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Landscape Pattern – Marl Prairie/Slough Gradient

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Executive Summary

In the southern Everglades, vegetation in both the marl prairie and ridge and slough landscapes is sensitive to large-scale restoration activities associated with the Comprehensive Everglades Restoration Plan (CERP) authorized by the Water Resources Development Act (WRDA) 2000 to restore the south Florida ecosystem. More specifically, changes in hydrologic regimes at both local and landscape scales are likely to affect vegetation composition along marl prairie-slough gradient resulting in a shift in boundary between plant communities in these landscapes. To strengthen our ability to assess how vegetation would respond to changes in underlying ecosystem drivers along the gradient, an improved understanding of reference conditions of plant community structure and function, and their responses to major stressors is important. In this regard, a study of vegetation structure and composition in relation to physical and biological processes along the marl prairie-slough gradient was initiated in 2005, and has continued through 2013 with funding from US Army Corps of Engineers (USACOE) (Cooperative Agreement # W912HZ-09-2-0018 Modification No.: P00003). This study addresses the hypothesis with respect to RECOVER-MAP monitoring item 3.1.3.5 – "Marl Prairie/Slough Gradients; patterns and trends in Shark Slough marshes and associated marl prairies".

The study design includes field sampling along five transects, namely MAP transects M1-M5, with the total length of 86.6 km. In 2013, field work was carried out on two of five transects. In the spring season, the sites on the marl prairie portions of Transects M3 were sampled, whereas in the wet season, the Shark Slough portion of Transect M4 was sampled. To examine the plant community responses to changes in hydrologic regimes, data analysis focused on the assessment of temporal changes in vegetation composition on the Marl Prairie portions of transects M1 and M3, sampled three times between 2005 and 2013. To assess the vegetation response to hydrologic changes, we first calculated vegetation-inferred hydroperiod using weighted averaging partial least square (WA-PLS) regression model, and determined the change in vegetation-inferred hydroperiod between successive samplings. A change in inferred-hydroperiod indicates the amount and direction of change in vegetation, expressed in units of days per year (0-365) along a gradient in hydroperiod.

In concurrence with the spatio-temporal variation in hydrologic regime that characterized the period 2005-2013, sites on the marl prairie portion of the transects, M1 and M3, showed a mixed pattern of vegetation change. The amount and direction of a shift in vegetation composition varied at both spatial and temporal scale. Transect M1, located in Northeast Shark Slough showed a drying trend whereas the Transect M3 that includes marl prairies on both sides of Shark Slough, showed spatially differentiation in vegetation change mainly due to differences in management related hydrologic changes. Sites located west of the slough showed a drying trend whereas sites east of the slough exhibited a wetting trend. While the drying trend west of the slough gives a hope to have improved habitat of Cape Sable seaside sparrow, wetting trend of marl prairie near the eastern Park boundary suggests that restoration objective of hydrating the rocky glades has been achieved in part. However, if water from the detention ponds continues to influence the vegetation in prairies, the water quality issue also needs to be addressed in future so that vegetation in the prairie does not shift to another stable state adapted to P-enriched soil due to canal water that is pumped in to the ponds.

General Background

Established to track the ecological effects of Everglades restoration, the Monitoring and Assessment Program (MAP) provides the data and analytical support necessary to implement adaptive management. In the Everglades, marsh vegetation in both marl prairie and ridge and slough landscapes is sensitive to large-scale restoration activities associated with the Comprehensive Everglades Restoration Plan (CERP) authorized by the Water Resources Development Act (WRDA) of 2000. 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 this area. In order to track these dynamics, Florida International University (Dr Michael Ross, Project Leader) has undertaken a study of vegetation structure and composition in relation to physical and biological processes along the marl prairie-slough gradient.

The study design includes field sampling along five transects, namely MAP transects M1-M5, with the total length of 86.6 km, in the Shark Slough basin. The vegetation monitoring transects, funded by US Army Corps of Engineers (USACOE) 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 in the ecotonal zone between marl prairie and peat-dominated ridge and sloughs.

This document summarizes research findings that are based on work done in the 3rd option year (2012/2013). During this year, vegetation at both the marl prairie and slough sites on Transect M3 was sampled. Spatio-temporal pattern of vegetation dynamics in the slough portion of Transect M3 as well as other three transects (M1, M2 and M4) has already been described in Sah et al. (2013). This report therefore summarizes vegetation dynamics in the marl prairie section of two transects, M1 and M3 on which we have concluded third sampling cycles since 2005-2006.

Landscape Pattern - Marl Prairie/Slough Gradient: Spatially differentiated vegetation changes in marl prairie landscape in the Everglades

1. Introduction

In an ecosystem, management-driven changes in major environmental drivers often lead to changes in plant community structure and composition. In fact, changes in an environmental driver may slowly erode community resilience, causing them to change in a particular direction until a threshold is reached, followed by an abrupt change in community characteristics (Folke et al. 2004). Such a shift in community characters are common in wetlands where species composition often is very sensitive to changes in hydrologic conditions, the major driver of wetland ecosystem functions. In the Greater Everglades, one of the largest wetlands in the world, past water management activities adversely impacted several ecosystems, leading to the implementation of a series of interrelated large scale restoration projects associated with the Comprehensive Everglades Restoration Plan (CERP) authorized by the Water Resources Development Act (WRDA) of 2000. These restoration projects are intended to influence the major drivers and stressors of the system to achieve desirable levels of ecosystem services by restoring the natural conditions that resemble the pre-drainage system.

In the Everglades, one of severely impacted systems is the seasonally flooded marl prairies, the recent habitat of Cape Sable seaside sparrow (CSSS), a federally listed endangered species. Short hydroperiod marl prairies flank both sides of the Shark River and Taylor Slough, two major drainage systems in the southern Everglades. Along the marl prairie-slough (MP-S) 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, the transition from marsh to prairie may take longer. In the southern Everglades, recent water management efforts have been directed towards ameliorating the adverse effects caused by 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 S12 structures along US 41 has been in place since 2002 to reverse the damage that were caused by the extended wet conditions in the mid-to-late -1990s. These modifications in water management activities, along with those planned under Central Everglades Planning Project (CEPP), including construction and operation of Tamiami Bridges, have affected, and are likely to influence water conditions within the Park, resulting in changes in vegetation communities and ecological processes.

In 2005, we initiated a long-term study of vegetation dynamics in relation to changes in underlying environmental drivers, especially hydrology, along the MP-S gradient represented by five transects of a total length of 85.8 km. 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. A detailed account of vegetation:environment relationship along the whole MP-S gradient and vegetation dynamics in the Shark Slough portion of the gradient, covering the period 1999-2012 was described in Sah et al. (2014). In this report, our focus is the vegetation changes on two transects M1 and M3, sampled three times since 2005-2006. Specifically, we address the changes in vegetation composition in the marl prairie portion of the gradient over eight-year period (2006-2013). We hypothesized that marl prairie vegetation follows the spatially differentiated temporal trend in hydrologic regimes, and over the eight years vegetation in eastern portion of marl prairie will change toward a wetter character while vegetation in the western marl prairies would shift toward a drier type.

2. Methods

2.2 Data acquisition

The study design includes field sampling along five transects, namely MAP Transects M1 to M5, ranged in length from 9.0 km to 35.8 km. Three transects, M1, M3 and M4 extend across the Shark Slough to adjacent short-hydroperiod marl prairie habitat (**Figure 1**). Transect M1, located in Northeastern Shark Slough (NESS), extends to marl prairie on the east of the slough only, whereas two transects, M3 and M4, extend to prairie on both sides of the slough. Transect M2 covers an area restricted to Shark River Slough (SRS), extending on both sides of L-67S canal. The southern transect, M5 covers an area in the coastal ecotone between fresh to brackish water ecosystems in the southeastern corner of SRS, extending to the east into fresh water marl prairies located on both sides of the main Park road. Moreover, 29.3 km of Transects M1, M2, M3 and M4 are in slough, and overlap with Shark Slough Transects, 1, 2, 3 and 5, respectively, that were established and sampled between 1998-2000 with funding from the DOI Critical Ecosystems Study Initiative program (CESI) (Ross et al. 2001; Ross et al. 2003).

Vegetation study on the MAP transects began in the Fall 2005, and the transects were sampled every three years thereafter. On these transects, vegetation structure and composition were quantitatively studied in a set of plots at discontinuous, moderately-spaced (200-500 m) locations. **Table 1** summarizes the years and numbers of sites sampled on the transects. The slough portion of the MAP transects was sampled in the wet season (July to November), accessing the sites by airboat or helicopter, depending on the Wilderness designation of the sites and the water level in the field. Marl prairie portions of the transects were sampled in the dry season (Dec. to May) and were accessed by helicopter for drop off and pickup, and on foot for sampling.

Table 1: Sites sampled on five MAP transects M1-M5 between 2005 and 2013.

Transect	Sampling Event	Sites Sampled			
		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
M2	E1			2005	25
	E2			2008	26
	E3			2011	25
M3	E1	2007	72	2006	37
	E2	2010	72	2009	37
	E3	2013	72	2012	37
M4	E1	2008	32	2007	55
	E2	2011	32	2010	55
M5	E1	2008	31		
	E2	2011	31		

2.2.1 Vegetation sampling

Vegetation was sampled 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. On each of five transects, the vegetation sampling plots were established at 200 to 500 m intervals. In the marl prairie section of the transects, the plots were established at 300 m intervals, and in the Shark Slough portion of the transects, the plot density varied between 2 to 4 plots per km (250-500 meter 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 sampling site, a PVC tube marked the SE corner of a 10 x 10 m tree plot. Nested within each tree plot, a 5 x 5 m herb/shrub plot was laid out, leaving a 1-m buffer strip along the southern and eastern border of the tree plot. In the 10 x 10 m tree plots, we measured the DBH and crown length and width of any woody individual ≥ 5 cm DBH, then calculated species cover assuming horizontally-flattened elliptical crown form. Within each 5 x 5 m 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 % 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 5 x 5 m plot. Species present in the 5 x 5 m plot but not found in any of the 1 m^2 subplots was assigned a mean cover of 0.01%. In addition, a suite of structural parameters was recorded in a 0.25 m^2 quadrat in the SW corner of each of the 5 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 ~5 cm width, measured at 4 points in each 0.25 m^2 quadrat; 3) Total vegetative cover, in %, and 4) live vegetation percent cover, expressed as a % of total cover.

2.2.2 Ground elevation and water depth measuremnets

In the slough portion of the transect, water depth was measured at the PVC, the marker of the plot, and in the center of five vegetation sub-plots in a 5 x 5 m plot. In the marl prairie section, vegetation was sampled in the dry season when there was frequently no standing water, thus water depth measurement was a problem. At those sites, we measured water depth once in 2008, particularly in the wet season when there was standing water at many sites. In addition, a Promark 3 GPS unit was used to measure elevation on marl prairie sites with no standing water.

2.3 Data Analysis

2.3.1 Hydroperiod and daily water depth estimation

We used field water depth-derived elevation and EDEN (Everglades Depth Estimation Network, http://sofia.usgs.gov/eden) water surface elevation data to estimate the hydrologic conditions at each sampling 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 for the same sampling date. Daily water levels for each plot were estimated based on ground elevation and the time series of water surface elevation extracted from EDEN database. We then calculated hydroperiod, the number of days per year when the location had water depth >0cm, and mean annual water depth for each plot. Previous studies have found that prairie and marsh vegetation composition are well-predicted by the previous 3-5 years of hydrologic conditions (Armentano et al. 2006; Ross et al. 2006; Zweig and Kitchens 2009). In this study, we averaged hydroperiod and mean annual water depth for the four water years (May 1st – April 30th) prior to each sampling event to examine the relationships between hydrologic parameters and vegetation composition.

2.3.2 Vegetation analysis

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. Then, we used non-metric multidimensional scaling (NMDS) ordination to visualize relationships among sites based on their similarities in vegetation composition. We performed NMDS on a matrix of Bray-Curtis dissimilarities among sampling units, with species' importance value first standardized by species' maximum. We then examined the relationship between vegetation composition and environment along a reference vector representing the hydrologic gradient. In NMDS, the community characteristics and environmental vectors, including one for mean annual water depth, were defined through a vector fitting technique in DECODA (Kantvilas and Minchin 1989; Minchin 1998). In the vector-fitting method, a vector is defined in the ordination in the direction that produces the maximum correlation between the measured community and environmental attribute and the scores of the sampling units. The statistical significance of such correlations was tested using a Monte-Carlo permutation test with 10,000 random permutations (Faith and Norris 1989).

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:

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

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

Vegetation change analysis 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 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 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 sampling). 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 vegetation-hydroperiod model is developed from all samples except one, and consequently applied to predict the hydroperiod of the left-out point on the basis of its vegetation. We used the C2 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 from 83 sites that included 11 sites on the Transect M1 and 72 sites on the Transect M3, respectively. The predicted hydroperiods for those sites were termed 'vegetation-inferred hydroperiod'. A change in vegetation-inferred hydroperiod between successive samplings reflects the amount and direction of change in vegetation, expressed in units of days per year (0-365) along a gradient in hydroperiod.

3. Results

Change in hydrology (2006-2013)

Over the sampling periods (2006-2013), hydrologic conditions in the marl prairie portions of the MP-S gradient varied between transects. On Transect 1, the 4-year period before E2 census was much drier than the years before E1, followed by slightly wetter conditions between E2 and E3 samplings (**Figure 2A**). Though, the difference in mean hydroperiod between the 4-year periods before E2 and E3 samplings was not statistically significant. In contrast, on Transect M3, which has marl prairies on both sides of the SRS, the hydrologic conditions varied over time independently. On this transect, the hydrologic conditions during E1 were similar both sides of the slough, but during E3, mean hydroperiod in the eastern prairie was 8 days longer than it was during E1. In contrast, mean hydroperiod in western prairie was 26 days shorter than the hydroperiod during E1 (**Figure 2B**).

Vegetation change (2006-2013)

The characteristic species of short hydroperiod marl prairie sites include muhly grass (*Muhlenbergia capillaris* ssp. *filipes*), little bluestem (*Schizachyrium rhizomatum*), back-top sedge (*Schoenus nigricans*), spadeleaf (*Centella asiatica*), rosy camphorweed (*Pluchea rosea*), among others. When considering MP landscapes from both sides of the SRS, species composition differed between eastern and western sites. This difference was significant (ANOSIM: $R = 0.475$, $p = 0.01$), particularly on Transect M3. The vegetation east of SRS was mostly dominated by muhly grass and sawgrass, whereas muhly grass had very low cover west of the SRS. On the west side of SRS, *S. rhizomatum, S. nigricans* and *Paspalum monostachyum* were more common than muhly.

Vegetation composition in the marl prairie portions of the both Transects M1 and M3 tracked the spatio-temporal variation in hydrologic conditions. In our analysis, a shift in vegetation composition over time in response to hydrologic changes is represented by the change in vegetation-inferred hydroperiod between successive samplings. The magnitude, and an increase or decrease in inferred hydroperiod reflects the amount and direction of change in vegetation composition, expressed in units of days (0-365) along a gradient in hydroperiod.

Six years after vegetation was first sampled in 2006 at marl prairie sites on M1, species composition had shifted toward a drier type (**Figure 3**). About 50% of sites showed that vegetation-inferred hydroperiod decreased by more than 30 days which was very much in compliance with the trend in observed mean hydroperiod that decreased by 40 days over the same period (**Figure 2**). The drying trend on this transect resulted in an increase in abundance (IV) of several species (*Muhlenbergia capillaris* var. *fillipes, Rhynchospora microcarpa, Centella* *asiatica, Symphyotrichum tenuifolium*) that are characteristic of the marl prairie environment (Pairwise t-Test: $p<0.05$). In contrast, the abundance of hydric species, *Bacopa caroliniana, Utricularia purpurea* and others decreased by 2-3 fold (Appendix 1). Over six years, between 2007 and 2013, vegetation change pattern at marl prairie sites of M3 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 *Schoenus nigricans* and *Paspalum monostachyum* accompanied by a decrease in abundance of *B. caroliniana, Eleocharis cellulosa* and *Rhynchospora tracyi*, the direction of change in vegetation composition in eastern prairie sites showed a mixed pattern. Several sites at the distal portions of the transect, especially close to the eastern Park boundary, exhibited an increase in inferred-hydroperiod, suggesting that species composition at these sites shifted toward a wetter type between 2007 and 2013 (**Figure 4**). Surprisingly, the abundance of representatives of both prairie and hydric species were observed to decrease on this section of the transect. However, not all major species decreased in cover; the abundance of *E. cellulosa* did not change during the period, and *R. tracyi* increased significantly.

The shift in vegetation composition observed in the marl prairie portions on M1 and M3 also resulted in changes in species richness and above ground plant biomass. Mean species richness increased significantly (Pairwise t-test) on M1 where a drying trend was observed (**Figure 5)**. On this transect, the mean (± SD) richness during E1, E2 and E3 was 8.3, 10.1 and 11.2, respectively. On the eastern portion of M3, there was no significant change in species richness. In contrast, on the western portion of M3, species richness decreased over time, and was significantly lower during the E2 (14 species/plot) than E1 (15.4 species/plot).

Above ground biomass on Transect M1 did not change significantly over the sampling period (**Figure 6)**. However, on Transect M3, the biomass varied over time, and the temporal variation pattern differed between eastern and western prairies (**Figure 6**). In the eastern prairie, the biomass was much lower during E2 (403 g m^{-2}) than E1 (768 g m^{-2}). The biomass increased between E2 and E3, but during E3, it was still only two thirds (521 g m^{-2}) of initial biomass. In contrary to the trend observed in the eastern prairie, the plant biomass west of SRS was lowest during E1 (550 g m^{-2}), and it continued to increase between successive samplings. The biomass during the E2 and E3 samplings were 647 g m^{-2} and 674 g m^{-2}, respectively.

4. Discussion

The marl prairie landscape, which is currently the only habitat of the Cape Sable seaside sparrow (CSSS), a federally listed endangered species, is highly dynamic and vegetation composition within this landscape changes rapidly in response to hydrologic changes, fire events, and their interactions. 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, species present in the vegetation mosaic are adapted to tolerate the alternating wet/dry conditions that are part of any flood-pulsed environment (Junk and Piedade 1997; Middleton 1999). However, the inherent ability of plants to survive and grow under various hydrologic regimes varies among species, and the differences in species' optimum flooding tolerances usually form the basis for variation in vegetation composition in these ecosystems. In marl prairies, species differences in hydroperiod optima and tolerances have been well-documented (Ross et al. 2006). Hence, any change in duration of inundation would affect the abundance of various species. These dynamics are reflected in changes we observed in relative cover of constituent species, resulting in shifts in vegetation composition towards either wetter or drier types.

Northeast Shark Slough, the site of Transect M1, has been kept relatively dry throughout the 1980s and 1990s (Van Lent et al. 1999) and this condition has changed little during recent years. Thus, the observed vegetation shift toward a drier type was not a surprise, especially considering that most years after the E1 sampling period in spring 2006 were relatively dry. Moreover, the discrepancy in the vegetation change pattern observed in the eastern and western prairies on M3 was primarily management-driven. Water conditions in the prairies west of SRS are influenced by 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 NP-205. This has caused the vegetation composition to shift toward a drier type in recent years. In contrast, vegetation on the eastern portion of Transect M3 shifted toward a wetter character. In this region, water pump structures at S332B and S332C, constructed under Interim Operation Plan (IOP) to provide protection for the adjacent CSSS habitat, deliver water from the L31N canal into a series of inter-connected 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 be entering ENP through subsurface flow. The purpose of operating pump stations along the L-31N canal includes lowering canal and groundwater levels and creating a continuous hydraulic ridge to control seepage back to the canal while protecting the marl prairie (sparrow habitat) from further deterioration (USACOE 2006). Pumping through S332B and C serves the management goal of re-hydrating the marl prairies of the Rocky Glades. Thus, a shift in vegetation towards the wetter types indicates that the management goal is being achieved, at least in part.

The difference in the temporal change pattern in species richness between eastern and western prairies was expected. In the marl prairie landscape, species richness is inversely related to hydroperiod and mean annual water depth (Ross et al. 2006). Thus, the increase in number of species with the drying trend in western prairie and the opposite trend in eastern prairie are in agreement with the previous studies (Sah et al. 2011). The findings suggest that raising water level in marl prairie regions will have negative impact on plant species richness.

On Transect M3, 38 vegetation monitoring plots burned in Mustang Fire in 2008, and the fire may have impacted vegetation structure and composition observed during samplings in 2009 and 2012. For instance, mean above ground biomass was 50% less in 2009 than it was in 2006. However, impact of the fire on species composition cannot be well discerned from the impact of an interaction between fire and post-fire hydrology, because there were not many unburned sites on the eastern portion of the Transect. Even at three unburned sites located at the distal end of the transect (0-600 m), vegetation shifted towards wetter type (**Figure 4**). In another study, a number of sites burned in Mustang fire, but located within and outside the influence of detention ponds, were sampled (Sah et al. 2011). The results from the study revealed that vegetation at both burned and unburned sites that were outside the influence of retention ponds shifted towards drier type (**Figure 7**). Thus, the findings of this study suggest that construction and operations of water pumps and detention ponds adjacent to the canals have caused the shift in vegetation composition towards wetter type. However, water flow from the 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 upper Taylor Slough basin showed significant trajectory along the vector representing the phosphorus gradient, possibly due to influence of seepage water from the detention ponds. In this study, we did not work on the possible impact of nutrient on vegetation change. However, if water from the detention ponds continues to influence the vegetation in prairies, the water quality issue also needs to be addressed in future so that vegetation in the prairie adjacent to the ponds does not shift to another stable state adapted to P-enriched soil (Hagerthey et al. 2008) due to canal water that is pumped in to the ponds.

In summary, regional differences in hydrologic regimes resulting from alternative management strategies have caused variation in species composition along the marl prairie slough gradient, and have also brought on temporal change in vegetation composition in marl prairies. The occurrence of these changes coincided with changes in hydrologic regimes on either side of Shark River Slough. The temporal changes in vegetation composition across the gradient are likely to have affected the position and attributes of transition zones in ways not yet fully understood. Our results provide feedback for the adaptive management of Everglades wetland ecosystems along the marl prairie-slough gradient.

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Figures

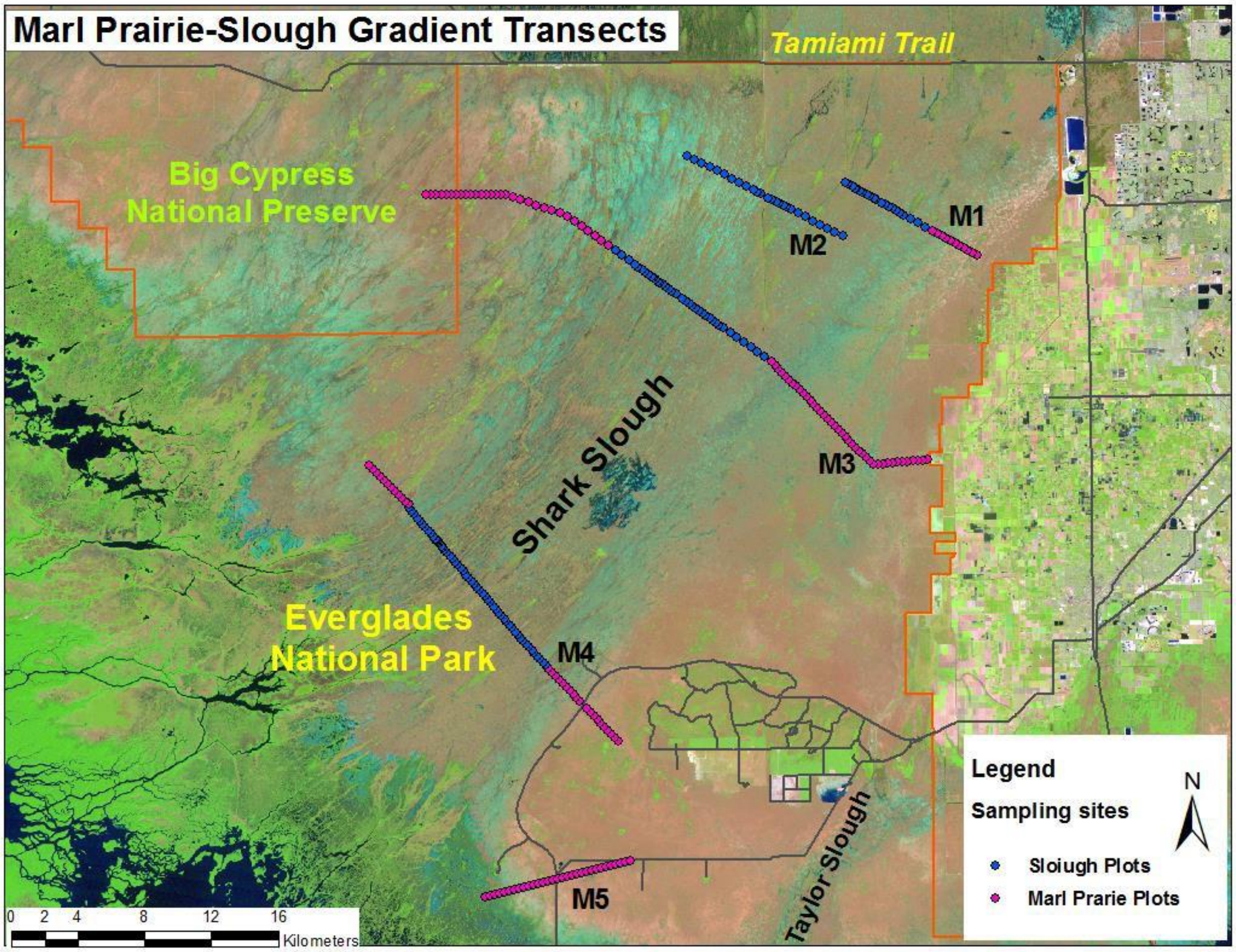

Figure 1: Location map of Marl prairie-Slough Gradient Study plots on Transects M1-M5. Slough plots represent long hydroperiod and marl prairie plots represent short hydroperiod plots.

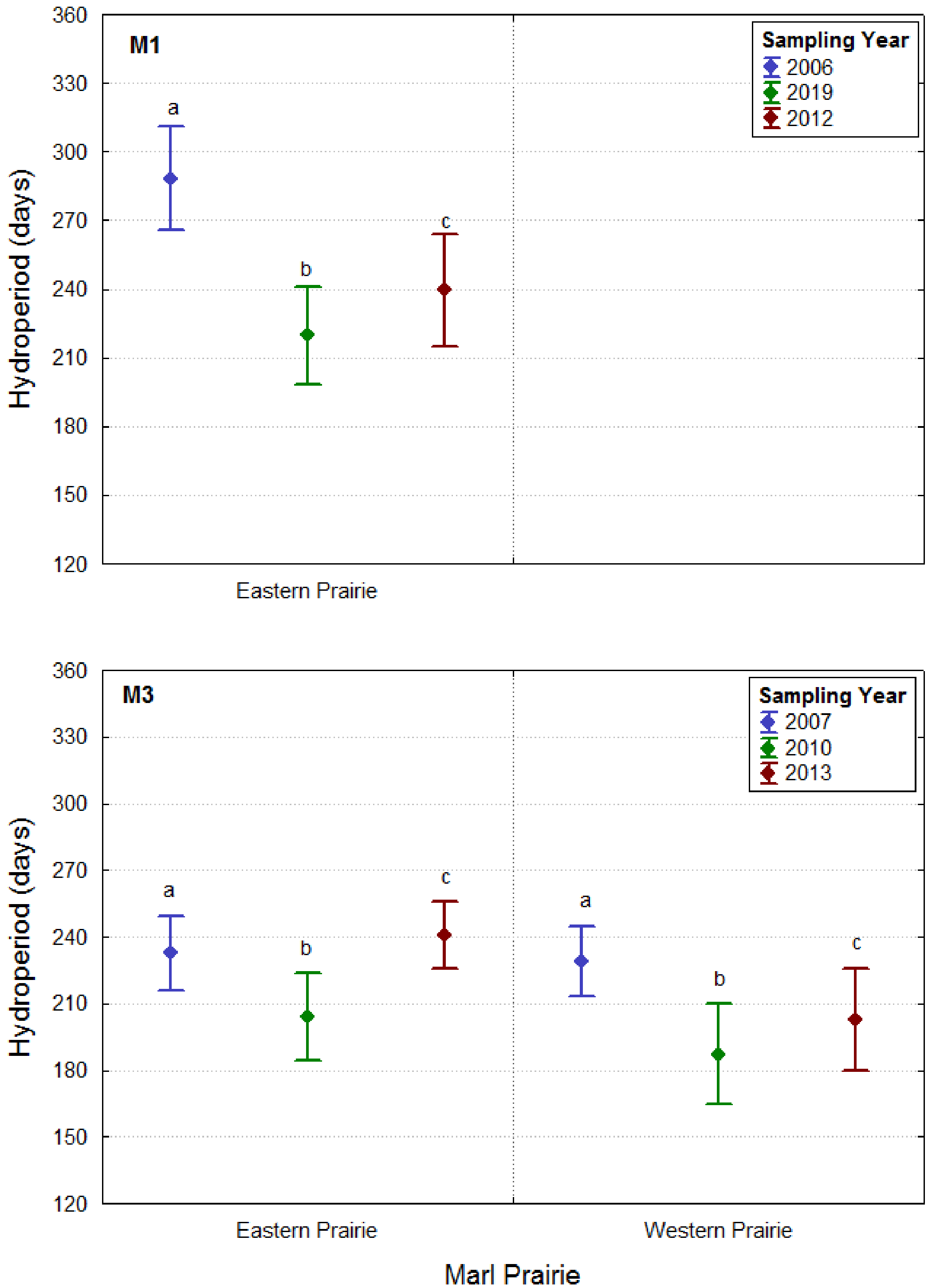

Figure 2: Mean (±95% CI) hydroperiod averaged over four years prior to vegetation sampling in the marl prairie portions of MAP transects M1 and M3 sampled between 2005 and 2014. Transect M3 has marl prairies both sides (East & West) of Shark Slough, Different letters represent significant (pair-wise t-test; $p < 0.05$) difference in hydroperiod between sampling period on the particular section of individual transects.

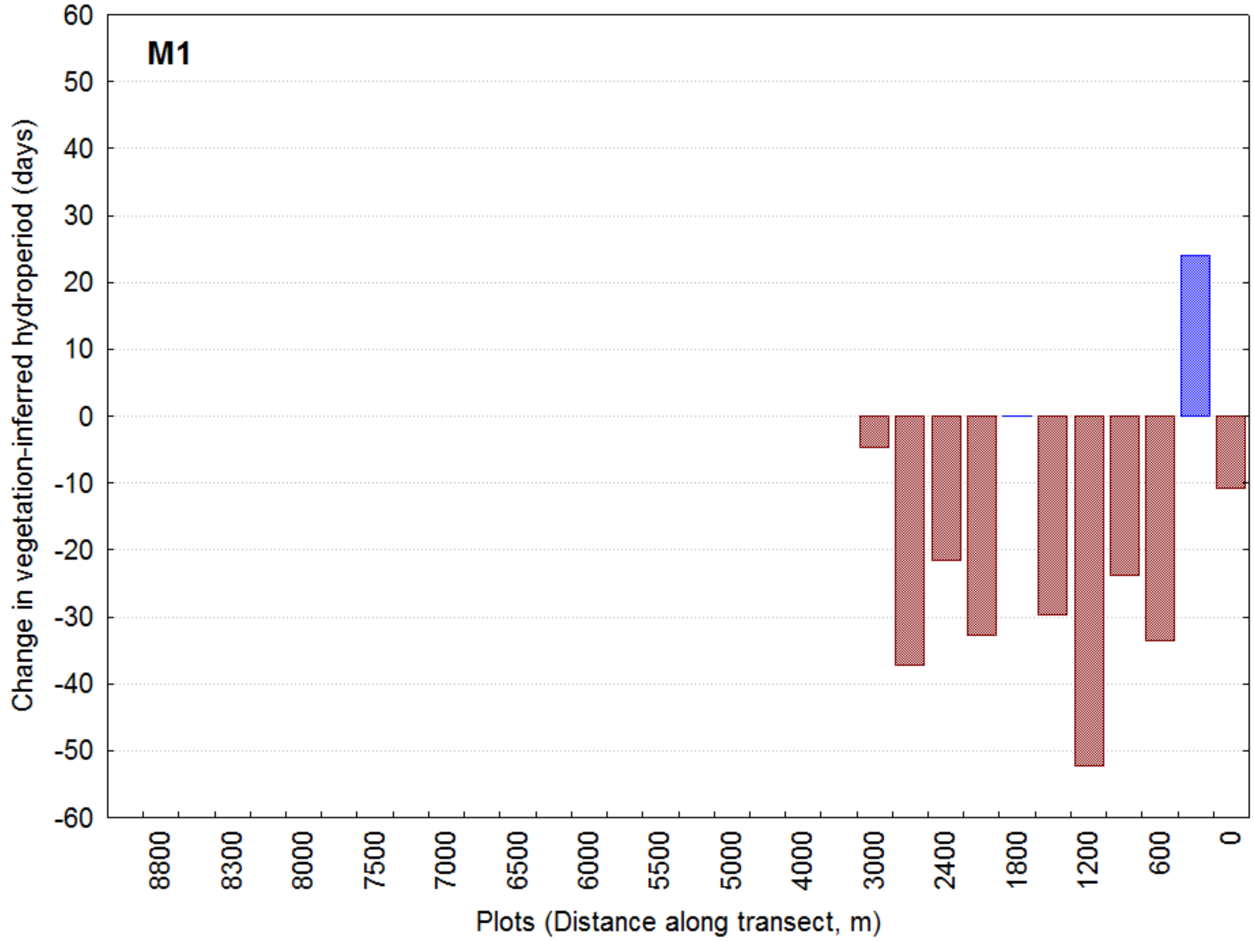

Figure 3: Change in vegetation-inferred hydroperiod from 1st sampling, E1 (2006) to the 3rd sampling, E3 (2012) for vegetation monitoring plot on the marl prairie portion of the Transect M1.

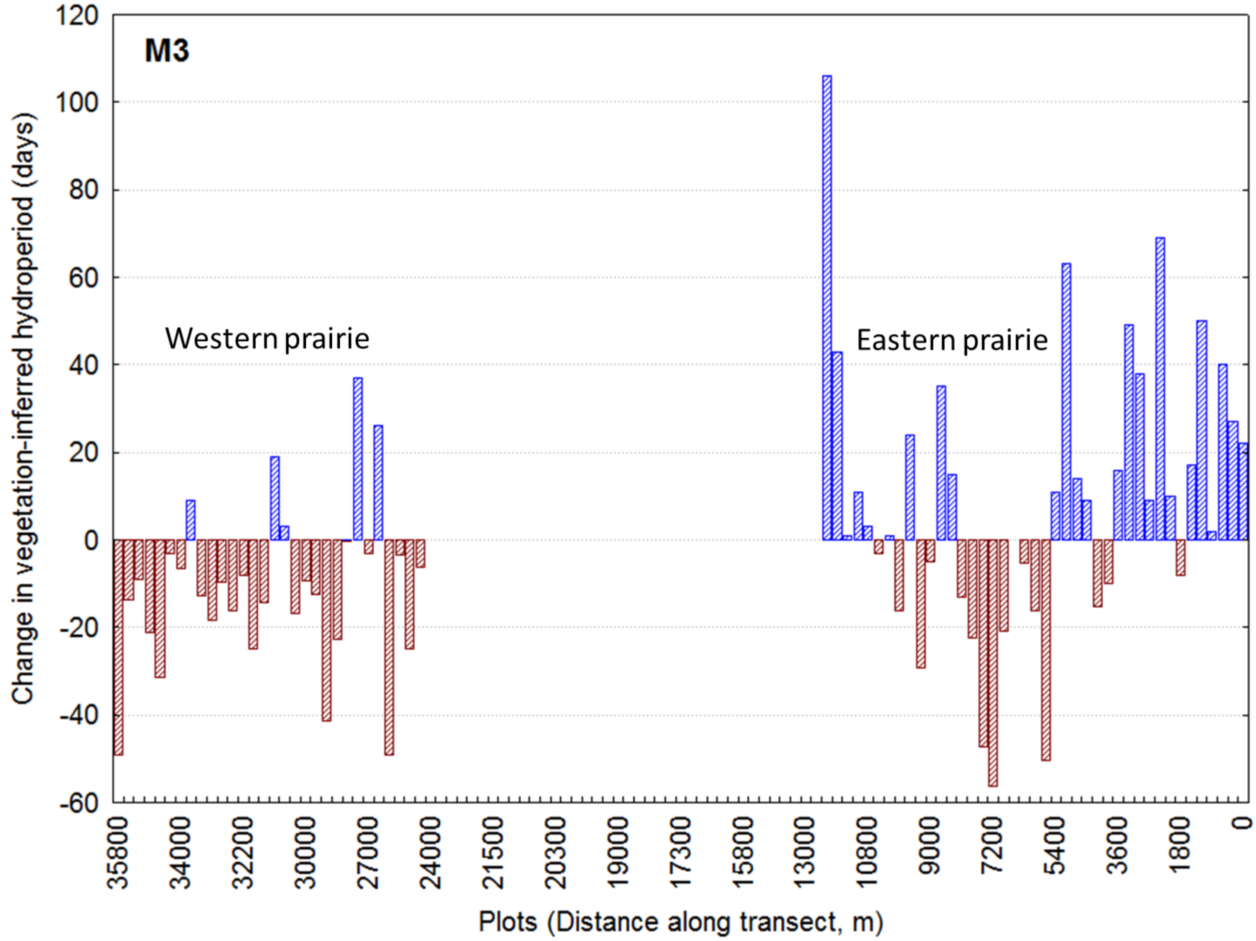

Figure 4: Change in vegetation-inferred hydroperiod from 1st sampling, E1 (2007) to the 3rd sampling, E3 (2013) for vegetation monitoring plot on the marl prairie portion of the Transect M3.

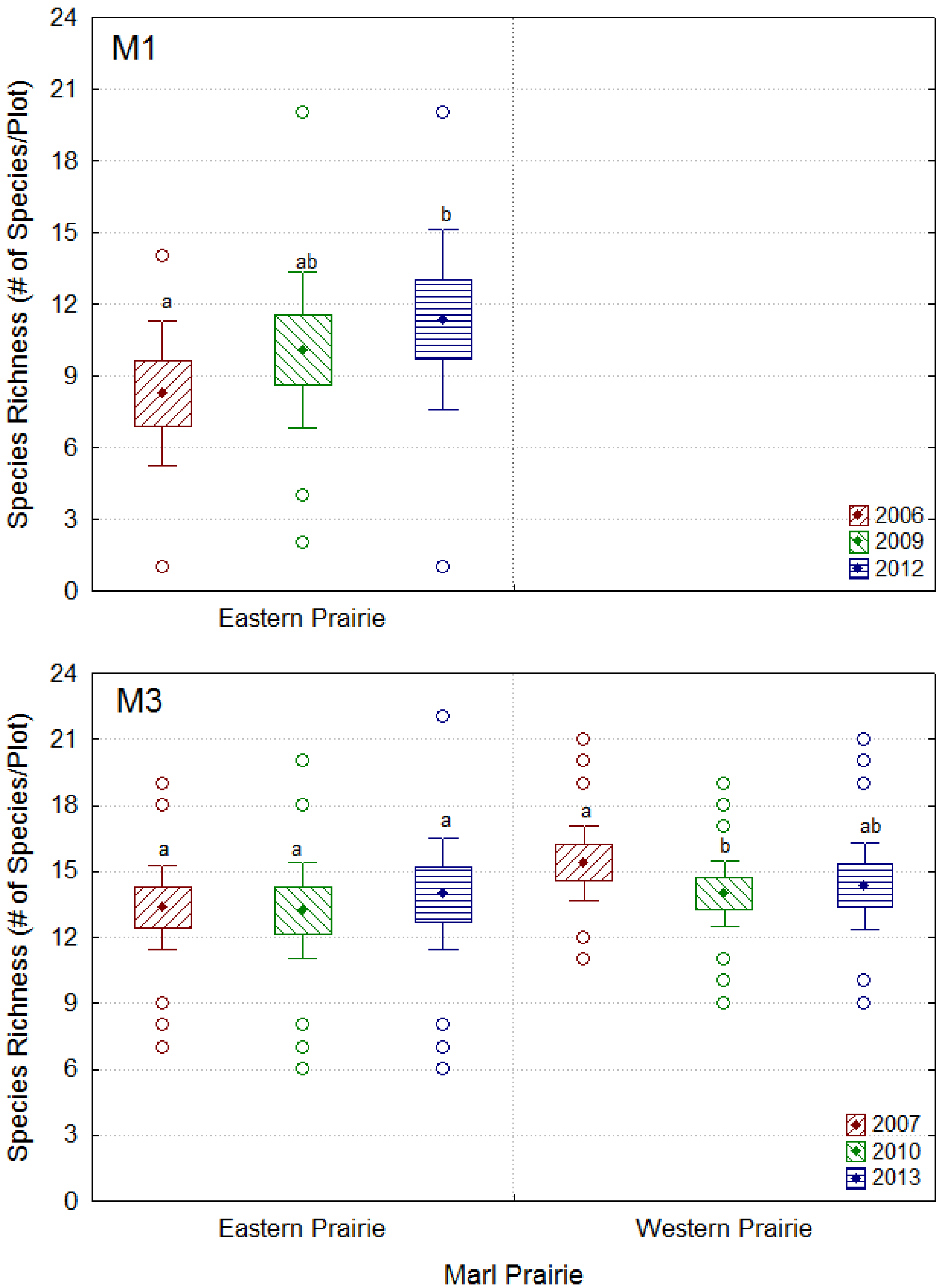

Figure 5: Box Plots showing mean (± SE, 95% CI, and outliers) species richness in marl prairie portion of MP-S gradient transects M1 and M3 sampled multiple times between 2006 and 2014. Different letters represent significant (pair-wise t-test; $p < 0.05$) difference in mean species richness among years on individual transects.

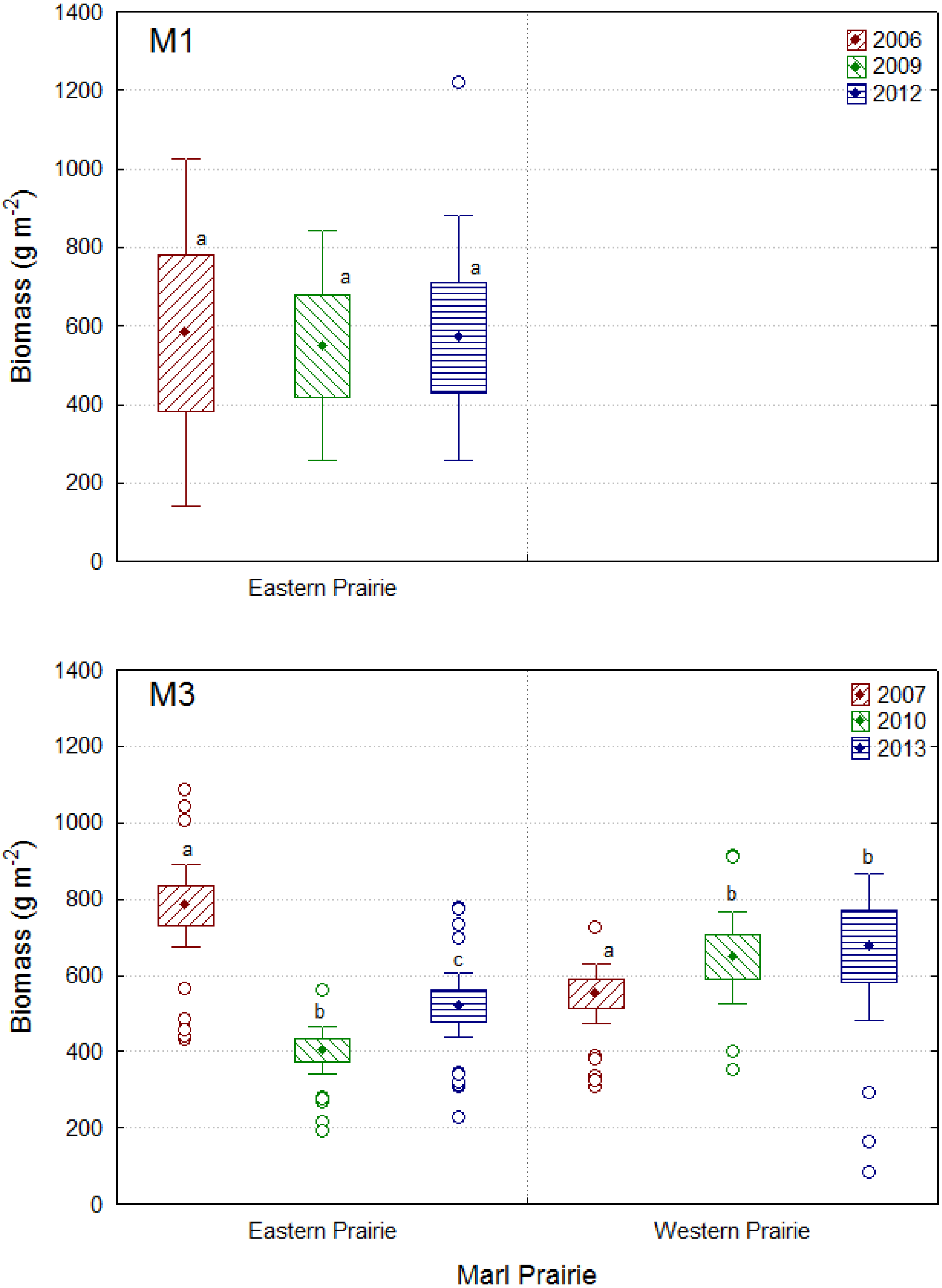

Figure 6: Box Plots showing mean (± SE, 95% CI, and outliers) above ground biomass in marl prairie portion of MP-S gradient transects M1 and M3 sampled three times between 2006 and 2014. Different letters represent significant (pair-wise t-test; $p < 0.05$) difference in mean above ground biomass among sampling years on individual transects.

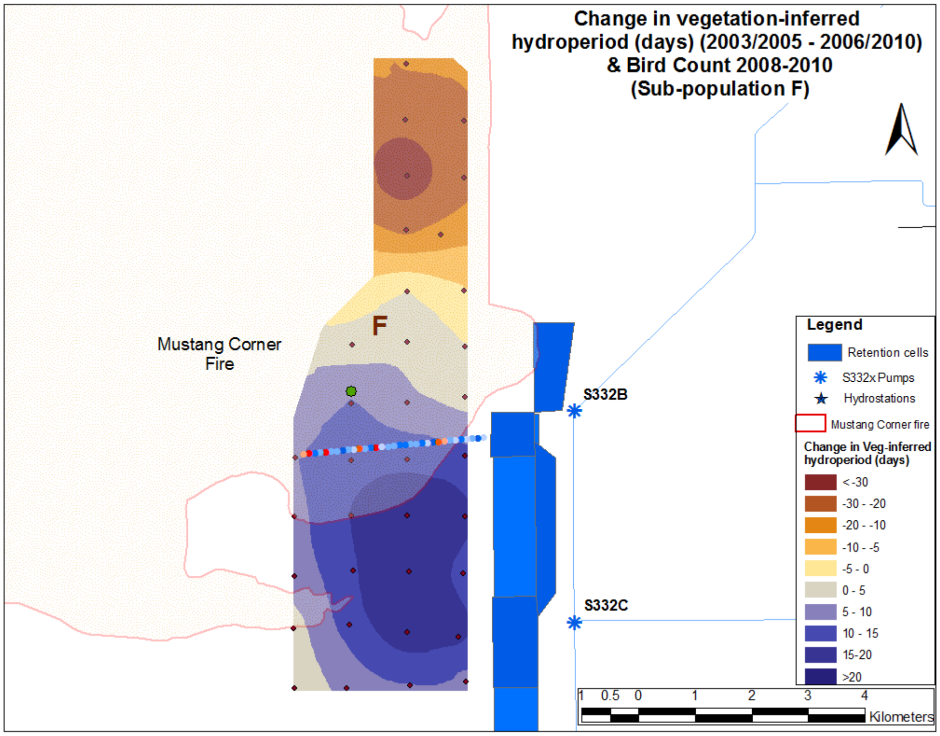

Figure 7: Change in vegetation-inferred hydroperiod in sub-population F between the two sampling periods, 2003-2005 and 2006-2010, and sites with number of sparrows recorded over three years, 2008 to 2010. (**Source: Sah et al. 2011**)

Appendices

Appendix 1: Importance value index (IV) of species present at the marl prairie sites of Transect M1 and M3 that were three times between 2005 and 2013.

Species	M1			M3					
				M3E			M3W		
	2006	2009	2012	2007	2010	2013	2007	2010	2013
Aeschynomene pratensis	0.81	1.52	0.06		0.01		0.79	0.56	0.09
Agalinis linifolia		0.46			0.20	0.02	0.15	0.07	0.11
Agalinis sp.						0.00			
Aletris bracteata					0.02	0.01			
Andropogon glomeratus var. *glomeratus*				0.01					
Andropogon virginicus	0.69	1.05	2.43	0.02	0.46	0.37	0.34	0.46	0.02
Anemia adiantifolia				0.11					
Angadenia berteroi				0.10	0.05	0.00			
Annona glabra	0.42		0.18	0.08	0.06	0.06	3.58	1.96	0.60
Ardisia escallonioides					0.01	0.00			
Aristida purpurascens			0.38	0.04	0.95	0.74	0.02	0.13	0.56
Aristida stricta				0.02					
Asclepias lanceolata				0.16	0.07	0.00	0.03	0.16	0.08
Asclepias longifolia									0.04
Symphyotrichum bracei							0.33		
Symphyotrichum dumosum				0.01	0.08	0.02	0.64	2.23	0.32
Symphyotrichum subulatum				0.92					
Symphyotrichum tenuifolium	1.75	1.17	3.09		4.99	0.66	0.06	2.54	0.59
Aster sp.				0.08					
Bacopa caroliniana	3.94	1.14	1.50	2.27	1.95	0.95	4.64	4.43	1.37
Baccharis halimifolia		0.04		0.11		0.08			
Bacopa monnieri							0.04	0.48	
Blechnum serrulatum				0.59	0.10	0.30			
Buchnera americana				0.01					
Capraria biflora						0.00			
Cassytha filiformis				0.70	0.29	0.05	3.81	0.59	0.71
Centella asiatica	2.77	3.00	3.56	3.27	0.70	0.40	3.04	4.64	2.49
Cephalanthus occidentalis						0.00	0.01		0.00
Chiococca parvifolia				0.04					
Cirsium horridulum					0.05	0.00			
Cladium mariscus ssp. *jamaicense*	40.94	41.35	37.42	47.57	38.03	22.79	20.38	22.39	24.44
Coelorachis rugosa								0.01	
Conoclinium coelestinum					0.42				
Crinum americanum		0.31	0.54				1.72	1.03	0.53
Cyperus haspan			0.06	0.01	0.14	0.01			
Cyperus sp.					0.08				

Species	M1			M3					
				M3E			M3W		
	2006	2009	2012	2007	2010	2013	2007	2010	2013
Dichanthelium aciculare			0.04			0.03			
Dichanthelium dichotomum				1.11	1.64	0.01			
Diodia virginiana						0.00			
Dyschoriste angusta									0.07
Echinochloa sp.							0.01		
Eleocharis baldwinii			0.04			0.03			
Eleocharis cellulosa	9.88	13.72	9.91	3.25	4.94	3.59	2.35	2.08	1.28
Eleocharis elongata					0.08				
Eragrostis elliottii	0.27		0.84	0.87	0.81	0.03	0.20	0.32	0.15
Eriocaulon compressum								0.15	
Erigeron quercifolius				0.07	0.12	0.01	0.06		
Eugenia axillaris				0.08		0.00			
Eupatorium capillifolium		0.36	0.04	1.30					
Eupatorium leptophyllum					0.49	0.16			
Eupatorium mikanioides		0.29	0.04	0.18	0.11	0.00	0.16	0.24	0.08
Eustachys petraea				0.11		0.12			0.04
Flaveria linearis				0.36					
Fuirena breviseta	0.07		0.21	0.01	0.59	0.15	0.01		
Habenaria repens								0.07	
Helenium pinnatifidum								0.01	
Heliotropium polyphyllum				0.15	0.09	0.00			
Hibiscus grandiflorus				0.01			0.07	0.01	
Hydrolea corymbosa						0.00			
Hymenocallis palmeri				0.17	0.07	0.05	1.16	1.18	0.62
Hyptis alata				0.38	0.25	0.04	0.04	0.10	
Hypericum cistifolium					0.07				
Hypericum hypericoides						0.00			
Ipomoea sagittata		1.20	0.03	0.27	0.15	0.16	0.37	0.34	0.10
Iva microcephala			0.59	0.14	0.46	0.08			
Justicia angusta	0.90	0.96	1.33	0.27	1.02	0.08	0.96	1.56	0.47
Kosteletzkya virginica					0.03	0.10			0.02
Leersia hexandra	0.21	0.78	0.35		0.16		0.23	0.70	0.31
Linum medium				0.01	0.02				0.03
Lobelia glandulosa					0.03	0.01	0.14		
Ludwigia alata				0.03	0.34	0.10			0.00
Ludwigia microcarpa	0.22	0.06	0.93	0.19	0.63	0.11	0.06	0.80	0.07
Ludwigia repens		1.38		1.20	0.81	0.08	0.32	0.05	
Melaleuca quinquenervia		0.22							
Metopium toxiferum				0.20					
Mikania scandens	0.27		0.18	1.55	1.84	0.09	0.14	0.14	
Mitreola petiolata			0.23	0.71	0.08	0.00	0.81	0.28	0.18

Species	M1			M3					
				M3E			M3W		
	2006	2009	2012	2007	2010	2013	2007	2010	2013
Muhlenbergia capillaris var. filipes	2.46	5.42	4.32	7.49	7.74	3.55	0.61	0.39	0.18
Morella cerifera	0.12			0.62	0.01	0.30	0.06	0.17	0.03
Myrsine floridana				0.14					
Nymphoides aquatica				0.01	0.03		0.07	0.20	0.00
Nymphaea odorata								0.05	
Oxypolis filiformis	0.50	0.14	0.09	0.11	0.48	0.04	0.16	0.18	0.17
Panicum dichotomiflorum					1.57				
Panicum hemitomon	0.21		0.07	0.22	0.93	0.20	2.15	1.54	0.20
Panicum rigidulum				0.04	0.13	0.18	0.04	0.14	0.00
Panicum tenerum	4.38	4.35	5.74	3.05	5.43	2.22	3.37	6.77	1.75
Panicum virgatum		0.61	0.03	0.61	0.15	0.06	5.59	7.57	5.06
Panicum sp.					0.11				
Parthenocissus quinquefolia						0.00			
Paspalidium geminatum				0.05		0.11	0.14	0.61	0.02
Paspalum monostachyum					0.05	0.06	4.29	8.47	5.60
Passiflora suberosa					0.01	0.02			
Peltandra virginica	0.74	1.16	0.21	0.11	0.06	0.01	0.01		0.12
Persea borbonia				0.20	0.10	0.38	0.03	0.13	0.00
Phytolacca americana						0.01			
Phyllanthus caroliniensis				0.05					
Phyla nodiflora	1.39	0.51	0.44	3.77	0.89	0.58	0.10	0.09	
Phyla stoechadifolia		0.74	0.47	0.70	0.10	0.04			
Phyllanthus sp.									0.02
Pinguicula pumila				0.01					
Piriqueta cistoides ssp. caroliniana									0.02
Pluchea rosea	1.61	2.67	1.55	4.10	4.50	1.02	3.40	3.20	1.00
Polygala balduinii				0.01					
Polygala grandiflora				0.10	0.04	0.00			0.03
Polygonum hydropiperoides		0.79	0.75	0.31	0.15	0.06	0.17	0.09	0.02
Pontederia cordata	0.27	0.58	0.27		0.35	0.00	0.42	0.41	0.02
Proserpinaca palustris		0.72	0.19	0.75	0.54	0.19	0.30	0.06	0.00
Psychotria nervosa				0.35					
Pteridium aquilinum				0.58	0.34	0.25			
Randia aculeata				0.38	0.01	0.08			
Rhus copallinum						0.25			
Rhynchospora colorata				0.01	0.15	0.03	0.13	0.06	0.00
Rhynchospora divergens					0.85	0.86			
Rhynchospora inundata	0.25		1.12	0.12			4.66	1.70	0.53
Rhynchospora microcarpa	0.05		1.35	0.69	1.38	0.71	9.21	3.00	2.71
Rhynchospora miliacea		1.56							
Rhynchospora tracyi	11.80	9.08	13.12	0.61	4.54	1.08	10.18	4.70	4.93

Species	M1			M3					
				M3E			M3W		
	2006	2009	2012	2007	2010	2013	2007	2010	2013
Rhynchospora sp.				0.02					
Sabatia grandiflora				0.06	0.14		0.12		
Sabal palmetto				0.01	0.02		0.01		
Saccharum giganteum		0.18	0.22	0.18	0.06	0.01	0.01	0.07	0.00
Sagittaria lancifolia				0.61	0.59	0.12	0.77	1.04	0.15
Salix caroliniana	0.21	0.22	0.32	0.08		0.28	0.12		0.16
Samolus ebracteatus				0.37	0.23	0.05			
Funastrum clausum							0.18	0.38	
Schoenolirion albiflorum								0.19	0.05
Schoenus nigricans				0.01	0.01	0.05	1.24	1.73	2.80
Schizachyrium rhizomatum		0.15	0.24	2.97	2.72	1.85	4.64	5.71	4.17
Schinus terebinthifolius				0.08		0.01			
Scirpus sp.							0.09		
Setaria parviflora			0.69	0.74	0.08		0.01	0.22	
Sideroxylon salicifolium				0.01	0.05	0.00			
Smilax laurifolia				0.02					
Solidago fistulosa					0.16				
Solidago stricta		0.03	0.13	0.29	0.82	0.08	0.17		0.02
Taxodium distichum var. imbricrium							0.05		
Teucrium canadense					0.29	0.04		0.11	
Thalia geniculata					0.03		0.01	0.12	0.02
Thelypteris kunthii				0.01					
Toxicodendron radicans				0.39	0.06	0.21			
Trema micrantha					0.22	0.07			
Typha domingensis	6.34	0.94	1.84				0.35	0.67	1.17
Unknown grass							0.03		
Unknown sp01							0.06		
Unknown sp02						0.00	0.14		
Unknown sp03						0.00	0.04		
Unknown sp04							0.08		
Unknown sp05							0.05		
Unknown sp06					0.10				
Utricularia cornuta									0.02
Utricularia foliosa	0.05	0.09	0.51	0.08	0.01	0.00		0.02	
Utricularia purpurea	6.49	1.04	2.36		0.09	1.43		0.42	
Utricularia subulata								0.01	
Utricularia sp.					0.01				
Vernonia blodgettii					0.16	0.00			
Vitis rotundifolia				0.16					