Ruiz. (2015) Landscape Pattern – Marl Prairie/Slough Gradient: Decadal Vegetation Change in Shark River Slough and adjacent Marl Prairies. Final Report-2014 (2005-2014) submitted to US Army Engineer Research and Development Center. Cooperative Agreement #: W912HZ-09-2-0018. May, 2015. 86 pp.

Sah, J. P., M. S. Ross, S. Stoffella, and R. Vidales. (2017a). Landscape Pattern – Marl Prairie/Slough Gradient: patterns and trends in Shark Slough marshes and associated marl prairies. Annual Report–Year 1 (2014-2015) submitted to US Army Engineer Research and Development Center. CA #: W912HZ-14-2-0023: Aug 2017. 24 pp.

Sah, J. P., M. S. Ross, S. Stoffella, R. Vidales and A. Martinez-Held. (2017b). Landscape Pattern – Marl Prairie/Slough Gradient: patterns and trends in Shark Slough marshes and associated marl prairies. Annual Report–Year 2 submitted to US Army Engineer Research and Development Center. CA #: W912HZ-14-2-0023: Aug 2017. 40 pp.

Sah, J. P., M. S. Ross, S. Stoffella, A. Maritnez-Held and A. Jirout. (2017c). Landscape Pattern – Marl Prairie/Slough Gradient: patterns and trends in Shark Slough marshes and associated marl prairies. Annual Report–Year 3 submitted to US Army Engineer Research and Development Center. CA #: W912HZ-14-2-0023: December 2017. 51 pp.

Sah, J. P., M. S. Ross, S. Stoffella and R. Vidales (2018) Landscape Pattern – Marl Prairie/Slough Gradient: patterns and trends in Shark Slough marshes and associated marl prairies. Annual Report-Year 4 (2014-2018) submitted to US Army Engineer Research and Development Center. CA #: W912HZ-14-2-0023: Dec 31, 2018. 59 pp.

Sah, J. P., Snyder, J. R., Ross, M. S., Stoffella, S., Vidales, R., Pulido, C. and Sandoval, J. 2019. Evaluation of Vegetation Response to Changes in Hydrologic Parameters within Cape Sable Seaside Sparrow Habitat, Everglades National Park, Florida/ Re-sampling of vegetation survey sites within Cape Sable seaside sparrow habitat. Annual (Year 2) Report submitted to U.S. Army-ERDC, Vicksburg, MS (CA # W912HZ-17-2-0003) and South Florida Natural Resources Center, Everglades & Dry Tortugas National Parks. Homestead, FL (CA # P16AC00032). 2019. 50 pp.

Sinsabaugh, R. L., S. Findlay, P. Franchini, and D. Fischer (1997) Enzymatic analysis of riverine bacterioplankton production. Limnology and Oceanography **42**: 29–38.

Smith III, T. J., A. M. Foster, and J. W. Jones (2015) Fire history of Everglades National Park and Big Cypress National Preserve, Southern Florida. Open file Report 2015-1034, U.S. Department of the Interior, U.S. Geological Survey.

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

Stewart, M.A., T. N. Bhatt, R. J. Fennema and D. V. Fitterman. (2002). The Road to Flamingo: an Evaluation of Flow Pattern Alterations and Salinity Intrusion in the Lower Glades, Everglades National Park. Open File Report # 02-59. US Geological Survey.

USACE (U.S. Army Corps of Engineers) (2006). Interim Operational Plan for Protection of the Cape Sable seaside sparrow, Central and Southern Florida Project for Flood Control and Other Purposes, Final Supplemental Environmental Impact Statement, 2006. Jacksonville District, Jacksonville, Florida.

USACE (U.S. Army Corps of Engineers) (2011) Everglades Restoration Transition Plan (ERTP): Final Environmental Impact Statement. U.S. Army Corps of Engineers, Jacksonville, FL.

USACE (U.S. Army Corps of Engineers) (2014) CERP – Central Everglades Planning Project (CEPP): Final Integrated Project Implementation Report and Environmental Impact Statement. U.S. Army Corps of Engineers, Jacksonville District, FL.

USACE (U.S. Army Corps of Engineers) (2020). *Final Environmental Impact Statement - Combined Operation Plan*. U.S. Army Corps of Engineers, Jacksonville, Florida.

USFWS (U.S. Fish and Wildlife Service) (2016) Biological Opinion for the Everglades Restoration Transition Plan-2006. Submitted to U.S. Army Corps of Engineers, Jacksonville, FL.

Van Lent T., R. W. Snow and F. E. James (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.

Watts, D., M. Cohen, J. Heffernan, and T. Osborne. 2010. Hydrologic Modification and the Loss of Self-organized Patterning in the Ridge-Slough Mosaic of the Everglades. Ecosystems **13**: 813-827.

Wright, A. L., and K. R. Reddy. (2001a) Heterotrophic microbial activity in northern Everglades wetland soils. Soil Science Society of America Journal **65**: 1856–1864.

Wright, A. L., and K. R. Reddy. (2001b) Phosphorus loading effects of extracellular enzyme activity in Everglades wetland soils. Soil Sci. Soc. Am. J. **65**: 588–595

Zweig, C. L. and W. M. Kitchens (2008) Effects of landscape gradients on wetland vegetation communities: information for large-scale restoration. Wetlands **28**: 1086-1096

Zweig, C. L., and W. M. Kitchens (2009). Multi-state succession in wetlands: A novel use of state and transition models. Ecology **90**: 1900–1909.

Appnedices

Appendix 1: Mean (± 1 SD) soil properties at the selected sites along MP-S gradient on the Transect M3 and M6.

Transect	Site ID	Bulk Density	TN (mg g-1)	TC (mg g-1)	OC (mg g-1)	IC (mg g-1)	TP (µg g-1)
M3	M3-00300	0.547 ± 0.043	6.7 ± 0.66	138.1 ± 15.4	44.9 ± 2.8	93.2 ± 14.3	208.9 ± 34
M3	M3-01500	0.544 ± 0.073	6.1 ± 2.51	147.7 ± 13.9	43.5 ± 20.1	104.1 ± 7	163.4 ± 54.8
M3	M3-02700	0.760 ± 0.099	2.8 ± 0.99	138.8 ± 5.3	22.7 ± 5.6	116.2 ± 2.5	100.5 ± 20.9
M3	M3-04800	0.410 ± 0.046	7.3 ± 1.9	155.2 ± 4.4	51.9 ± 8.9	103.3 ± 5.7	197.6 ± 73
M3	M3-06000	0.472 ± 0.098	9.2 ± 2.74	141.9 ± 9.5	72.4 ± 23.8	69.5 ± 30.5	197.8 ± 35.8
M3	M3-07200	0.343 ± 0.027	13.4 ± 2.14	150.8 ± 14.9	138.8 ± 20.6	12 ± 16.4	337.8 ± 104.3
M3	M3-08400	0.315 ± 0.057	14.1 ± 5.47	170.3 ± 61.9	164.9 ± 60.8	5.4 ± 8.2	310 ± 111.2
M3	M3-09900	0.497 ± 0.115	7.6 ± 4.73	157.2 ± 19.8	81.5 ± 19.2	75.8 ± 0.5	261.9 ± 191.8
M3	M3-11400	0.184 ± 0.003	18.9 ± 10.08	270.8 ± 59.9	209.7 ± 114.9	61.1 ± 55	357.7 ± 164.4
M3	M3-14000	0.177 ± 0.043	10.6 ± 2.3	226.9 ± 28.6	119.5 ± 32.9	107.4 ± 4.3	177.3 ± 24.3
M3	M3-16000	0.076 ± 0.015	21.8 ± 12.84	321.4 ± 173.1	292.5 ± 176.9	28.9 ± 5.8	347.1 ± 25.5
M3	M3-17000	0.087 ± 0.021	28.1 ± 2.11	408.5 ± 17.8	381 ± 9.1	27.4 ± 9	269.9 ± 16.9
M3	M3-18300	0.088 ± 0.009	32.5 ± 0.43	444.1 ± 9.1	392.2 ± 19.2	51.8 ± 24.4	262.1 ± 25.1
M3	M3-20800	0.085 ± 0.026	28.5 ± 2.05	441.3 ± 10.1	399 ± 23.8	42.2 ± 16.3	367.4 ± 56
M3	M3-22500	0.118 ± 0.033	31.9 ± 1.31	408.5 ± 15.1	404 ± 13	4.5 ± 2.7	339 ± 29.2
M6	M6-00000	0.321 ± 0.054	11.5 ± 1.2	182.6 ± 7.3	69.6 ± 11.8	113.0 ± 4.6	217.7 ± 45.4
M6	M6-00100	0.383 ± 0.094	11.3 ± 2.0	185.1 ± 13.2	73.3 ± 16.5	111.8 ± 4.4	206.6 ± 53.7
M6	M6-00200	0.257 ± 0.090	16.7 ± 4.5	230.7 ± 34.3	132.2 ± 45.8	98.5 ± 11.5	348.9 ± 112.9
M6	M6-00300	0.260 ± 0.048	7.8 ± 0.3	173.3 ± 9.5	56.3 ± 7.8	117.0 ± 1.7	134.4 ± 7.7
M6	M6-00400	0.304 ± 0.145	9.3 ± 2.5	175.5 ± 8.3	67.8 ± 27.2	107.7 ± 20.4	166.5 ± 83.2
M6	M6-00500	0.424 ± 0.118	8.2 ± 1.0	175.0 ± 7.7	57.1 ± 10.3	117.9 ± 2.6	120.5 ± 12.4
M6	M6-00600	0.246 ± 0.067	9.1 ± 1.1	189.6 ± 10.2	70.6 ± 15.4	119.0 ± 5.3	114.9 ± 35.4
M6	M6-00700	0.273 ± 0.006	11.1 ± 4.8	192.3 ± 22.8	83.6 ± 36.8	108.7 ± 13.9	186.1 ± 117.2
M6	M6-00800	0.301 ± 0.041	10.2 ± 1.1	184.1 ± 11.3	72.8 ± 10.8	111.3 ± 2.1	189.9 ± 24.4
M6	M6-00900	0.297 ± 0.028	10.6 ± 0.6	195.1 ± 7.6	80.1 ± 8.0	115.1 ± 1.6	180.6 ± 17.4
M6	M6-01000	0.213 ± 0.001	13.9 ± 1.1	222.6 ± 8.8	110.6 ± 9.4	112.0 ± 1.5	275.1 ± 2.7
M6	M6-01100	0.218 ± 0.028	13.8 ± 1.9	216.2 ± 17.5	106.3 ± 21.5	109.9 ± 4.4	232.6 ± 23.6
M6	M6-01200	0.165 ± 0.064	18.4 ± 7.9	271.3 ± 77.9	183.6 ± 110.2	87.7 ± 32.4	304.6 ± 153.8
M6	M6-01300	0.121 ± 0.025	23.2 ± 5.0	309.9 ± 38.7	234.3 ± 64.1	75.6 ± 26.1	418.8 ± 139.2
M6	M6-01400	0.210 ± 0.066	13.8 ± 2.2	249.9 ± 46.1	133.6 ± 45.1	116.3 ± 0.9	186.9 ± 17.7
M6	M6-01500	0.218 ± 0.050	9.5 ± 1.0	206.7 ± 19.1	87.3 ± 19.8	119.4 ± 0.8	139.8 ± 19.8
M6	M6-01600	0.222 ± 0.019	10.8 ± 3.0	209.9 ± 32.4	90.8 ± 33.7	119.1 ± 1.3	139.1 ± 37.2
M6	M6-01700	0.227 ± 0.070	8.4 ± 2.7	192.3 ± 25.0	72.7 ± 26.7	119.6 ± 1.9	118.7 ± 45.9
M6	M6-01800	0.298 ± 0.079	7.8 ± 3.2	182.2 ± 22.8	60.8 ± 23.8	121.4 ± 1.0	85.2 ± 20.1
M6	M6-01900	0.191 ± 0.057	11.0 ± 0.9	222.1 ± 21.0	102.2 ± 21.3	119.9 ± 0.3	136.3 ± 16.8
M6	M6-02000	0.087 ± 0.022	17.4 ± 3.6	245.3 ± 24.6	127.5 ± 25.4	117.8 ± 1.0	152.4 ± 19.8
M6	M6-02200	0.253 ± 0.072	7.8 ± 1.0	181.9 ± 12.8	61.7 ± 13.2	120.2 ± 0.6	109.5 ± 17.4
M6	M6-02300	0.248 ± 0.018	10.7 ± 2.2	202.7 ± 25.9	84.0 ± 26.8	118.6 ± 1.1	162.1 ± 38.1

Transect	Site ID	Bulk Density	TN (mg g-1)	TC (mg g-1)	OC (mg g-1)	IC (mg g-1)	TP (µg g-1)
M6	M6-02400	0.113 ± 0.035	26.2 ± 1.6	376.5 ± 57.3	267.9 ± 48.0	108.6 ± 10.1	369.6 ± 47.0
M6	M6-02500	0.152 ± 0.064	13.6 ± 3.8	202.7 ± 59.9	88.8 ± 56.9	113.9 ± 5.1	196.7 ± 33.1
M6	M6-02600	0.158 ± 0.011	14.6 ± 1.2	235.6 ± 24.2	119.3 ± 23.8	116.3 ± 1.0	187.1 ± 57.5
M6	M6-02700	0.139 ± 0.060	14.6 ± 3.2	233.4 ± 16.8	116.4 ± 18.5	117.0 ± 1.7	147.3 ± 17.4
M6	M6-02800	0.084 ± 0.028	17.8 ± 3.4	229.9 ± 53.0	117.0 ± 55.1	113.0 ± 4.0	174.2 ± 13.9
M6	M6-02900	0.195 ± 0.039	9.5 ± 1.8	181.0 ± 10.0	98.8 ± 19.1	82.2 ± 10.9	113.3 ± 35.4
M6	M6-03100	0.192 ± 0.023	13.3 ± 3.6	220.1 ± 27.7	125.8 ± 45.0	94.3 ± 21.9	160.5 ± 48.7
M6	M6-03200	0.149 ± 0.032	10.4 ± 3.9	196.0 ± 54.9	77.3 ± 56.3	118.7 ± 1.4	148.6 ± 37.9
M6	M6-03300	0.256 ± 0.102	9.2 ± 1.9	177.8 ± 40.6	59.0 ± 41.2	118.8 ± 2.0	117.7 ± 29.1

Appendix 2: Results (delta and slope values) of trajectory analysis for sites on Shark Slough portions of transects M1, M2, M3 and M4 along hydroperiod vector for 1999-2019 period. N1 and N2 are the number of survey years during Shark Slough transect and Marl prairie-Slough gradient study, respectively. P-values <0.1 are in bold.

Shark Slough Transect -ID	Transect	Site ID	N1	N2	Delta	p-value	Slope	p-value
T1_0	M1	M1-05000	1	5	-0.133	0.335	-0.011	0.228
T1_300	M1	M1-05300	1	4	-0.042	0.433	-0.006	0.290
T1_500	M1	M1-05500	1	5	-0.502	0.206	-0.028	0.164
T1_800	M1	M1-05800	1	4	-0.270	0.253	-0.022	0.126
T1_1000	M1	M1-06000	1	5	0.081	0.420	0.010	0.286
T1_1300	M1	M1-06300	1	5	-0.181	0.249	-0.012	0.185
T1_1500	M1	M1-06500	1	5	-0.242	0.284	-0.016	0.210
T1_1900	M1	M1-06900	1	5	-0.067	0.404	-0.003	0.435
T1_2000	M1	M1-07000	1	5	0.086	0.331	0.006	0.245
T1_2300	M1	M1-07300	1	5	0.019	0.465	-0.001	0.432
T1_2500	M1	M1-07500	1	5	-0.076	0.403	-0.003	0.419
T1_2800	M1	M1-07800	1	5	0.216	**0.082**	0.010	**0.073**
T1_3000	M1	M1-08000	1	5	-0.407	**0.060**	-0.020	**0.058**
T1_3260	M1	M1-08260	1	5	0.213	**0.074**	0.009	**0.085**
T1_3300	M1	M1-08300	1	5	0.000	0.512	-0.001	0.446
T1_3500	M1	M1-08500	1	5	0.126	0.189	0.006	0.220
T1_3800	M1	M1-08800	1	5	-0.009	0.482	-0.001	0.451
T1_4000	M1	M1-09000	1	5	-0.170	0.171	-0.005	0.279
T2_0	M2	M2-03500	1	5	-0.258	0.178	-0.015	0.152
T2_300	M2	M2-03800	1	5	0.253	0.157	0.013	0.132
T2_500	M2	M2-04000	1	5	-0.361	0.169	-0.030	0.048
T2_800	M2	M2-04300	1	5	-0.213	0.130	-0.009	0.173
T2_1000	M2	M2-04500	1	5	-0.123	0.238	-0.007	0.222
T2_1300	M2	M2-04800	1	5	-0.141	0.190	-0.007	0.174
T2_2000	M2	M2-05500	1	5	-0.453	**0.024**	-0.023	**0.012**
T2_2260	M2	M2-05760	1	5	0.004	0.484	-0.003	0.327
T2_2500	M2	M2-06000	1	5	-0.552	**0.082**	-0.029	**0.063**
T2_3000	M2	M2-06500	1	5	0.273	0.129	0.016	**0.071**
T2_3500	M2	M2-07000	1	5	-0.130	0.330	-0.006	0.349
T2_4000	M2	M2-07500	1	5	-0.138	0.259	-0.008	0.327
T2_4500	M2	M2-08000	1	5	-0.130	0.242	-0.004	0.362
T2_5000	M2	M2-08500	1	5	-0.198	0.224	-0.021	**0.065**
T2_5500	M2	M2-09000	1	5	-0.324	0.118	-0.023	**0.057**
T2_6000	M2	M2-09500	1	5	0.100	0.355	0.004	0.355
T2_6500	M2	M2-10000	1	5	-0.104	0.148	-0.004	0.232
T2_7000	M2	M2-10500	1	5	0.025	0.401	0.001	0.405
T3_0	M3	M3-15500	1	4	-0.786	**0.017**	-0.046	**0.015**
T3_300	M3	M3-15800	1	4	0.030	0.455	-0.006	0.441

Shark Slough Transect -ID	Transect	Site ID	N1	N2	Delta	p-value	Slope	p-value
T3_500	M3	M3-16000	1	4	-0.531	**0.008**	-0.027	**0.024**
T3_800	M3	M3-16300	1	4	0.064	0.337	0.006	0.264
T3_1000	M3	M3-16500	1	4	-0.229	**0.099**	-0.010	0.165
T3_1300	M3	M3-16800	1	4	-0.145	0.240	-0.005	0.310
T3_1500	M3	M3-17000	1	4	-0.362	0.102	-0.021	0.103
T3_1800	M3	M3-17300	1	4	-0.511	**0.077**	-0.028	**0.095**
T3_2000	M3	M3-17500	1	4	-0.392	**0.053**	-0.024	**0.058**
T3_2300	M3	M3-17800	1	4	-0.144	0.284	-0.001	0.511
T3_2500	M3	M3-18000	1	4	-0.220	0.135	-0.015	0.102
T3_2800	M3	M3-18300	1	4	-0.340	**0.060**	-0.019	**0.070**
T3_3000	M3	M3-18500	1	4	-0.377	**0.095**	-0.022	**0.093**
T3_3500	M3	M3-19000	1	4	0.003	0.501	0.002	0.366
T3_3800	M3	M3-19300	1	4	-0.297	**0.084**	-0.020	**0.067**
T3_4000	M3	M3-19500	1	4	0.047	0.323	0.005	0.233
T3_4300	M3	M3-19800	1	4	-0.165	0.221	-0.018	0.043
T3_4500	M3	M3-20000	1	4	-0.257	0.116	-0.015	0.109
T3_4700	M3	M3-20200	1	4	-0.201	0.185	-0.012	0.191
T3_4800	M3	M3-20300	1	4	-0.340	**0.017**	-0.021	**0.024**
T3_5000	M3	M3-20500	1	4	-0.373	**0.043**	-0.022	**0.039**
T3_5200	M3	M3-20700	1	4	0.261	0.145	0.012	0.135
T3_5300	M3	M3-20800	1	4	-0.247	**0.081**	-0.013	**0.094**
T3_5500	M3	M3-21000	1	4	-0.394	**0.053**	-0.019	**0.090**
T3_5800	M3	M3-21300	1	4	-0.122	0.314	-0.017	0.142
T3_6000	M3	M3-21500	1	4	-0.186	0.298	-0.020	0.126
T3_6300	M3	M3-21800	1	4	-0.132	0.181	-0.012	**0.063**
T3_6500	M3	M3-22000	1	4	-0.280	**0.074**	-0.016	**0.079**
T5_0	M4	M4-07000	1	4	0.088	0.321	0.009	0.165
T5_300	M4	M4-07300	1	4	-0.004	0.484	0.004	0.392
T5_500	M4	M4-07500	1	4	-0.034	0.325	-0.002	0.323
T5_800	M4	M4-07800	1	4	-0.025	0.480	0.001	0.466
T5_1000	M4	M4-08000	1	4	0.064	0.364	0.004	0.328
T5_1300	M4	M4-08300	1	4	-0.313	**0.019**	-0.015	**0.032**
T5_1500	M4	M4-08500	1	4	-0.253	0.133	-0.018	**0.084**
T5_1800	M4	M4-08800	1	4	-0.183	0.139	-0.006	0.264
T5_2000	M4	M4-09000	1	4	-0.255	**0.084**	-0.013	**0.098**
T5_2300	M4	M4-09300	1	4	0.015	0.460	0.002	0.366
T5_2500	M4	M4-09500	1	4	-0.394	**0.016**	-0.024	**0.009**
T5_2800	M4	M4-09800	1	4	-0.053	0.424	0.005	0.400
T5_3000	M4	M4-10000	1	4	-0.036	0.351	0.001	0.442
T5_3300	M4	M4-10300	1	4	-0.254	**0.095**	-0.015	**0.090**
T5_3500	M4	M4-10500	1	4	-0.242	0.137	-0.015	0.112

Shark Slough Transect -ID	Transect	Site ID	N1	N2	Delta	p-value	Slope	p-value
T5_3800	M4	M4-10800	1	4	-0.202	0.272	-0.010	0.293
T5_4000	M4	M4-11000	1	4	-0.273	0.146	-0.009	0.280
T5_4300	M4	M4-11300	1	4	-0.198	0.192	-0.012	0.177
T5_4500	M4	M4-11500	1	4	-0.680	**0.075**	-0.041	**0.069**
T5_8700	M4	M4-15700	1	3	-0.014	0.468	0.000	0.486
T5_8800	M4	M4-15800	1	4	-0.405	**0.022**	-0.021	**0.030**
T5_9000	M4	M4-16000	1	4	-0.110	0.354	-0.004	0.435
T5_9100	M4	M4-16100	1	3	0.113	0.173	0.004	0.353
T5_9260	M4	M4-16260	1	3	-0.197	**0.069**	-0.017	**0.041**
T5_9280	M4	M4-16280	1	3	-0.167	0.132	-0.013	0.104
T5_9300	M4	M4-16300	1	4	0.205	0.123	0.015	0.047
T5_9500	M4	M4-16500	1	4	-0.121	0.446	0.018	0.304
T5_9800	M4	M4-16800	1	4	-0.364	**0.038**	-0.016	**0.091**
T5_10000	M4	M4-17000	1	4	-0.402	**0.025**	-0.019	**0.054**
T5_10300	M4	M4-17300	1	4	0.504	**0.080**	0.040	**0.010**
T5_10500	M4	M4-17500	1	4	0.083	0.249	0.004	0.300
T5_10800	M4	M4-17800	1	4	0.197	0.124	0.010	0.159
T5_11000	M4	M4-18000	1	4	0.341	**0.026**	0.020	**0.015**
T5_11300	M4	M4-18300	1	4	-0.544	**0.003**	-0.025	**0.020**
T5_11500	M4	M4-18500	1	4	-0.141	0.171	-0.007	0.177
T5_11800	M4	M4-18800	1	4	-0.378	**0.013**	-0.017	**0.026**

Appendix 3: Importance value index (IV) of species present at the marl prairie sites of Transect M1, M2E and M3-M5 that were surveyed two to five times between 2005 and 2019 (M2E was established in 2015, and surveyed only twice, 2015 and 2019). Marl prairie sites on Transects M3, M4 and M5 were surveyed 4 times between 2005 and 2019. The Transects M3 (M3E & M3W) and M4 (M4E & M4W) are on both sides of the Shark River Slough. M4E is separated further into M4E_1 and M4E_2, and the transect M5 into M5E and M5W based on east and west side of the Park road. MWR is the western most end of M5 dominated by red mangrove. Transect M6 was established and surveyed only once in 2019. For SPCODE-2019, * indicates C_4 species.

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M1					M2E		M3E				M3W			
			2006	2009	2012	2015	2019	2015	2019	2007	2010	2013	2016	2007	2010	2013	2016
2	AESPRA	*Aeschynomene pratensis*	0.81	1.52	0.06	2.19	1.44	0.49	0.68		0.01		0.12	0.79	0.56	0.48	1.29
3	AGALIN	*Agalinis linifolia*		0.46					0.02		0.20	0.20	0.27	0.15	0.07	0.54	0.87
4	AGAXX1	*Agalinis sp.*										0.05					
5	ALEBRA	*Aletris bracteata*									0.02	0.08	0.05				
6	AMBART	*Ambrosia artemisiifolia*											0.04				
7	ANDGLO*	*Andropogon glomeratus var. glomeratus*								0.01			0.05				
8	ANDVIR*	*Andropogon virginicus*	0.69	1.05	2.43	0.24	0.03	0.14	0.16	0.02	0.46	0.38	0.26	0.34	0.46	0.06	0.23
9	ANEADI	*Anemia adiantifolia*								0.11							
10	ANGBER	*Angadenia berteroi*								0.10	0.05	0.05	0.08				
11	ANNGLA	*Annona glabra*	0.42		0.18	0.15	0.17	0.45	0.44	0.08	0.06	0.08	0.06	3.58	1.96	0.81	0.78
12	ARDESC	*Ardisia escallonioides*									0.01	0.00	0.02				
13	ARIPUR*	*Aristida purpurascens*			0.38			0.77		0.04	0.95	1.06	0.94	0.02	0.13	0.59	0.29
14	ARISTR	*Aristida stricta*								0.02							
15	ASCLAN	*Asclepias lanceolata*						0.03	0.08	0.16	0.07	0.01	0.04	0.03	0.16	0.47	0.23
16	ASCLON	*Asclepias longifolia*														0.22	0.04
17	ASTADN	*Symphyotrichum adnatum*						0.07									
18	ASTBRA	*Symphyotrichum bracei*				2.94		0.92	0.61				2.05	0.33			1.19
20	ASTDUM	*Symphyotrichum dumosum*				0.47				0.01	0.08	0.09	0.38	0.64	2.23	1.24	1.04
21	ASTSUB	*Symphyotrichum subulatum*								0.92							
22	ASTTEN	*Symphyotrichum tenuifolium*	1.75	1.17	3.09		1.07				4.99	3.42	0.11	0.06	2.54	2.00	0.36
23	ASTXX1	*Aster sp.*								0.08							
24	BACCAR	*Bacopa caroliniana*	3.94	1.14	1.50	4.95	4.71	4.65	5.14	2.27	1.95	2.10	1.21	4.64	4.43	4.86	3.11
25	BACGLO	*Baccharis glomeruliflora*											0.13				

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M1					M2E		M3E				M3W			
			2006	**2009**	**2012**	**2015**	**2019**	**2015**	**2019**	**2007**	**2010**	**2013**	**2016**	**2007**	**2010**	**2013**	**2016**
26	BACHAL	*Baccharis halimifolia*		0.04						0.11		0.09					
27	BACMON	*Bacopa monnieri*												0.04	0.48		
28	BLESER	*Blechnum serrulatum*						0.07	0.13	0.59	0.10	0.25	0.27				
30	BUCFLO	*Buchnera americana*								0.01			0.04				0.11
31	CAPBIF	*Capraria biflora*										0.00					
32	CASFIL	*Cassytha filiformis*								0.70	0.29	0.21	0.19	3.81	0.59	1.86	1.37
34	CENASI	*Centella asiatica*	2.77	3.00	3.56	4.63	3.54	1.54	1.87	3.27	0.70	2.27	0.16	3.04	4.64	5.07	2.85
35	CEPOCC	*Cephalanthus occidentalis*				0.17						0.02		0.01		0.02	0.01
36	CHIPAR	*Chiococca parvifolia*						0.29		0.04			0.05				
37	CHRICA	*Chrysobalanus icaco*											0.07				
38	CIRHOR	*Cirsium horridulum*									0.05	0.01	0.01				
39	CLAJAM	*Cladium jamaicense*	40.94	41.35	37.42	27.65	32.52	34.49	34.26	47.57	38.03	36.51	42.34	20.38	22.39	24.67	25.86
40	COERUG	*Coelorachis rugosa*													0.01		
41	CONCOE	*Conoclinium coelestinum*									0.42						
43	CRIAME	*Crinum americanum*		0.31	0.54	0.33		0.23	0.23				0.01	1.72	1.03	1.43	2.37
46	CYPHAS	*Cyperus haspan*			0.06					0.01	0.14	0.03					
48	CYPXX1	*Cyperus sp.*									0.08						
49	DICACI	*Dichanthelium aciculare*			0.04			0.11				0.29	0.15				
50	DICDIC	*Dichanthelium dichotomum*				0.16	0.21	0.06	0.08	1.11	1.64	0.05	1.76				0.13
51	DICXX1	*Dichanthelium sp.*						0.33									
52	DIOVIR	*Diodia virginiana*										0.00					
53	DYSANG	*Dyschoriste angusta*						0.11								0.08	
54	ECHXX1*	*Echinochloa sp.*												0.01			
55	ELEBAL	*Eleocharis baldwinii*			0.04							0.35					
56	ELECEL	*Eleocharis cellulosa*	9.88	13.72	9.91	7.14	15.45	27.15	21.71	3.25	4.94	5.14	3.59	2.35	2.08	2.57	2.43
57	ELEELO	*Eleocharis elongata*							0.17		0.08						
58	ELEGEN	*Eleocharis geniculata*				0.06											
59	ERAELL*	*Eragrostis elliottii*	0.27		0.84	0.16		0.07		0.87	0.81	0.13	0.32	0.20	0.32	0.36	0.37

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M1					M2E		M3E				M3W			
			2006	2009	2012	2015	2019	2015	2019	2007	2010	2013	2016	2007	2010	2013	2016
60	ERICOM	*Eriocaulon compressum*													0.15		0.04
61	ERIQUE	*Erigeron quercifolius*								0.07	0.12	0.08		0.06			
62	EUGAXI	*Eugenia axillaris*								0.08		0.00					
63	EUPCAP	*Eupatorium capillifolium*		0.36	0.04					1.30							
64	EUPLEP	*Eupatorium leptophyllum*				0.26	0.03				0.49	1.08	0.37				
65	EUPMIK	*Eupatorium mikanioides*		0.29	0.04	0.21	0.18			0.18	0.11	0.03	0.02	0.16	0.24	0.40	0.53
66	EUSPET*	*Eustachys petraea*								0.11		0.10				0.21	
69	FLALIN*	*Flaveria linearis*								0.36							
70	FUIBRE	*Fuirena breviseta*	0.07		0.21	0.03	0.09	0.06		0.01	0.59	0.25	0.12	0.01			0.07
73	HABREP	*Habenaria repens*													0.07		
74	HELPIN	*Helenium pinnatifidum*													0.01		0.11
75	HELPOL	*Heliotropium polyphyllum*						0.20	0.02	0.15	0.09	0.01	0.11				
76	HIBGRA	*Hibiscus grandiflorus*								0.01			0.05	0.07	0.01		0.08
77	HYDCOR	*Hydrolea corymbosa*										0.01					
78	HYMLAT	*Hymenocallis latifolia*															0.66
79	HYMPAL	*Hymenocallis palmeri*								0.17	0.07	0.37	0.41	1.16	1.18	2.19	1.46
80	HYPALA	*Hyptis alata*								0.38	0.25	0.17	0.27	0.04	0.10		0.05
81	HYPCIS	*Hypericum cistifolium*									0.07						
82	HYPHYP	*Hypericum hypericoides*										0.02					
84	IPOSAG	*Ipomoea sagittata*		1.20	0.03	0.71	0.41	0.48	0.71	0.27	0.15	0.47	0.62	0.37	0.34	0.25	0.57
85	IVAMIC	*Iva microcephala*			0.59	0.77	0.22	0.40	0.32	0.14	0.46	0.64	0.12				
87	JUNMEG	*Juncus megacephalus*															0.01
88	JUSANG	*Justicia angusta*	0.90	0.96	1.33	1.44	1.25	0.47	0.33	0.27	1.02	0.47	1.16	0.96	1.56	2.16	1.50
89	KOSVIR	*Kosteletzkya virginica*									0.03	0.11				0.14	
90	LEEHEX	*Leersia hexandra*	0.21	0.78	0.35	0.19					0.16			0.23	0.70	0.88	1.44
91	LINMED	*Linum medium*								0.01	0.02					0.11	0.11
92	LOBGLA	*Lobelia glandulosa*									0.03	0.05		0.14			0.16
93	LUDALA	*Ludwigia alata*				0.33	0.04	0.06	0.11	0.03	0.34	0.18	0.12			0.02	

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M1					M2E		M3E				M3W			
			2006	**2009**	**2012**	**2015**	**2019**	**2015**	**2019**	**2007**	**2010**	**2013**	**2016**	**2007**	**2010**	**2013**	**2016**
94	LUDCUR	*Ludwigia curtissii*				0.30		0.03	0.36				0.36				
95	LUDMIC	*Ludwigia microcarpa*	0.22	0.06	0.93	0.04	0.73			0.19	0.63	0.61	0.10	0.06	0.80	0.38	0.19
96	LUDREP	*Ludwigia repens*		1.38				0.06		1.20	0.81	0.29		0.32	0.05		
97	LUDXX1	*Ludwigia sp.*							0.02				0.44				
100	MELQUI	*Melaleuca quinquenervia*		0.22													
101	METTOX	*Metopium toxiferum*								0.20							
102	MIKSCA	*Mikania scandens*	0.27		0.18			0.07	0.16	1.55	1.84	0.73	1.06	0.14	0.14		0.05
103	MITPET	*Mitreola petiolata*			0.23			0.20		0.71	0.08	0.01	0.39	0.81	0.28	0.74	2.04
104	MORCER	*Morella cerifera*	0.12			0.07		0.15		0.62	0.01	0.22	0.67	0.06	0.17	0.30	0.09
105	MUHCAP*	*Muhlenbergia capillaris var. filipes*	2.46	5.42	4.32	7.90	0.42	3.17	2.06	7.49	7.74	6.86	7.07	0.61	0.39	0.32	0.17
106	MYRFLO	*Myrsine floridana*								0.14			0.05				
107	NYMAQU	*Nymphoides aquatica*								0.01	0.03			0.07	0.20	0.02	0.18
108	NYMODO	*Nymphaea odorata*													0.05		
109	OXYFIL	*Oxypolis filiformis*	0.50	0.14	0.09	0.09	0.27	0.04	0.14	0.11	0.48	0.33	0.10	0.16	0.18	0.29	0.21
110	PANDIC	*Panicum dichotomiflorum*									1.57						
111	PANHEM	*Panicum hemitomon*	0.21		0.07	1.16	1.53	1.38	0.76	0.22	0.93	0.71	0.14	2.15	1.54	1.01	0.60
112	PANRIG*	*Panicum rigidulum*								0.04	0.13	0.94		0.04	0.14	0.05	
113	PANTEN*	*Panicum tenerum*	4.38	4.35	5.74	3.65	3.52	1.45	1.80	3.05	5.43	5.18	5.06	3.37	6.77	2.76	4.95
114	PANVIR*	*Panicum virgatum*		0.61	0.03	0.33		0.41		0.61	0.15	0.17	0.59	5.59	7.57	7.95	6.58
115	PANXX1	*Panicum sp.*									0.11						
116	PARQUI	*Parthenocissus quinquefolia*										0.00	0.15				
117	PASGEM*	*Paspalidium geminatum*				0.17	0.37	1.55	0.21	0.05		0.63	0.12	0.14	0.61	0.13	0.28
118	PASMON*	*Paspalum monostachyum*									0.05	0.08	0.21	4.29	8.47	7.09	5.02
119	PASSUB	*Passiflora suberosa*									0.01	0.07					
120	PELVIR	*Peltandra virginica*	0.74	1.16	0.21	0.06	0.37		0.03	0.11	0.06	0.15	0.27	0.01		0.44	0.06
121	PERBOR	*Persea borbonia*								0.20	0.10	0.23	0.75	0.03	0.13	0.04	0.03
135	PERHYD	*Persicaria hydropiperoides*		0.79	0.75	0.06		0.19		0.31	0.15	0.54	0.09	0.17	0.09	0.37	
124	PHYAME	*Phytolacca americana*										0.03					

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M1					M2E		M3E				M3W			
			2006	2009	2012	2015	2019	2015	2019	2007	2010	2013	2016	2007	2010	2013	2016
125	PHYCAR	*Phyllanthus caroliniensis*						0.05		0.05							
126	PHYNOD	*Phyla nodiflora*	1.39	0.51	0.44	2.66	2.02	1.08	0.87	3.77	0.89	3.30	0.60	0.10	0.09		
127	PHYSTO	*Phyla stoechadifolia*		0.74	0.47	0.89	0.83	0.60	0.60	0.70	0.10	0.11	0.32				
128	PHYXX1	*Phyllanthus sp.*														0.05	
129	PINPUM	*Pinguicula pumila*								0.01							
130	PIRCAR	*Piriqueta cistoides ssp. caroliniana*														0.07	
131	PLUODO	*Pluchea odorata*											0.03				
133	POLBAL	*Polygala balduinii*						0.07		0.01							
134	POLGRA	*Polygala grandiflora*								0.10	0.04	0.06	0.04			0.29	0.13
136	PONCOR	*Pontederia cordata*	0.27	0.58	0.27	0.33	0.21				0.35	0.02		0.42	0.41	0.09	0.06
138	PROPAL	*Proserpinaca palustris*		0.72	0.19	0.07				0.75	0.54	0.61	0.24	0.30	0.06	0.02	0.16
139	PSYNER	*Psychotria nervosa*								0.35			0.01				
140	PTEAQU	*Pteridium aquilinum*								0.58	0.34	0.15	0.20				
141	QUEXX1	*Quercus sp.*															0.01
142	RANACU	*Randia aculeata*								0.38	0.01	0.17	0.26				
144	RHUCOP	*Rhus copallinum*										0.12	0.09				
145	RHYCOL	*Rhynchospora colorata*								0.01	0.15	0.08	0.01	0.13	0.06	0.01	0.07
146	RHYDIV	*Rhynchospora divergens*				0.03		1.11	0.16		0.85	1.17	0.01				0.09
147	RHYINU	*Rhynchospora inundata*	0.25		1.12	1.35	1.37	0.65	1.97	0.12			0.09	4.66	1.70	0.76	1.31
148	RHYMIC	*Rhynchospora microcarpa*	0.05		1.35	0.44	1.55	1.76	2.61	0.69	1.38	1.40	1.81	9.21	3.00	3.91	3.16
149	RHYMIL	*Rhynchospora miliacea*		1.56													
150	RHYTRA	*Rhynchospora tracyi*	11.80	9.08	13.12	15.89	17.39	9.57	9.46	0.61	4.54	2.86	2.70	10.18	4.70	8.00	5.77
151	RHYXX1	*Rhynchospora sp.*								0.02							
152	SABGRA	*Sabatia grandiflora*								0.06	0.14		0.04	0.12			0.29
153	SABPAL	*Sabal palmetto*						0.03	0.03	0.01	0.02			0.01			
154	SACGIG*	*Saccharum giganteum*		0.18	0.22	0.60	0.39			0.18	0.06	0.08	0.21	0.01	0.07	0.02	0.18
155	SAGLAN	*Sagittaria lancifolia*				0.15	0.34	0.16	0.50	0.61	0.59	1.35	0.53	0.77	1.04	0.46	0.58
156	SALCAR	*Salix caroliniana*	0.21	0.22	0.32	0.33				0.08		0.97	0.03	0.12		0.37	0.36

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M1					M2E		M3E				M3W			
			2006	2009	2012	2015	2019	2015	2019	2007	2010	2013	2016	2007	2010	2013	2016
157	SAMEBR	*Samolus ebracteatus*						0.05		0.37	0.23	0.09	0.16				
158	SARCLA	*Funastrum clausum*												0.18	0.38		
159	SCHALB	*Schoenolirion albiflorum*													0.19	0.16	
160	SCHNIG	*Schoenus nigricans*								0.01	0.01	0.09	0.01	1.24	1.73	1.85	2.21
161	SCHRHI*	*Schizachyrium rhizomatum*		0.15	0.24			0.11		2.97	2.72	4.28	5.32	4.64	5.71	4.68	8.78
162	SCHTER	*Schinus terebinthifolius*						0.01		0.08		0.11					
164	SCIXX1	*Scirpus sp.*												0.09			
165	SETPAR*	*Setaria parviflora*			0.69	1.58	3.74	0.37	0.56	0.74	0.08		0.65	0.01	0.22		
166	SIDSAL	*Sideroxylon salicifolium*								0.01	0.05	0.00					
167	SMILAU	*Smilax laurifolia*								0.02							
169	SOLFIS	*Solidago fistulosa*									0.16						
170	SOLSTR	*Solidago stricta*		0.03	0.13			0.39	0.58	0.29	0.82	0.70	0.25	0.17		0.05	0.18
172	TAXDIS	*Taxodium distichum var. imbricrium*												0.05			
173	TEUCAN	*Teucrium canadense*						0.01	0.03		0.29	0.32	0.04		0.11		
174	THAGEN	*Thalia geniculata*									0.03			0.01	0.12	0.09	
176	THEKUN	*Thelypteris kunthii*								0.01							
183	TOXRAD	*Toxicodendron radicans*								0.39	0.06	0.23	0.65				
184	TREMIC	*Trema micrantha*									0.22	0.06	0.02				
185	TYPDOM	*Typha domingensis*	6.34	0.94	1.84	3.82								0.35	0.67	0.72	0.38
186	UNKGR1	*Unknown gr01*											0.05	0.03			0.05
194	UNKX16	*Unknown sp16*						0.21									
195	UNKX17	*Unknown sp17*											0.02				
201	UNKX23	*Unknown sp23*							0.24								
202	UNKX24	*Unknown sp24*							0.16								
203	UNKX25	*Unknown sp25*							0.13								
204	UNKXX1	*Unknown sp01*												0.06			
205	UNKXX2	*Unknown sp02*										0.04		0.14			
206	UNKXX3	*Unknown sp03*										0.04		0.04			

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M1					M2E		M3E				M3W			
			2006	2009	2012	2015	2019	2015	2019	2007	2010	2013	2016	2007	2010	2013	2016
207	UNKXX4	*Unknown sp04*												0.08			
208	UNKXX5	*Unknown sp05*												0.05			
209	UNKXX6	*Unknown sp06*									0.10						
210	UNKXX7	*Unknown sp07*													0.04		
211	UNKXX8	*Unknown sp08*												0.05			
213	UTRCOR	*Utricularia cornuta*					0.05	0.34	3.66							0.10	
214	UTRFOL	*Utricularia foliosa*	0.05	0.09	0.51				0.20	0.08	0.01	0.02	0.96		0.02		0.56
216	UTRPUR	*Utricularia purpurea*	6.49	1.04	2.36		0.29		4.31		0.09	2.21	4.32		0.42		1.28
218	UTRSUB	*Utricularia subulata*													0.01		
219	UTRXX1	*Utricularia sp.*									0.01						
220	VERBLO	*Vernonia blodgettii*									0.16	0.04	0.02				
221	VITROT	*Vitis rotundifolia*								0.16			0.04				

Appendix 3: Contd. **Transect M4** (M4E_1, M4E2, MW)

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M4E_1				M4E_2				M4W			
			2008	**2011**	**2014**	**2017**	**2007**	**2011**	**2014**	**2017**	**2008**	**2011**	**2014**	**2017**
2	AESPRA	*Aeschynomene pratensis*					0.47	0.41		0.72	2.88	1.77	1.29	0.48
3	AGALIN	*Agalinis linifolia*		0.18	0.18	0.46	1.12	0.79	0.26	0.32		0.29		
5	ALEBRA	*Aletris bracteata*		0.02	0.02	0.15								
9	ANEADI	*Anemia adiantifolia*	0.02		0.11	0.15								
10	ANGBER	*Angadenia berteroi*	0.23	0.02	0.28	0.31								
11	ANNGLA	*Annona glabra*	0.17				0.18				1.05		0.09	0.03
13	ARIPUR*	*Aristida purpurascens*	0.29	0.40		0.57								
15	ASCLAN	*Asclepias lanceolata*	0.03	0.03	0.34							0.14	0.02	
16	ASCLON	*Asclepias longifolia*		0.20										
18	ASTBRA	*Symphyotrichum bracei*	2.27		3.75	0.15	0.12						0.14	
20	ASTDUM	*Symphyotrichum dumosum*	1.78	2.40	1.07	2.35	0.20		0.23		0.48	0.76	0.72	0.70
22	ASTTEN	*Symphyotrichum tenuifolium*		3.51		3.90		0.26				0.52	0.34	0.38
24	BACCAR	*Bacopa caroliniana*					4.89	7.22	6.32	6.25	5.11	4.11	7.13	3.80
27	BACMON	*Bacopa monnieri*						1.69				1.87		
29	BOECYL	*Boehmeria cylindrica*										0.11		
32	CASFIL	*Cassytha filiformis*	1.93	2.11	1.18	1.05					4.00	5.59	4.80	3.63
34	CENASI	*Centella asiatica*	0.55	0.21	0.61	0.27	0.23				1.49	1.85	1.03	0.65
35	CEPOCC	*Cephalanthus occidentalis*										0.35		
36	CHIPAR	*Chiococca parvifolia*	0.14	0.21	0.40									
38	CIRHOR	*Cirsium horridulum*		0.02	0.14									
39	CLAJAM	*Cladium jamaicense*	23.76	24.94	20.56	33.17	41.77	37.09	42.91	42.96	44.82	35.27	41.15	53.62
42	CONERE	*Conocarpus erectus*	5.40	1.01	2.29	0.08								
43	CRIAME	*Crinum americanum*									0.92	2.63	2.78	1.30
46	CYPHAS	*Cyperus haspan*									0.05		0.03	
49	DICACI	*Dichanthelium aciculare*				0.16								
50	DICDIC	*Dichanthelium dichotomum*	0.57	0.35	0.25	0.60	0.45							

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M4E_1				M4E_2				M4W			
			2008	2011	2014	2017	2007	2011	2014	2017	2008	2011	2014	2017
53	DYSANG	*Dyschoriste angusta*	1.55	3.76	0.93	1.00								0.59
56	ELECEL	*Eleocharis cellulosa*					12.48	24.20	22.99	27.69	2.62	4.44	5.79	5.23
59	ERAELL*	*Eragrostis elliottii*		0.33	0.14	0.31					0.03	0.42		
60	ERICOM	*Eriocaulon compressum*								0.25				
65	EUPMIK	*Eupatorium mikanioides*	0.39	0.48	0.45	0.29					0.02	0.33	0.11	0.24
67	EVOSER	*Evolvulus sericeus*		0.14										
68	FICAUR	*Ficus aurea*									0.05			
70	FUIBRE	*Fuirena breviseta*	0.02				0.51		0.09				0.03	
71	FUISCI	*Fuirena scirpoidea*						0.29						
72	GALVOL	*Galactia volubilis*									0.23			
74	HELPIN	*Helenium pinnatifidum*		0.40	0.37	0.34	0.76	0.26	0.35	0.04	0.22	0.05	0.12	0.11
75	HELPOL	*Heliotropium polyphyllum*	0.80	0.76	1.20	1.37								
77	HYDCOR	*Hydrolea corymbosa*									1.46	1.24	0.05	1.11
79	HYMPAL	*Hymenocallis palmeri*	0.17	1.09	0.86	0.51	0.30	0.71	0.08	1.22	0.51	0.31	0.40	1.27
80	HYPALA	*Hyptis alata*	0.37	0.53	0.14	0.44					0.33	0.20		
83	ILECAS	*Ilex cassine*		0.50	0.14									
84	IPOSAG	*Ipomoea sagittata*	1.01	0.61	1.40	1.18	0.04		0.09		0.71	0.36	1.80	0.98
85	IVAMIC	*Iva microcephala*	1.10	0.46	1.02	0.94								
86	JACCUR	*Jacquemontia curtissii*			0.14	0.02								
88	JUSANG	*Justicia angusta*	0.04			0.17		0.67	0.97	1.65	1.49	2.68	1.77	1.70
89	KOSVIR	*Kosteletzkya virginica*									0.05			
90	LEEHEX	*Leersia hexandra*					0.23	0.39			0.76	0.03	0.16	0.31
93	LUDALA	*Ludwigia alata*									0.56	1.12		0.76
94	LUDCUR	*Ludwigia curtissii*				0.15								
95	LUDMIC	*Ludwigia microcarpa*	0.18	0.78										
96	LUDREP	*Ludwigia repens*					0.48				1.31	3.48	0.80	0.38
97	LUDXX1	*Ludwigia sp.*											0.23	
98	MAGVIR	*Magnolia virginiana*	0.03				0.04							

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M4E_1				M4E_2				M4W			
			2008	2011	2014	2017	2007	2011	2014	2017	2008	2011	2014	2017
99	MELNIV	*Melanthera nivea*	0.22	1.40	0.33	0.66								
101	METTOX	*Metopium toxiferum*				0.06								
102	MIKSCA	*Mikania scandens*	2.01	2.18	2.55	2.45			0.09	0.28			0.73	2.39
103	MITPET	*Mitreola petiolata*					0.49	0.27	0.05	0.04			0.11	
104	MORCER	*Morella cerifera*		0.12	0.36	0.19								
105	MUHCAP*	*Muhlenbergia capillaris var. filipes*	10.43	14.48	11.41	11.38							0.14	0.46
106	MYRFLO	*Myrsine floridana*	0.31		0.26	0.02								
107	NYMAQU	*Nymphoides aquatica*							0.20					
108	NYMODO	*Nymphaea odorata*					0.04					0.14		
109	OXYFIL	*Oxypolis filiformis*	0.03		0.21	0.15	0.17	0.49	0.26	1.19			0.04	0.12
111	PANHEM	*Panicum hemitomon*					0.91	0.91		0.40	1.68	2.37	0.90	0.51
112	PANRIG*	*Panicum rigidulum*					0.06							
113	PANTEN*	*Panicum tenerum*	3.63	2.82	1.14	2.37	0.49		0.30	0.04	1.12	0.86	1.56	1.61
114	PANVIR*	*Panicum virgatum*	1.85	3.78	3.00	3.47	0.04		0.82	0.04	2.42	3.23	1.47	1.60
117	PASGEM*	*Paspalidium geminatum*				0.17			0.41	0.25				
118	PASMON*	*Paspalum monostachyum*	2.33	2.38	4.60	1.71					0.12			
119	PASSUB	*Passiflora suberosa*		0.02										
120	PELVIR	*Peltandra virginica*					0.23		0.54	0.41	0.28	0.04	0.27	0.44
121	PERBOR	*Persea borbonia*	0.06				0.04	0.09						
135	PERHYD	*Persicaria hydropiperoides*					0.05				0.37		0.33	
126	PHYNOD	*Phyla nodiflora*	6.00	4.00	5.26	4.74	0.45	0.06	0.26		0.16			
127	PHYSTO	*Phyla stoechadifolia*	1.17	0.28	0.36	0.45								
128	PHYXX1	*Phyllanthus sp.*	0.26											
130	PIRCAR	*Piriqueta cistoides ssp. caroliniana*		0.02		0.32								
132	PLUROS	*Pluchea rosea*	6.32	5.98	4.42	4.80	1.17	1.28	1.58	1.06	2.54	1.27	1.31	1.37
134	POLGRA	*Polygala grandiflora*	0.30	0.14		0.49								
136	PONCOR	*Pontederia cordata*					1.06	0.29	0.09	1.42	0.51	2.35	1.47	1.14
138	PROPAL	*Proserpinaca palustris*	0.03	0.37			0.23	0.88	0.09		0.21	0.74	0.98	0.18

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M4E_1				M4E_2				M4W			
			2008	2011	2014	2017	2007	2011	2014	2017	2008	2011	2014	2017
145	RHYCOL	*Rhynchospora colorata*	0.02	0.14	0.14									
147	RHYINU	*Rhynchospora inundata*					0.68		1.23	0.28	0.46	1.53	1.25	0.92
148	RHYMIC	*Rhynchospora microcarpa*	0.64	2.64	2.82	2.09	0.82	0.69		0.21	0.62	0.39	0.65	1.69
150	RHYTRA	*Rhynchospora tracyi*	0.44	0.35	0.48	2.24	8.40	3.05	3.88	5.70	4.94	1.68	1.42	1.75
153	SABPAL	*Sabal palmetto*		0.23	0.03									
155	SAGLAN	*Sagittaria lancifolia*					1.80	2.35	1.13	1.22	0.68	0.82	0.81	1.59
157	SAMEBR	*Samolus ebracteatus*	0.12	0.02		0.15								
158	SARCLA	*Funastrum clausum*									0.05		0.06	
160	SCHNIG	*Schoenus nigricans*									1.49	1.35	0.91	1.58
161	SCHRHI*	*Schizachyrium rhizomatum*	9.17	7.40	7.55	6.83					3.47	3.60	4.28	1.57
165	SETPAR*	*Setaria parviflora*				0.16								
168	SMIXX1	*Smilax sp.*		0.02										
170	SOLSTR	*Solidago stricta*	0.98	0.29	0.70	0.32	0.20							
171	SPABAK*	*Spartina bakeri*	1.42	0.31	1.20									
172	TAXDIS	*Taxodium distichum var. imbricrium*	9.27	3.26	13.18	3.77	9.87	6.75	12.97	5.78				
173	TEUCAN	*Teucrium canadense*	0.12	1.84	1.83	0.47		0.35						
174	THAGEN	*Thalia geniculata*									0.42	1.75	3.37	1.33
177	TILBAL	*Tillandsia balbisiana*								0.05				
178	TILFLE	*Tillandsia flexuosa*					0.04							
179	TILPAU	*Tillandsia paucifolia*	0.07	0.08			0.33	0.11		0.11				
185	TYPDOM	*Typha domingensis*									6.94	7.70	6.39	2.46
187	UNKGR2	*Unknown gr02*				0.15								
189	UNKX11	*Unknown sp11*						0.39						
193	UNKX15	*Unknown sp15*			0.21									
197	UNKX19	*Unknown sp19*				0.15								
198	UNKX20	*Unknown sp20*				0.15								
212	UNKXX9	*Unknown sp09*									0.11			
213	UTRCOR	*Utricularia cornuta*					0.41							

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M4E_1				M4E_2				M4W			
			2008	2011	2014	2017	2007	2011	2014	2017	2008	2011	2014	2017
214	UTRFOL	*Utricularia foliosa*						3.68	1.10	0.41	0.05	0.26	0.79	
215	UTRGIB	*Utricularia gibba*					4.16				0.02	0.05		
216	UTRPUR	*Utricularia purpurea*					3.60	4.40	0.71		0.22			
222	VITSHU	*Vitis shuttleworthii*					0.04							

Appendix 3: Contd. **Transect M5** (M5R, M5W, M5E) and M6

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M5E				M5W				M5R				M6
			2008	**2011**	**2014**	**2018**	**2008**	**2011**	**2014**	**2018**	**2008**	**2011**	**2014**	**2018**	**2019**
2	AESPRA	*Aeschynomene pratensis*													3.86
3	AGALIN	*Agalinis linifolia*				0.30									
8	ANDVIR*	*Andropogon virginicus*	0.02												
10	ANGBER	*Angadenia berteroi*				0.13									
11	ANNGLA	*Annona glabra*	0.16			0.02				0.03					0.02
15	ASCLAN	*Asclepias lanceolata*		0.23	0.55										0.01
18	ASTBRA	*Symphyotrichum bracei*	0.34		1.53		0.46		0.42						
20	ASTDUM	*Symphyotrichum dumosum*	2.12	3.68	2.04		0.66	0.27	0.32						0.10
22	ASTTEN	*Symphyotrichum tenuifolium*		1.10		0.37		1.90							0.01
24	BACCAR	*Bacopa caroliniana*													6.52
32	CASFIL	*Cassytha filiformis*	0.94		3.23	3.02	2.37	0.05	2.49	0.76					1.05
33	CATBER	*Catopsis berteroniana*									0.16				0.06
34	CENASI	*Centella asiatica*	0.87		0.02	0.02									
39	CLAJAM	*Cladium jamaicense*	29.10	26.66	22.84	34.86	44.30	34.48	32.84	40.63	26.86	27.38	21.94	24.08	25.99
43	CRIAME	*Crinum americanum*	3.33	5.94	5.18	4.32	2.12	2.66	3.66	2.79					7.38
53	DYSANG	*Dyschoriste angusta*													0.01
56	ELECEL	*Eleocharis cellulosa*	2.47	4.22	5.11	5.84	31.62	38.66	43.71	42.20	6.75	7.97	2.50	10.08	18.59
59	ERAELL*	*Eragrostis elliottii*		0.25				0.17							0.06
61	ERIQUE	*Erigeron quercifolius*		0.09											
65	EUPMIK	*Eupatorium mikanioides*			0.21										
70	FUIBRE	*Fuirena breviseta*						0.24							
71	FUISCI	*Fuirena scirpoidea*													0.15
74	HELPIN	*Helenium pinnatifidum*	0.67	2.03	1.12	0.63	0.35	0.18	0.03	0.16					0.06
77	HYDCOR	*Hydrolea corymbosa*				0.16									0.09
79	HYMPAL	*Hymenocallis palmeri*	2.81	4.16	4.12	4.17	1.05	0.07		0.82					0.77
80	HYPALA	*Hyptis alata*	0.03		0.16	0.14									

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M5E				M5W				M5R				M6
			2008	2011	2014	2018	2008	2011	2014	2018	2008	2011	2014	2018	2019
84	IPOSAG	*Ipomoea sagittata*	2.53		3.01	1.01									0.05
85	IVAMIC	*Iva microcephala*	0.27		0.15	0.24									0.21
88	JUSANG	*Justicia angusta*	0.13	0.49	0.13	1.48	0.31	0.48		0.32					0.60
90	LEEHEX	*Leersia hexandra*	0.21		0.94	0.23									
92	LOBGLA	*Lobelia glandulosa*	0.17		0.21				0.18						
93	LUDALA	*Ludwigia alata*		0.55											
95	LUDMIC	*Ludwigia microcarpa*	0.11	0.20	0.29										
96	LUDREP	*Ludwigia repens*	0.41	0.37	0.79										
102	MIKSCA	*Mikania scandens*	0.03		0.24										
103	MITPET	*Mitreola petiolata*		0.33											
104	MORCER	*Morella cerifera*	0.02	0.12	0.18	0.02			0.39						
105	MUHCAP*	*Muhlenbergia capillaris var. filipes*	14.97	13.57	11.96	7.59	0.52	2.33							0.32
107	NYMAQU	*Nymphoides aquatica*													1.16
109	OXYFIL	*Oxypolis filiformis*	0.02	0.02	0.02		0.03	0.18	0.21						0.21
111	PANHEM	*Panicum hemitomon*	0.46					0.13							9.21
113	PANTEN*	*Panicum tenerum*	1.25	0.53	0.94	0.65	0.74	0.43	0.21	0.36					0.99
114	PANVIR*	*Panicum virgatum*	5.17	6.86	5.96	5.49	1.12	1.47	1.14	1.88					0.90
117	PASGEM*	*Paspalidium geminatum*	0.09	0.13	0.21										1.00
118	PASMON*	*Paspalum monostachyum*	0.41	3.97	2.04	2.14									
120	PELVIR	*Peltandra virginica*				0.11									0.07
121	PERBOR	*Persea borbonia*	0.02												
135	PERHYD	*Persicaria hydropiperoides*			0.08										
123	PHRAUS	*Phragmites australis*	0.12												
126	PHYNOD	*Phyla nodiflora*	1.82	0.02	1.56		0.46								
130	PIRCAR	*Piriqueta cistoides ssp. caroliniana*	0.14		0.02										
132	PLUROS	*Pluchea rosea*	2.20	2.43	0.98	1.43		0.11							0.31
134	POLGRA	*Polygala grandiflora*	0.02												
136	PONCOR	*Pontederia cordata*			0.02										

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M5E				M5W				M5R				M6
			2008	2011	2014	2018	2008	2011	2014	2018	2008	2011	2014	2018	2019
138	PROPAL	*Proserpinaca palustris*	0.37	0.79	0.30	0.02									
143	RHIMAN	*Rhizophora mangle*	0.09				0.75	1.06	2.15	3.85	60.17	58.40	65.10	61.19	2.35
145	RHYCOL	*Rhynchospora colorata*		0.19											
146	RHYDIV	*Rhynchospora divergens*							0.18						
147	RHYINU	*Rhynchospora inundata*	0.62	0.58	0.95	0.72									
148	RHYMIC	*Rhynchospora microcarpa*	1.24	2.74	2.99	3.33	0.35		2.47	2.37					0.05
150	RHYTRA	*Rhynchospora tracyi*	7.96	3.73	6.31	10.84	2.37	2.36	1.27	2.83					6.30
155	SAGLAN	*Sagittaria lancifolia*	0.11	0.23	0.12	0.52	3.24	2.94	0.56	0.50					3.56
159	SCHALB	*Schoenolirion albiflorum*		0.02											0.02
160	SCHNIG	*Schoenus nigricans*	0.12	0.30		0.31									
161	SCHRHI*	*Schizachyrium rhizomatum*	13.19	12.39	10.48	8.45	6.24	5.55	5.15	0.36					0.92
165	SETPAR*	*Setaria parviflora*		0.02											
170	SOLSTR	*Solidago stricta*	0.35		0.49		0.28	0.13	0.35						0.07
171	SPABAK*	*Spartina bakeri*	1.93	1.03	2.29	1.13									
172	TAXDIS	*Taxodium distichum var. imbricrium*		0.02		0.18									0.02
173	TEUCAN	*Teucrium canadense*			0.09										
177	TILBAL	*Tillandsia balbisiana*									0.16			3.60	0.22
178	TILFLE	*Tillandsia flexuosa*									1.78				0.06
179	TILPAU	*Tillandsia paucifolia*									0.31	2.07	0.77		0.06
180	TILREC	*Tillandsia recurvata*													0.06
181	TILUTR	*Tillandsia utriculata*									0.88				
182	TILXX1	*Tillandsia sp.*											0.77		
185	TYPDOM	*Typha domingensis*													0.45
190	UNKX12	*Unknown sp12*						0.35							
191	UNKX13	*Unknown sp13*						0.02							
192	UNKX14	*Unknown sp14*			0.13										
199	UNKX21	*Unknown sp21*													0.01
200	UNKX22	*Unknown sp22*													0.05

SPP No.	SPCODE-2019	Species name 2019 (ITTIS)	M5E				M5W				M5R				M6
			2008	2011	2014	2018	2008	2011	2014	2018	2008	2011	2014	2018	2019
206	UNKXX3	*Unknown sp03*				0.11									
212	UNKXX9	*Unknown sp09*	0.15												
213	UTRCOR	*Utricularia cornuta*	0.48		0.05										
214	UTRFOL	*Utricularia foliosa*						1.72				4.18	8.73	1.05	0.35
215	UTRGIB	*Utricularia gibba*		0.02				0.66							0.08
216	UTRPUR	*Utricularia purpurea*				0.03	0.66	1.29	1.90		2.95		0.20		5.65
217	UTRRES	*Utricularia resupinata*						0.12	0.39	0.14					
220	VERBLO	*Vernonia blodgettii*													0.01