Evaluation of Vegetation Response to Changes in Hydrologic Parameters within Cape Sable Seaside Sparrow Habitat, Everglades National Park, Florida

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Cover photo: Vegetation survey in sub-population A.

Executive Summary

Both the Cape Sable seaside sparrow (CSSS), a federally endangered species, and vegetation within its habitat are highly sensitive to changes in hydrologic regime. In the Everglades, the CSSS has remained at the center of the water management strategies primarily because a decline in sparrow population in the early 1990s was attributed in part to management-induced alterations in hydrologic regimes. Guided by the 1999 CSSS Biological Opinion, a number of changes in water management activities have been implemented since the early 2000s. Questions are now whether the water management activities aimed at mitigating damage to Everglades' ecosystems caused by past management would affect the CSSS habitat within its six sub-populations (A-F), and if the impact on vegetation structure and composition would vary spatially and temporally in relation to the preferred CSSS habitat conditions. Moreover, the results of hydrologic modelling associated with Everglades Restoration Transition Plan (ERTP) and Central Everglades Planning Project (CEPP) have suggested an improvement in habitat condition to the east of sub-populations A and E, while areas in the western portion of sub-population B and E may become wetter and thus less suitable for the sparrows. Thus, the objectives of our study were to establish baseline vegetation data in newly identified potential habitat, and to assess the changes in vegetation condition in previously surveyed portions of sub-populations A-C, E and F.

Over five years, 2017-2021, 867 plots were surveyed, including 161 along transects and 706 CSSS census points. The surveyed sites included 532 existing plots that were established and surveyed for the first time in 2003-2005, and 198 new sites, i.e., surveyed for the first time between 2016 and 2020. In 2021, 137 sites were resurveyed that had been sampled in 2016 or in first four years of the current study period (2017-2021). In 2017, sites were surveyed only in sub-population A, particularly in two distinct areas (hN and hS) identified as improved potential future CSSS habitat. Over the next four years (2018-2021) sites in all five (A, B, C, E and F) sub-populations, as well as in the areas between C and F, and between E and F were surveyed. Vegetation survey was done following the method described in Ross et al. (2006). Vegetation change analysis included calculation of changes in vegetation-inferred hydroperiod, followed by trajectory analysis. A change in vegetation-inferred hydroperiod between successive surveys reflects the amount and direction of change in vegetation, expressed in units of days (0-365) along a gradient in hydroperiod. In trajectory analysis, two statistics (delta and slope) were calculated to quantify the magnitude and rate of change in vegetation composition along the hydrologic gradient, and were based on the shift in position of sites along a hydrologic vector within non-metric multidimensional scaling (NMDS) ordination space. Sites surveyed over five years (2017-2021) were classified using cluster analysis, and changes in vegetation type since the 2003/2005 survey were examined.

The hydrologic condition of the vegetation survey sites surveyed during 2017-2021 survey showed a distinct spatio-temporal pattern. Averaged over the sites surveyed in both 2003/2005 and 2017/2021 studies, the four-year average hydroperiod and annual mean water depth differed significantly among survey periods in all five sub-populations, and they also varied spatially.

Vegetation in the southern and southwestern portions of sub-populations A and B, and throughout C, E and F were wetter in 2017-2021 than during previous surveys. In contrast, in the northeastern portion of A (in the hN area), sites were drier during the 2017/2021 survey than the previous surveys. Both vegetation-inferred hydroperiod and trajectory analysis results revealed that vegetation composition in the hN area of sub-population A shifted towards a composition indicative of relatively dry conditions. Several sites in this area changed from marsh to wet prairie vegetation type. In contrast, the majority of sites in the southern and western portion of this sub-population experienced a change towards a more hydric vegetation type, suggesting a continued deterioration of CSSS habitat in these areas. Likewise, vegetation shifted towards a wetter type in the western and southern portions of sub-population B, while composition in the central and northeastern portions of the sub-population B changed little. These results were not unexpected, as sites in the southwestern portion of sub-population A and southern portion of B are also affected by rising ground water levels, partially caused by sea level rise, and in the hS area and western portion of B, sites are possibly affected by a gradual increase in water flow through the Shark River Slough. This trend is likely to continue in the future, suggesting that the small population of sparrows in sub-population A, reported as recently as 2018, will continue to be restricted to the northeastern and eastern portion of the habitat. Likewise, in sub-population B, which has the highest concentrations of sparrows among all sub-populations, the extent of suitable habitat will likely shrink, affecting CSSS populations. In such a situation, the most viable management option could be the assisted improvement of habitat quality in the northeastern and central-eastern portion of sub-population A. That can include burning followed by managing hydrologic conditions not to exceed 20 cm for at least 3-5 months after fire. In this connection, a large portion of this sub-population burned in the 2020 Guava and Moonfish fires. While these fires might contribute to the habitat improvement, their effects on vegetation, and ultimately on sparrow habitat, also depend on water conditions in post-fire years, as we observed in other sub-populations after 2005 and 2008 fires.

In the eastern sub-populations, a shift in vegetation towards wetter type in C, eastern E and throughout F is possibly the result of a broader restoration strategy, including the rehydration of the Rocky Glades, where CSSS habitat deterioration was believed to have resulted from over-drainage followed by frequent fire. Therefore, in these sub-populations, a shift in vegetation towards a more mesic type could possibly be considered as an improvement in CSSS habitat. However, because of additional effects of water seepage from the nearby detention ponds, the shift in vegetation composition was expected to be of greater magnitude close to the Park boundary than in interior portions of the habitat. Thus, the observed changes in vegetation throughout sub-population E and most of F seem to be the result of ongoing comprehensive water management activities, including seepage from the detention ponds and increased water deliveries to the Park through Northeast Shark River Slough (NESRS). Moreover, the 2017/2021 surveys were done within 5 years of the extreme high water conditions during spring 2016, when marl prairies in those three sub-populations were flooded for an extended period. These areas remained relatively dry during the 2017 dry season, but were again wetter in 2018 and 2021. Thus, these unusual highwater conditions might have further enhanced the vegetation trajectory to wetter type in that region. However, at most sites, the vegetation remained a wet-prairie type. Sites in these sub-populations are likely to continue on their current trajectories, as water delivery through the Tamiami Bridges and culverts to the Park through NESRS is expected to increase in years to come. Thus, a compensatory strategy to offset the negative consequences of such highwater events as well as the increased water delivery should be in place so that the areas do not get much wetter and become unsuitable for sparrows. In addition, water flow from detention ponds towards prairies in the Park may have adverse consequences, especially P-loading in soils due to long-term exposure of the canal-side sites to seepage. Thus, if water from the detention ponds continues to influence vegetation in the adjacent prairies, the water quality issue also needs to be addressed so that the affected marl prairies do not shift to another stable state more adapted to P-enriched soil.

Finally, if maintaining the existing sparrow populations of sub-populations B and E, and increasing the population west of Shark River Slough and in the smaller eastern sub-populations are the objectives, then ideally, those strategies that achieve desirable sparrow habitat conditions in the target areas while satisfying the broader ecosystem restoration goals of the Comprehensive Everglades Restoration Plan (CERP) should be considered. Moreover, only continued monitoring of these wetlands will ascertain the direction of vegetation change in response to change in hydrologic conditions due to future restoration activities associated with Central Everglades Project plan (CEPP), Combined Operation Plan (COP) and other components of CERP.

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General Background

The Cape Sable seaside sparrow (CSSS) as well as the vegetation within its habitat range are highly sensitive to natural and management-caused changes in both water and fire regimes. With a broad goal of assessing the response of marl prairie ecosystems to Everglades restoration efforts, a study intended to characterize marl prairie vegetation and monitor its responses to hydrologic alterations and fire within the habitat of sparrow's six sub-populations (A-F) was conducted between 2003 and 2010 with funding from U.S. Army Corps of Engineers (USACE). In the first three years of the project (2003-2005), we completed a detailed account of vegetation composition and structure within occupied sparrow habitat (Ross et al. 2006). Subsequently, during 2006-2010, subsets of sites in all six sparrow sub-populations (A-F) were re-visited annually to assess vegetation dynamics over space and time. The subset surveyed each year included both unburned and burned sites (Sah et al. 2010, 2011). After a three-year interruption, the vegetation study was resumed in FY2014 with funding from Everglades National Park (ENP). In FY2014, the focus of the study was to assess the impact of the fire-hydrology interaction on vegetation along a wide range of hydrologic conditions (Sah et. al. 2015), and in FY2016, a number of new sites were established and surveyed in the northeastern portion of sub-population A and the western portion of sub-population E (Sah et al. 2016).

The hydrologic modelling carried out using the Regional Simulation Model (RSM) tool to evaluate the potential impact of Everglades Restoration Transition Project (ERTP) predicted that habitat in the eastern portion of CSSS sub-population A would be relatively dry (USCACE 2011, 2014; USFWS 2016) in comparison to 1990s and existing hydrologic conditions. Likewise, under CEPP-ALT 4R2, the recommended restoration alternative for Central Everglades Planning Project (CEPP), the CSSS habitat suitability index (HIS), calculated using a habitat suitability modeling approach, suggested that some additional areas northeast of currently occupied habitat in sub-population A would exhibit improved hydrologic condition that is more suitable than without restoration (Pearlstine et al. 2016). In addition, the areas to the east of sub-population E were also projected to improve. In contrast, the areas in the western portion of sub-populations B and E were expected to be relatively wet and thus, less suitable habitat for sparrow mainly due to increase flow of water in the Shark River Slough. Thus, vegetation monitoring focusing on these most sensitive areas, as well as those within other sub-populations was initiated in FY 2017 with funding from Everglades National Park (Task Agreement # P13AC01271, Cooperative Agreement # H5000-06-0104), and US Army Corps of Engineers – Engineer Research and Development Center (USACE-ERDC CA # W912HZ-17-2-0003). The results of vegetation surveys completed in first four years of this study were described in annual reports (Sah et al. 2018., 2019, 2020, 2021). The monitoring work within the marl prairie landscape continued in FY 2021.

In the field, when vegetation survey was done under these two separate funding sources, we ensured that the sites to be surveyed under each project were complementary, but not duplicative. However, when we were in the field, and the sites to be surveyed under these projects were within the same vicinity, we surveyed them seamlessly so that federal resources allocated for field research in both projects were utilized with maximum efficiency. This report includes a comprehensive assessment of the vegetation structure and composition from all sites, surveyed together over five years (FY 2017-2021) under both projects.

In 2017, the study focused on the establishment and vegetation survey of two new transects, one in the southeastern portion of sub-population A and the second east of sub-population E. In addition, a subset of existing transect and census sites was also surveyed within sub-population A. The major activities in 2018 included site establishment and vegetation survey in two new areas, between sub-populations C and F (hereafter called 'CF), and between sub-populations of E and F (hereafter called 'EF'). In addition, a subset of existing census sites also was surveyed within sub-population A, B, E and F. In 2019, however, we sampled only existing sites that had been established and surveyed for the first time during 2003-2005 in five sub-populations (A-C, E and F). In 2020, a year when field work was partly affected by helicopter flight restrictions within the Park due to the COVID-19 pandemic, vegetation survey under the ENP-funded project focused on only those sites that were accessible by foot from the Main Park Road. Moreover, while vegetation survey at the USACE-funded sites was partly (sub-populations C, E and F) done before such restrictions were in place, the survey within sub-population A was delayed until early- to mid-June. Finally, in 2021, normal routine of the vegetation survey resumed. This year, we initiated a new 4-year cycle of vegetation survey, that was in par with the previous two vegetation survey events (2006-2009 and 2017-2020). During this 4-year period (2021-2024), the target sites to be re-surveyed are distributed in all five sub-populations (A-C, E and F) and also included CF and EF sites. The vegetation re-survey plan assumed the continuation of funding from both USACE and NPS-ENP beyond the existing five-year funding that were scheduled to be ended by the end of 2021.

Over the 2017-21 period, vegetation survey of both new and old sites was typically done in the spring of each year, followed by water depth measurement at the new sites in the wet season of the same year. Water depth was also measured at a subset of previously surveyed census sites, particularly at those sites for which field water depth-based ground elevation data were not available. This report primarily describes the vegetation characterization at new sites surveyed for the first time in 2017 and 2018, and temporal changes in vegetation structure and composition in relation to changes in hydrologic conditions at the previously surveyed transect (in sub-populations A, E and F) and census sites (in sub-populations A-C, E and F) that were re-surveyed over five years (2017-2021) of the current funding cycle.

1. Introduction

In the Everglades, the Cape Sable seaside sparrow (CSSS), a federally endangered species, is a pivot point for water management operations primarily because a decline in sparrow population in the early 1990s was attributed in part to management-induced alterations in hydrologic regimes. In general, CSSS populations respond to changes in both hydrology and fire regime, either directly through their nesting success or failure (Pimm et al. 2002; Baiser et al. 2008; Bencoster et al. 2019; Bencoster and Romañach 2022), or indirectly, mediated through vegetation change in their habitat (Nott et al. 1998). Human influence on both these factors is pervasive, through the management of the extensive south Florida canal system, and through the fire management policies or plans of Everglades National Park (ENP) and Big Cypress National Preserve (BCNP). The questions today are whether the water management activities aimed at mitigating damage to Everglades' ecosystems caused by past management affect the CSSS habitat, and how the impact on vegetation structure and composition vary spatially and temporally in relation to the preferred CSSS habitat conditions.

The Cape Sable seaside sparrow was originally described from brackish coastal marsh habitat, but currently inhabits freshwater short hydroperiod marl prairies present on both flanks of the Shark River and Taylor Sloughs. The marl prairie habitat has gone through many transitions in hydrologic and fire regime due to management-induced changes in water flow pattern in the southern Everglades. Such changes in habitat conditions during the 1980s and 1990s resulted in an unexpected decline in sparrow numbers in four of six sub-populations. Guided by the 1999 CSSS Biological Opinion, water management activities have affected occupied and adjacent potential CSSS habitat which had deteriorated due to extreme water conditions before the late 1990s. For instance, regulatory schedules for the S-12s structures along Tamiami Trail – first followed under the operational objectives of Interim Structural and Operation Plan (ISOP)/Interim Operational Plan (IOP) (USACE 1999; USFWS 2002), and recently under the objectives of Combined Operational Plan (USACE 2020) - have produced low water levels at NP-205 and nearby areas, resulting in vegetation characteristic of drier conditions in the northeastern part of sub-population A (Sah et al. 2011, 2016, 2018, 2019, 2021). In contrast, in the eastern marl prairies, operated under Interim Operation Plan (IOP) to provide protection for the adjacent CSSS habitat (USFWS 2002), the S332B and S332C pump structures deliver water from the L31N canal into a series of inter-connected detention ponds. In these areas, both the overflow above a fixed-crest weir and subsurface seepage from the pond to adjacent marl prairies in ENP have helped to control seepage back to the canal and to protect the sparrow habitat from further deterioration (USACE 2007). Accordingly, vegetation in areas adjacent to the canal has shifted towards a more mesic type (Sah et al. 2011, 2021), presumably improving the CSSS habitat, as these areas were considered over-drained and therefore vulnerable to frequent fires initiated near the ENP border; such fires adversely impacted the habitat and resulted in reduced sparrow numbers (Pimm et al. 2002). These vegetation trajectories are subject to change due to ongoing as well as future restoration activities associated with Comprehensive Everglades Restoration Plan (CERP) and its recently outlined components, such as Everglades Restoration Transition Plan (ERTP), Central Everglades Planning Project (CEPP) and Combined Operations Plan (COP) (USACE 2011, 2014, 2020; USFWS 2016).

During CEPP planning, the Refined Recommended Plan (i.e., Alternative 4R2) has been considered the best alternative in comparison to the existing condition baseline (ALT EC) (USACE 2014). Modeled under these two scenarios, CEPP-ALT EC and CEPP-ALT 4R2, the CSSS habitat suitability index suggests that the latter would result in areas of sparrow habitat within both western (sub-population A) and eastern (B, E and F) sub-populations becoming wetter and hence less suitable than at present (Pearlstine et al. 2014). The eastern sub-populations are also expected to be impacted by the potential increase in water deliveries to the Park under COP operations (USACE 2020). Specifically, conditions along the western edge of sub-population E, one of the two largest and most persistent sub-populations, will be wetter than the sparrow prefers (Pearlstine et al. 2016), in association with increased water flow through the Blue Shanty area as well as Northeast Shark River Slough (USACE 2014; 2020). In contrast, the model also predicts that some additional suitable habitat may become available outside the recent range of CSSS occurrence. In particular, the eastern portion of CSSS sub-population A and adjoining areas to the northeast of currently occupied habitat are expected to exhibit improved conditions (Pearlstine et al. 2014, 2016). The results of hydrologic modelling associated with the Everglades Restoration Transition Plan (ERTP) and Central Everglades Planning Project (CEPP) have also suggested an improvement in habitat condition in the eastern portion of the sub-population A, especially two distinct areas, identified as CSSS-A habitat north and south (hN and hS) (USACE 2011, 2014; USFWS 2016).

Changes in hydrologic conditions due to ongoing and future water management efforts are likely to affect fire regimes within the CSSS habitat. Like in several other ecosystems, both fire and flooding are common also in Everglades, where wetland plant communities have evolved in response to the interplay of both fire and hydrologic regimes (Gunderson 1994; Lockwood et al. 2003; Duever and Roberts 2013). Moreover, in areas where the probability of wildfire is high at the onset of the rainy season, there is a likelihood that a wildfire will be closely followed by flooding, thus affecting the trajectories of post-fire vegetation recovery. The chances of such events are high in the Everglades, where wildfires caused by natural lightning are frequent early in the rainy season (Slocum et al. 2007).

In a seasonally-flooded wetland, the rate and extent of post-fire vegetation recovery vary with vegetation type, soil characteristics, fire intensity, and pre- and post-fire hydrologic conditions. Vegetation after a single burn event in some wetlands returns to a pre-burn state within 3-4 years (Pahl et al. 2003; LaPuma et al. 2007). However, in an area where vegetation is denuded either due to a single intense disturbance or multiple sequential disturbances, such as fire followed by flooding, the vegetation succession may result in changes in community characters by removing dominant species and facilitating the growth of opportunistic species. Sudden dieback of dominant species may occur when the aerial shoots are burned-off in a fire and are submerged by post-fire flooding, thus cutting off the oxygen supply to the rhizomes and resulting in death of the plants (Herndon et al. 1991; Kirkman and Sharitz 1994; Ponzio et al. 2004). Plants can avoid such a drowning effect by growing enough to maintain their apices above the water level. However, the interval between subsequent disturbances, such as fire followed by flooding, may affect their ability to regrow, and thus determine the fate of the plants, ultimately affecting the trajectory of post- disturbance vegetation dynamics.

In Everglades, habitat conditions in some sensitive areas likely to be impacted by future water management were regularly monitored between 2003 and 2010 (Ross et al. 2006; Sah et al. 2010, 2011). Consequently, these areas contain an established network of monitoring sites at both fine (sites at 100 m along the transects) and broad landscape scales (sites 1 km apart in a gridded layout). In 2016, a number of vegetation monitoring sites were added in areas identified by modeling as potential suitable habitat southeast of sub-population A or to be adversely impacted by the water management activities western portion of sub-population E. However, the existing monitoring network did not include sites in the area to the northeast of occupied habitat in sub-population A, nor east of sub-population E, where habitat conditions are expected to improve. Thus, the major objectives of the study we initiated in FY 2017 were to establish baseline vegetation data, at both fine and broad scales, in newly identified sensitive areas, and to assess the changes in vegetation condition in the existing habitat of sub-populations (A-C, E and F) within the marl prairie landscape.

2. Methodology

2.1 Data Collection

2.1.1 Study area

The study area included existing and future potential CSSS habitat within the marl prairie landscape. Between 2003 and 2005, hereafter termed as "Sampling event E1", we established a network of 901 vegetation-monitoring sites in the marl prairies, most of which were congruent with sparrow census sites. In 2006, 5 sites, particularly were added to the network resulting in a total of 906 sites (Figure 1). Most of the census sites in all six sub-populations A-F and transect sites in sub-populations A and F were re-surveyed between 2006 and 2009, hereafter termed as "Sampling event E2".

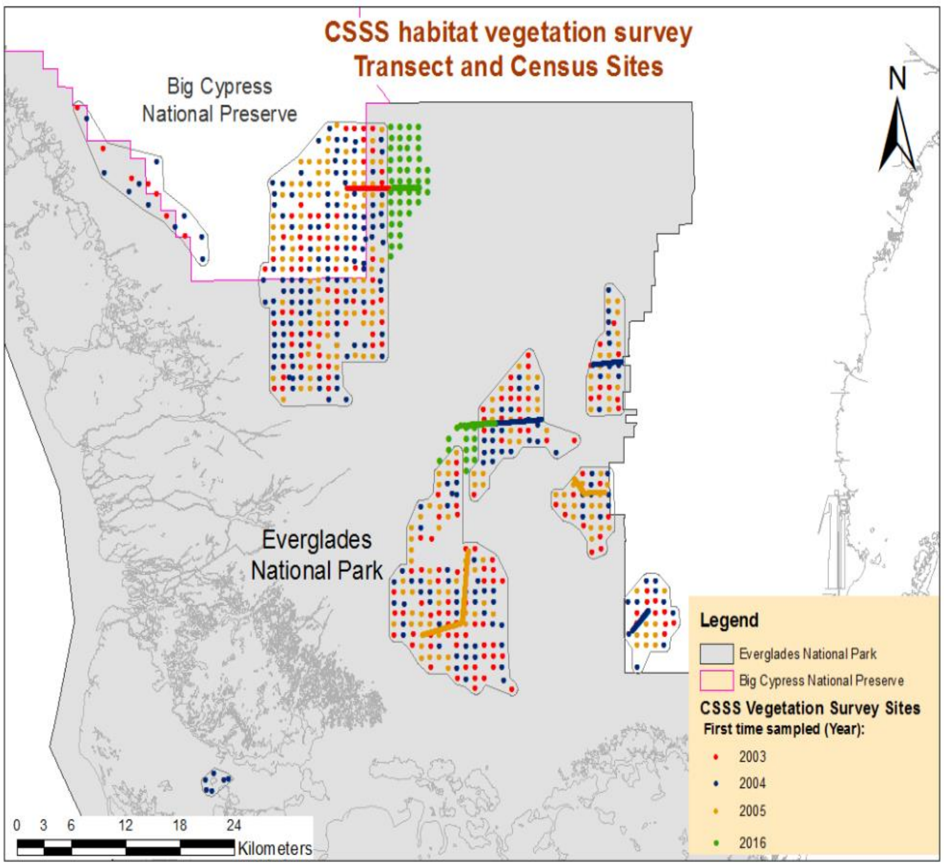

Figure 1: A network of vegetation monitoring sites that were established and surveyed for the first time before 2017-2020. In the beginning of vegetation monitoring within the CSSS habitat, 906 sites (293 transect and 613 census sites) were established over three years (2003-2005), and were surveyed at least twice in a 7-year period (2003-2009). In 2016, an additional 103 sites (45 transect and 58 census sites) were established and surveyed for the first time.

While the vegetation-survey network was widespread and covered almost all the recent range of CSSS habitat (Figure 1), it did not include all sparrow census sites established in

1981/1992 or added later. Specifically, the sparrow census sites not included in the vegetation survey were mostly in the northeast portion of sub-population A (hN_NE), and the 55 sites in other populations, including 17 sites in the western portion of sub-population E (West-E). Thus, in 2016, we extended the existing Transect A eastward for 3 km to capture potential CSSS habitat and Transect E westward for 4 km until the prairie transitioned into the ridge-and-slough landscape.

Altogether, 867 plots sites, including 706 census and 161 transect sites were surveyed over five years, 2017-2021 (Table 1, Figure 2). These included the sites under both ENP- and USACE-funded projects. In the spring of 2017, the first year of the current 5-year (2017-2021) project period, 184 sites, including 131 existing and 53 new sites, were surveyed. Those included 69 transect sites and 115 census sites. Out of 53 new sites, 19 and 24 sites were along new transects in the southern portion of sub-population A and east of sub-population E, respectively. These additional sites were expected to capture fine scale changes in habitat conditions that will possibly be impacted by the hydrological changes caused by ongoing and planned restoration activities (USCACE 2014; USFWS 2016). In 2018, 2019, 2020 and 2021, 215, 181, 104 and 183 sites were surveyed, respectively. In 2018, all the surveyed sites were census sites - 61 new and 154 existing sites. Among the 61 new sites, 27 sites were between sub-populations C and F (hereafter, called ‘CF), 30 were between sub-populations of E and F (hereafter, called ‘EF’), and four sites were in sub-population E. In 2019, only the previously surveyed sites were sampled, including 33 transect and 148 census sites.

Table 1: Sites surveyed within CSSS habitat between 2017 and 2021. * Sites were established in the area between existing boundary of sub-populations C and F, and between E and F. ** Old = Sites established and sampled for the first time during the 2003-2005 survey. New = Sites established and sampled for the first time between 2016 and 2018.

Sub-population	Site type	Old/New**	Year				
			2017	2018	2019	2020	2021
A	Census	Old	105	39	46	45	59
		New	10				13
	Transect	Old	26				
		New	19				15
B	Census	Old		61	48	11	35
C	Census	Old			25	12	10
E	Census	Old		20	29	10	15
		New		4			8
	Transect	Old				26	
		New	24				18
F	Census	Old		34			10
	Transect	Old			33		
CF*	Census	New		27			
EF*	Census	New		30			

In 2020, vegetation survey work commenced on March 2, but was intermittently disrupted due to restrictions associated with Covid-19 pandemic. Over four weeks, we surveyed 51 sites, mostly in sub-populations C and E, and 4 sites in sub-population A. After nine days of survey between March 2^{nd} and 27^{th}, we were unable to continue the field work, primarily due to stay-athome order issued by Florida's Governor. While the order was lifted on May 4, 2020, a restriction on helicopter flights within the Park was still in place. Likewise, FIU Office of Research and Economic Development (ORED) helicopter guidelines for field operations during the Covid-19 pandemic were still being developed. However, during that period we surveyed 14 sites including 11 ENP-funded and 3 USACE-funded sites, by walking from the Main Park Road. Later, following the FIU ORED helicopter guidelines for field operations dated May 26, 2020, we resumed our field work by helicopter on June 1, 2020, and surveyed all the remaining USACE-funded sites in sub-population A.

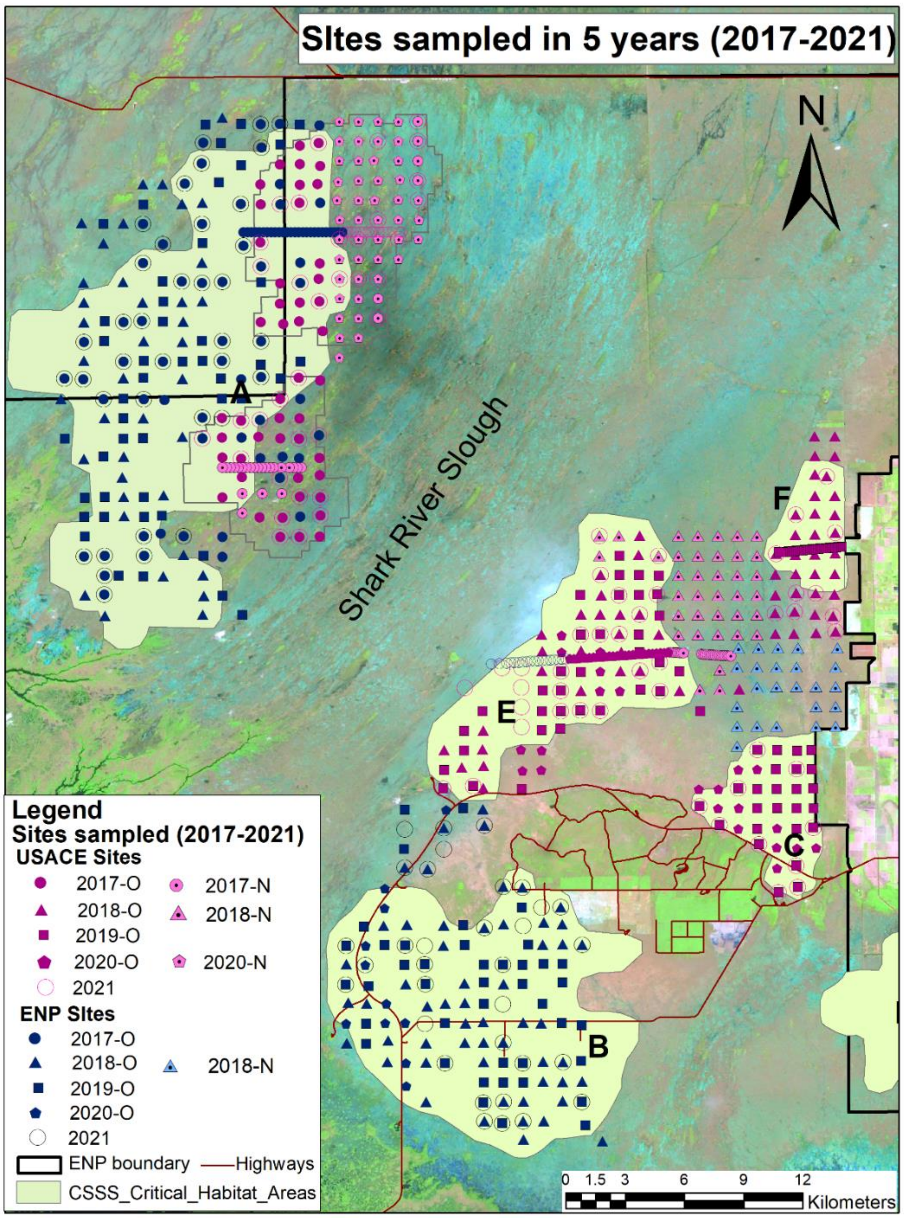

Figure 2: Vegetation Survey sites surveyed in 2017 (filled circle), 2018 (triangle), 2019 (square), 2020 (pentagon) and 2021 (Open Circle). The sites surveyed in those five years included both USACE and ENP-funded sites, in pink and blue color, respectively, and previously established ('O') and new (N) sites, including those surveyed for the first time in 2016. All but 7 census sites surveyed in 2021 were sites that were also surveyed between 2017 and 2020.

Census sites surveyed over 2017-2021 included 71 new sites and a subset of 485 previously surveyed sites in five sub-populations, A, B, C, E and F (Table 1; Figure 2). Among the 71 new sites, 10 were in sub-population A, 27 in between C & F (CF), 30 in between E & F (EF) and four sites were in sub-population E. Re-surveyed census sites included 235 sites in sub-population A, 120 sites in B, 37 sites in C, 59 sites in E, and 34 sites in F. In sub-population A, a number of census sites, including all 10 new sites and 45 sites that were initially surveyed in 2016 were in the eastern portion of the sub-population, where two distinct areas (hN and hS) have been identified as improved potential future CSSS habitat (USACE 2014; USFWS 2016). In total, we surveyed 79 and 41 census sites within the hN and hS areas, respectively (Figure 2). In 2021, the re-surveyed census sites included 122 sites that were surveyed for the fourth time since they were established between 2003 and 2005, and 21 sites that were established and surveyed for the first time between 2016 and 2018.

Transect sites surveyed during the same 5-year period included 43 new sites and 118 previously surveyed sites. Among 43 new transect sites, 19 were within the hS habitat area of sub-population A, and 24 were east of sub-population E. Both of these transects were established and surveyed for the first time in 2017. Previously surveyed transects sites included 26 within the hN area of sub-population A, 18 sites in western portion of sub-populations E, and 26 and 33 sites on existing transects within sub-population E and F, respectively (Figure 2). The transect sites surveyed within sub-population A were established in 2003, and those in E and F were initially sampled in 2004. Sites on Transects A and F were surveyed three times prior to the current survey period, but those on Transect E were only surveyed once. In addition, 33 sites that were established and surveyed for the first time in 2016, were also re-surveyed in 2021. Those included 15 sites in the hN area, and 18 sites in the western portion of the sub-population E.

2.1.2 Vegetation survey

At each survey location, vegetation was surveyed in a N-S oriented, 1 x 60 m rectangular plot beginning 3 m south of a rebar established to permanently mark the survey site, following the methods described in Ross et al. (2006). Nested within the plots were ten 0.25 m^2 (0.5 x 0.5 m) subplots (compositional sub-plots), arrayed at 6-meter intervals along the baseline (east side) beginning at Meter 5. In each subplot, we made an ocular estimate of cover (live + dead) of each species. We also noted any additional species present in the 1 x 60 m plot, and assigned these species a mean cover of 0.01% for the plot as a whole. In addition, a suite of structural parameters was recorded in 30 0.25 m^2 (0.5 x 0.5 m) subplots (structural sub-plots) arrayed at every two meters beginning at Meter 1. Structural measurements included three attributes: 1) Canopy height, i.e., the tallest vegetation present within a cylinder of ~5 cm width, measured at 4 points in each quadrat; 2) Total vegetative cover, in percent; and 3) live vegetation, expressed as a percent of total cover. In the compositional sub-plots of the new sites, we also measured soil depth at 4 points in each quadrant by probing to bedrock with a 1-cm diameter aluminum rod.

2.1.3 Hydrology

Hydrological variables used in this study were based on elevations determined from either topographic survey data in combination with water depth measured in the field (for transect sites) or only measured water depths (for 473 census sites). If there was standing water at the time of vegetation survey, we measured water depth in compositional sub-plots within each 1x 60 m plot. At the new census sites where there was no standing water in Spring 2017 and 2018, we measured water depth at 3-5 locations within the 1x 60 m plot under flooded conditions during the wet season in 2017 and 2018, respectively. However, at the new transect sites we measured water depth only near the re-bar, which served as reference benchmark for determining elevation of the compositional sub-plots, as the relative elevation of the plots with reference to the re-bar had been previously determined using an auto level at the time of vegetation survey.

Later, using the water surface elevations provided by Everglades Depth Estimation Network (EDEN) for the specific date, we calculated ground elevation for each plot. EDEN daily water surface elevation data (http://sofia.usgs.gov/eden/models/watersurfacemod_download.php) were then used to calculate annual mean daily water depth and hydroperiod for each site. Hydroperiod of each year was defined as the discontinuous number of days in a year when water level was above the ground surface. In addition, we also computed mean wet and dry season water depths, as these variables are also considered to have a significant relationship with vegetation structure and composition in wetlands, especially in the ridge and slough landscape (Hotaling et al. 2009; Zweig and Kitchens 2008).

Finally, the four-year average hydroperiod and annual mean daily water depth for most sites (99%) were calculated using ground elevation derived from topographic surveys in combination with the field measurements elevation model (DEM) database in EDEN. However, these (1%) sites were not included in comprehensive analysis to describe the hydrologic conditions of these areas. Moreover, for sites that were surveyed twice over five years, during the 2017-2021 study, the hydroperiod values for only the latest survey, i.e., 2021 survey was considered.

2.2 Data Analysis

2.2.1 Vegetation classification

We used cluster analysis to classify the 684 sites that were surveyed during the 2017/2021 study, including both new and previously surveyed sites, examined the spatial distribution of vegetation types, and noted any temporal change in vegetation types at previously surveyed sites. However, to keep the vegetation type identified at those sites consistent with the classification adapted for the marl prairie vegetation encompassing all sub-populations, the analysis also included vegetation data collected at 608 census sites surveyed in 2003-2005 within both historical (Cape Sable) and recent range (six sub-populations) of CSSS habitat. Following a procedure, described in Ross et al. (2006), i.e., we eliminated species that were present in less than 12 sites, and relativized the species data by plot total. We then used the Bray-Curtis dissimilarity as our distance measure, and the flexible beta method to calculate relatedness among groups and/or individual sites (McCune and Grace 2002). Dendrograms were cut to arrive at the same ten vegetation groups that had been recognized based on data only from the initial 608 census sites (Ross et al. 2006). Those ten vegetation types were broadly grouped in two categories, Wet Prairie (WP) and Marsh (M) types (Ross et al. 2006).

2.2.2 Vegetation-environment relationships

To examine the relationship between vegetation composition and existing hydrological conditions, vegetation data were first summarized by a non-metric multidimensional scaling (NMDS) ordination, in which cover data were relativized by species maximum. The hydrology vector was derived by calculating plot level hydroperiod, using mean plot elevation and EDEN daily water surface elevation data over 31 years (1991-2021). In ordination space, vectors for the hydrologic gradient were defined by a vector fitting technique in DECODA (Minchin 1998). In this method, a gradient is defined in the direction through the ordination that produces maximum correlation between the measured environmental attribute and the 3-dimensional ordination axis scores of the survey units along the vector. The statistical significance of such correlations is tested using a Monte-Carlo permutation test with 1,000 random permutations, as samples in a given ordination space are not independent (Minchin 1998). The orientation of the ordination is then rotated so that hydroperiod has a perfect correlation ($r = 1.0$) with axis-1, the ordination's principal axis.

2.2.3 Change in vegetation composition

Vegetation change analysis included calculation of vegetation-inferred hydroperiod, the hydroperiod for a site indicated from its vegetation composition using a Weighted Averaging Partial Least Square (WAPLS) regression model (Armentano et al. 2006; Ross et al. 2006; Sah et al. 2011). A change in vegetation-inferred hydroperiod between successive surveys reflects the amount and direction of change in vegetation, expressed in units of days (0-365) along a gradient in hydroperiod.

Additionally, vegetation response to hydrologic change was also analyzed with trajectory analysis (Minchin et al. 2005; Sah et al. 2014), which uses a change in community composition along a vector representing hydrologic condition. Trajectory analysis was used for the sites that were surveyed three times or more. In five years (2017-2021), 59 transect sites were surveyed for the 4th time, whereas 399 census sites were surveyed for the third time since the initial survey in 2003-2005. Among these were 95 census sites that were burned at least once over the period 2003-2019.

For trajectory analysis, the vegetation data was first summarized using a non-metric multidimensional scaling (NMDS) ordination. Prior to NMDS, species composition data was standardized by species' maximum abundance i.e., all abundance values for a species were divided by the maximum abundance attained by that species. In 3-dimensional ordination space, the reference vector for the hydrologic gradient was defined by a vector fitting technique (Minchin

1998), and then orientation of the ordination was rotated so that annual mean daily water depth had a perfect correlation (r = 1.0) with axis-1, the ordination's principal axis. In trajectory analysis, two statistics (delta (Δ) and slope) were calculated to quantify the degree and rate of change in vegetation composition along the hydrology vector, respectively (Minchin et al. 2005; Sah et al. 2014). In this analysis, the delta was calculated as the displacement along the target vector and slope was calculated as the linear regression coefficient of projected scores on the target vector in survey years. The statistical significance of both delta (Δ) and slope was tested using Monte Carlo simulations with 1,000 permutations.

2.2.4 Species structure and biomass

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 = Total crown cover (%), and Ht = Mean crown height (cm).

To account for the variability inherent in the repeated measurement of vegetation structural variables (vegetation height, total cover and green cover) and above ground biomass, Linear Mixed Models were used. General Linear Mixed Models were used to examine differences in structural variables between Wet Prairie (WP) and Marsh (M) sites and among survey years. Vegetation cover and biomass data were square root-transformed to approximate normality. Models were run in R v.4.0.4 (R Core Team, 2021) using the *lmer* function in the 'lme4' package (Bates, 2014). Sites (PlotID) were treated as a random variable. We treated sampling event (Sampyear) as a fixed effect to examine the differences in cover, height, and biomass among sampling events that was done in a post hoc test using *glht* function implemented in 'multicomp' package.

3. Results

3.1 Hydrologic Conditions

Across five sub-populations (A, B, C, E and F) and the areas between Sub-populations C and F ('CF') and between E and F ('EF'), the hydrologic condition of the vegetation survey sites surveyed in five years (2017-2021) showed a distinct spatial pattern (Figure 3). During the most recent survey (2017-2021) across all the survey sites, including those in CF and EF regions, the 4-year average hydroperiod ranged between 2 and 365 days, with a mean (± SD) of 227 (± 72) days and a median of 236 days. Similarly, the mean daily water depth ranged between -33.9 and 46.6 cm with a mean (± SD) of 2.7 (±13.4) cm and median of 3.8 cm.

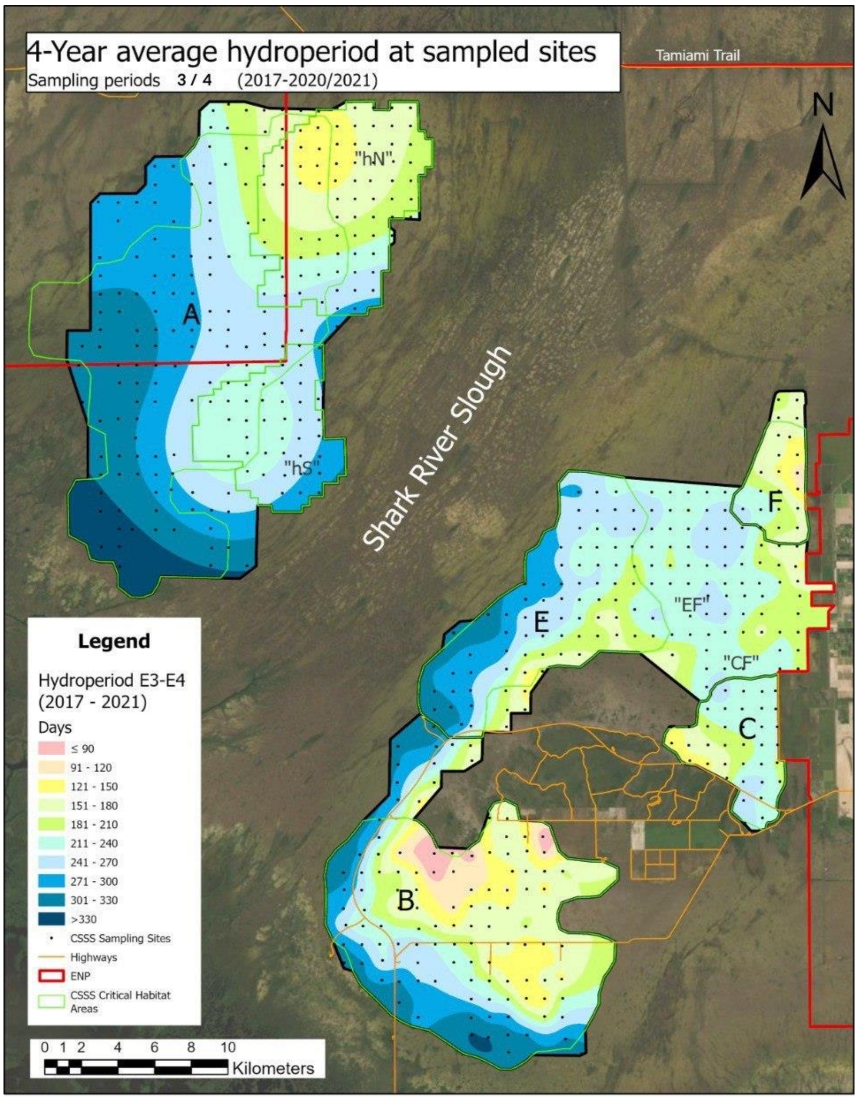

Figure 3: Four-year mean discontinuous hydroperiod at 2017/2021 vegetation survey sites in sub-populations A, B, C, E and F, and the sites between C and F, and between E and F. The values were averaged over four years prior to the survey, and calculated only for those sites for which field measurements of water depth were available, and the sites were surveyed during both 2003/2005 and 2017/2021 surveys. For sites that were surveyed twice over five years, during the 2017-2021 study, the hydroperiod values are given for only the latest survey, i.e., 2021 survey.

3.1.1 *Change in hydrologic conditions*

Long-term change in hydrologic conditions at the survey sites was mainly based on the census sites (n=447) surveyed in both 2003/2005 and 2017/2021 surveys. At these sites, during the recent survey, the hydroperiod ranged between 2 and 365 days, with a mean (± SD) of 231 (± 75) days and a median of 240 days. Similarly, the mean daily water depth ranged between -33.9 and 46.6 cm with a mean (± SD) of 3.5 (±14.0) cm and median of 2.1 cm. Both the hydroperiod and daily mean water depth at these sites significantly differed among the three surveys (Kruskal-Wallis Test: KW-H $_{(2,1339)}$ = 50.0, $p < 0.001$, and KW-H $_{(2,1339)}$ = 38.1, $p < 0.001$, respectively). The median hydroperiod in 2017/2021 was 240 days, i.e., 28.5 and 34.5 days higher than the median values in 2003/2005 and 2006/2009, respectively. The median water depth (2.1 cm) at these sites was 3.4 and 5.2 cm higher during the recent survey than in the two previous surveys.

Sub-population A

During the 2017/2021 survey in sub-population A, 4-year average hydroperiod values ranged between 47 and 365 days, with a mean (± SD) of 260 (± 65) days and a median of 271 days, and were about 30 days longer than values averaged across all sub-populations. The 4-year average mean daily water depth ranged between -18.7 and 46.6 cm with the mean (± SD) of 10.1 (±12.6) cm and median of 10.8 cm water depth. These values were more than 7 cm higher than the global averages. Across all the regions, i.e., hN, hS and W within this sub-population, vegetation sites were slightly wetter in recent years (2017/2021) than during the 2003/2005 and 2006/2009 surveys, as mean hydroperiod was 12 days longer and daily mean water depth was 1.5 cm deeper in 2017/2021 than 16 years ago (Table 2; Figures 4, 5). However, during the recent survey, the hydrologic condition was not the same throughout the sub-population A (Figure 3).

Table 2: Four-year mean discontinuous hydroperiod and annual mean daily water depth at 2017/2021 vegetation survey sites in different regions of CSSS sub-populations A and sub-populations B, C, E and F. The values were calculated using only the sites with field measurements of water depth, which were surveyed during both 2003/2005 and 2017/2021 surveys. For sites that were surveyed twice over five years, during the 2017-2021 study, the hydrologic values from only the latest survey, i.e. 2021 survey, were used. The hydroperiod and daily water depth values were calculated using the ground elevation derived from the field measurements of water depth and EDEN daily water surface elevation data.

Sub-pop.	**Region**	**4-year average hydroperiod (days)**						**4-year annual mean daily water depth (cm)**			
		N	2003/2005		**N**	2017/2021		2003/2005		2017/2021	
			mean (±sd)	median		mean (±sd)	median	mean (±sd)	median	mean (±sd)	median
A	hN	28	195 (±57)	202	28	181 (±73)	189	-1.0 (±8.4)	-1.5	-3.6 (±9.5)	-4.4
	hS	35	215 (±51)	231	35	241 (±58)	260	2.3 (±8.9)	4.2	6.0 (±9.2)	8.2
	W	127	269 (±45)	276	127	282 (±53)	295	12.4 (±9.8)	12.1	14.2 (±11.5)	14.5
B	-	127	181 (±80)	185	127	214 (±90)	224	-4.9 (±12.1)	-5.9	1.9 (±13.4)	0.0
C	-	37	151 (±38)	154	37	207(±45)	216	-15.8 (±12.0)	-16.8	-3.8 (±11.6)	-5.1
E	-	59	171 (±62)	178	59	217 (±52)	216	-10.9 (±10.2)	-11.9	-2.1 (±9.9)	-3.6
F	-	34	121 (±71)	118	34	184 (±52)	190	-19.0 (±14.2)	-20.7	-10.0 (±12.9)	-12.6

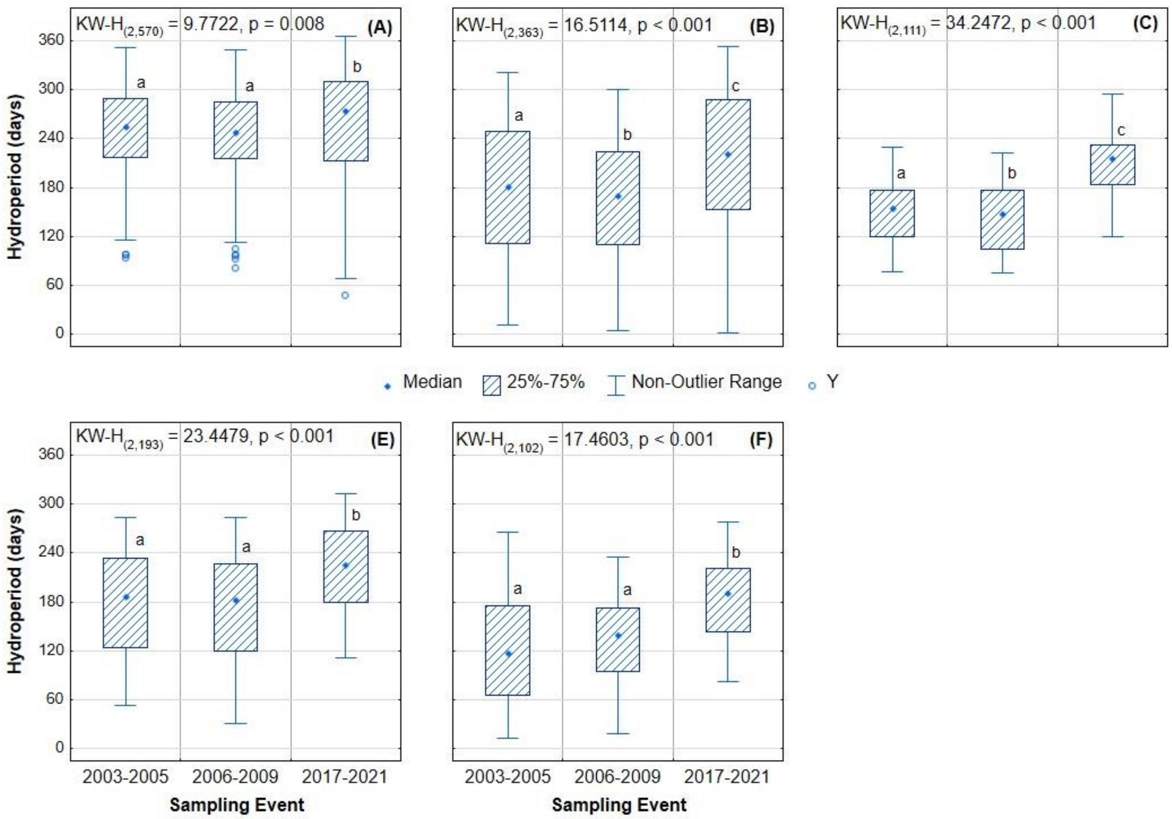

Figure 4: Four-year average hydroperiod at sites that had ground elevation based on field measurements of water depth and EDEN water surface elevation, and surveyed in sub-populations A, B, C, E and F during three periods: 2003/2005, 2006/2009 and 2017/2020. For sites that were surveyed twice over five years, during the 2017-2021 study, the hydroperiod values for only the latest survey, i.e., 2021 survey were considered in calculating median for this period.

Sample sites in the northeastern region (hN) of sub-population A were much drier than the sites in other portions of the sub-population (Figure 3; Table 2). In the hN area, the mean hydroperiod was 181 ± 72 days (median = 189 days), and water depth was -3.6± 9.5 cm (median = -4.4 cm). In contrast, the hS area and western portion of the sub-population had mean hydroperiods of 241 ± 58 and 282 ± 53 days, and mean water depths of 6.0 ± 6.2 and 14.2 ± 11.5 cm, respectively (Table 2). Moreover, hydrologic conditions at many sites in the hN area were drier in 2017/2021 than during previous surveys, whereas the several sites in the western and southern portions (hS) of the sub-population had become wetter over 16 years. For instance, mean hydroperiod at the sites in the hN area was 14 days shorter, but at the sites in hS and western-A were 26 and 7 days longer in 2017/2021 than in 2003/2005 (Table 2; Figure 6). Likewise, mean water depth at the sites in the hN area was 2.6 cm lower but sites in hS and western-A were 3.7 cm and 1.8 cm higher during the recent survey than sixteen years ago.

In the northeastern region (hN) of sub-population A, drier hydrological conditions in recent years than one and half decades ago are primarily the result of restriction on water deliveries since 2002 through S12 structures located along Tamiami Trail. While the restrictions on S12C and S12D have been relaxed in last few years, S12A and S12B remain closed each year for varying periods of time between November 1st and July 15th with an objective to maintain water level at the stage recorder NP205 <6 feet for 60 consecutive days during the sparrow's breeding season, i.e., between March 1 and July 15. In the northeastern region, the reduced flow through the S12 structures (Appendix A1), especially during the dry season, have resulted in a mean water level of <210 for several years, and the mean dry season water level lower than the values during the mid to late 1990s (Figure 7).

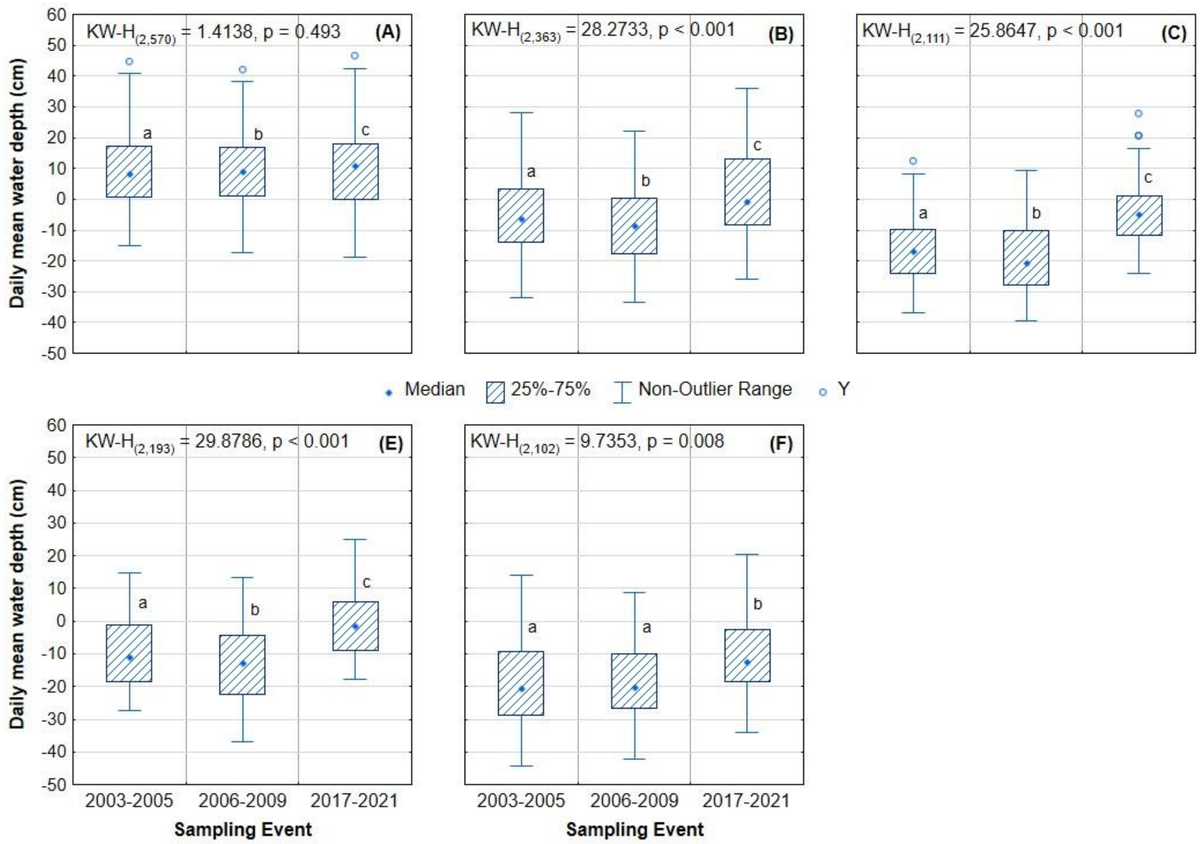

Figure 5: Four-year average annual mean daily water depth at sites had ground elevation based on field measurements of water depth and EDEN water surface elevation, surveyed in sub-populations A, B, C, E and F during three periods: 2003/2005, 2006/2009, and 2017/2021. For sites that were surveyed twice over five years, during the 2017-2021 study, the hydroperiod values for only the latest survey, i.e., 2021 survey were considered to calculate average for this period.

Eastern sub-populations (B, C, E and F)

In comparison to sub-population A, vegetation survey sites in sub-populations B, C, E and F are relatively dry, but in recent years they have become wetter than they were during the 2003/2005 and 2006/2009 surveys (Figure 4 and 5 B, C, E and F). The most distinct change in hydrologic condition was observed in sub-populations C and F, where mean hydroperiods were 56 and 63 days longer and mean water depths were 12.0 and 9.0 cm deeper during 2017/2021 than in 2003/2005, respectively. In sub-populations B and E, mean hydroperiods were 33 and 46 days longer, while mean water depths were 6.8 and 8.8 cm deeper in recent years than 16 years ago, respectively (Table 2; Figures 4, 5). In sub-population B, the increase in hydroperiod was mostly in the western and southern regions, while in C, E and F, the increase in hydroperiod was throughout the sub-populations (Figure 6).

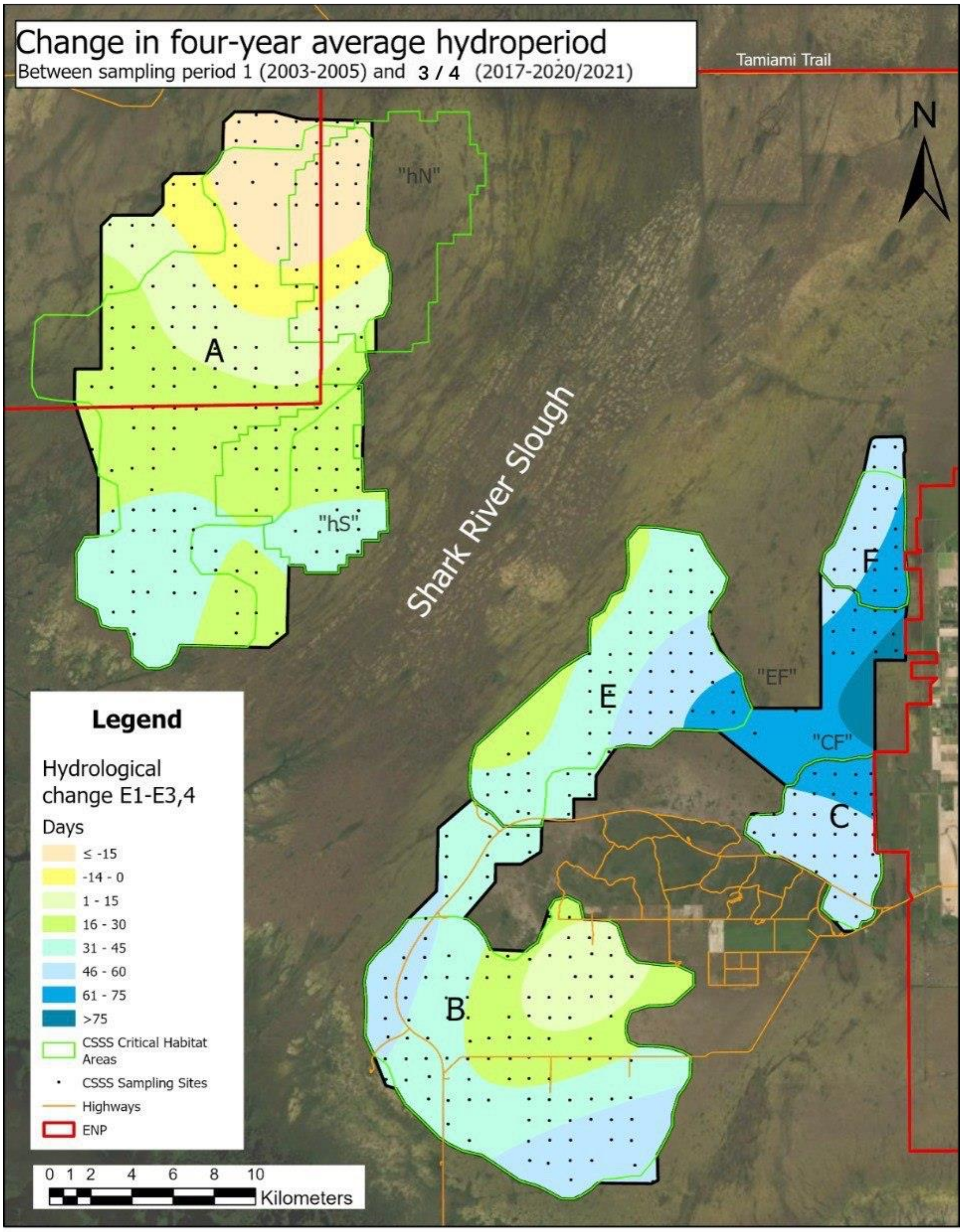

Figure 6: Change in four-year mean discontinuous hydroperiod between 2003/2005 and 2017/2021 survey periods at 2017/2021 vegetation survey sites in sub-populations A, B, C, E and F. The values were calculated only for those sites for which field measurements of water depth were available, and the sites were surveyed during both 2003/2005 and 2017/2021 surveys. For sites that were surveyed twice over five years, during the 2017-2021 study, the hydroperiod values are given for only the latest survey, i.e., 2021 survey.

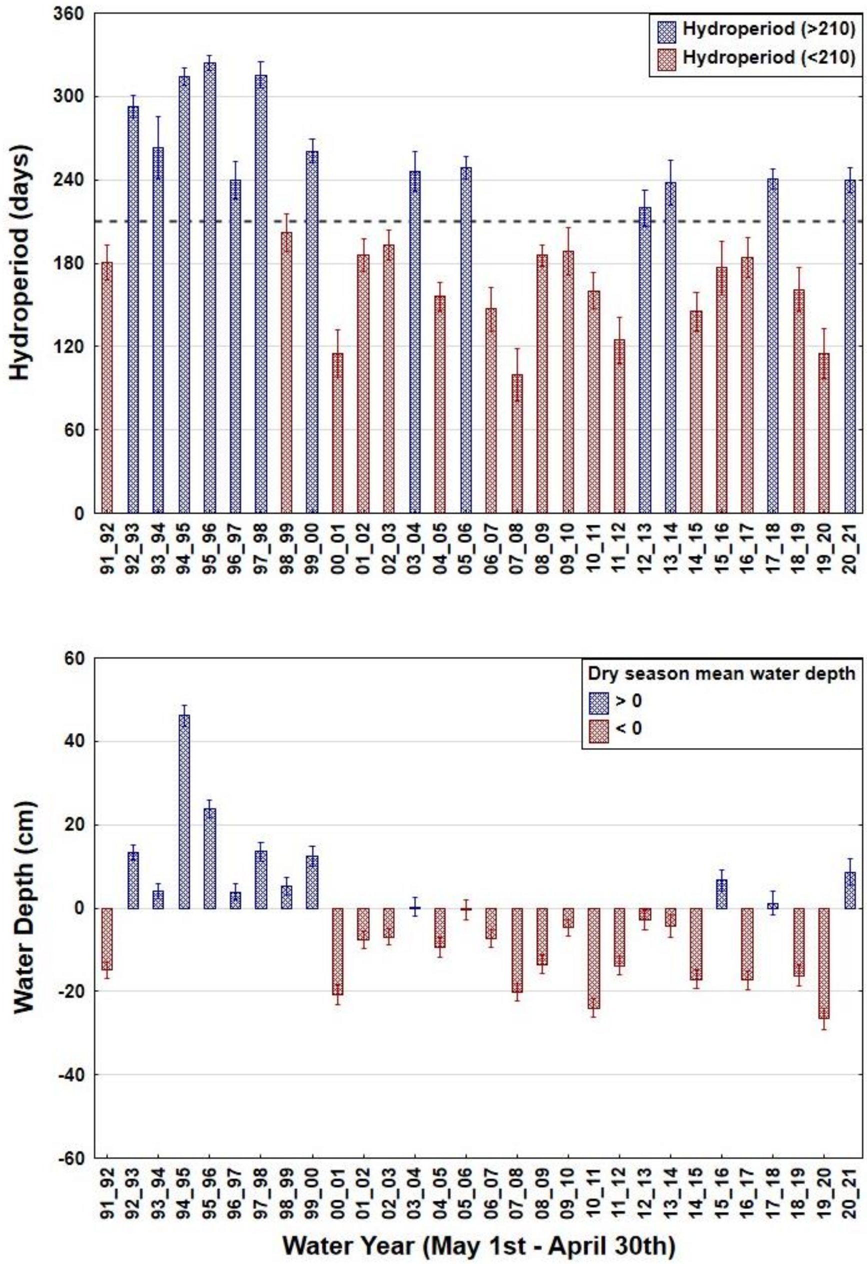

Figure 7: Annual mean hydroperiod and dry season mean water depth averaged over 79 vegetation survey sites that are within the hN area of sub-population A.

3.2 Vegetation Composition and Classification

During the 2017/2021 survey, vegetation composition was recorded at 867 sites, including 706 census and 161 transect sites. Among them, 71 census and 43 transect sites were surveyed for the first time, while the rest of the sites were resurveyed. At those sites, vegetation was classified into the nine vegetation types (Figure 8) that had been previously defined within the marl prairie landscape (Ross et al. 2006). *Spartina* marsh that was recorded at six sites during the first survey (2003-2005) was not found at the resurveyed sites. Moreover, many sites that were resurveyed during the latest survey were of a different vegetation type than what was present at those sites during the previous surveys, suggesting a shift in species composition in response to changes in hydrologic regimes and/or other drivers over the study period.

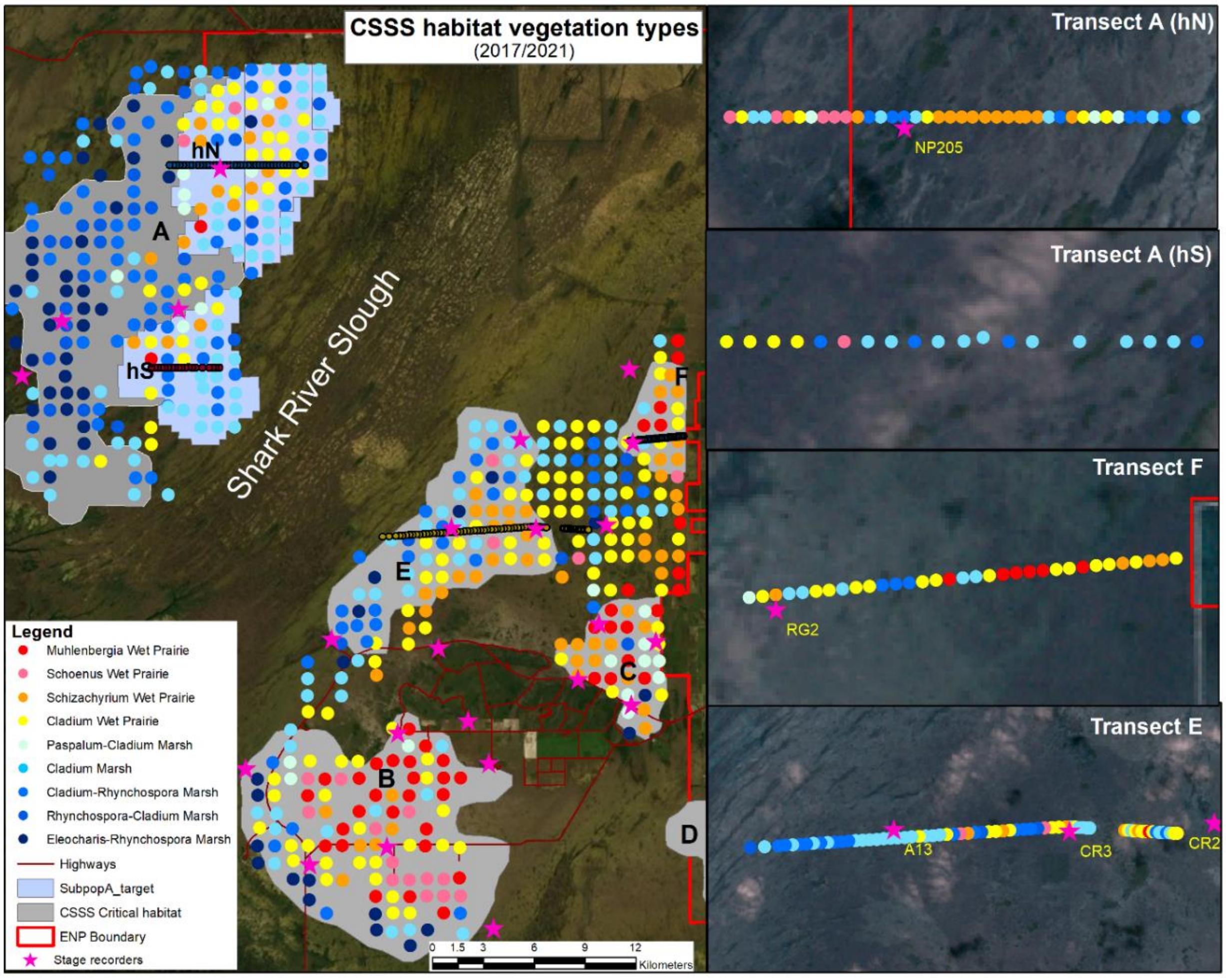

Figure 8: Spatial distribution of vegetation types at the 2017/2021 survey sites in sub-populations A, B, C, E and F, and in CF and EF areas. Vegetation type at each site was identified through cluster analysis of species cover values at these sites plus 608 census sites surveyed in three years (2003/2005). In the cluster analysis, the cluster diagram was cut in a way so that the same 10 vegetation types identified in Ross et al. (2006) were obtained. Vegetation types represent dry (red) to wet (dark blue) community types. For sites that were surveyed twice over five years, during the 2017-2021 study, the species cover values used were from the latest survey, i.e., 2021 survey.

3.2.1 Vegetation composition at new transect and census sites

The transect sites that were surveyed for the first time were located in the southern portion of sub-population A and east of sub-population E. Vegetation composition differed between those two transects. In sub-population A, a majority (83%) of the new sites had marsh vegetation, including *Cladium* Marsh (CM), *Cladium-Rhynchospora* Marsh (CRM) and *Rhynchospora-Cladium* Marsh (RCM) (Figure 8). In contrast, at the newly established sites on the extended part of Transect E, half of the sites were of WP type, mainly *Cladium* WP (CWP) and *Schizachyrium* WP (SCWP), and most of the other sites were *Cladium* Marsh (Figure 8).

New census sites were in the southern portion of sub-population A (10 sites), and in the area between sub-populations C and F (CF: 27 sites) and between E and F (EF: 30 sites). While the majority of the new sites in sub-population A had marsh vegetation types, the vegetation at the CF and EF sites was mostly of the WP type (Figure 8). However, the sites in EF were more hydric in nature than the sites in CF. For instance, in the EF area, 61% of the sites had marsh vegetation, mostly *Cladium* Marsh and *Cladium-Rhynchospora* Marsh. The remaining 39% had WP vegetation of a single type, *Cladium* WP. In contrast, vegetation at 81% of the sites in the CF area were WP types, including *Muhlenbergia* WP (MWP), *Schizachyrium* WP and *Cladium* WP (Figure 8).

3.2.2 Vegetation composition at re-surveyed sites

In sub-population A, 41 transect sites and 235 census sites were resurveyed during the period, half (55.4%) in either the hN or hS areas. Resurveyed sites also included 45 census and 15 transect sites that were surveyed for the first time just five years ago, i.e., in 2016, and all of them were in the north-eastern portion (hN) of the sub-population. At the transect sites that were surveyed for the first time in 2003, vegetation dynamics over 14 years (2003-2017) has been described in detail in Sah et al (2019), and is briefly mentioned in Section 3.3 of this report. Distribution of vegetation types among the resurveyed census sites within this sub-population were not uniform (Figure 8). The western portion of the sub-population and hS area had a disproportionately high percentage (94.5% and 74.3.8%, respectively) of sites in one of the Marsh (M) vegetation types, which is characterized by longer hydroperiods. In hS, more than half (53.8%) of the sites were CM, and the remaining sites were of other marsh types, whereas in western-A, only 18% of sites were CM. Among the remaining sites, 32% were CRM and 48% were marshes dominated by either beakrush (*Rhynchospora) or* spikerush (*Eleocharis*). Vegetation at two sites were co-dominated by *Paspalum* and *Cladium*. In contrast, in hN, which includes 45 sites surveyed for the first time, 47% of the sites were wet prairie (WP) vegetation types, with shorter hydroperiods, and almost 60% of these were CWP and 32% were SCWP. The *Schoenus* WP (SOWP) or MWP types were present at three census sites.

In the eastern sub-populations (B, C, E & F), 101 transect and 265 census sites were resurveyed. The resurveyed sites also included 18 transect and 8 census sites in sub-population E that were surveyed for the first time in 2016. Vegetation composition differed between transects in sub-populations E (TE) and F (TF), and along the gradient from east to west on TE (Figure 8). The western portion of transect TE, established in 2016, had only marsh sites (50% CM and 50% CRM or RCM type), whereas the eastern portion of the same transect, established in 2004, had 50% of sites of marsh types and other 50% of WP vegetation types. In contrast, 72% of the transect sites in sub-population F were wet prairie vegetation types, and 60% of those were CWP and 25% MWP types. The *Schizachyrium* WP type was present at 15% of sites.

Among the 265 resurveyed census sites in eastern sub-populations, 61.5% were of the wet prairie (WP) type. However, these sub-populations differed in vegetation character. For instance, during the recent survey, at almost half (46.3%) of the surveyed sites in sub-population E, vegetation was of the marsh type (Figure 8). In sub-population E, WP vegetation was present only at the central, eastern, and southeastern sites. Among the sites with WP vegetation in these four sub-populations, 38% were CWP, whereas SCWP, MWP and SOWP types were present at 28%, 24% and 10% of sites, respectively. Marsh vegetation was prevalent also in the western and southern portions of B, and at very few locations in C and F. About 40% of the marsh sites were the CM and 10% of sites were PCM, while the rest comprised various combinations of *Cladium*, *Rhynchospora* and *Eleocharis* Marsh types.

3.3 Vegetation Change (2003/2005 – 2017/2021)

In conjunction with hydrologic changes observed over these 18 years, a shift in vegetation composition was also detected at several sites in the surveyed sub-populations. In 2017/2021, both transect and census sites were resurveyed in sub-populations A, E and F, but only census sites were resurveyed in sub-population B and C. Thus, the following analyses of vegetation change apply to transect sites in sub-populations A, E and F, and to census sites in all five sub-populations.

3.3.1 Change in vegetation composition

Transect sites

Transect A (TA), established in 2003, extends east (2 km) and west (3 km) from NP-205, and the temporal change in vegetation along this transect represents changes in hydrologic conditions within the sub-region. This transect was surveyed four times, in 2003, 2006, 2010, and 2017. Vegetation composition on this transect differed significantly between the four survey years (ANOSIM: Global R = 0.232, p-value <0.001), and the difference in composition between 2003 and subsequent surveys increased over time. For instance, the differences in composition were stronger between 2003 and 2017 than between any other pair of survey years (Table 3).

Table 3: Global R and p-values from analysis of similarity (ANOSIM) testing for among-year differences in vegetation composition on Transect A sampled in 2003, 2006, 2010 and 2017. n=51 during 2003, 2006 and 2010 surveys, and n = 26 in 2017.

	Sampling years		
	2003	**2006**	**2010**
2006	0.137***		
2010	0.244***	0.261***	
2017	0.314***	0.277***	0.238***

p-value: * <0.05, ** <0.01, *** <0.001

On Transect A, the mean cover of *Bacopa caroliniana* and *Panicum virgatum*, both prevalent in wetter portions of marl prairies (Ross et al. 2006), significantly decreased between 2003 and 2017 (Table 4). The mean cover of two other species with a relatively wide range of hydrologic tolerances, *Cladium jamaicense* and *Rhynchospora tracyii*, also decreased from 13.2% and 1.36% in 2003 to 10.8% and 0.24% in 2010, respectively. However, their mean cover again increased to 12.9% and 1.21% in the next 7 years, between 2010 and 2017. In contrast, the mean cover of *S. rhizomatum*, a dominant species in short-hydroperiod prairies, increased from 3.69% in 2003 to 7.7% in 2010, and remained at 6.6% in 2017. Other species whose mean cover significantly (pair-wise t-test; p<0.5) increased between 2003 and 2017 were *Centella asiatica*, and *Crinum americanum*.

Table 4: Mean cover (%) of major species on Transect A in 2003, 2006, 2010 and 2017. Different superscript letters indicate significant difference (Pair-wise t-test; p-value <0.05) in species' cover between years. During the first three sampling years (2003, 2006 & 2010), 51 sites were sampled each year, whereas in 2017, only 26 sites were sampled.

Species	2003	2006	2010	2017
Bacopa caroliniana	0.36^{a}	0.87^{b}	0.20^{c}	0.04^{d}
Centella asiatica	0.27^{a}	0.18^{b}	1.45^{c}	0.53^{d}
Cladium jamaicense	13.20^{a}	10.18^{b}	10.83^{bc}	12.96^{ac}
Crinum americanum	0.18^{a}	0.35^{b}	0.63^{c}	0.43^{bc}
Coleataenia *tenera*	1.38^{a}	0.28^{b}	1.86^{a}	0.31^{b}
Panicum virgatum	1.15^{a}	1.07^{ac}	2.28^{b}	0.99^{c}
Paspalum monostachyum	2.83^{ac}	2.02^{b}	3.63^{c}	1.84^{ab}
Rhynchospora tracyi	1.36^{a}	2.57^{b}	0.24^{c}	1.21^{a}
Schoenus nigricans	3.98^{a}	2.03^{b}	2.01^{b}	2.91^{ab}
Schizachyrium rhizomatum	3.69^{a}	4.18^{a}	7.73^{b}	6.59^{ab}

In sub-populations E and F, sites along transect were established at every 100 m and surveyed for the first time in 2004. The transect sites in sub-population E (TE sites) were re-surveyed only in 2020, whereas those in sub-population F (TF sites) were re-surveyed four times, in 2009, 2010, 2014 and 2019, primarily because 70% of the sites on that transect burned in 2008 and the sites were re-surveyed between 2009 and 2014 to assess the post-fire vegetation dynamics in the burned area (Sah et al. 2015). Moreover, in 2020, only half of the TE sites, i.e., sites at every 200 m, were surveyed. On both TE and TF transects, vegetation composition significantly differed between 2004 and the recent (2017/2021) survey (ANOSIM: n = 26; Global R = 0.333, p-value <0.001, and n=33, R = 0.323, p-value <0.001, respectively).

In 2016, Transect A and E were extended east- and westward for three and four kilometers, respectively. The sites on these transects were re-surveyed during the recent survey. In five years, vegetation composition on both of those new transects did not change much (ANOSIM: R = 0.033; p = 0.163, and R = 0.065, p = 0.072, respectively).

Census sites

In sub-populations B, C, E, and F, species composition in 2017/2021 was significantly different (ANOSIM: p<0.05) from previous surveys (Table 3). However, in Sub-population A, the pattern was not the same in all three regions within the sub-population. In western-A, the difference in species composition between the first and third survey was significant. In this region the difference between two most recent surveys was also much stronger than in the other two regions (hN and hS). In hN, a set of 45 census sites was surveyed for the first time in 2016, and was resurveyed in 2020. At those sites, the difference in vegetation composition between the two surveys was also significant (ANOSIM: $R = 0.147$; $p<0.001$).

Table 3: Global R and *p*-values (in parenthesis) from analysis of similarity (ANOSIM) testing differences in vegetation composition among three surveys: 2003/2005, 2006/2009 and 2017/2021. Analysis based on 405 census sites surveyed during all three surveys.

Sub-populations/Regions (# of sites/survey)		2003/2005 – 2006/2009	2006/2009 – 2017/2021	2003/2005 – 2017/2021
A	**All** (184)	0.010 **(0.013)**	0.027 **(0.001)**	0.038 **(0.001)**
	hN (27)	0.035 (0.072)	0.021 (0.158)	0.041 **(0.048)**
	hS (33)	0.048 **(0.029)**	0.076 **(0.007)**	0.056 **(0.001)**
	W (124)	0.002 (0.285)	0.040 **(0.001)**	0.022 **(0.003)**
B (102)		0.042 **(0.001)**	0.064 **(0.001)**	0.088 **(0.001)**
C (35)		0.045 **(0.026)**	0.272 **(0.001)**	0.207 **(0.001)**
E (55)		0.074 **(0.001)**	0.364 **(0.001)**	0.304 **(0.001)**
F (29)		0.086 **(0.007)**	0.273 **(0.013)**	0.154 **(0.001)**

3.3.2 Change in vegetation-inferred hydroperiod

Transect sites

On Transect A, a change in vegetation composition between 2003 and 2006 was not limited to species that are indicative of wetter or drier environments, as the difference in median vegetation-inferred hydroperiod between 2003 and 2006 was not statistically significant (Figure 9). In contrast, median vegetation-inferred hydroperiod was significantly lower in 2010 and 2017 than in both the 2003 and 2006 samples. However, the difference in median vegetation-inferred hydroperiod between 2010 and 2017 was not significant. The median vegetation-inferred hydroperiod in 2003, 2006, 2010 and 2017 were 247, 243, 218 and 212 days, respectively. The change in vegetation-inferred hydroperiod on transect A over the complete study period paralleled changes in hydroperiod referenced to stage level at NP-205 (Figure 9).

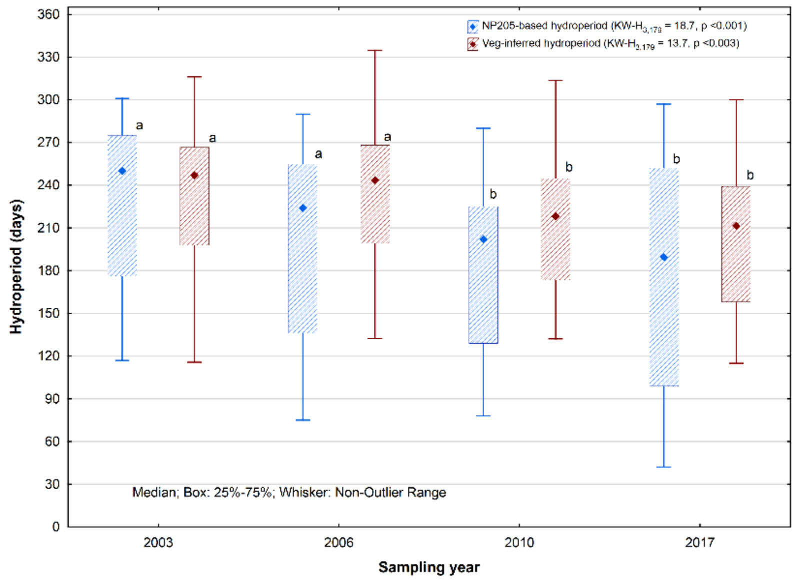

Figure 9: Box-plot showing median (box = 25% and whisker = 75% quartiles) hydroperiod (NP-205 based) and vegetation-inferred hydroperiod (days) at the sites on Transect A sampled in 2003, 2006, 2010 and 2017. In the first three surveys, n = 51, whereas in the 2017 survey, n = 26.

Census sites

Across all five sub-populations, vegetation-inferred hydroperiod differed significantly among the three surveys (Non-parametric Friedman ANOVA; N =406, df = 2; $\chi 2$ = 72.4; p < 0.001). Moreover, the change in inferred-hydroperiod was positively correlated with the change in 4-year average hydroperiod (r = 0.36; p = <0.001) and mean daily water depth (r = 0.38; p = <0.001) (Figure 10). However, the magnitude and direction of change in inferred-hydroperiod varied among sub-populations, and among different regions within some of these sub-populations.

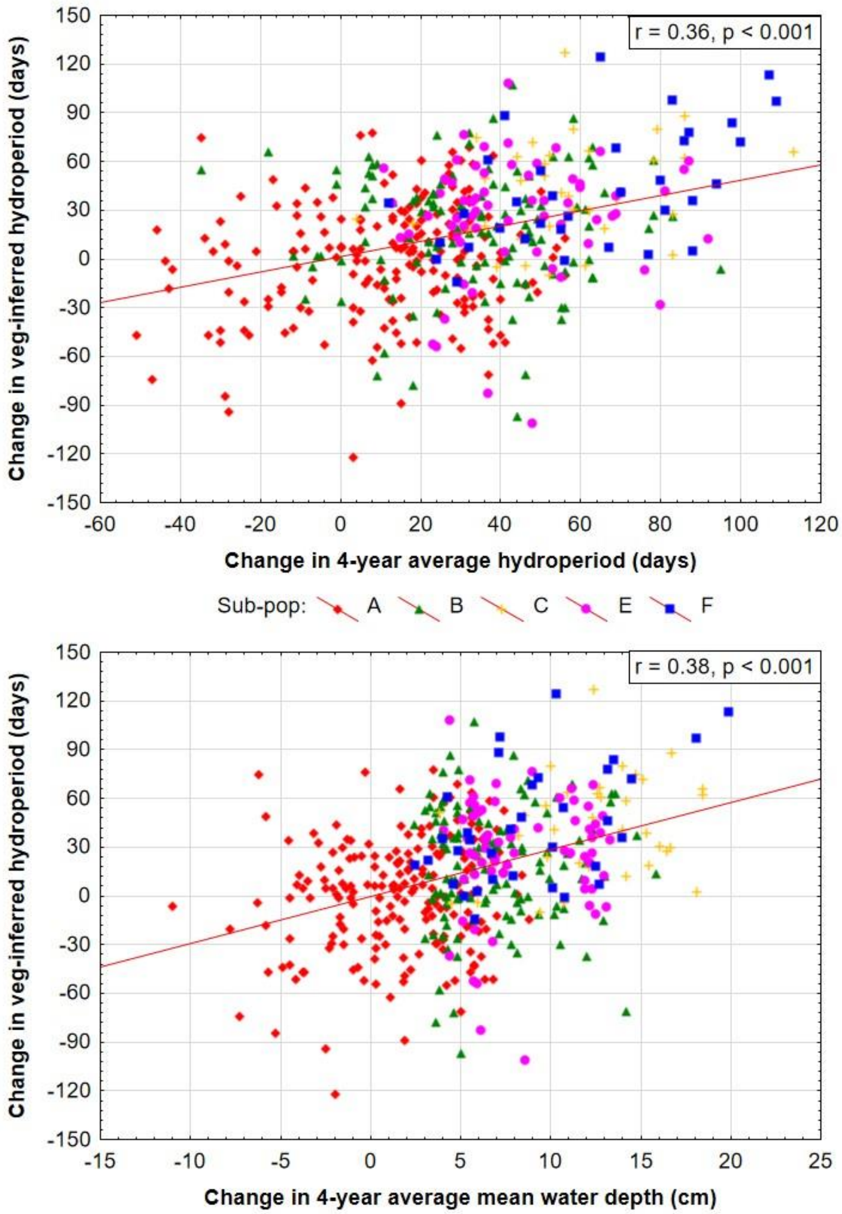

Figure 10: Relationship between change in hydrologic conditions (4-year average hydroperiod and mean water depth) and change in vegetation-inferred hydroperiod between 2003/2005 and 2017/2021 surveys at the sites surveyed in 2017/2021 in sub-population A, B, C, E and F. For sites that were surveyed twice over five years, during the 2017-2021 study, values used were from the latest survey, i.e., 2021 survey.

Sub-population A:

In sub-population A, the mean (±SD) vegetation-inferred hydroperiods were 265 (±43), 270 (±46) and 265 (±39) days, and medians were 264, 275 and 271 days in 2003/2005 (E1), 2006/2009 (E2) and 2017/2021 (E34) surveys, respectively. The inferred-hydroperiod significantly differed among the three surveys, and it was significantly higher in E2 than in both 2003/2005 and 2017/2021 surveys (Wilcoxon matched-pairs test: p = 0.007 and 0.021, respectively) (Figure 11). The difference in inferred- hydroperiod between the 2003/2005 and 2017/2021 surveys was not significant. Nevertheless, the direction of change in inferred-hydroperiod varied spatially. Most (71%) of the sites in hN had shorter vegetation-inferred hydroperiod in 2017/2021 than in 2003/2005 (Figure 11). During the three surveys in hN, the mean inferred-hydroperiods were 236 (±34), 225 (±38) and 218 (±37) days, respectively. In contrast, at more than two-thirds of sites in hS, mean vegetation-inferred hydroperiod was higher in 2017/2021 than previous two surveys. Surprisingly, the sites in the western portion of the sub-population showed mixed results. More than half (53.5%) of the sites had 1 to 78 days higher vegetation-inferred hydroperiod in the third survey than in the previous two surveys, but hydroperiods in the rest were lower than before.

At sites surveyed in 2016 and 2020 in the eastern portion of hN, the mean inferred hydroperiods were almost same (236 days), whereas median inferred-hydroperiod increased from 237 days in 2016 to 248 days in 2020, suggesting that species composition at some sites in that region shifted towards more hydric type in four years. In fact, 62% of sites had 2 to 64 days higher inferred-hydroperiod in 2020 than in 2016.

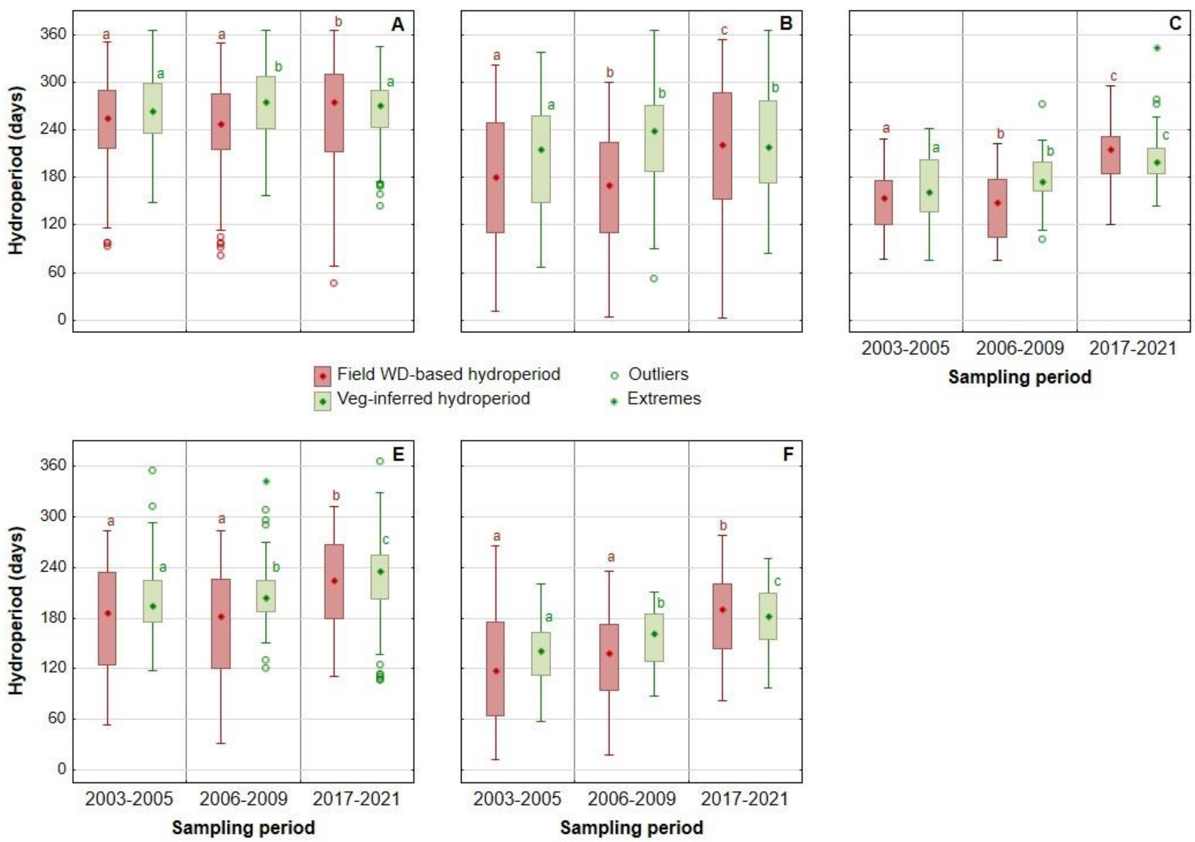

Figure 11: Box-plot showing median (box = 25-75% quartiles and whisker = non-outlier range) field water-depth hydroperiod (in red) and vegetation-inferred hydroperiod (days) (in green) averaged over census sites surveyed during 2003/2005, 2006/2009 and 2017/2021 surveys.

Eastern sub-populations (B, C, E and F):

While vegetation composition in four sub-populations (B, C, E and F) has shifted towards a more hydric type over the 16 years of our study (Figure 12), the magnitude of vegetation change along the hydrologic gradient differed among these sub-populations. For instance, in sub-populations B and E, mean vegetation-inferred hydroperiod increased by only 19-27 days, whereas it increased by 42 and 43 days in sub-populations C and F, respectively, where the vegetation is of a much drier type than in other sub-populations. Of course, changes in composition were not always spatially uniform within these sub-populations too. Notably, in sub-population B, increases in inferred-hydroperiod were concentrated in southern, western and some northeastern sites, whereas inferred-hydroperiod increased more consistently throughout sub-populations C, E and F (Figure 12).

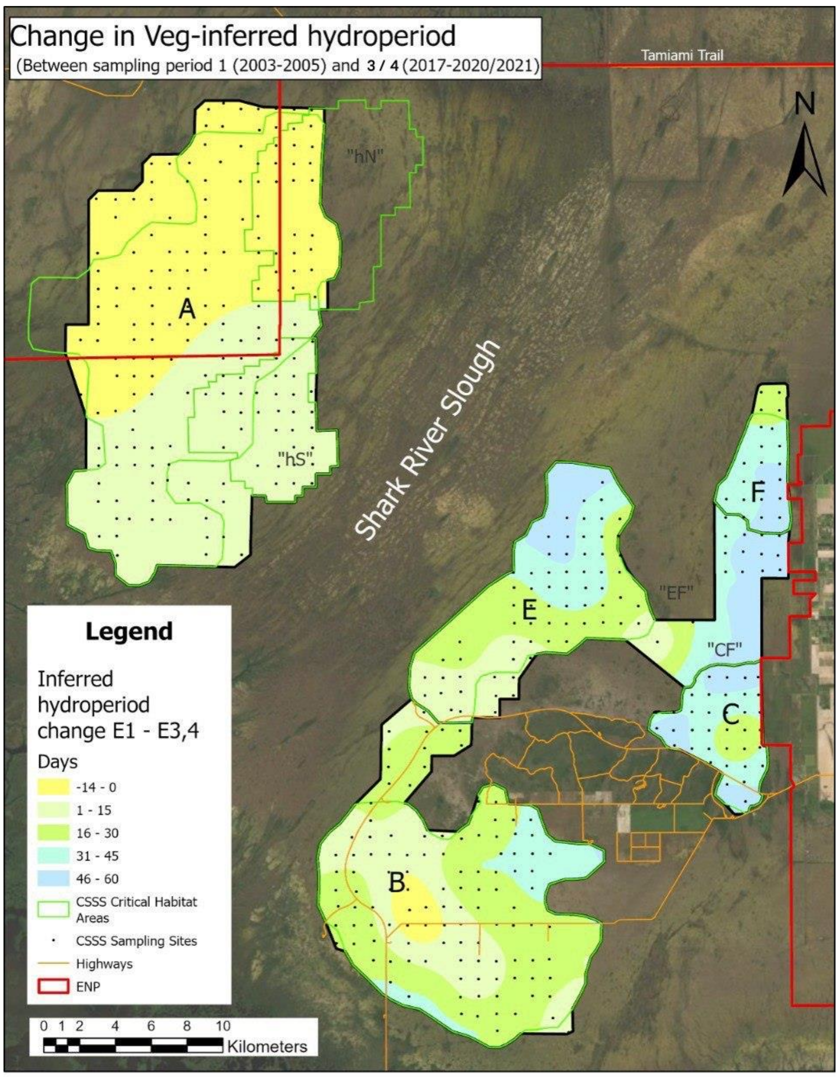

Figure 12: Map showing the spatial variation of changes in vegetation-inferred hydroperiod between 2003/2005 and 2017/2021 at the sites surveyed in both surveys in sub-populations A B, C, E, and F. In the eastern portion of hN region of sub-population A, change in vegetation-inferred hydroperiod at 45 sites are between 2016 and 2020 surveys. For sites that were surveyed twice over five years (2017-2021), values were used from the latest, i.e., 2021 survey.

3.3.3 *Change in vegetation types*

In concurrence with the significant differences described in overall species composition among survey years at both transect and census sites, vegetation type also changed at more than half (53.3%) of the recently re-surveyed transect (47.0%) and census (54.6%) sites during the sixteen-year period (Figure 13). However, the majority (70.4%) of these sites showed only a minor shift in vegetation composition, and therefore remained in the same two broad categories of vegetation type, described by Ross et al. (2006): marsh or wet prairie vegetation. For instance, among the 244 census sites that changed from one vegetation type to another, 102 remained in the marsh category. Most of these sites (M-M) were in the western portion of sub-population A, the southwestern portion of sub-populations B and E, and the southern portion of sub-population C. The 75 census sites that changed from one prairie type to another (WP-WP) were mostly in the central and eastern portion of sub-population A, or in sub-populations B, C and F.

In sub-population A, vegetation at 12 census and two transect sites changed from marsh to wet prairie type (M-WP) and an almost equal number (11) of census sites changed from a wet prairie to a marsh type (WP-M). The majority of sites that changed from marsh (M) to wet prairie type (WP) were in hN and some were in the eastern region, suggesting a drying trend in those areas. In contrast, in sub-populations B, C, E and F, the majority of transect (15 of 17) and census sites (39 of 44 sites) that showed a noticeable shift in vegetation composition between two categories changed from WP to marsh types (Figure 13), indicating the wetting trend in substantial areas of those sub-populations. The visible wetting trend was in the northwestern portion of sub-populations B and E, and the eastern portion of sub-population C.

Hydrologic conditions at the sites that showed either no change or a change in vegetation type differed significantly. Importantly, our analysis of differences in hydrologic conditions among sites showing different trends in vegetation was restricted to the 447 census sites whose hydrologic variables were calculated using ground elevation based on field water depth measurements. Over the study period, most prairie sites that changed from one prairie type to another or remained in the same type increased in mean hydroperiod, and this difference was significant across the sub-populations (Table 6).

Table 6: Four-year mean discontinuous hydroperiod and annual mean daily water depth at 2017/2021 vegetation survey sites at which vegetation type either did not change or changed from one type to another. For sites that were surveyed twice over five years, during the 2017-2021 study, values used were from the latest survey, i.e. 2021 survey.

Veg change group	N	4-year average hydroperiod (days)			4-year mean daily water depth (cm)		
		2003/2005	2017/2021	p-value	2003/2005	2017/2021	p-value
No change - Wet prairie (WP)	104	146 ± 55	185 ± 57	<0.001	13.2 ± 8.6	-6.0 ± 7.9	<0.001
WP-WP	75	136 ± 69	175 ± 71	<0.001	-15.1 ± 12.7	-7.4 ± 11.0	<0.001
WP-M	50	193 ± 63	231 ± 62	<0.001	-4.6 ± 11.5	2.6 ± 11.3	<0.001
No change – Marsh (M)	99	252 ± 47	276 ± 47	<0.001	8.7 ± 9.9	12.5 ± 10.4	<0.001
M-M	102	266 ± 46	284 ± 54	<0.001	11.0 ± 10.2	14.3 ± 11.7	<0.001
M-WP	17	165 ±59	174 ± 73	0.417	-6.7 ± 9.6	-5.5 ± 9.2	0.469

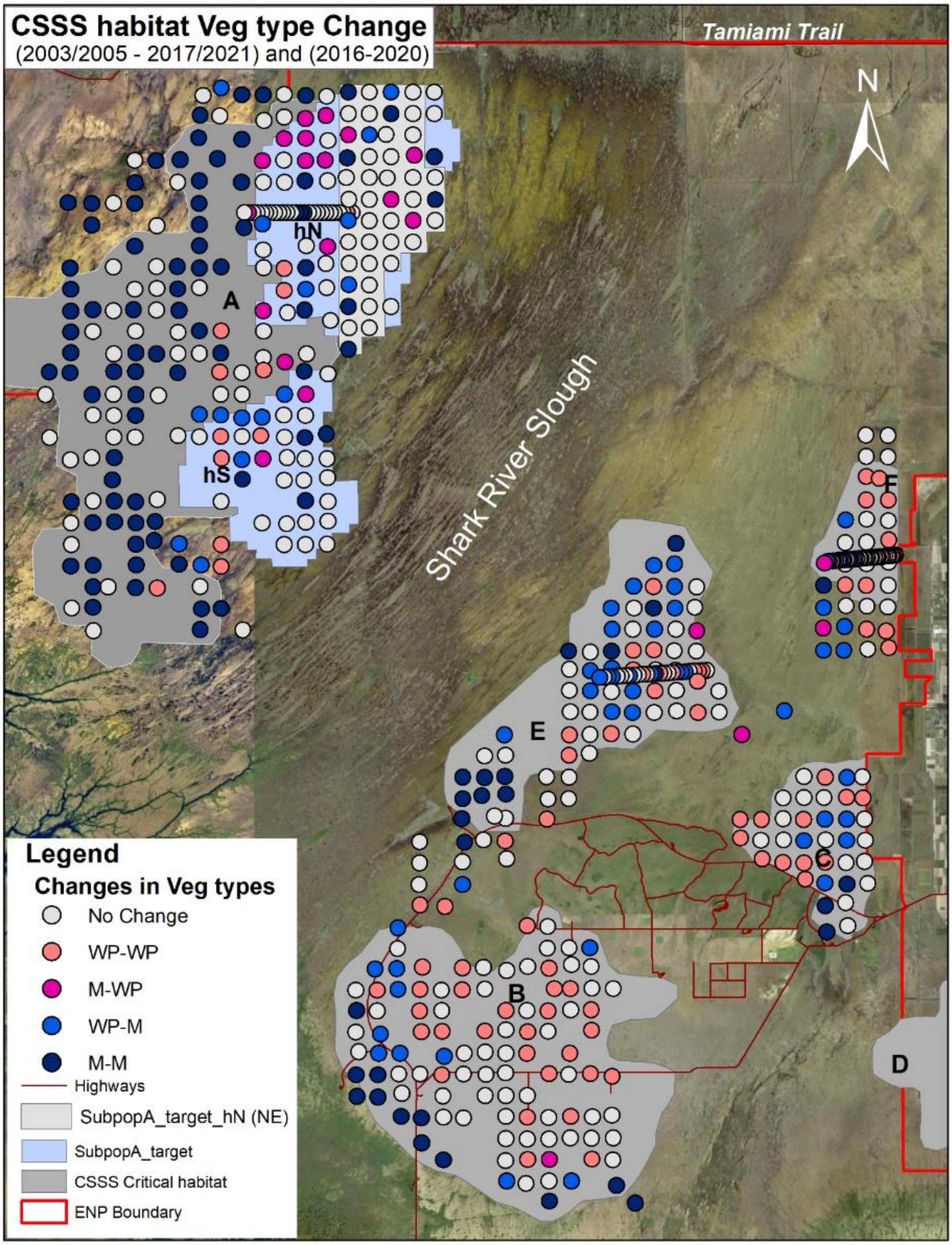

Figure 13: Change in vegetation types at the census and transect sites in sub-populations A, B, C, E and F between 2003/2005 and 2017/2021 surveys. WP-WP = One wet-prairie vegetation type to another wet-prairie type; M-WP = Marsh veg type to wet prairie type; WP-M = Wet prairie veg type to marsh type; M-M = One marsh veg type to another marsh type. For sites that were surveyed twice over five years, during the 2017-2021 study, only veg types for the latest survey, i.e. 2021 survey, were used.

During the 2017/2021 survey at the marsh sites that showed no change or a change from one marsh type to another, the mean four-year average hydroperiod was greater than 270 days, a flooding duration that was approximately 20 days higher than in 2003/2005 (Table 6). Similarly, at sites that changed from WP to marsh type, the mean hydroperiod in the most recent survey was 231 days, i.e., 38 days higher than during 2003/2005 survey. At the sites that remained wet prairies or changed from one wet prairie type to another, the mean hydroperiods were 185 ± 57 and 175 ± 71 days, respectively, but those values were 39 days higher than in the 2003/2005 survey. In contrast, the mean hydroperiod remained about the same at sites that changed from marsh to wet prairie type. At these sites, the mean hydroperiod and water depth during the 2017/2021 survey were 174 ± 73 days and -5.5 ± 9.2 cm, well within the range at other prairie sites. However, for the same period, while dry and wet season maximum and dry season mean and minimum did not change significantly (data not shown), wet season minimum water depth at these sites was significantly lower than for the 2003/2005 survey period (Figure 14).

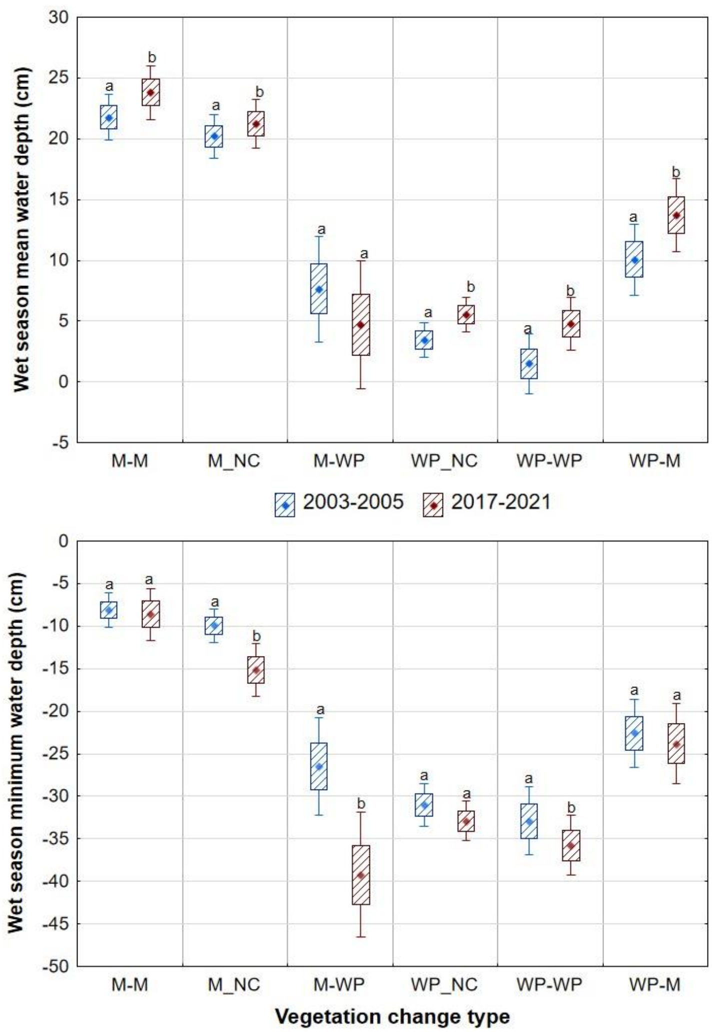

Figure 14: 4-year average wet season mean and minimum water depth (cm) during 2003/2005 and 2017/2021 surveys at the sites that changed from marsh vegetation type to wet prairie type. M=Marsh, WP=Wet prairie, NC= No change. For sites that were surveyed twice over five years (2017-2021), values were used from the latest, i.e., 2021 survey.

3.3.4 *Trajectory analysis*

The change in vegetation-inferred hydroperiod was corroborated with the trajectory of vegetation shift revealed in the trajectory analysis. During the first three surveys, 51 sites, located at every 100m on Transect A, were sampled each year, whereas in 2017, only 26 sites, located at every 200m, were sampled. Between the first Transect A sampling year (2003) and the most recent ones (2010 or 2017), 94% of the sites on Transect-A took an opposite trajectory along the vector of increasing hydroperiod, suggesting a trend from wetter to drier conditions. Among the sites that showed a shift in vegetation composition towards drier type, the magnitude (delta) and rate (slope) of trajectory shift was statistically significant at 40% of the sites. However, at those sites, the mean change towards drier vegetation, represented by a shift along the X-axis in the NMDS ordination (Figure 15), was more prominent between 2006 and 2010 than between 2003 and 2006 or between 2010 and 2017.

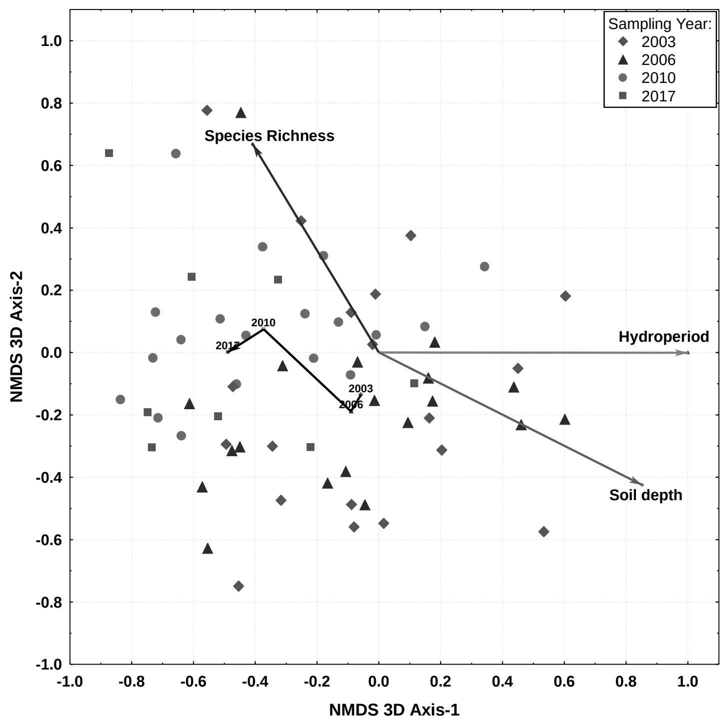

Figure 15: NMDS ordination bi-plots of site scores, the environmental vectors fitted in the ordination space, and the trajectory of centroid. The ordination is based on species abundance data collected at CSSS Transect A sites, sampled in 2003, 2006, 2010 and 2017. Only the sites that showed significant ($p \leq 0.1$) rate of change in species composition along the hydrology gradient are shown. The initial point and the end of the trajectory represent the 2003 and 2010 or 2017 sampling event, respectively.

Trajectory analysis results are presented in Figure 16, only for those census sites that were not burned between 2003 and 2008, and were surveyed at least three or more times, mainly to assess the shift in vegetation composition due to changes in hydrologic regimes. The results for the transect sites in sub-population A, that were sampled four times over the 15 year-period, are presented in Section 3.2.2. Likewise, for the sites, burned between 2003 and 2008 and surveyed 4-6 times after fire, trajectory analysis results are presented in Section 3.5.1.

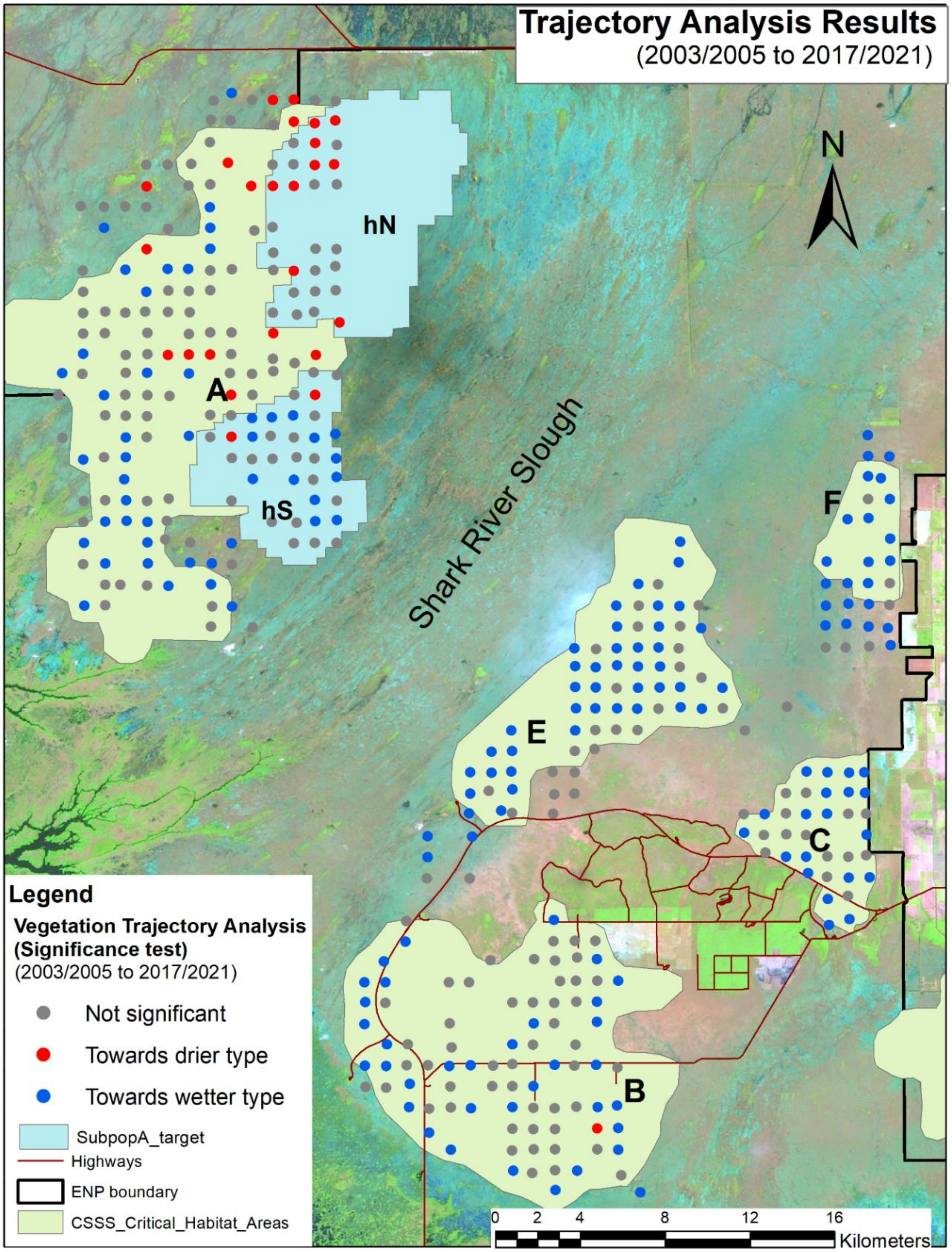

Figure 16: Sites showing a significant shift in vegetation composition between 2003/2005 and 2017/2021 surveys in sub-populations A, B, C, E and F. Significance of site trajectory was obtained by trajectory analysis. Only the sites

that were not burned between 2003 and 2008 and were surveyed at least 3 times were included in trajectory analysis. For sites that were surveyed twice over five years (2017-2021), values were used from the latest, i.e., 2021 survey.

Within the sub-population A, the spatially differentiated change in vegetation-inferred hydroperiod was paralleled by the trajectory analysis results, which also revealed a variable direction of shift in vegetation composition. In the sub-population, less than half (36.5%) of census sites showed a shift in vegetation composition towards drier type. Of those sites, the magnitude (delta) and rate (slope) of trajectory shift was statistically significant at 35% of the sites, and most of these were within hN and adjacent areas (Figure 16; Appendix A2). Among the sites (63.5%) that showed a wetting trend, the trajectory shift was statistically significant at about 39.0% of the sites. These sites were mostly in western sub-population A and the hS area (Figure 16).

Across the four eastern sub-populations, only 10% of resampled sites showed vegetation trajectory toward drier type, and of those sites, the magnitude (delta) and rate (slope) of trajectory shift was statistically significant at only 4.5% of the sites. In contrast, among the sites (90%) that showed a shift in vegetation composition toward wetter type, the magnitude (delta) of trajectory shift was statistically significant at 61.3% of the sites. However, the proportion of sites showing a vegetation trajectory toward drier or wetter type was not the same in all four sub-populations. In sub-population B, 17% of sites showed a shift toward drier type, whereas in sub-populations C and E, only 5.5% of sites showed that trend. In contrast, in sub-population F, all sites showed vegetation trajectory shift only toward wetter type.

The magnitude (delta) and rate (slope) of the shift in vegetation composition in trajectory analysis were well explained by temporal changes in hydrologic conditions. For instance, both the changes in four-year average hydroperiod and annual mean daily water depth were significantly correlated ($r^2 > 0.19$, $p < 0.01$) with delta and slope, the statistics produced in the trajectory analysis (Figure 17). Similar relationships of vegetation change to dry and wet season mean and wet season minimum water depths were observed (Figure 18 and 19d). Notably, while dry season maximum water depth had a significant relationship to vegetation shift (Figure 19a), change in species composition was unrelated to wet season maximum water depth (Figure 19b).

As expected, most of the sites that changed from marsh to prairie type had negative delta/slope values, indicating a shift toward drier vegetation type (Figure 20). Most of those sites were in the northeastern portion of sub-population A (Figure 16). Similarly, several sites in sub-population F experienced wetter water conditions in recent years, and the vegetation shift at those sites reflected the same trend (Figure 20). However, despite a shift in species composition towards relatively wet type, in sub-population F, most of the sites had been of the wet prairie type in 2003/2005 and remained so in the most recent survey.

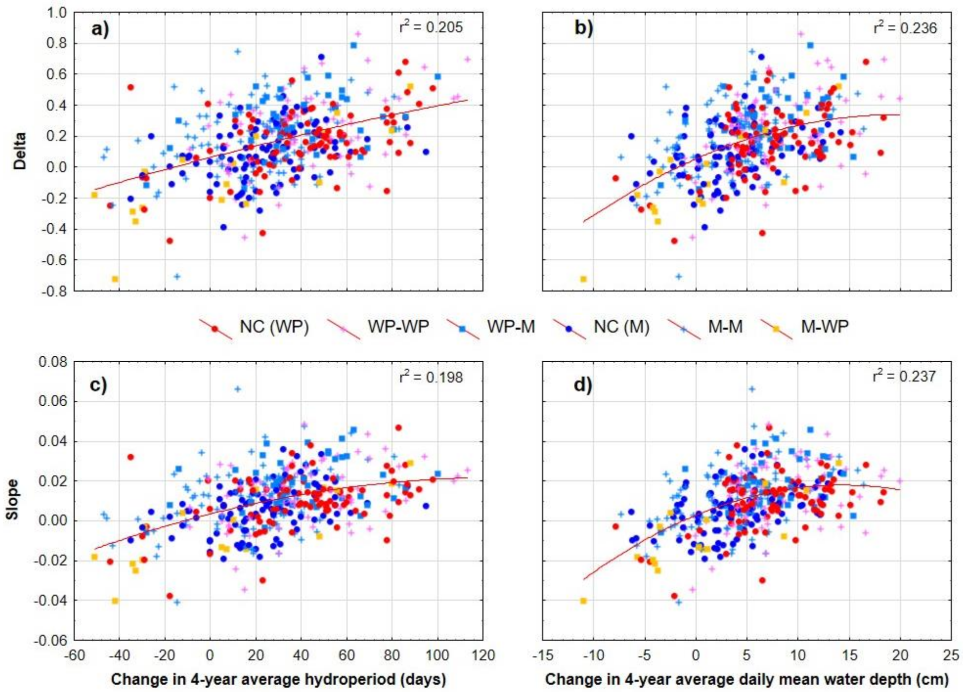

Figure 17: Relationship between change in hydrologic conditions (4-year mean hydroperiod and water depth) and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within the NMDS ordination space. Color of symbols represent no change or change in vegetation types. NC = No change; M = Marsh; WP = Wet prairie.

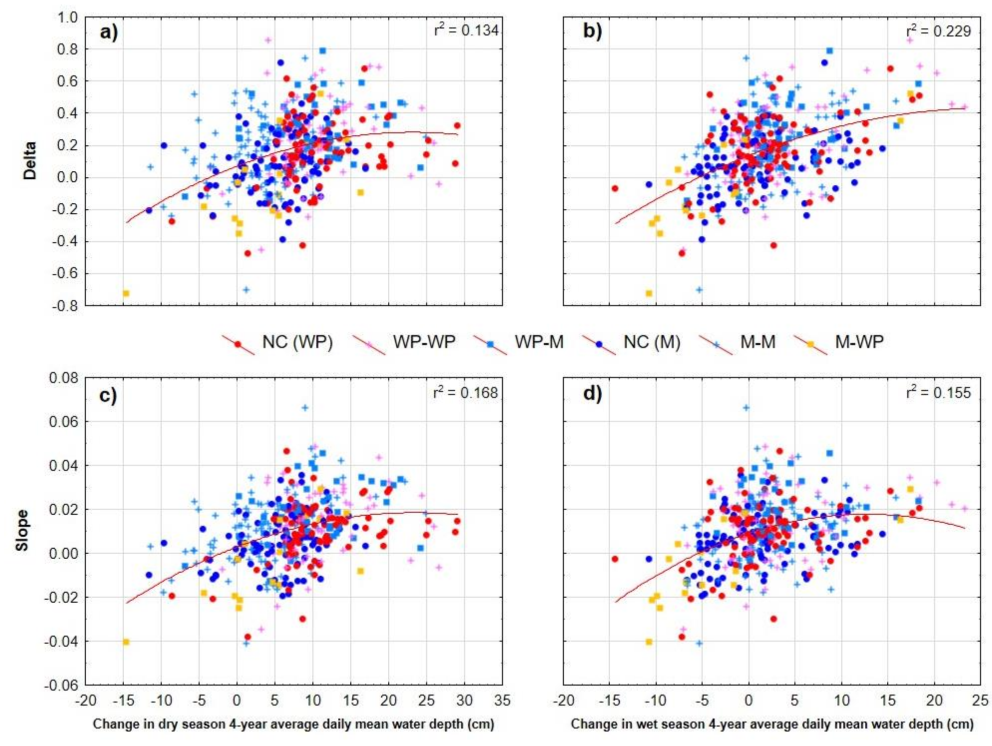

Figure 18: Relationship between change in dry and wet season mean water depth and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within the ordination space. Color of symbols represent no change or change in vegetation types. NC = No change; M = Marsh; WP = Wet prairie.

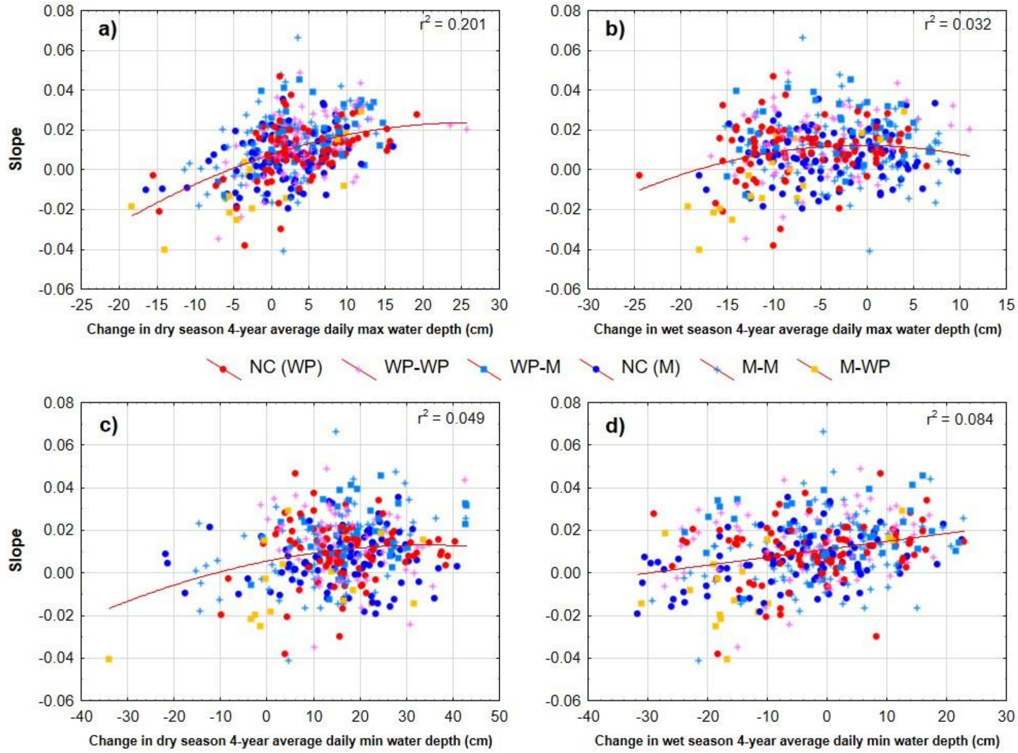

Figure 19: Relationship between change in dry and wet season maximum and minimum water depth and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within ordination space. Color of symbols represent no change or change in vegetation types. NC = No change; M = Marsh; WP = Wet prairie.

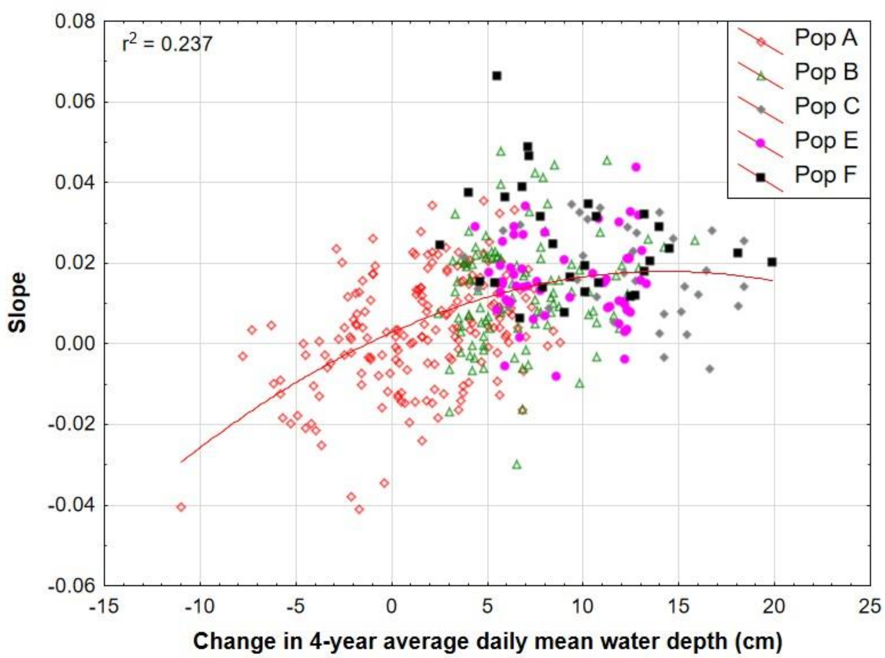

Figure 20: Relationship between change in 4-year daily mean water depth and rate (slope) of vegetation change. The slope is a statistic obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within the NMDS ordination space. Color of symbols represent sub-populations (A, B, C, E and F).

3.3.5 Change in Major Species Abundance

Together with the shift in vegetation composition toward relatively dry or wet types in the last 16 years (Section 3.2), the mean cover of some of the most abundant species (Mean cover across all sites >0.5%) also changed in all five sub-populations studied during the recent survey (2017-2021). In general, mean cover of spikerush (*Eleocharis cellulosa*) and lemon bacopa (*Bacopa caroliniana*), which are indicators of relatively wet conditions in marl prairies (Ross et al. 2006) increased in all sub-populations (Table 7). Likewise, mean cover of beak rush (*Rhynchospora tracyi*) increased in all sub-populations, but A. In contrast, the mean cover of sawgrass (*Cladium jamaicense*) decreased in all sub-populations, and that of muhly grass (*Muhlenbergia capillaris*) decreased in eastern sub-populations but increased in sub-population A (Table 7). While the direction of change in sawgrass varied spatially within each sub-population (Figure 21), the decrease in muhly grass cover was spatially consistent in three eastern sub-populations C, E and F, but varied spatially in A and B. In the sub-population B, the most obvious decrease in muhly grass cover was in the western and southern portions which have become wetter in recent years than before (Section 3.1). The most visible decrease in muhly grass cover was in sub-population C (Figure 22), in which its mean cover decreased from 12.2% to 3.8% over one and half decades. When the sites that were surveyed only after at least three years of time since last fire (TSLF) across all the sub-populations, the relationship between change in sawgrass cover and hydroperiod or mean water depth was not significant, whereas the change in muhly grass cover was significantly affected by the changes in hydroperiod (r = -0.21, p <0.001), annual mean daily water depth (r = -0.28, p <0.001) and dry and wet season average (r = -0.31, p <0.001 and r = =0.13, p = 0.009, respectively) and dry season maximum (r = 0.26. p <0.001) water depths.

Table 7: Mean species cover in five sub-populations within which sites were surveyed in both sampling event E1 (2003-2007) and during the most recent survey (2017-2021). For sites that were surveyed twice over five years, during the 2017-2021 study, only veg types for the latest survey, i.e. 2021 survey, were used.

Species	2003-2005					2017-2021				
	A	B	C	E	F	A	B	C	E	F
Cladium jamaicense	16.74	16.77	10.30	20.69	18.06	12.92	11.22	7.35	10.97	16.41
Bacopa caroliniana	1.44	0.09	0.04	0.09	0.08	1.57	0.26	0.06	0.13	0.24
Eleocharis cellulosa	2.33	0.51	0.15	0.13	0.01	3.81	1.89	2.39	0.97	0.22
Muhlenbergia capillaris	0.19	5.57	12.20	2.15	6.73	0.26	3.16	3.80	0.52	3.08
Paspalum monostachyum	0.63	0.42	0.93	0.21	0.05	0.30	0.19	0.70	0.06	0.05
Rhynchospora tracyi	3.90	0.63	0.34	0.49	0.69	1.68	1.29	1.67	1.27	2.11
Schoenus nigricancs	0.51	2.08	0.32	0.59	0.20	0.39	1.17	0.06	1.01	0.30
Schizachyrium rhizomatum	2.69	4.07	4.52	5.04	3.86	1.10	1.87	5.12	4.67	5.40

Mean cover of gulfdune paspalum (*Paspalum monostachyum*) also decreased in all sub-populations. However, the change in cover of other two species, blue stem grass (*Schizachyrium rhizomatum*) and black-top sedge (*Schoenus nigricans*) that are commonly found at the wet prairie sites of marl prairies showed mixed results. The mean cover of these species decreased in sub-populations A and B, increased in sub-population F and did not significantly change in C and E.

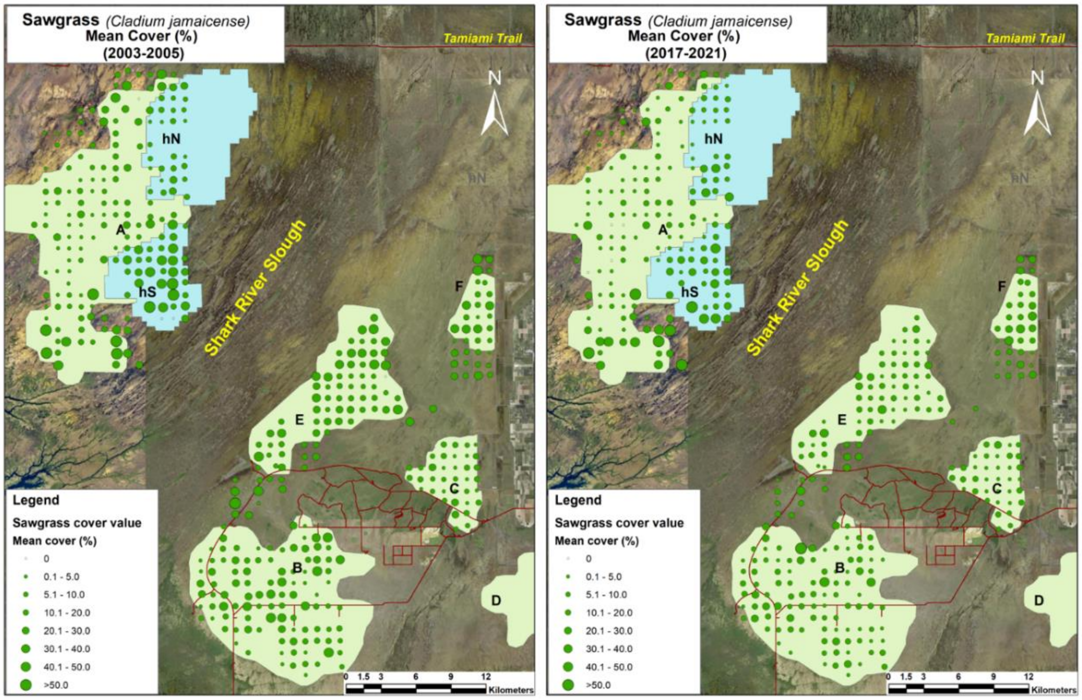

Figure 21: Mean cover of sawgrass (*Cladium jamaicense*) at the vegetation monitoring sites surveyed in both 2003/2005 and 2017/2021 sampling events within CSSS sub-populations A-C, E and F. For sites that were surveyed twice over five years (2017-2021), values were used from the latest, i.e., 2021 survey.

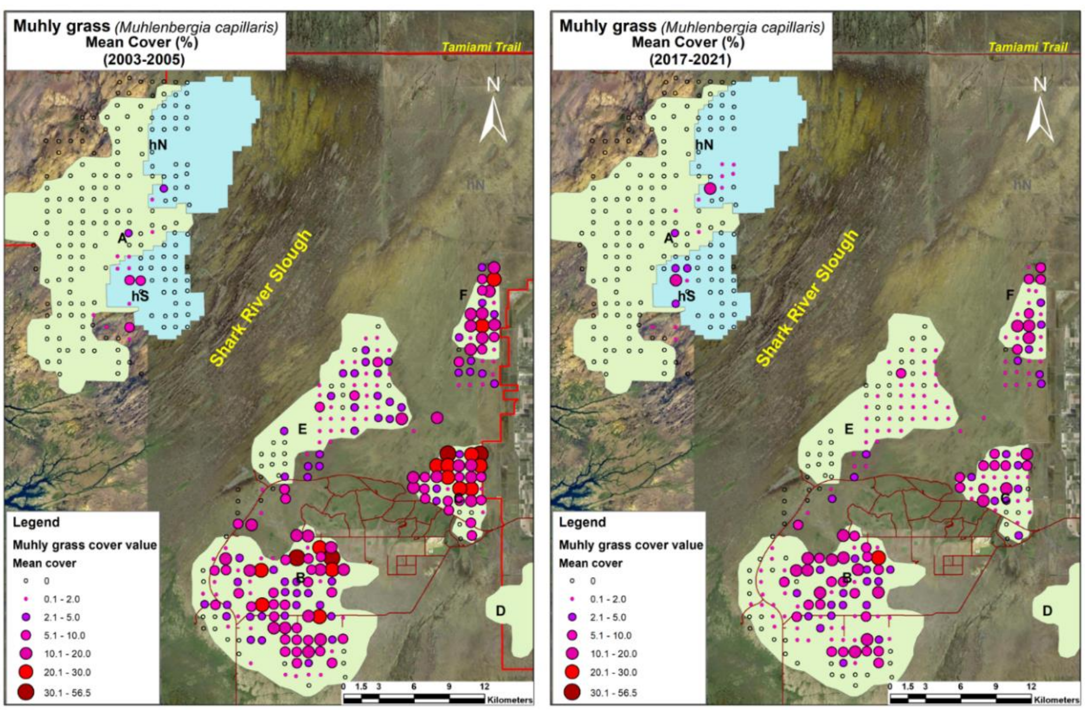

Figure 22: Mean cover of muhly grass (*Muhlenbergia capillaris*) at the vegetation monitoring sites surveyed in both 2003/2005 and 2017/2021 sampling events within CSSS sub-populations A-C, E and F. For sites that were surveyed twice over five years (2017-2021), values were used from the latest, i.e., 2021 survey.

3.4 Vegetation Structure and Biomass

Vegetation change over sixteen years was marked also by changes in vegetation structure (vegetation total cover, green cover, and height) and aboveground biomass (Figure 23; Appendix A3). These structural changes reflected the differences in hydrologic conditions and vegetation composition among different sub-populations described above.

In sub-population A, mean vegetation cover during the 2017/2021 survey was not significantly different (General linear mixed mode (GLMM): Tukey test, p<0.01) from the value during previous two surveys (Figure 23A). Similar results were also found in sub-populations C and E. However, in these two sub-populations, the mean cover tended to be lower during the most recent survey than during the previous two surveys. In B and F, differences in mean cover among the three surveys were statistically significant. Especially, the cover was significantly lower during the second survey (2006/2009) than the first (2003/2005) and the recent survey (2017/2021), mainly because during the 2006/2009 survey in those two sub-populations, several sites were surveyed 1-4 years after fire. In comparison to vegetation cover, mean vegetation height was significantly higher in 2017/2021 than in the previous two surveys in all sub-populations except E in which mean height was higher than during the 2006/2009 survey, but did not differ from the value during the first survey, 16 years ago (Figure 23B).

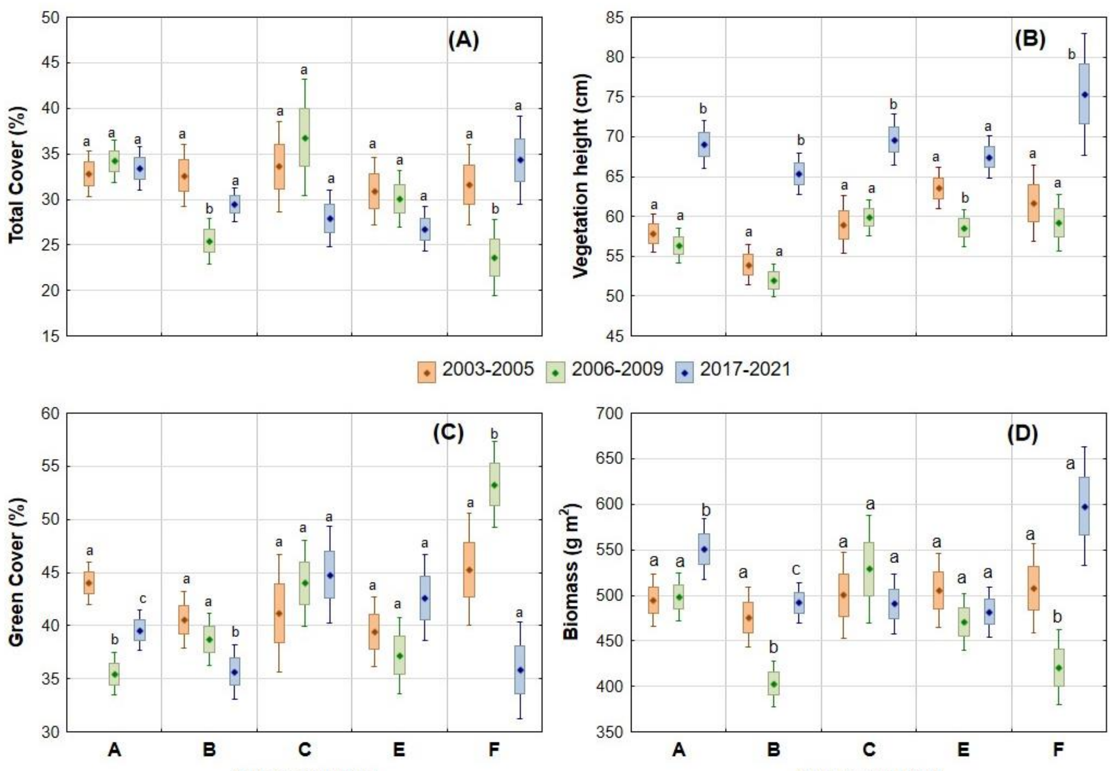

Figure 23: Box-plots (mean, SE, 95% CI) showing the vegetation structure, (A) total vegetation cover, (B) vegetation height, (C) green vegetation cover (as a percent of total cover), and (D) aboveground biomass in four sub-populations within which a number of sites were surveyed during three surveys, 2003/2005, 2006/2009, and 2017/2021. For sites that were surveyed twice over five years, during the 2017-2021 study, only vegetation structure variables for the latest survey, i.e., 2021 survey, were used.

Over the full study period (2003-2021), which included three surveys (E1-E3), green percent cover, expressed as a percent of total vegetation cover, decreased in sub-populations A, B and F (Figure 23C), indicating the accumulation of dead materials over time. During the most recent survey (2017/2021), percent green cover in sub-populations C and E tended to be higher than in the previous two surveys, and the differences among the three surveys were not significant. In sub-populations A, B and F, the increase in total cover and/or vegetation height was accompanied by an increase in mean above ground biomass (Figure 23D). In these areas, aboveground biomass in 2017/2021 was almost 10-25% higher than 1.5 decades earlier. However, aboveground biomass in sub-populations C and E was slightly lower in 2017/2021 than in the 2003/2005 survey, though the difference was not statistically significant. In the northeastern portion of sub-population, A, differences in vegetation cover and aboveground biomass between two surveys (2016 and 2020) were not significant. However, mean vegetation height had significantly (GLMM: Tukey test, p = 0.008) increased, and the four-year average hydroperiod was positively related with vegetation height. Figure 24 shows the spatial variation in aboveground biomass in all five sub-populations.

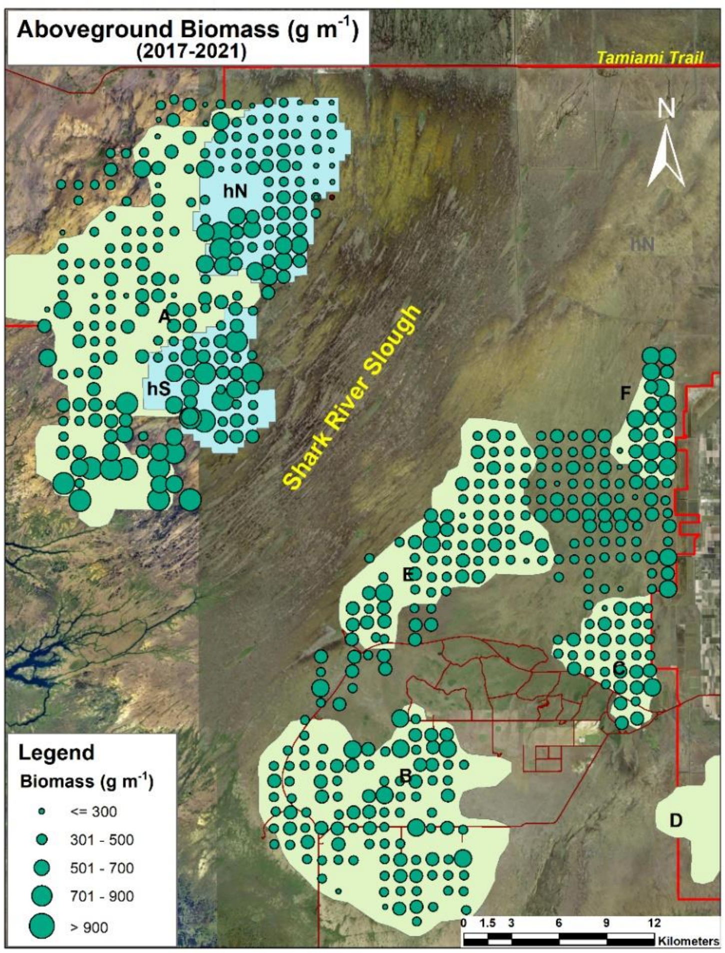

Figure 24: Mean aboveground plant biomass (g m^{-1}) at 2017/2021 vegetation survey sites in sub-populations A, B, C, E and F. For the sites that were surveyed twice over five years, during the 2017-2021 study, the biomass values are given for only the latest survey, i.e. 2021 survey.

Across the sampling events, both hydroperiod and mean annual water depth had significant effects on vegetation structural characteristics in sub-populations A and F, but their effects on such characteristics in other three sub-populations were not so strong at the surveyed sites. Nonetheless, differences in vegetation cover and biomass between wet prairie (WP) and marsh (M) sites were significant across in sub-populations A and B (Table 8). In general, total vegetation cover and biomass were higher at WP sites than M sites. In contrast, the green percent cover was higher in wet areas (at marsh sites) than the sites with relatively shorter hydroperiod (WP Sites). However, the magnitude of such differences in biomass in sub-populations A and B, in percent green cover in sub-population C was not the same during the first (2003-2005) and the last (2017-2014) survey (GLMM: Vegtype*Survey > 0.5). In sub-populations E and F, the differences in structural characteristics between WP and M sites were not significant during any of two surveys. Moreover, vegetation height did not differ between those two vegetation types in any sub-population.

Table 8: Mean (± 1 SD) vegetation structure values (total cover (%), height (cm), green vegetation cover (as a percent of total cover), and aboveground biomass (g m^{-2}) averaged for two major vegetation categories, wet prairie (WP) and marsh (M) in five-populations during both surveys, 2003/2005 and 2017/2021. P-values are from General Linear Model for the full model followed by reduced model, using one sampling event at a time when the interaction term was not significant. For sites that were surveyed twice over five years, during the 2017-2021 study, only vegetation structure variables for the latest survey, i.e., 2021 survey, were used.

Sub-Population	2003-2005			2017-2021			Survey* Vegtype p-value
	M	WP	p-value	M	WP	p-value	
Total cover (%)							
A	30.1 ± 15.7	46.1 ± 20.9	**<0.001**	31.8 ± 15.5	41.1 ± 19.7	**0.005**	0.161
B	18.7 ± 13.1	38.8 ± 18.2		27.5 ± 10.6	30.8 ± 10.3		**<0.001**
C	40.5 ± 20.0	32.6 ± 14.0	0.309	32.8 ± 11.3	25.9 ± 7.8	**0.051**	0.988
E	25.5 ± 12.6	32.0 ± 14.3	0.161	25.1 ± 10.1	27.8 ± 8.8	0.203	0.467
F	27.1 ± 12.4	32.6 ± 12.8	0.306	27.1 ± 11.3	36.9 ± 13.8	0.081	0.138
Vegetation height (cm)							
A	57.1 ± 17.5	61.6 ± 10.5	0.163	67.8 ± 22.7	74.7 ± 12.9	0.093	0.294
B	54.9 ± 15.4	53.5 ± 13.6	0.615	63.9 ± 16.9	66.4 ± 12.9	0.343	0.437
C	54.9 ± 18.7	59.6 ± 9.4	0.374	70.7 ± 9.5	69.2 ± 10	0.672	0.228
E	63.3 ± 13.1	63.6 ± 9.2	0.940	68.3 ± 10.3	66.9 ± 10.3	0.630	0.686
F	61.5 ± 24.4	61.7 ± 10.9	0.970	72.1 ± 30.2	76.5 ± 18.7	0.609	0.313
Percent green of total cover (%)							
A	44.5 ± 14.9	41.4 ± 8.9	0.244	39.5 ± 13.6	40.0 ± 12.1	0.855	0.328
B	45.4 ± 17.7	38.4 ± 13.2	**0.015**	37.1 ± 14.6	34.7 ± 14.5	0.360	0.221
C	55.6 ± 23.0	38.9 ± 14.6		42.3 ± 11	45.9 ± 14.6		**0.029**
E	46.0 ± 14.8	38.0 ± 11.8	0.068	42.4 ± 15.4	42.8 ± 15.9	0.936	0.200
F	45.0 ± 11.7	45.3 ± 16.0	0.959	42.9 ± 12.7	33.3 ± 12.5	**0.057**	0.076
Biomass (g m^{-2})							
A	468 ± 190	623 ± 205	**<0.001**	532 ± 230	641 ± 229	**0.009**	0.448
B	365 ± 156	525 ± 182		473 ± 139	504 ± 120		**<0.001**
C	539 ± 206	494 ± 133	0.557	534 ± 104	472 ± 94	0.089	0.750
E	469 ± 155	513 ± 153	0.380	474 ± 123	487 ± 93	0.556	0.572
F	501 ± 192	509 ± 132	0.787	537 ± 210	620 ± 176	0.236	0.076

3.5 Fire and Vegetation

Vegetation composition at the surveyed sites was also affected by fires that burned several sites between 2003 and 2021 (Table 9). Since burned sites were not always visited immediately after fire, any site (i.e., survey plot) located within the official fire boundary was considered to be burned. Among the transect and census sites in sub-populations A-F that were sampled for the first time in 2003/2005, 377 sites burned at least once in 19 years, and 55 of those sites burned two or three times during the period. Among the 377 burned sites, 238 sites, including 37 transect and 211 census sites, were sampled during the recent (2017/2021) survey (Figure 25). However, the majority (54.1%) of sites just burned in 2020 fires. While altogether 159 sites were resurveyed over five years (2017-2021), only 45 sites were resurveyed after fire in 2020.

In vegetation classification for the burned sites that had both pre- and post-fire data, the results revealed that vegetation type at 83% of them either did not change, or changed but remained within the same broad two categories, wet prairie and marsh. At 27 (16%) sites, post-fire vegetation changed from prairie to marsh type, while only at two sites was the change from marsh to prairie type.

Table 9: Number of transect and census sites that were first time surveyed during 2003/2005 survey and burned between 2003 and 2021. The total number of sites includes 55 sites that burned two or three times.

Sub-Population	2003	2005	2006	2007	2008	2012	2014	2015	2017	2018	2019	2020	2021	Total # of Sites (burns)
A	4		2	2	16		23	19			3	178		247
B	16	16		10					6	3	12	19		82
C				2		3						7		12
D	21	7									8			36
E	1				9									10
F	1				46	4					1			52
Total	**43**	**23**	**2**	**14**	**71**	**7**	**23**	**19**	**6**	**3**	**24**	**204**		**439**

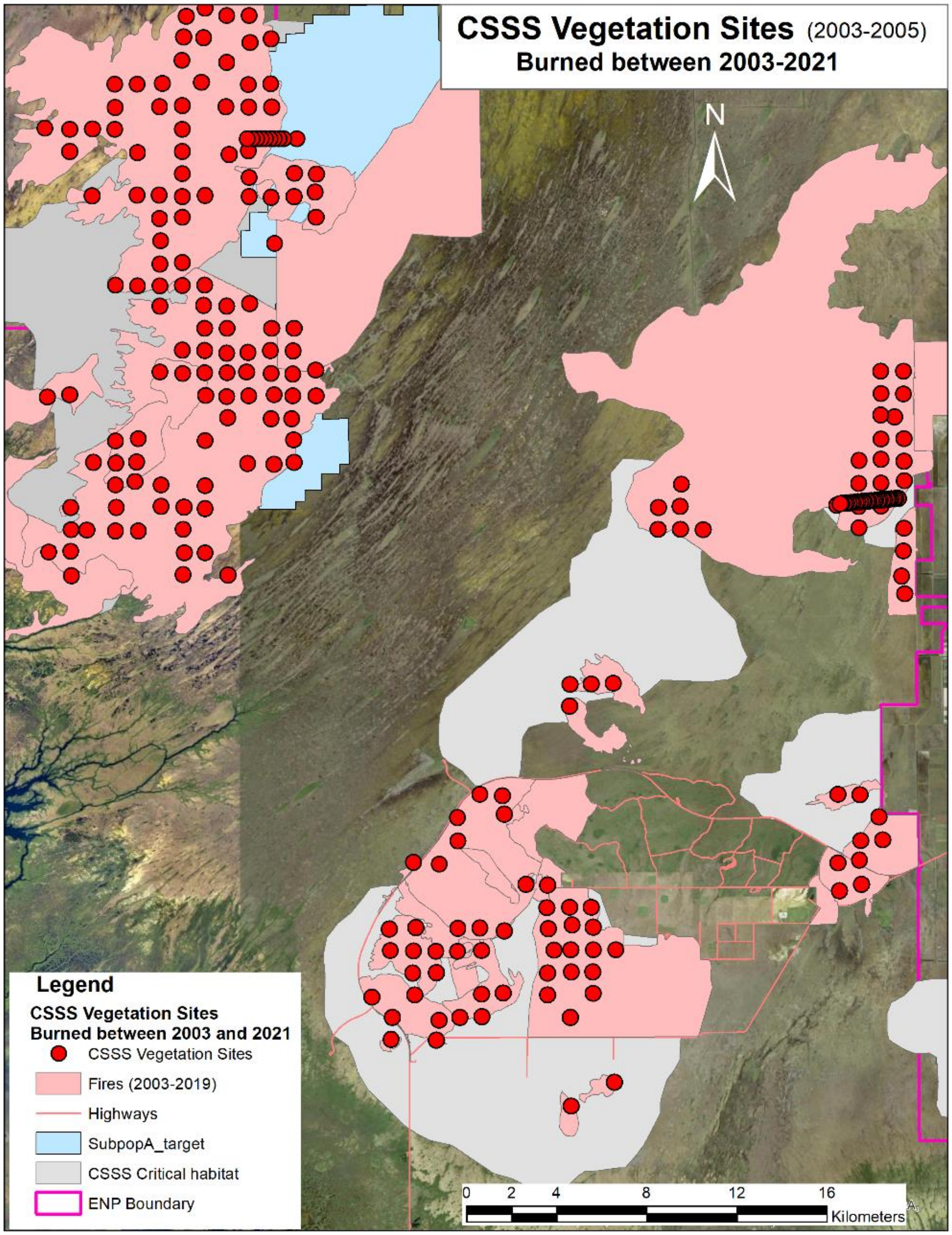

Figure 25: CSSS vegetation survey sites burned between 2003 and 2021. (A) Burned census sites that were surveyed in both 2003/2005 and 2017/2021 samplings. (B) Both transect and census vegetation sites burned in 2020.

For the sites burned between 2003 and 2008, vegetation dynamics up to six post-fire years (i.e., until 2014) were described in detail in previous reports (Sah et al. 2015). Thirty-six of those sites burned again between 2014 and 2019. The results of recent analysis are presented below in sub-section 3.5.1. Moreover, out of 265 sites burned after 2008, a post-fire survey was done for the first time at 85 sites during the recent survey (2017-2021). Among those 85 burned sites, 43 sites, including 37 sites in sub-population A and 4 sites in C and 2 sites in B, had pre-fire data collected between 2017 and 2020, and post-fire data in 2021, i.e. one year after 2020 fire. The NMDS ordination results illustrates that the vegetation composition at many of those 2020-burned sites was different in one-year postfire from the composition prior to the fire. However, some sites did not show such difference in composition (Figure 26). In fact, total cover increased between pre- and one-year postfire surveys at 16% of sites and decreased by <5% at 14% of burned sites, suggesting that those sites either were not burned or were only partially burned.

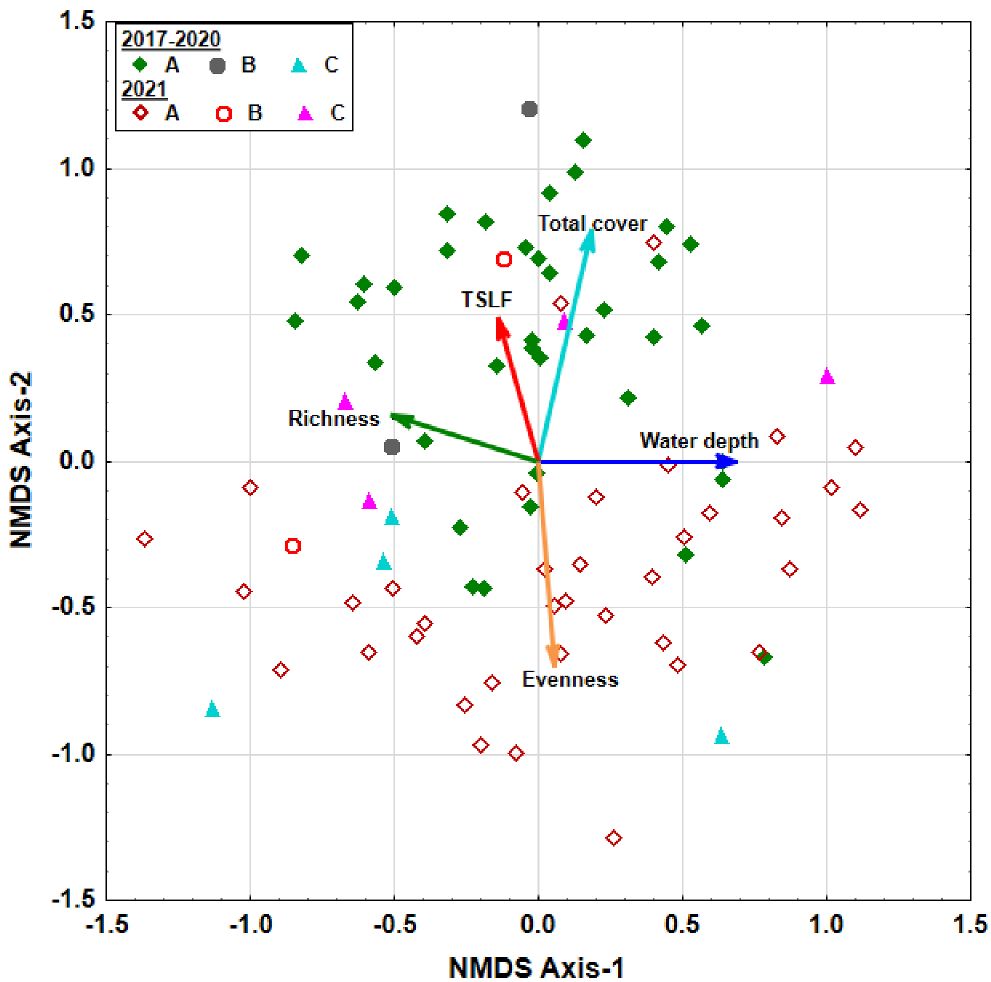

Figure 26: NMDS ordination biplots of site scores, with the environmental and community characteristic vectors fitted in the ordination space. The ordination is based on species abundance data collected at 2020-burned sites in sub-populations A, B and C during 2017-2020 survey (prior to fire) and again in 2021 (one year after 2020 fire).

3.5.1 *Vegetation dynamics in relation to fire and flooding*

The detailed analysis of vegetation dynamics in relation to fire and pre- and post-fire hydrology is currently limited to the sites burned between 2005 and 2008. The 2005-burn group primarily included the sub-population D sites burned in May 2005 (May_05) and sub-population B sites burned in August (Aug_05) that were flooded by about a foot (30 cm) of water by Hurricane Katrina (landfall in South Florida on Aug 25, 2015) within 7-15 days of fire. (Sah et al. 2011, 2015). In contrast, 2008-burn sites included the sites burned in four different fires; Mustang Corner (MC_08), West Camp (WC_08), Lime Tree (LT_08) and Radius Rod (RR_08) in sub-populations A, E and F. Moreover, the 2005- and 2008 burn sites were surveyed up to 6 post-fire years, and then recently again after 9-15 years of burn. For these sites, vegetation dynamics, including the changes in vegetation structural characteristics are summarized here.

Pre- and post-burn species composition

Results of non-metric multidimensional scaling (NMS) ordination revealed that pre-burn vegetation composition at the 2005 and 2008 burned sites varied along the hydrologic gradient. Between two groups of sites burned in 2005, May_05 sites were towards the wetter end of the gradient than the Aug_05 wet prairie sites (Figure 27). Similarly, among the 2008-burned groups, the LT_05 sites were at the wettest end of the gradient, while MC_08 and WC_08 sites had mostly wet prairie vegetation, but with a wide range of hydrologic conditions. The sites burned in the Mustang Corner and Radius Rod fires in sub-population E had intermediate hydrologic conditions. In general, sites with vegetation adapted to relatively short hydroperiod had higher species richness than wetter sites.

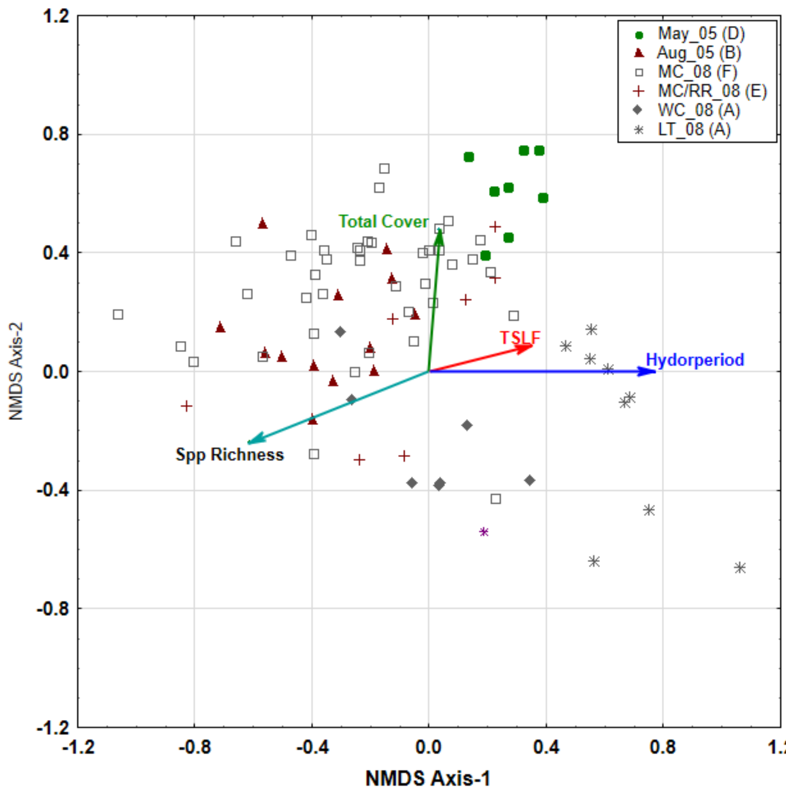

Figure 27: Non-metric multidimensional scaling (NMDS) ordination based on pre-burn species cover at the 2005 and 2008-burned sites. Environmental and community characteristic vectors were fitted within ordination space. TSLF = Time since last fire. Sites are grouped by fire and sub-population. May_05 and Aug_05 are the sites burned in May and August 2005, respectively. MC_08, WC_08, LT_08 and RR_08 are the sites burned in 2008 (Mustang Corner, West Camp, Lime tree and Radius Rod, respectively). Letter in parenthesis represents the CSSS sub-population.

After the fire, vegetation composition in both May_05 and Aug_05 groups were very different from pre-burn vegetation. In both groups, vegetation composition even five years after fire differed significantly from pre-burn vegetation (ANOSIM: May_05 - R = 0.633, p = 0.001; Aug_05 - R = 0.417, p = 0.001) (Table 10). While the May_05 burn sites in sub-population D were not sampled, the most recent survey of Aug_05 sites in sub-pop B showed that vegetation composition had not returned to pre-burn condition even 12 to 15 years after fire, and mean total plant cover at those sites were only 61% of the initial cover (Figure 28a). Slow recovery of vegetation composition at these sites probably resulted from post-fire hydrologic conditions, as the majority of sites burned in 2005 experienced substantial flooding after fire. In contrast, within the majority of the 2008-burned groups, vegetation composition even two years after fire was not significantly different from pre-burn, suggesting rapid vegetation recovery (Table 11). As expected, total plant cover at the MC_08 and other 2008-burned sites recovered nearly to the pre-fire levels in six years after fire, and during the most recent survey (2017-2020), the total species cover ranged between 87% and 115% of pre-burn vegetation cover (Figure 28 b-d). Surprisingly, at the sites burned in the Mustang Corner fire (MC_08), where post-fire conditions immediate after fire were not especially wet, vegetation composition during surveyed post-fire years (1, 2, 6 and 9/12 years) were significantly different (ANOSIM: p = 0.001) from pre-burn vegetation. In the same vicinity, the vegetation composition at the unburned sites on Transect F did not differ much among sampling years.

Table 10: Global R and *p-values* from analysis of similarity (ANOSIM) testing for among-year differences in vegetation composition before and after fire for two 2005-burn groups, May_05 and Aug_05. (*p-value*: *** = 0.001, ** = 0.01, * = 0.05)

	May_05 (Sub-pop D; n=8)					
	Pre-burn	**Post_Yr-1**	**Post_Yr-2**	**Post_Yr-3**	**Post_Yr-4**	**Post_Yr-5**
Post_Yr-1	**0.511***					
Post_Yr-2	**0.609***	**0.347**				
Post_Yr-3	**0.546***	**0.444***	0.027			
Post_Yr-4	**0.719***	**0.462***	0.031	-0.016		
Post_Yr-5	**0.633***	**0.473***	0.012	-0.107	0.006	
Post_Yr-12_15	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
	Aug_05 (Sub-pop B; n=13)					
Post_Yr-1	**0.723***					
Post_Yr-2	**0.677***	**0.293***				
Post_Yr-3	**0.511***	**0.282***	0.058			
Post_Yr-4	**0.425***	**0.320***	**0.132***	0.023		
Post_Yr-5	**0.417***	**0.365***	**0.113***	-0.007	-0.020	
Post_Yr-12_15	**0.179**	**0.637***	**0.364***	**0.236***	**0.146**	**0.116***

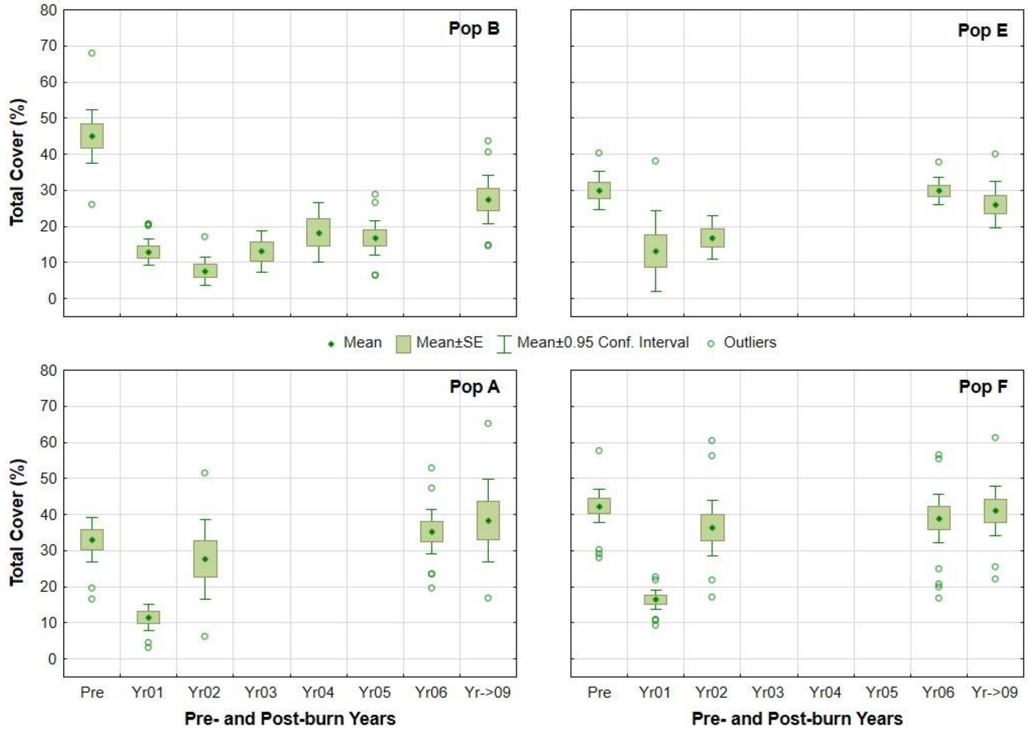

Figure 28: Box plots (Mean, ±SD and 95% CI) of vegetation cover in pre- and post-burn survey years at the sites burned in 2005 (Sub-population B), and 2008 (Sub-populations A, E and F).

Table 11: Global R and *p-values* from analysis of similarity (ANOSIM) testing for among-year differences in vegetation composition before and after fire for two 2008-burn groups (WC_08 and LT_08) in sub-pop A and one fire group (MC_08) in sub-pop F. Sites in sub-pop E from two fire groups (MC_08 and RR_08) were grouped together (*p-values*: *** = 0.001, ** = 0.01, * = 0.05)

MC_08 (Sub-pop F; n=44)					**MC-RR_08** (Sub-pop E; n=7)				
	Pre-burn	**Post_Yr-1**	**Post_Yr-2**	**Post_Yr-6**		**Pre-burn**	**Post_Yr-1**	**Post_Yr-2**	**Post_Yr-6**
Post_Yr-1	**0.299*** **				**Post_Yr-1**	0.161			
Post_Yr-2	**0.199*** **	**0.122*** **			**Post_Yr-2**	0.062	0.082		
Post_Yr-6	**0.158*** **	**0.213*** **	**0.195*** **		**Post_Yr-6**	-0.074	0.021	-0.037	
Post_Yr-9_12	**0.132*** **	**0.315*** **	**0.234*** **	**0.058*** **	**Post_Yr-9_12**	**0.219***	**0.293***	0.075	0.047
WC_08 (Sub-pop A: n=7)					**LT_08** (Sub-pop A; n=9)				
Post_Yr-1	**0.256***				**Post_Yr-1**	**0.140***			
Post_Yr-2	0.009	0.003			**Post_Yr-2**	0.084	0.030		
Post_Yr-6	-0.084	0.007	-0.152		**Post_Yr-6**	0.010	0.115	0.087	
Post_Yr-9_12	0.021	0.067	-0.058	-0.171	**Post_Yr-9_12**	0.052	0.117	0.157	-0.058

In 2005-burned plots, while green cover, as the percent of total cover, and vegetation height at the 2005-burn sites were more or less similar to pre-burn conditions, aboveground biomass at those sites was still less than three-fourths of the pre-burn biomass (Appendix A4). However, at sites in the 2008-burn group, biomass was on par with vegetation cover, ranging from 94% of pre-burn biomass in sub-population E to 117% in sub-population A. In sub-population F, where the Mustang Corner fire burned a large swathe of the landscape in May 2008, biomass in 2017, i.e., 9 years after fire, was 115% of pre-burn biomass (Figure 29).

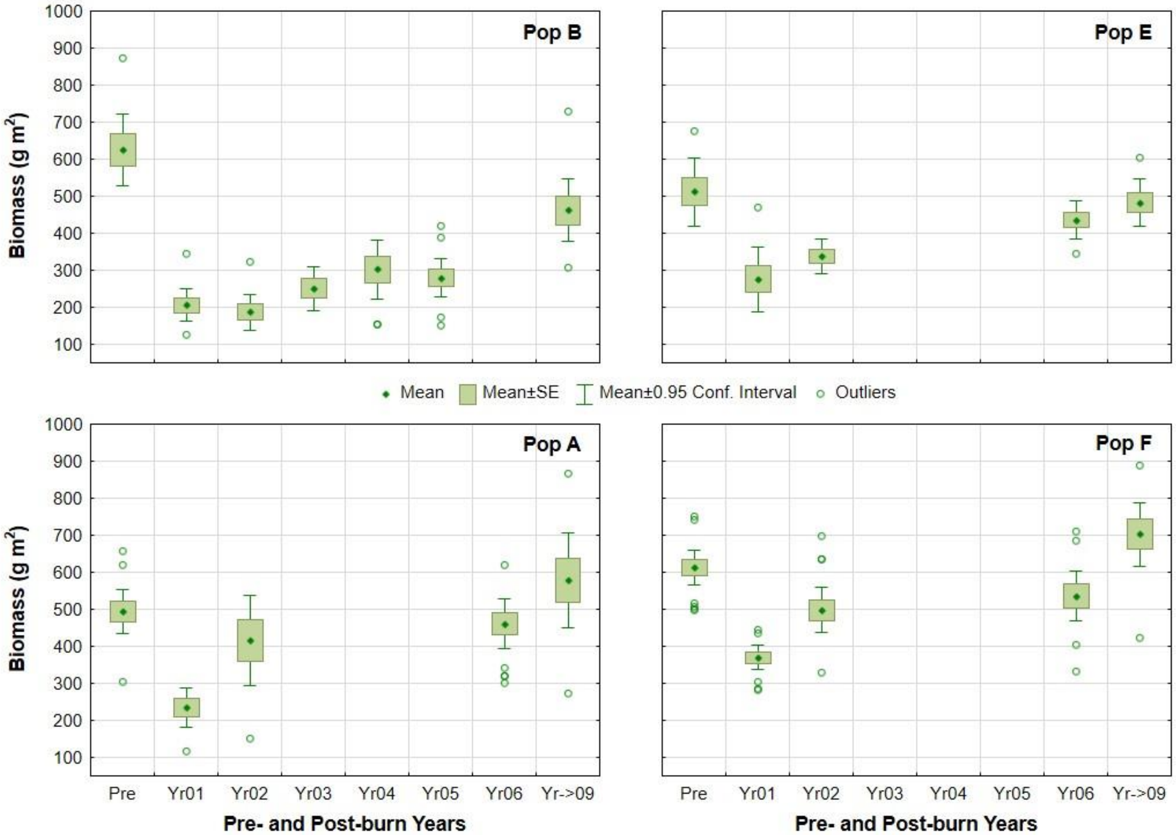

Figure 29: Box plots (Mean, ±SD and 95% CI) of aboveground plant biomass in pre- and post-burn survey years at the sites burned in 2005 (Sub-population B), and 2008 (Sub-populations A, E and F).

Fire usually impacts community composition by reducing the abundance of dominant species and facilitating the growth of light-demanding opportunistic species. This effect is well illustrated in rank-abundance plots that include both the relative abundance of species and evenness. At the sites burned in 2005, the relative cover of dominant species like sawgrass (*C. jamaicense*), muhly grass (*M. capillaris*), bluestem (*S. rhizomatum*), and blacktop sedge (*Schoenus nigricans*) was considerably lower even 12-15 years after fire compared to pre-fire levels, resulting in large shifts in species rank abundance curve (Figure 30b). At those sites, especially in the Aug_08 group, the curve was remarkably different from and less steep than the pre-burn curve, indicating that the community had become more heterogeneous. In contrast, in the 2008-burned groups, there was not much difference in curves between pre-burn and post-fire years, except, at the MC_08 sites which showed a significant shift one year after fire. However, by 9 to 12 years after the fire, the curve had returned to its pre-burn condition (Figure 30c).

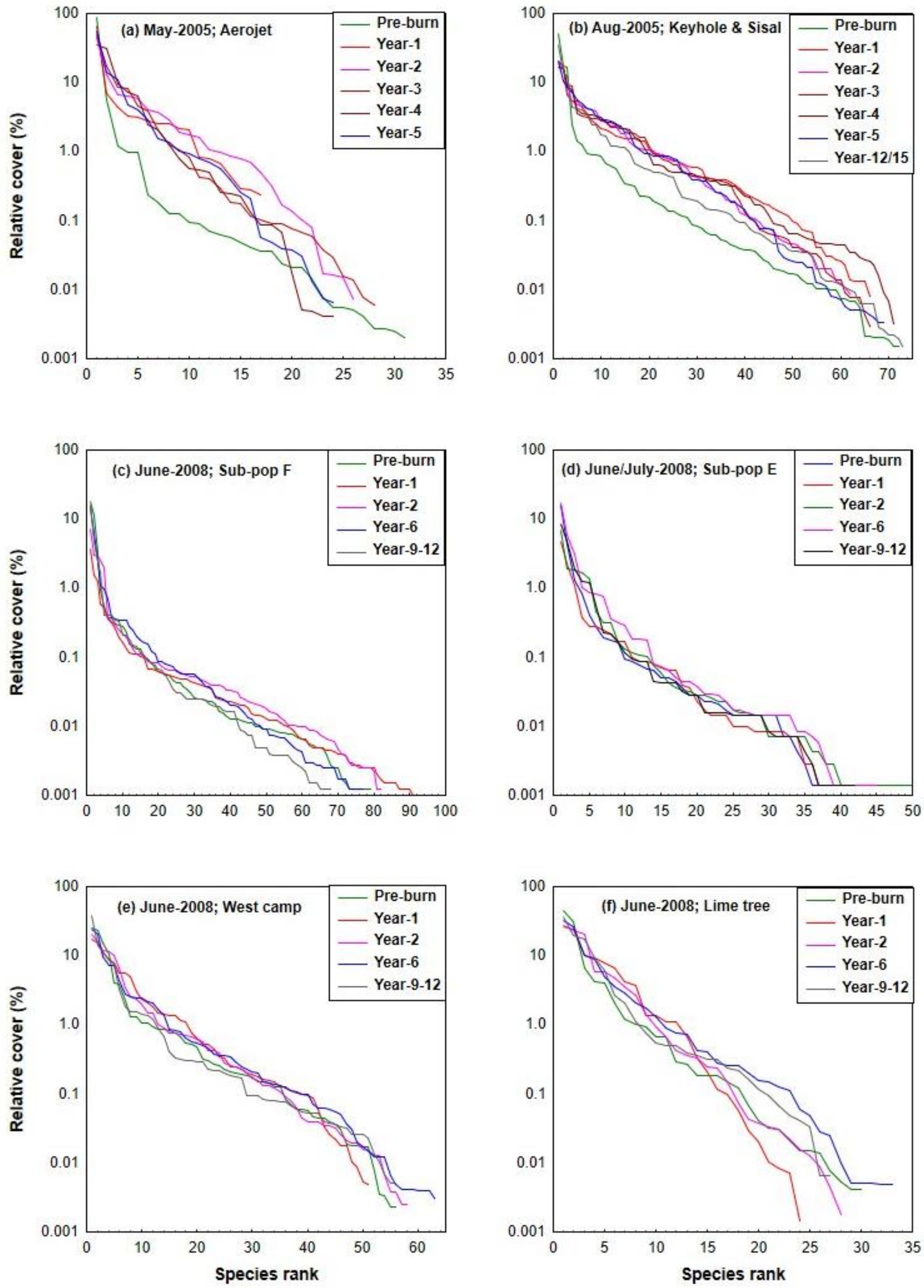

Figure 30: Species rank abundance at the sites burned in 2005 or 2008 fires. Sites from two fires, Keyhole and Sisal (2005) are lumped together, as sites after both fires were immediately flooded after fire. Likewise, sites in sub-population E from two fires Mustang Corner and Radius Rod are lumped together.

In burned plots, the change pattern in relative abundance of species differed among different groups of sites. At Aug_05 sites, relative cover of four dominant species, i.e., sawgrass (*Cladium jamaicense*), bluestem (*Schizachyrium rhizomatum*), muhly grass (*Muhlenbergia capillaris* var. *filipes*) and black-top sedge (*Schoenus nigricans*) decreased significantly immediately after fire followed by flooding, and remained much lower than before the fire even five years later (Figure 31b). Interestingly, at May_05 sites also, where water level increased gradually, providing ample opportunity for the re-growth of plants after fire, a large decrease in the relative cover of sawgrass (*C. jamaicense*) was observed (Figure 31a). Five years after the fire, the mean relative cover of sawgrass was only 55% in comparison to 90% one year before the fire. Persistence of the relatively low cover of these dominant species in post-fire years sites also facilitated the growth of other species. For instance, at the Aug_05 sites, relative cover of several minor species, such as spadeleaf (*Centella asiatica*), southern beakrush (*Rhynchospora microcarpa*), gulfdune paspalum (*Paspalum monostachyum*) and bluejoint panicgrass (*Panicum tenerum*) was higher in the fifth year after fire than in pre-burn samples. Relatively low cover of three dominant species (*C. jamaicense*, *M. capillaris* and S. *rhizomatum*) at Aug_05 sites was persistent even after 12-15 years after fire (Figure 31b)

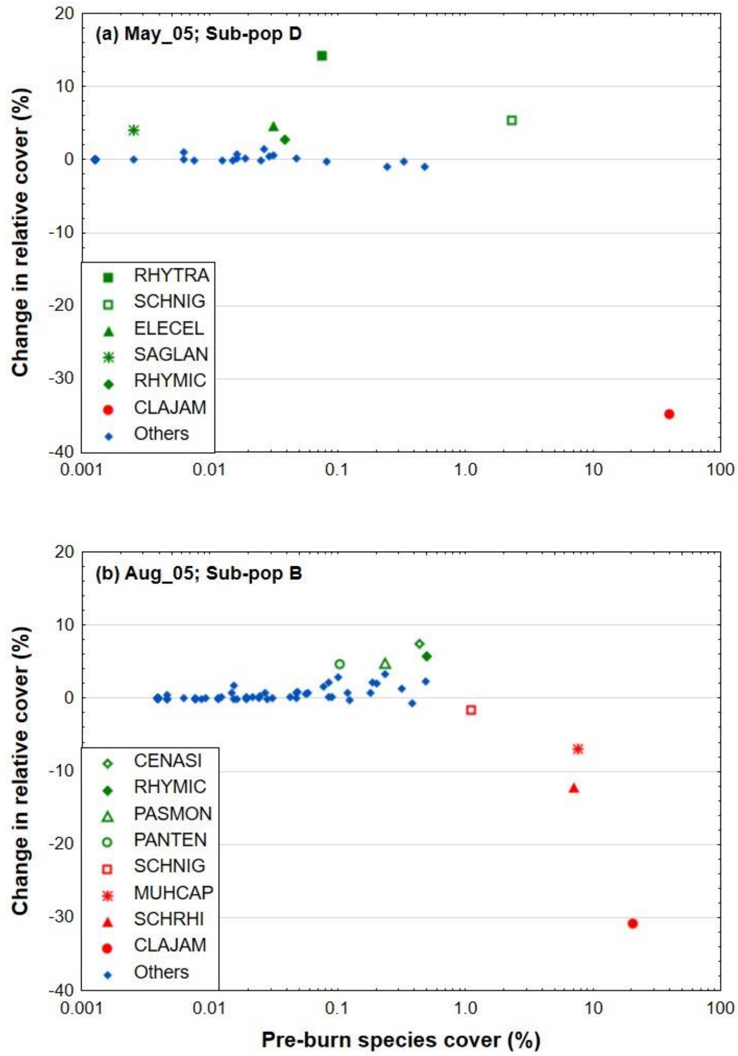

Figure 31: Change in the relative cover of species in five years after fire at the sites burned in (a) May 2005 (May_05) and (b) August 2005 (Aug_05) in CSSS sub-population D and B, respectively. The sites were sampled 0-3 years before fire, and re-sampled annually for five years after fire.

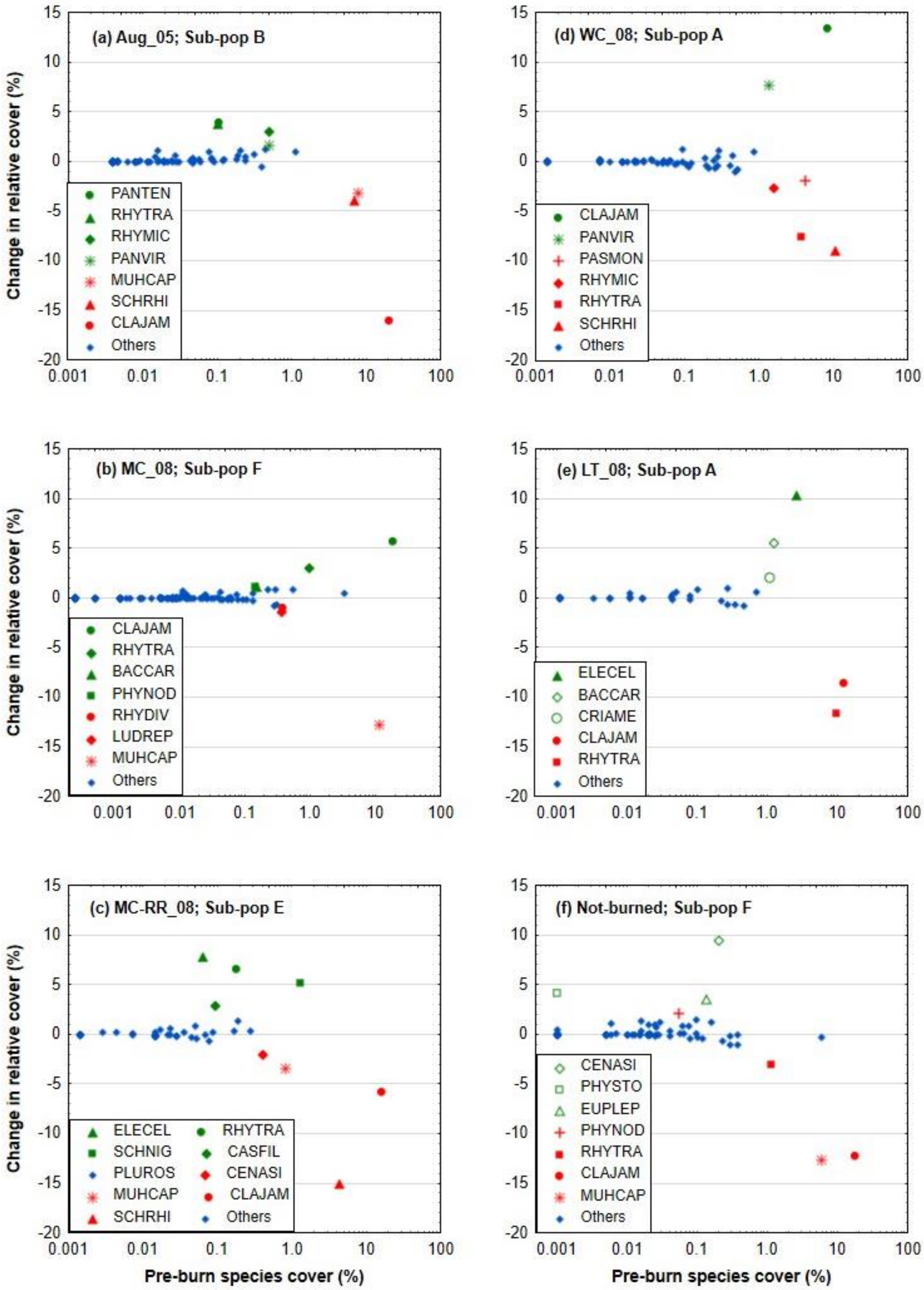

Figure 32: Change in the relative cover of species in 9 to 15 after fire at the 2005- and 2008-burned sites in CSSS sub-populations A, B, E and F. The sites were sampled 0-3 years before fire, and re-sampled in 1, 2, 5 or 6 years after fire, and then again during the recent survey (2017-2021), i.e., 9 to 15 years after fire.

In contrast to 2005-burned sites, dominant species in 2008-burned sites experienced only a minimal (<20%) decrease in relative cover (Figure 32a-e). At the MC_08 sites within sub-population F and MC-RR_08 sites in sub-population E, a decrease of 10 and 20% of pre-burn cover of *M. capillaris* var. *filipes* and *S. rhizomatum*, respectively, was in response to the increased hydroperiod in those areas. Decrease in cover of these two dominant species that are indicators of relatively dry conditions was supplemented by an increase in cover of more hydric species, including *R. tracyi*, *Bacopa caroliniana* and *Phyla nodiflora* at MC_08 sites and *Eleocharis cellulosa* and *R. tracyi* at MC-RR_08 sites (Figure 32b, c). Similarly, on unburned sites along Transect F, there was also a decrease in muhly grass and sawgrass over time, suggesting an influence of hydrology on vegetation composition in that area. The same pattern was observed at LT_08 sites, located in western part of population A, while the cover of other hydric species (*E. cellulose, B. caroliniana*) increased (Figure 32e). At the WC_08 sites in sub-population A, relative cover of *C. jamaicense* increased in relation to pre-burn condition while there was minimal decrease (<10%) in relative cover of other dominant species (Figure 32d).

Trajectories of vegetation change

The post-fire vegetation change pattern was also analyzed using trajectory analysis. In the analysis, the pre-burn samples were positioned in ordination space near the high end of the TSLF vector, and the burned sites that approached the pre-burn condition were likely to show a significant shift along individual vectors towards the respective pre-burn sites. The degree of a shift in position of sites in 2005- and 2008- burned groups varied (Figure 33).

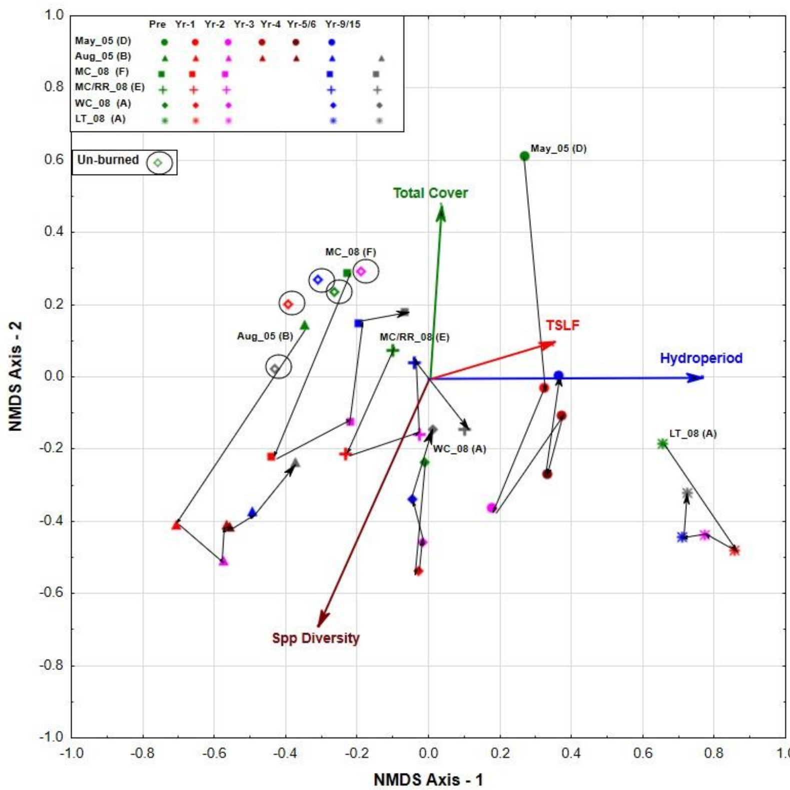

Figure 33: Non-metric multidimensional scaling (NMS) ordination based on total cover at sites burned in 2005 or 2008 and sampled prior to burn and 1 to 5 or 6 years after fire and then between 2017-2020, i.e., 9 to 15 years after fire. (A) Centroids of 2005 and 2008-burned sites grouped by burn year, fire and sub-population. Sites burned in 2005 are sub-grouped in May-burned and Aug-burned sites. (B). Unburned sites (UB_08; symbols with open diamonds) are the sites sampled at the same frequency at which the sites burned in Mustang Corner (MC_08) fire were sampled.

The shift in position of the sites back toward their reference position, expressed as the amount (Δ) and rate (slope) of change in vegetation composition, was significant for 50% sites in MC_08 and WC_08 groups (Appendix A5). In the May_05 group, in which sites were sampled until only five years after fire, none of the them showed a significant shift toward the target. Interestingly, <40% of Aug_05 sites showed a significant rate of shift in position after 12-15 years of fire. However, five years after fire when both groups were sampled, mean degree (delta) and rate (slope) of change in vegetation composition were higher in the May_05 than in the Aug_05 sites. Moreover, at 50% sites in those two fire groups, the slope in trajectory analysis was negative (Appendix A5), suggesting that vegetation composition at those sites were then on an opposite trajectory than normal, which might have led to a vegetation state different from that which predominated prior to burn.

The rate of post-fire vegetation changes at individual sites flooded immediately after fire was influenced by post-fire hydrologic conditions. For both the 2005 and 2008-burned sites, we used EDEN water surface elevation data to quantify the real time water depth when sites were burned, and during post-fire vegetation regrowth. Real time mean water depth was the average of daily mean water level in relation to ground elevation for three consecutive days, starting from one-day before the burn date. Using the daily mean water depth at each site, we then also calculated mean and maximum water depth for various post-fire periods: 1, 3 and 6 months, 1, 2, 3, 4 and 5 years after burn date. Vegetation recovery at the burned sites was negatively ($r = -0.33$; $p = 0.002$) affected by water conditions at the time of burn, and the effects were much more pronounced at the prairie sites, particularly in sub-populations A, B and D. The sites which had the water level near or above the ground level showed slow recovery (Figure 34 a, b).

Post-fire water conditions were likewise very influential. The recovery process at the prairie sites was impeded when mean post-fire water depth was 20 cm or more over one to three months after fire, and maximum water level exceeded 30 cm during the same period (Table 12; Appendix A6a, f and A7a, f). Within three months, when water depth exceeded >50 cm, as was observed in sub-pop D, it had a deleterious effect on vegetation recovery even at the marsh sites (Appendix A6g and A7g), where mean water depth was <20 cm for the first month after fire (Appendix A6a and A7a), but later increased and the sites remained flooded with more than 30 cm of water for almost 6 months (Appendix A6c and A7c). The relationship between the vegetation trajectory parameters and mean water depth, averaged over 2 post-fire years and beyond was non-significant (Table 12; Appendix A6e, j and A7e, j), suggesting that the water conditions for the first post-fire year were more important for vegetation recovery than the later years (Figure 35).

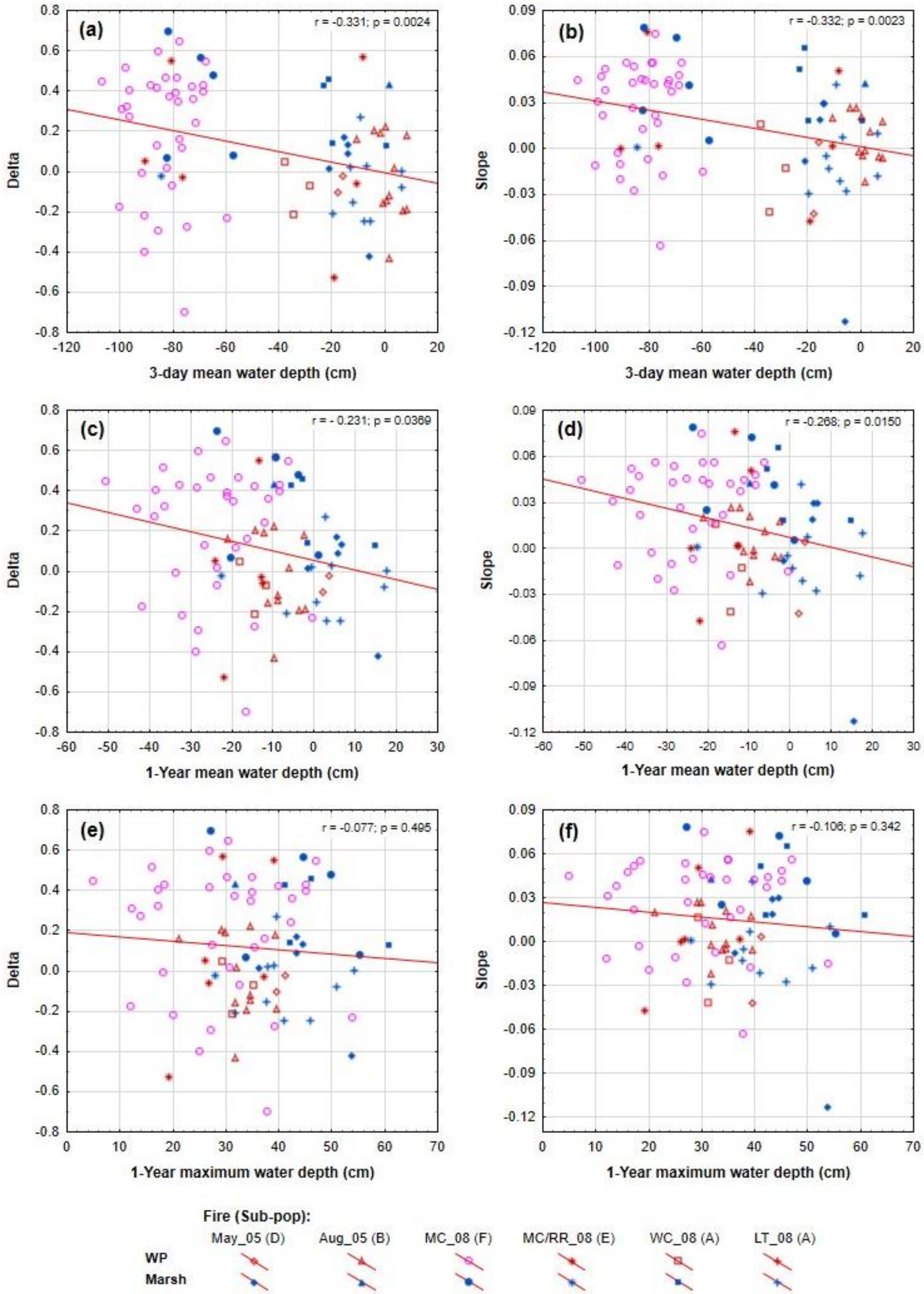

Figure 34: Relationship between hydrologic conditions (water level) and a change in species composition at the sites, expressed as delta (Δ) and slope that quantify the degree and rate of change in vegetation composition along the reference vectors in the ordination space. The colored symbols represent different burn groups May_05, Aug_05, MC_08, WC_08, LT_08 and RR_08) and sub-populations (in parenthesis) and two vegetation types (WP = Wet prairie, and M = Marsh).

Table 12: Correlation coefficient (r) and p-value for the relationship between hydrologic conditions (water level) and a change in species composition at the sites, expressed as delta (Δ) and slope that quantify the degree and rate of change in vegetation composition along the reference vectors in the NMDS ordination space.

Period	Month(s)	Mean water depth				Max water depth			
		delta (Δ)		slope (S)		delta (Δ)		slope (S)	
		r	p	r	p	r	p	r	p
3-Day	0.1	-0.33	**0.002**	-0.33	**0.002**				
1-Month	1.0	-0.34	**0.002**	-0.34	**0.002**	-0.33	**0.003**	-0.34	**0.002**
3-Month	3.0	-0.31	**0.005**	-0.32	**0.003**	-0.25	**0.025**	-0.28	**0.011**
6-Month	6.0	-0.20	**0.007**	-0.25	**0.026**	-0.08	0.495	-0.11	0.342
1-Year	12.0	-0.23	**0.037**	-0.27	**0.015**	-0.08	0.495	-0.11	0.342
2-Year	24.0	-0.10	0.356	-0.15	0.190	-0.08	0.495	-0.11	0.342
3-Year	36.0	-0.10	0.384	-0.15	0.190	-0.08	0.500	-0.11	0.345
4-Year	48.0	-0.15	0.182	-0.19	0.085	-0.08	0.500	-0.11	0.345
5-Year	60.0	-0.13	0.264	-0.17	0.130	-0.03	0.788	-0.06	0.583

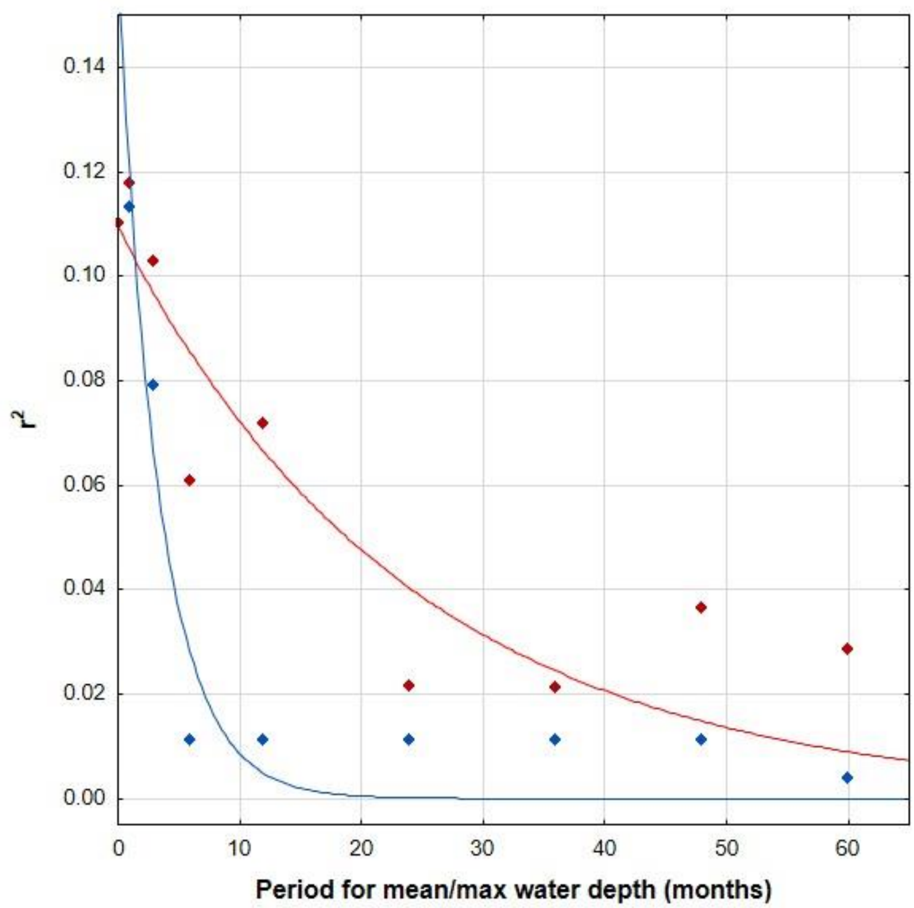

Figure 35: Change in coefficient of determination (r^2) between water conditions (mean and max RWL) and slope (rate of change in vegetation composition) over time.

3.6 Vegetation and Recent CSSS Habitat Usage

The Cape Sable seaside sparrow (CSSS) population survey is conducted annually by Everglades National Park personnel. Since an annual sparrow survey was not done in 2020, primarily due to restrictions caused by Covid-19 pandemic, our analysis of occurrence of sparrows in relation to vegetation survey sites is based on the survey data, collected during four survey years, 2017-2019 and 2021. In those four years, 577 sparrow census points were visited at least once in six sub-populations (A-F), while 404 points were visited all three years. Among those 577 points, 154 (26.7%) had at least one bird recorded in one of those years (Figure 36).

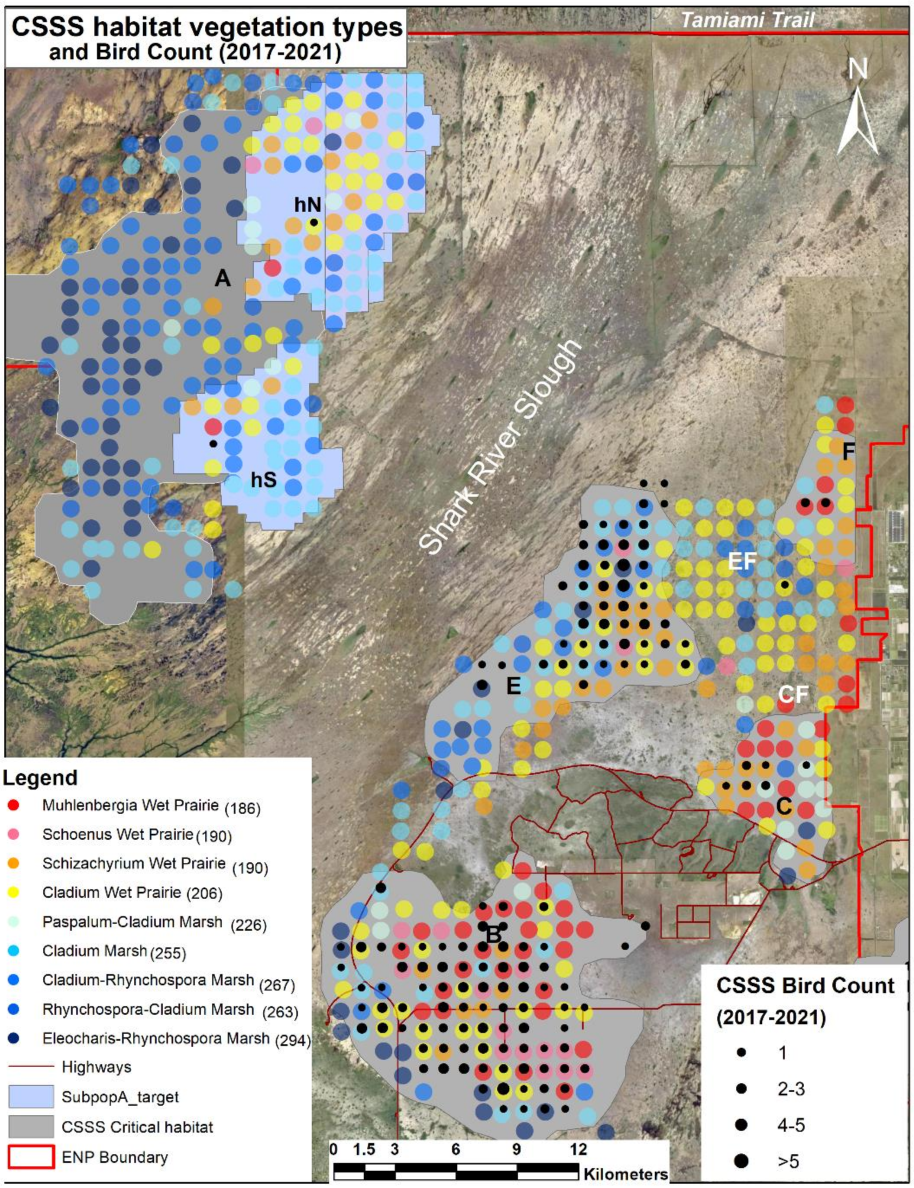

Figure 36: Map showing the vegetation types at the census sites (in background) surveyed between 2017 and 2021 and the number of birds at the sparrow census points with at least one bird recorded during the annual sparrow survey in any of four years (2017-2019, and 2021). In the legend, numbers in parentheses are the mean vegetation-inferred hydroperiod (days) averaged over the census sites with the vegetation type observed during the 2017-2021 survey.

Over five years (2017-2021), the number of census points visited in six sub-populations ranged between 32 in sub-population F to 179 in sub-population B, whereas the percent of visited sites with sparrow records ranged from 1.3% in sub-population A to 46.9% in sub-population B (Figure 37a). Those sparrow census points differed in vegetation characteristics and included all nine vegetation types that have been identified using vegetation composition data in five sub-populations (A-C, E and F) and the sites between C and F (CF) and between E and F (EF) sub-populations. Sub-population D was not included in this ongoing vegetation monitoring program.

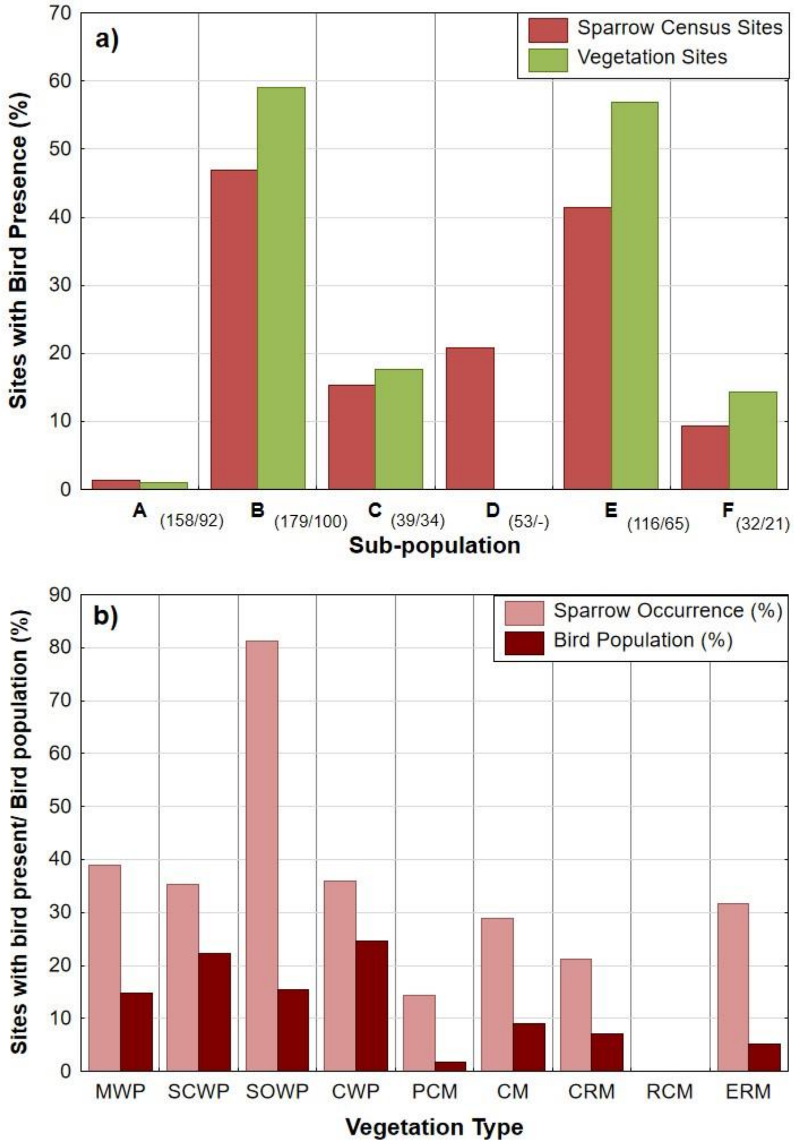

Figure 37: Percent of sites at which at least one sparrow was recorded during the annual sparrow survey in any of three years (2017-2019). Percent of sites with sparrows are by sub-populations (A) and vegetation types (B). MWP = *Muhlenbergia* Wet Prairie (WP); SCWP = *Schizachyrium* WP; SOWP = *Schoenus* WP; PCM = *Paspalum-Cladium* Marsh, CM = Cladium Marsh; CRM = *Cladium-Rhynchospora* Marsh; RCM = *Rhynchospora-Cladium* Marsh; ERM = *Eleocharis-Rhynchospora* Marsh.

The vegetation survey plots are fixed, but the location of sparrow and vegetation census points differ by as much as a few hundred meters. Thus, we selected the visited sparrow census points located within 250 m of our vegetation census plots surveyed over five years (2017-2021). Altogether, 323 vegetation survey plots, including 4 and 7 sites in CF and EF, respectively, coincided with sparrow census points, and sparrows were observed in 106 (32.8%) of them at least once in four survey years (2017-2019, 2021). The percent of vegetation sites with sparrows ranged between 1.1% in sub-population A and 59.0% in sub-population B (Figure 37a).

The vegetation survey sites represented all nine vegetation types, ranging from 10 sites of *Rhynchospora-Cladium* Marsh to 78 sites of *Cladium* Wet Prairie. However, sparrows were not distributed uniformly across all vegetation types. Sparrows occurred in higher number in prairie sites than marsh sites (Figure 37b, 38). For instance, CSSS occupied more than three-fourths (81.3%) of *Schoenus* Wet Prairie site (n = 16) and 38.9% of *Muhlenbergia* Wet Prairie in those years. Likewise, sparrows occurred at 35.9% of *Cladium* Wet Prairie sites, more than the *Cladium* Marsh sites (28.8%). Given the differences in the number of sites visited per vegetation type, *Cladium* Wet Prairie, which was present at 20.7% of visited vegetation census sites, had the highest percent (24.1%) of bird occurrence and nearly the same proportion of the total sparrow count during the study period (Appendix A8).

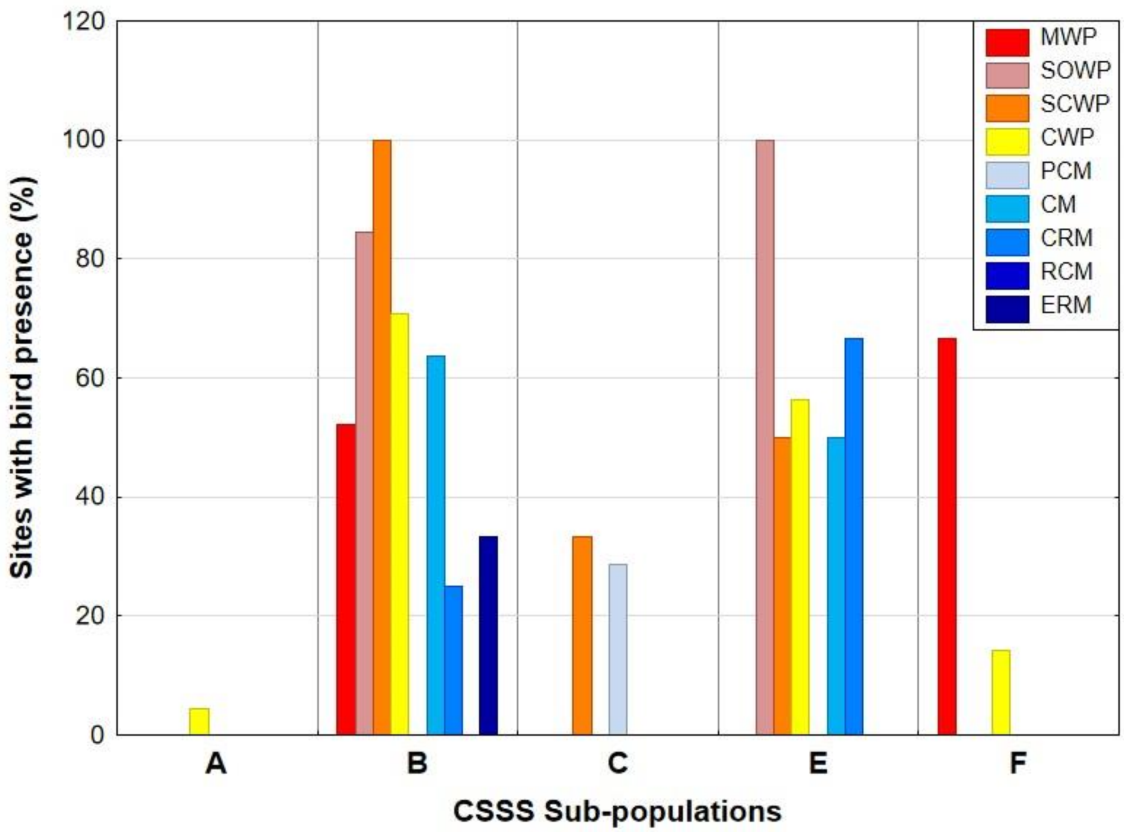

Figure 38: Percent of sites with different vegetation types separately in each of five sub-populations that had sparrows recorded during the annual sparrow survey in any of three years (2017-2019). Vegetation type codes are the same as in Figure 37b.

The five sparrow sub-populations differed in the association between vegetation type and sparrow occurrence. With the highest number of sparrows, the population in CSSS sub-population B was distributed across all the vegetation types in a similar pattern as observed across all the sites. However, in sub-population E, with the 2nd highest sparrow population, the number of marsh sites with sparrow records was higher than any other sub-population (Figure 38). In the smaller sub-populations (C and F) in the eastern prairies as well as sub-population A, sparrows were predominantly present at the prairie sites. For instance, in sub-population A, where very few birds were recorded in recent years (2016-2021), sparrow occurrence was mostly restricted to *Cladium* Wet Prairie within the hN and hS regions (Figure 39).

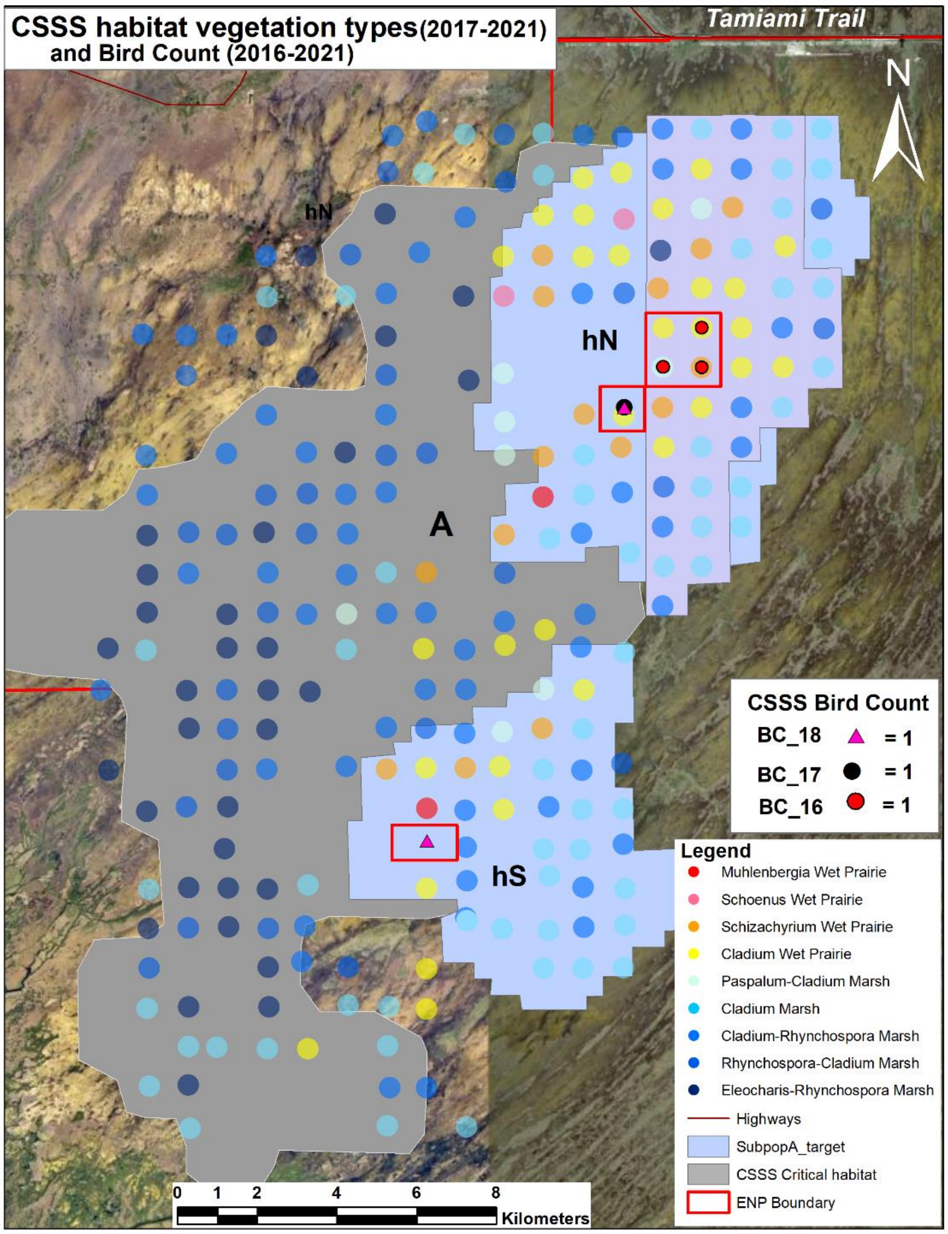

Figure 39: Distribution of vegetation types with the habitat of CSSS sub-population A and the sites at which sparrows were recorded during the annual sparrow survey between 2016-2021.

4. Discussion

In the southern Everglades marl prairies on both sides of Shark River Slough, hydrologic conditions have changed over recent decades (2003-2021), mainly due to changes in water management activities. Such alterations in hydrologic regime have resulted in a shift in vegetation composition that, in harmony with hydrologic change, showed distinct spatial patterns. These patterns were more obvious in sub-populations A, B and C, whereas in sub-populations E and F, changes in both hydrologic conditions and vegetation characteristics were more homogeneous across the areas.

Hydrologic alterations are a major cause of habitat degradation in wetlands, including floodplains and other wetland types (Toth et al. 1998; Dudgeon 2000; Acreman et al. 2007). Thus, restoration activities that result in modification of hydrologic characteristics are considered a crucial step in habitat restoration (Acreman et al. 2007). In the Everglades, where preferred habitat of threatened or endangered species were lost or degraded by extreme or multi-decadal practice of hydrologic alteration (Nott et al. 1998; Jenkins et al. 2003; Bennetts et al. 2002), several restoration activities were initiated in 2000 (USACE 1999). These restoration efforts, which involve adaptive water management activities (RECOVER 2010; LoSchiavo et al. 2013), have already shown improvements in habitat conditions in some regions, and are expected to continue to do so throughout the landscape, especially with the implementation of several projects conceived under Comprehensive Everglades Restoration Plan (CERP) and its recently outlined components, such as Everglades Restoration Transition Plan (ERTP), Central Everglades Planning Project (CEPP), and Combined Operational Plan (COP) (USACE 2011, 2014, 2020). Vegetation dynamics observed in the marl prairie landscape during this study suggests changes, including both improvements and deterioration, in habitat conditions for the Cape Sable seaside sparrow on both sides of the Shark River Slough.

This study shows that the vegetation composition in the southern and western portions of sub-population A has remained either the same or shifted towards a wetter type, which might have caused further deterioration in sparrow habitat. At some of the sites at which vegetation remained within the marsh categories, vegetation-inferred hydroperiod had decreased (Figure 12), suggesting that a wetting trend is not ubiquitous in that region. In contrast, vegetation in the northeastern portion of this sub-population has shifted towards a drier type, indicating an improvement in habitat conditions in this area. The improvement was primarily in terms of increase in prairie vegetation in comparison to marsh type which was the result of high water conditions deteriorated habitat conditions in that area in 1990s (Nott et al. 1998). This improvement is at least in part the product of the management strategy implemented in the region over last two decades. Even before the implementation of CERP-related restoration efforts, guided by the 1999 CSSS Biological Opinion (USACE 1999, USFWS 2002), several water management activities under Interim Operation Plan (IOP) were directed towards improving CSSS habitat that had deteriorated due to extreme water conditions earlier in the1990s. The result was that since 2002, regulatory schedules have been imposed on water deliveries through the S-12 structures.

These regulations caused reduced water delivery through S12 structures (Appendix A1) to have low water levels at NP-205 and nearby areas for several years, which might be more natural for marl prairies, resulting in a less hydric vegetation type in the northeastern part of sub-population A (Sah et al. 2011; 2015). In this portion of sub-population, A, our results show that the trend in vegetation shift towards a drier type, first confirmed in 2010 (Sah et al. 2011), has continued in recent years. This might be the reason 60% of all the prairie sites (23% of vegetation survey sites) within sub-population A, are in the hN region, and the rest of them are either in the hS regions or in between these two regions. Such changes in vegetation composition and the presence of prairie vegetation were probably the primary reason that sparrows had continued to occupy that part of sub-population A in recent years, though still in low numbers (Figure 39; *see also* Sah et al. 2015). Moreover, considering the same sites (n = 190) surveyed during both E1 (2003-2005) and the recent survey (2017-2021) in sub-population A, muhly grass (*Muhlenbergia capillaris*), an indicator of relatively dry marl prairies and suitable sparrow habitat, was present at 18 sites during the 2017/2021 survey. There were only two sites more than that were in E1 survey. However, the increase in muhly was concentrated in the northeastern portion of the sub-population, where the number of sites with muhly increased from 3 to 9, while the number of sites with muhly grass decreased from 11 to 7 in the south. Nevertheless, the mean percentage of muhly is still much lower (<2% at most sites) in the hN area sub-pop A in comparison to the sites in sub-population B that have sparrows (Figure 22). In the northeastern portion of sub-population A, the improving trend in marl prairie habitat conditions is expected to continue under the planned management activities described in CEPP and COP. During CEPP planning, the Refined Recommended Plan (i.e., Alternative 4R2) has been considered the best alternative in comparison to the existing condition baseline (ALT EC) (USACE 2014). Likewise, in COP, Alternative Q+ (ALTQ+) has been considered the preferred plan. In these scenarios, flow connectivity between Water Conservation Areas 3A and 3B will be restored and water will be allowed to flow eastward and southward into the Park, primarily through NESRS (USACE 2014, 2020), potentially resulting in less water in the prairies west of Shark River Slough. Under that management scenario, the recently observed trend of vegetation change towards a drier type in this part of the CSSS range may be expected to continue.

In contrast to the northeastern portion of sub-population A, the southern and western portions of this sub-population experienced a wetter hydrologic regime than one and half decades ago. In this area, recent vegetation change towards a wetter type in response to more hydric conditions is indicative of continued deterioration of sparrow habitat. The continued wetting trend in the western portion of sub-population A is partly due to increased runoff from WCA-3A through Big Cypress National Preserve, resulting in an increase in flows through the culvert and bridges on Tamiami Trail and the Loop Road Kotun et al. (2009). Vegetation in coastal Florida, including the southwestern part of sup-population A, is also influenced by sea level rise, but the extent of that influence toward the interior Everglades is uncertain. Only a thorough investigation using species indicators of sea level rise along transects in this portion of CSSS habitat could help in answering this question. The more hydric condition than previous surveys in hS, the southeastern portion of sub-population A, was probably due to increases in water volume in southern SRS, caused by increased water delivery from the WCAs into the Park. In recent years, the NESRS region received more water delivery from the WCAs during the 2016 emergency operations (Abtew and Ciuca, 2017), and due to implementation of the MOD Water Delivery Project components, including the Increment (Increment 1, 1.1, 1.2 and 2) Field Tests associated with the Combined Operation Plan (COP) that that took place between 2015 and 2019, followed by its full implementation in August 2020 (USACE, 2020). Though, after the full implementation of COP, water delivery to NESRS did not begin until early spring of 2021, when the use Tamiami Trail Flow Formula (TTFF) started. However, even under the Field Tests, a large volume of water was delivered every year into the Park, primarily to NESRS. Most of that water flows south through southern SRS, affecting the vegetation in the slough and adjacent prairies. More than two thirds of sites surveyed in this area showed an increase in vegetation-inferred hydroperiod. Likewise, most of the sites that showed a significant shift in trajectory in the ordination toward increasing wetness were in this region. In a related RECOVER monitoring project, we found similar trends during a survey of Transect M4, which runs through the southern SRS and the south of Sub-population A along the marl-prairie slough gradients (Sah et al. 2020, 2022). Since this region has been identified as potential future improved habitat, regular monitoring of sites will ascertain the direction of vegetation change in response to change in hydrologic conditions due to future restoration activities associated with CEPP, COP and other components of CERP (USCACE 2014, 2020; USFWS 2016). This is especially important, as the area has not only been identified as potentially improved habitat (USFWS 2014, 2016; Haider et al. 2021), but also during the annual CSSS survey, sparrow was recorded at least at one site as recent as in 2018 (Figure 39).

Vegetation change in sub-population B was also spatially variable. In western and southern portions of this sub-population, vegetation shifted toward a wetter type, while composition in the rest of the area changed little. These results are not unexpected, as sites in the southern portion of sub-population B are affected by rising ground water levels, partially caused by sea level rise, and sites in the western portion are affected by gradual increase in water flow though the SRS. While a large portion of this sub-population still has prairie vegetation, a reason why the sub-population holds the largest CSSS population, the wetting trend in some portions is likely to continue in the future, which may further limit the extent of suitable habitat for this sparrow sub-population.

In the other two eastern sub-populations, E, and F, we observed a shift towards a wetter vegetation type at most sites, as well as in C at the easternmost sites, close to the Park boundary. Again, this was not surprising given the nature of Everglades' restoration efforts carried out in this part of the Park. For instance, the S332B and S332C pump structures, which began operation under Interim Operation Plan (IOP) to provide protection for the adjacent CSSS habitat (USFWS 2002) and are still in operation, deliver water from the L31N canal into a series of inter-connected detention ponds. Though, these structures may have reduced pumping duration under COP (USACE 2020). In these areas, both the overflow above a fixed-crest weir and subsurface seepage from the pond to adjacent marl prairies in ENP have helped to control seepage back to the canal and to protect the sparrow habitat from deterioration due to over-drainage, which results in frequent fires that adversely impact habitat and reduce sparrow numbers (Pimm et al. 2002). Therefore, a shift in vegetation towards a more mesic type could possibly be considered as an improvement in the CSSS habitat. However, the shift in vegetation composition was expected to be of greater magnitude close to the Park boundary than in interior portions of the habitat. Thus, the observed changes in vegetation throughout sub-population E and most of F do not seem to result exclusively from the water management activities described above, but rather the combined effects of water seepage from detention ponds and increased water flow through NESRS. The wetting trend in southern and western portions of sub-population E is impacting the sparrow sub-population E which has been robust for some time. However, most sparrows are now present in the central and eastern portions of the sub-population, where vegetation is still mostly prairie type (Figure 20). In fact, in all three (C, E and F) sub-populations, more than two thirds of sites at which sparrows were recorded in recent years (2017-2021) still have prairie type vegetation. Such a number is much higher in sub-population B, which is not surprising when compared to the trend in other sub-populations.

Our most recent surveys were done 1-5 years after the extreme event of dry season high water conditions that occurred in spring 2016, when marl prairies in the eastern sub-populations were flooded for an extended period (Sah et al. 2016, 2017). At the surveyed sites in sub-populations C, E and F, the mean hydroperiods in 2016 were 308, 342 and 313 days, respectively, which were 161, 157 and 188 days higher than mean hydroperiods averaged over 25-years (1991-2015) prior to that extreme event. In a normal year, water level in the eastern marl prairies drops as much as 100 cm below the ground surface in the dry season (Sah et al. 2011). But in these three sub-populations, dry season mean daily water depth in WY 2015/2016 were 8.6, 13.2 and 12.6 cm, while the 24-year average values were -28.4, -17.1 and -29.8 cm, respectively. These areas remained relatively dry during the 2017 dry season, but were again wetter in 2018, resulting in a 4-year average preceding our most recent survey much higher (7-10 cm) than during previous surveys (Figure 6; Table 2). Moreover, in sub-populations F, and some portions of C and E, we observed a vegetation shift towards a more mesic type, but at most of the sites, the vegetation type did not change from WP to marsh type, despite the very wet dry seasons of 2016 and 2018. That may be the reason why these sub-populations, especially C and F, hold the sparrows, though in small number, which occupy predominantly prairie sites (Figure 36). In a separate study in sub-population D, which is outside the park and where vegetation is monitored every two years with funding from SFWMD, the vegetation has also shown a trend of shifting towards a wetter type. While increasing numbers of sparrows were recorded in the area between 2018 and 2022 (Virzi and Murphy 2018; Virzi and Tafoya 2019, 2020; ENP helicopter survey), almost all sparrows' nests and most sparrows in 2020 were observed within the core area where prairie vegetation is still dominant (Sah et al. 2022), possibly also because the adult sparrows show site fidelity behavior (Werner 1975; Dean and Morrison 2001; Pimm et al. 2002; Benscoter and Romañach 2022).

In the Everglades marl prairies and ridge & slough landscapes, hydrology-mediated changes in vegetation composition are usually visible within 3-4 years (Armentano et al. 2006;

Zweig and Kitchens 2008; Sah et al. 2014). However, the lag time could be longer depending on the pattern and magnitude of hydrologic changes, including annual variability in hydrologic regime. In addition, unusual extreme hydrologic condition may also disrupt vegetation trajectories. In general, extreme weather events, such as tropical storms, cold events, flooding and drought, are well recognized as the critical drivers of vegetation change in different ecosystems (Allen and Breshears 1998; John et al. 2013), including those in South Florida (Miao et al. 2009; Ross et al. 2009). Thus, the unusually highwater conditions in the dry season of 2016, and to lesser extent in 2018 and 2020/2021, might have further enhanced the vegetation trajectory to a wetter type in that region, but the time between such events and first few years of this study has been short, and thus the actual effects of such a highwater condition might not have been realized yet.

Together with shifts in species composition, changes in vegetation structure within the four sub-populations were also observed. In particular, we observed a significant increase in biomass and a decrease in green cover over one and a half decades. Since the analysis of vegetation structure was applied separately to unburned and burned sites, the increase in biomass at the unburned sites was expected. In concurrence with this increase in total biomass, the reduced green cover suggests that the increase in biomass was mostly due to accumulation of dead materials that adds to the fuel in the system. Fire is an integral part of the marl prairie landscape, and while a fire frequency of 1-10 years is considered normal within this landscape, some portions of the potential CSSS habitat, especially in sub-population A, had not burned in >30 years. Thus, the increase in dead biomass in such areas needed immediate attention (Sah et al. 2019). However, in 2020, two fires (Guava and Moonfish) burned a large portion of sub-population A. Currently, the findings of vegetation responses to those fires are based on only 37 sites that were sampled in 2021, i.e., one year after fire. A minimal difference in species composition (Figure 26) and in total cover between pre- and 1-postfie year at 30% of the sites suggested that those two fires were patchy in nature, i.e. several sites were either not burned or only partially burned. A detail analysis of area burned in the Guava fire using the LANDSAT 8 image also revealed that the areas within the existing fire boundary were not uniformly burned, and actual acreage of burned area was less than the total area within the given fire boundary (Pablo Ruiz – *personal communication*). In fact, spatial patchiness of fire in an area is not a strange phenomenon, as the distribution of above ground biomass (or fuel) has never been uniform in marl prairies, primarily due to differences in wetness of the sites and time since last fire (Ross et al. 2006). Aboveground biomass in the northeastern and western portion of sub-population A has been generally lower and patchier than southeastern portion (Sah et al. 2009).

The observed pattern of post-fire vegetation dynamics in marl prairies burned in 2005 and in some fires of 2008 differs from results reported for other fires. In seasonally-flooded wetlands, several authors have reported that vegetation returns to pre-burn conditions within 3-5 years of fire after a single burn (Werner 1975; Pahl et al. 2003; La Puma et al. 2007). In fact, a similar pattern of vegetation recovery was also reported at two wet prairie sites burned in spring 2003, and sampled annually for four years thereafter (Sah et al. 2009, 2015). The discrepancy between the results of the present study and earlier research is probably due to differences in post-fire hydrologic conditions, as the majority of sites burned in 2005, particularly Aug_05 sites in sub-population B, were flooded after fire. The highwater conditions 1-2 months after fire in Population D (May_05) also had a significant impact on vegetation composition. At those sites, not only did vegetation composition differ between pre-burn and 5-15 years post-burn, but cover and biomass at Aug_05 sites in sub-population B also did not return to pre-burn levels even after 12-15 years. For instance, vegetation cover and biomass at Aug_05 sites in sub-population B are still only 60% of pre-burn conditions (Figures 28, 29).

It was surprising to us that vegetation composition at the sites in sub-populations E and F (MC/RR_08 and MC_08 groups, respectively) remained different from pre-burn even 9-12 years after the fire. These sites were not flooded immediately after fire, but both burned and unburned sites in these groups were under water in early spring of 2009, 9 months after fire, primarily due to seepage from the adjacent retention ponds (Sah et al. 2011, 2015). In contrast to the burned sites in MC_08 group, the unburned sites in the same area showed minimal change in composition over the same sampling period. Moreover, at sites located to the north, outside the range of influence of the retention ponds, vegetation recovery at burned sites was faster than at southern sites impacted by the retention ponds (Sah et al. 2015). This dissimilarity in vegetation response pattern at burned sites with different post-fire hydrologic conditions, as well as differences in vegetation response to dry season high water conditions at burned and unburned sites, suggests that flooding in the dry season even 1-year after fire can severely affect marl prairie vegetation composition and impede its recovery.

In South Florida, where the likelihood of wildfire from lightning is much higher at the onset of the rainy season, flooding within 1-3 months of fire is common. However, what is important here is the rapidity and extent to which water rises after fire. The impact of post fire flooding on vegetation recovery becomes severe when there is a rapid rise in water level, when water depth rises to elevations more than about 20-30 cm above the surface in the following three months after fire. This happens especially in marl prairies, where most graminoids normally resprout and grow rapidly within a few weeks of fire, but when their aerial shoots are consumed and subsequently submerged by post-fire flooding, they may succumb to flooding-induced oxygen deficiency in their surviving belowground parts (Ball 1990; Kirkman and Sharitz 1994; Ponzio et al. 2004). Other Everglades studies have also reported that the synergistic effects of fire and flooding that submerge the remnant culms of plants can be locally detrimental to species such as sawgrass (*C. jamaicense*) and muhly (*M. capillaris var. filipes*) (Herndon et al. 1991; Snyder and Schaffer 2004). Moreover, a steep decrease in the cover of dominant species usually provides conditions suitable for the growth of opportunistic species. The relatively low cover of dominant species at the May_05 and Aug_05 sites in 5 and 12-15 post-fire years, respectively, also seemed to facilitate the growth of other species.

Trajectory analysis contributed to our assessment of vegetation recovery dynamics in post-fire years. In this analysis, while many of the 2008-burned sites demonstrated a significant shift in species composition towards pre-burn conditions, none of the May_05 and < 40% of Aug_05 sites showed such a significant shift. Surprisingly, even after 9-12 years of fire, only 50% of MC_08 sites in sub-population F showed significant shift in vegetation composition towards pre-burn conditions. Our expectation was that vegetation recovery, i.e., the mean rate of change, would be much faster in MC_08 than in the May_05 and Aug_05 group. Visual analysis of trajectories revealed that the trajectory of several MC_08 sites had changed their course after the 2014 survey, and shifted towards the vegetation composition that was indicative of wetter conditions than in previous years. This was mainly due to the changing hydrologic conditions in the area as the result of increased water deliveries in NESRS since 2015, as described above.

Surprisingly, even though vegetation cover has not fully recovered at many burned sites, 60% of them now hold the sparrows. In fact, it is even more remarkable, as among the 57 sites that burned at least once over 16 years, between 2003 and 2019 and have both vegetation and annual sparrow survey data, only one third had one or more sparrows recorded in any of three years, 2017-2021. The reason could be that at some of the burned sites, the change in vegetation type seems mostly driven by hydrologic changes, as most of them that changed in type between the two major vegetation categories shifted from prairie to marsh type, making them less suitable for the sparrow occupancy.

Management implications:

The spatially variable trends in both hydrologic and vegetation changes in marl prairies on both sides of Shark River Slough observed in this study suggest that a comprehensive strategy that recognizes this variability may be required for effective management of sparrow habitat. For instance, the sustained wetting trend in the southern and western portions of both sub-populations A and B suggests that the small population of sparrows in sub-population A, reported until as recent as 2018, will continue to be restricted to the northeastern and eastern portion of the habitat. Likewise, in sub-population B, which has the highest concentrations of sparrows among all sub-populations, the extent of suitable habitat will likely shrink, affecting CSSS populations. Given a likely future scenario that includes both increasing sea level and restoration activities aimed at increasing the water delivery into the Park through Shark River Slough, this trend is likely to continue. In such a situation, the management may have little option except assisted improvement of habitat quality, such as burning followed by the management of hydrologic conditions not to exceed water level >20 cm in first 3-5 months, in the northeastern and central-eastern portion of sub-population A. In connection to this, a large portion of this sub-population burned in 2020 fires (Guava and Moonfish). While these fires might contribute to the habitat improvement, their effects on vegetation, and ultimately on sparrow habitat, also depends on water conditions in post-fire years, as was observed in other sub-populations after 2005 and 2008 fires. Because of unprecedented high-water conditions in early dry season of 2020-2021, a large volume of water was delivered into the Park (Appendix A1). The S12s that were scheduled to be closed on November 1st (S12-A) and Jan 1st (S12-B) were not closed until mid- to late January 2021. Thus, the effect of this dry season highwater on vegetation requires close inspection.

In the eastern populations, where habitat degradation has been attributed to over drainage and frequent fires, the area may benefit from the restoration effort of hydrating the rocky glades.

However, extreme events like the unusually high-water conditions that occurred in the 2016 dry season, repeated to a lesser extent in 2018, and then again in 2020/2021, can affect achievement of restoration goals. This is especially important, as water delivery through the Tamiami Bridges and culverts to the Park through NESRS is expected to increase in years to come. Thus, a compensatory strategy to offset the negative consequences of such events as well as the increased water delivery should be in place so that the areas do not get much wetter and become unsuitable for sparrows. In addition, water flow from detention ponds towards prairies in the Park may have adverse consequences as well. For instance, periphyton near inflow structures was found to have 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 a significant trajectory along a vector representing the soil phosphorus gradient, possibly due to the influence of seepage water from the detention ponds. If water from the detention ponds continues to influence vegetation in the adjacent prairies, the water quality issue also needs 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).

Finally, if maintaining the existing sparrow populations of sub-populations B and E, and increasing the population west of Shark River Slough and in some of the eastern sub-populations (C and F) are the objectives, then ideally, the strategies that achieve desirable sparrow habitat conditions in the target areas while satisfying the broader ecosystem restoration goals of the Comprehensive Everglades Restoration Plan (CERP) should be considered. Moreover, only the continued monitoring of the sites in these areas will ascertain the direction of vegetation change in response to change in hydrologic conditions due to future restoration activities associated with Central Everglades Project plan (CEPP), Combined Operation Plan (COP), and other components of CERP.

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Appendices

Appendix A1: Monthly flow through S12 (S12A, S12B, S12C, and S12D) structures (Data source: DBHYDRO)

Year	Month	S12A	S12B	S12C	S12D	Year	Month	S12A	S12B	S12C	S12D
	Jan	0	0	0	11760		Jan	0	0	0	1528
	Feb	0	0	585	4458		Feb	0	0	0	208.2
	Mar	0	0	1628	0		Mar	0	0	0	0
	Apr	0	0	474	209		Apr	0	0	0	0
	May	0	0	0	1193		May	0	0	0	0
1981	Jun	0	0	0	2480	**2001**	Jun	0	0	0	336
	Jul	0	0	0	3523		Jul	41	0	218	371
	Aug	0	0	1145	4448		Aug	3544	4673	12410	10887
	Sep	301	0	13663	8336		Sep	7791	7929	16016	16047
	Oct	4687	4973	16041	9192		Oct	17161	16333	25887	28088
	Nov	4448	4167	13666	6343		Nov	0	18725	29079	29663
	Dec	1872	1105	9349	3897		Dec	0	7604	11053	14783
	Jan	0	0	4721	4578		Jan	0	0	0	5361
	Feb	0	0	2602	1980		Feb	0	0	0	2306
	Mar	1	0	710	1171		Mar	0	0	0	2992
	Apr	0	0	0	1220		Apr	0	0	0	2667
	May	0	0	0	1088		May	0	0	0	275.9
1982	Jun	2899	2778	4652	9904	**2002**	Jun	276	516	731	2420.6
	Jul	22119	16086	29374	43590		Jul	11265	10935	20232	18252
	Aug	21137	17046	26491	38477		Aug	15471	13171	24238	20797
	Sep	12816	11577	17899	23234		Sep	15805	12505	24023	19629
	Oct	22683	15430	24521	39983		Oct	13630	9465	20368	18389
	Nov	22214	14390	23079	31792		Nov	0	2937	5122	9879
	Dec	834	7719	14524	1103		Dec	0	0	0	6579
	Jan	0	7076	6518	0		Jan	0	0	0	5074
	Feb	7149	9847	12368	13949		Feb	0	0	0	2247
	Mar	13754	11529	15726	26860		Mar	0	0	0	2318
	Apr	5446	4565	7548	16042		Apr	0	0	0	4416
	May	1687	1609	3354	8090		May	0	0	0	5934
1983	Jun	2768	2861	8062	1942	**2003**	Jun	0	0	2240	13981
	Jul	3332	4501	10955	0		Jul	3702	5108	20178	18086
	Aug	4654	4400	12273	0		Aug	11817	9465	21547	19252
	Sep	8795	6533	16037	0		Sep	16414	14723	25844	25015
	Oct	14061	10123	21277	0		Oct	20809	15988	32091	26657
	Nov	11357	9971	21559	0		Nov	0	12148	25965	22696
	Dec	11821	11349	20503	0		Dec	0	9204	18576	17461
	Jan	12707	11599	19450	0		Jan	0	0	3417	7329
1984	Feb	8188	7263	10602	0	**2004**	Feb	0	0	0	2995
	Mar	5755	5427	9206	0		Mar	0	0	0	5098
	Apr	5703	3739	8095	0		Apr	0	0	0	3148

Year	Month	S12A	S12B	S12C	S12D
	May	2647	1682	3062	288
	Jun	4981	1833	7283	9950
	Jul	7079	5509	9964	12486
	Aug	6922	5101	7923	7625
	Sep	9802	7529	10431	11835
	Oct	10689	9081	11062	12497
	Nov	4486	4519	6214	7032
	Dec	3757	3436	6624	8566
	Jan	1215	1083.2	1706	2436
	Feb	251	228.6	802.1	1177
	Mar	52	18	57	298.8
	Apr	155	176.3	1006.8	1328.5
	May	766	347.2	334.1	96.6
1985	Jun	27	118.5	41.6	95
	Jul	224	519.2	728.7	1353.9
	Aug	5516	5870	8531	6299
	Sep	8214	8005	8930	8486
	Oct	8899	8956	8744	9668
	Nov	4529	4329	4421	4414
	Dec	1444	1177	1366	1253
	Jan	734	1109	1339	956
	Feb	437	790	938	810
	Mar	676	980	1114	930
	Apr	2579	2702	2516	2723
	May	684	832	876	894
1986	Jun	765	972.3	938.4	1064
	Jul	9336	8596	13342	15388
	Aug	8536	7857	8747	8907
	Sep	4910	5011	5274	5713
	Oct	4202	3694	3984	4589
	Nov	801	1062	1126	1182
	Dec	95	195	418	357
	Jan	895	1035	1388	1060
	Feb	457	673	1090	1121
	Mar	1151	1417	1472	1409
	Apr	2187	2314	2209	2409
	May	1110	1289	1345	1441
1987	Jun	276	308.6	417.8	398.8
	Jul	0	0	0	0
	Aug	0	0	0	0
	Sep	45	57	147.4	56
	Oct	3005	2970	3280	3389
	Nov	4653	4529	4694	5042

Year	Month	S12A	S12B	S12C	S12D
	May	0	0	0	1393.6
	Jun	0	0	0	0
	Jul	0	0	0	0
	Aug	769	1041	4931	5616
	Sep	14110	12907	25274	20309
	Oct	27993	21906	42200	34530
	Nov	398	16204	31160	25835
	Dec	0	1934	7545	18926
	Jan	0	0	0	1369
	Feb	0	0	0	0
	Mar	0	0	0	126
	Apr	0	0	0	2951
	May	0	0	0	2969
2005	Jun	2897	1973	5987	11377
	Jul	21015	16384	25381	29795
	Aug	22373	14874	37250	32814
	Sep	22332	18165	30100	29911
	Oct	21147	17706	33436	28766
	Nov	9642	17368	33270	24315
	Dec	0	12419	28092	18536
	Jan	0	0	12005	19124
	Feb	0	0	0	4976
	Mar	0	0	0	1326
	Apr	0	0	0	87.7
	May	0	0	0	0
2006	Jun	0	0	0	0
	Jul	0	0	906	1810
	Aug	1018	892	2336	10163
	Sep	10759	8966	18766	18391
	Oct	11143	11484	20797	17581
	Nov	0	704	6696	9006
	Dec	0	0	0	1328
	Jan	0	0	0	0
	Feb	0	0	0	0
	Mar	0	0	0	0
	Apr	0	0	0	0
	May	0	0	0	0
2007	Jun	0	0	0	351
	Jul	42	0	0	387
	Aug	162	0	0	35.6
	Sep	61	0	0	90
	Oct	732	1597	2584	2683
	Nov	0	2472	2500	3075

Year	Month	S12A	S12B	S12C	S12D
	Dec	5257	5386	6061	6202
	Jan	2978	3115	3260	3135
	Feb	1573	1366	1512	1373
	Mar	747	845	889	777
	Apr	61	60	510.9	481.5
	May	0	0	0	0
1988	Jun	443	510	472.3	394
	Jul	1481	1575	1503	1177
	Aug	10668	9214	12623	14068
	Sep	9281	7301	19232	23044
	Oct	6552	5652	8288	9755
	Nov	1503	1541	2961	1531
	Dec	0	0	553	681
	Jan	0	0	0	0
	Feb	0	0	0	0
	Mar	0	0	0	0
	Apr	0	0	0	0
	May	0	48.4	68	0
1989	Jun	0	0	0	0
	Jul	0	0	0	0
	Aug	0	0	0	0
	Sep	49	142.6	365	316.3
	Oct	1902	1875	2155	1528
	Nov	1132	1249	1643	1648
	Dec	55	117	161	241.6
	Jan	0	0	0	103.8
	Feb	0	0	0	0
	Mar	0	0	0	0
	Apr	0	0	0	0
	May	0	0	0	0
1990	Jun	11	8.8	251.6	692
	Jul	0	0	1296	2752
	Aug	0	0	2074	3663
	Sep	0	469.8	2195	4672
	Oct	419	1247	3634	5957
	Nov	154	438.3	3124	4512
	Dec	0	0	515.1	1012.9
	Jan	0	0	386	636
	Feb	0	0	1456	2943
1991	Mar	0	0	1182	2523
	Apr	0	0	722.7	1085
	May	53	176.9	1277	2076
	Jun	709	876	2226	4659

Year	Month	S12A	S12B	S12C	S12D
	Dec	0	103	127.9	620
	Jan	0	0	0	0
	Feb	0	0	0	121
	Mar	0	0	0	1426
	Apr	0	0	0	3574
	May	0	0	0	4408
2008	Jun	0	0	0	195
	Jul	1807	3609	6272	9594
	Aug	10275	9498	19985	19750
	Sep	19311	17484	31610	32419
	Oct	23684	22051	36272	40350
	Nov	286	16857	24829	29033
	Dec	0	4044	7006	14179
	Jan	0	0	450	673
	Feb	0	0	0	0
	Mar	0	0	0	0
	Apr	0	0	0	0
	May	0	0	0	0
2009	Jun	0	0	0	3481
	Jul	3381	3386	7273	14444
	Aug	6871	7576	15142	17399
	Sep	9552	10075	19571	23646
	Oct	7861	9605	17641	20712
	Nov	0	4055	6386	6480
	Dec	0	999	1435	1174
	Jan	0	0	1322	1891
	Feb	0	0	0	6565
	Mar	0	0	0	12209
	Apr	0	0	0	11768
	May	0	0	0	10648
2010	Jun	0	0	0	11207
	Jul	1485	16	5507	12378
	Aug	5841	5332	13531	16744
	Sep	7577	8118	15171	18112
	Oct	7384	7368	13500	17373
	Nov	0	1503	4481	6026
	Dec	0	12	158.9	186
	Jan	0	0	0	0
	Feb	0	0	0	0
2011	Mar	0	0	0	0
	Apr	0	0	0	0
	May	0	0	0	0
	Jun	0	0	0	0

Year	Month	S12A	S12B	S12C	S12D	Year	Month	S12A	S12B	S12C	S12D
	Jul	5178	7016	12420	15197		Jul	0	0	0	0
	Aug	12189	9847	16905	21004		Aug	0	0	0	745
	Sep	4154	4972	9561	12920		Sep	0	0	0	8532
	Oct	6765	11499	14861	20534		Oct	3070	3000	12819	16809
	Nov	2089	4194	7715	10211		Nov	0	17313	31901	25613
	Dec	0	457	2010	4923		Dec	0	9641	18146	16563
	Jan	0	0	399.1	4639		Jan	0	0	664	7587
	Feb	0	0	0	4137		Feb	0	0	0	2864
	Mar	0	0	0	3048		Mar	0	0	0	2300
	Apr	0	0	0	3274		Apr	0	0	0	202
	May	0	0	0	1628		May	0	0	0	5327
1992	Jun	85	76	977	2420	**2012**	Jun	0	0	0	15547
	Jul	7363	6564	11626	15795		Jul	3941	4503	8536	18678
	Aug	10286	8767	14387	17661		Aug	6153	6601	13552	16034
	Sep	18016	16351	23270	25754		Sep	8607	9095	17887	22563
	Oct	17770	16154	24917	26226		Oct	16013	15223	26387	32240
	Nov	8243	11145	20606	24445		Nov	207	13822	22694	25549
	Dec	2867	5199	6891	12517		Dec	0	9309	18612	21212
	Jan	3167	5802	8672	11038		Jan	0	0	4412	6329
	Feb	17112	12911	14932	20623		Feb	0	0	0	3232
	Mar	17965	12787	19029	21470		Mar	0	0	0	856
	Apr	13913	10150	16123	18252		Apr	0	0	0	93
	May	8273	5938	11347	12749		May	0	0	4745	6110
1993	Jun	11817	9332	12921	15555	**2013**	Jun	0	0	11447	11545
	Jul	6238	5279	13638	14135		Jul	5984	5929	19702	23347
	Aug	1016	4891	5826	6065		Aug	13015	11968	23308	26473
	Sep	0	3413	5153	7945		Sep	11712	10555	21312	24659
	Oct	8131	11881	16822	22459		Oct	10053	9381	18776	23987
	Nov	7311	13618	17441	21992		Nov	114	8061	15502	20674
	Dec	224	3236	4772	5904		Dec	0	2545	5625	12399
	Jan	743	884	1813	2408		Jan	0	0	1440	1374
	Feb	1025	1439	1977	2205		Feb	0	0	0	7067
	Mar	2136	3801	6713	4875		Mar	0	0	0	12352
	Apr	755	1397	2284	3455		Apr	0	0	0	108
	May	680	1701	2450	3290		May	0	0	0	0
1994	Jun	1350	852	2982	3421	**2014**	Jun	0	0	63.7	1166
	Jul	5373	0	11563	11717		Jul	0	0	996	7563
	Aug	6834	0	12024	12951		Aug	2541	3142	8630	15712
	Sep	11094	6964	16567	19280		Sep	4921	5619	13055	19308
	Oct	28524	23049	33884	45510		Oct	5308	7096	15608	22649
	Nov	37820	30628	43400	56560		Nov	0	2988	8806	18159
	Dec	41400	38190	54320	72630		Dec	0	0	0	5654
1995	Jan	41720	35957	52000	64360	**2015**	Jan	0	0	0	5753

Year	Month	S12A	S12B	S12C	S12D	Year	Month	S12A	S12B	S12C	S12D
	Feb	23775	19055	32874	39560		Feb	0	0	0	7611
	Mar	17618	13139	24457	33201		Mar	0	0	0	1602
	Apr	8708	5213	12548	17415		Apr	0	0	0	0
	May	3610	3241	6919	9513		May	0	0	0	0
	Jun	1671	3929	7406	6374		Jun	0	0	0	0
	Jul	8380	5510	13084	17723		Jul	0	0	0	0
	Aug	10230	8886	20554	23430		Aug	0	0	0	0
	Sep	21659	18140	34084	43420		Sep	0	0	1280	2790
	Oct	35716	28831	42930	57130		Oct	4312	4895	14337	19546
	Nov	33526	24204	38560	50340		Nov	0	1896	4090	9404
	Dec	22721	16942	28545	37360		Dec	0	10357	21124	27750
	Jan	15774	10420	21541	25967		Jan	0	0	24561	29463
	Feb	1532	2960	4521	6290		Feb	2379	0	36090	37710
	Mar	0	245	761	1189		Mar	2558	0	30268	33164
	Apr	0	0	0	0		Apr	0	0	13318	17320
	May	0	0	0	0		May	0	0	5157	9416
1996	Jun	1572	1906	4863	12121	**2016**	Jun	0	0	5151	10336
	Jul	6517	5611	16135	18953		Jul	0	0	5830	10565
	Aug	9068	7287	16536	22017		Aug	3288	3300	10626	16429
	Sep	8303	6427	15447	20279		Sep	8380	7527	14896	23778
	Oct	9867	7704	16954	21395		Oct	8915	8110	16849	26050
	Nov	7845	7290	17266	20807		Nov	0	5803	12300	20967
	Dec	0	2146	9356	5688		Dec	0	0	0	159
	Jan	0	0	3495	0		Jan	0	0	0	0
	Feb	0	0	2808	0		Feb	0	0	0	0
	Mar	0	0	3416	0		Mar	0	0	0	0
	Apr	0	0	4627	0		Apr	0	0	0	0
	May	0	0	6955	0		May	0	0	0	0
1997	Jun	2554	2915	10218	7950	**2017**	Jun	727	723	13943	17464
	Jul	6899	5285	12564	19383		Jul	14199	13808	27188	34027
	Aug	11538	8102	18761	25938		Aug	13336	13167	25164	32620
	Sep	13002	10449	19235	25441		Sep	20790	18622	32946	35089
	Oct	12735	10263	18457	23172		Oct	38964	33817	52310	67180
	Nov	3609	3912	15623	9764		Nov	26645	23786	38946	50930
	Dec	0	0	12381	11462		Dec	9754	9902.4	21482	24772
	Jan	0	0	9606	22902		Jan	0	0	15329	22025
	Feb	0	0	9336	19885		Feb	0	0	145	7804
	Mar	0	0	10392	24125		Mar	0	0	0	0
1998	Apr	0	0	6062	18421	**2018**	Apr	0	0	0	0
	May	0	0	569	8473		May	0	0	4018	5809
	Jun	0	0	1248	1552		Jun	0	0	19307	24754
	Jul	0	0	393	379		Jul	4049	4049	18548	22607
	Aug	0	0	3673	5427		Aug	5113	5340	13441	19698

Year	Month	S12A	S12B	S12C	S12D	Year	Month	S12A	S12B	S12C	S12D
	Sep	3266	2238	6917	7375		Sep	7085	6990	15939	25075
	Oct	13338	9039	20033	15875		Oct	77	82.7	11267	14350
	Nov	14371	10339	21480	17180		Nov	0	0	0	0
	Dec	13599	10340	20665	17461		Dec	0	0	0	0
	Jan	0	0	8371	15085		Jan	0	0	0	0
	Feb	0	0	1800	10436		Feb	0	0	0	0
	Mar	0	0	0	2262		Mar	0	0	3064	0
	Apr	0	0	0	0		Apr	0	0	0	0
	May	0	0	0	0		May	0	0	0	0
1999	Jun	439	566	2514	3747	**2019**	Jun	0	0	100.47	1484
	Jul	10485	8881	18061	15552		Jul	394	395.8	1256	8457
	Aug	9720	8340	17863	16098		Aug	2838	3665.9	7433.8	15666
	Sep	13428	11617	21918	19054		Sep	3850	4293	9247	17057
	Oct	27499	24237	38926	40610		Oct	50	57.1	6753	13762
	Nov	37770	30962	46270	56450		Nov	0	0	0	0
	Dec	13602	21387	31712	30897		Dec	0	0	0	0
	Jan	0	0	23475	22055		Jan	0	0	0	0
	Feb	0	0	6993	5461		Feb	0	0	0	0
	Mar	0	0	0	0		Mar	0	0	0	0
	Apr	0	0	0	0		Apr	0	0	0	0
	May	0	0	0	0		May	0	0	0	0
2000	Jun	0	0	0	0	**2020**	Jun	0	0	4560.7	9961
	Jul	0	0	0	570		Jul	3115	3558	6478	13338
	Aug	232	276	3500	6137		Aug	8955	6553	7584	15708
	Sep	0	0	389	2303		Sep	8866	7170	8479	17274
	Oct	6764	6942	15105	16269		Oct	15429	12891	16650	32404
	Nov	2071	1836	4683	10056		Nov	31439	31384	46149	68200
	Dec	0	0	0	3173		Dec	33416	31272	45722	64640
							Jan	12074	13242.3	17796	33397
							Feb	0	32.7	9542	19100
							Mar	0	0	87.1	12829
							Apr	0	0	0	4962.3
							May	0	0	126.15	525.46
						2021	Jun	0	0	461.77	0
							Jul	0	0	2835.6	3756
							Aug	1789	1885.7	3916	8027
							Sep	37	4856	13261	1090.4
							Oct	0	758.3	23580	25864
							Nov	0	0	16798	28542
							Dec	0	0	0	21384

Appendix A2: Vegetation type for all sites, and delta and slope (amount and rate of change in the target direction, respectively) for sites that were not burned between 2003 and 2008 and sampled at least three times between 2003 and 2021. Vegetation types were determined using the cluster analysis. For sites that were surveyed twice over five years, during the 2017-2021 study, the hydroperiod values are given for only the latest survey, i.e. 2021 survey. Delta and Slope were calculated using trajectory analysis, in which the base year for change in vegetation was the 1st year of sampling, and the hydrology vector represent the increasing wetness in the non-metric multidimensional scaling (NMDS) ordination. Statistical significance ($p \leq 0.1$) of delta and slope was tested using Monte Carlo's simulations with 10,000 permutations. Prob. for the negative values of delta or slope are given as 1-prob (+ve shift). C= Census, T = Transect. CWP = *Cladium* Wet Prairie (WP), MWP = *Muhlenbergia* WP, SCWP = *Schizachyrium* WP, SOWP = *Schoenus* WP, CM = *Cladium* Marsh, PCM = *Paspalum-Cladium* Marsh, CRM = *Cladium-Rhynchospora* Marsh, RCM = *Rhynchospora-Cladium* Marsh, ERM = *Eleocharis-Rhynchospora* Marsh.

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
A	2003	2019	A-01-01	512149	2846885	RCM	CM	-0.075	0.310	-0.002	0.335
A	2003	2021	A-01-02	513139	2846878	CRM	RCM	-0.184	0.155	-0.018	0.020
A	2003	2021	A-01-03	514119	2846904	CM	CM	-0.208	0.033	-0.010	0.031
A	2003	2019	A-01-04	515129	2846856	CM	CRM	0.064	0.326	0.000	0.524
A	2003	2019	A-01-05	514124	2845851	CM	CM	-0.114	0.117	-0.009	0.068
A	2003	2017	A-01-06	515125	2844858	CRM	CWP	-0.181	0.149	-0.018	0.050
A	2003	2017	A-01-07	514102	2843847	SCWP	SCWP	-0.247	0.180	-0.021	0.134
A	2003	2017	A-01-08	516146	2842899	RCM	RCM	0.033	0.438	-0.010	0.271
A	2006	2019	A-01-10	512155	2844803	CM	CRM	-	-	-	-
A	2003	2019	A-03-01	511118	2833996	SCWP	CWP	0.134	0.216	0.000	0.501
A	2003	2021	A-03-02	513155	2834079	SCWP	CWP	-0.101	0.374	-0.007	0.307
A	2003	2019	A-03-03	515162	2834850	CRM	CRM	-0.165	0.086	-0.016	0.009
A	2003	2017	A-03-04	515132	2832965	CM	CWP	-0.109	0.244	-0.014	0.093
A	2003	2021	A-03-05	516090	2831118	CRM	RCM	0.465	0.007	0.018	0.028
A	2003	2021	A-03-06	515089	2830946	CM	CRM	0.528	0.002	0.022	0.005
A	2003	2017	A-03-07	513029	2831037	SCWP	CWP	0.231	0.072	0.012	0.148
A	2003	2017	A-03-08	511174	2831001	SCWP	CWP	-0.208	0.210	-0.024	0.085
A	2003	2021	A-03-09	511168	2831996	CWP	RCM	0.238	0.100	0.007	0.217
A	2003	2021	A-03-10	510182	2832018	SCWP	CRM	0.247	0.159	0.008	0.257
A	2003	2017	A-04-02	512186	2829011	CM	CRM	0.328	0.026	0.020	0.037
A	2003	2017	A-04-03	514251	2830027	CRM	CRM	0.294	0.049	0.013	0.138
A	2003	2017	A-04-04	516131	2829091	CRM	CRM	0.202	0.074	0.014	0.049
A	2003	2021	A-04-05	515117	2828015	CM	CRM	0.542	0.000	0.021	0.001
A	2003	2017	A-04-06	515133	2827012	CRM	CRM	0.068	0.256	0.009	0.056
A	2003	2021	A-04-07	516163	2827057	CM	CM	0.093	0.027	0.004	0.038
A	2006	2021	A-04-08	515108	2825981	CM	CM	-0.033	0.303	-0.001	0.492
A	2006	2021	A-04-09	514123	2825976	CM	CM	0.073	0.234	0.003	0.302
A	2003	2018	A-05-01	504238	2823026	CM	CM	0.017	0.034	0.001	0.050
A	2003	2021	A-05-02	505216	2823052	CRM	ERM	0.210	0.085	0.004	0.255
A	2003	2021	A-05-03	505226	2824020	CRM	CM	-0.110	0.230	-0.007	0.183
A	2003	2021	A-05-04	505225	2825013	CRM	ERM	0.458	0.011	0.018	0.033
A	2003	2021	A-05-05	507234	2825015	RCM	ERM	0.237	0.090	0.014	0.068

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
A	2003	2018	A-05-06	509224	2825064	CRM	CM	0.163	0.036	0.011	0.024
A	2003	2019	A-05-07	510251	2825027	CWP	CM	0.389	0.003	0.020	0.015
A	2003	2018	A-05-08	510217	2824036	CM	CM	0.211	0.025	0.014	0.024
A	2003	2018	A-05-09	510265	2822985	CM	CRM	0.005	0.490	0.002	0.442
A	2003	2019	A-06-02	505168	2830027	RCM	RCM	-0.014	0.480	0.001	0.450
A	2003	2018	A-06-03	506201	2830025	RCM	ERM	0.281	0.011	0.019	0.015
A	2003	2018	A-06-04	506210	2827998	CRM	ERM	0.235	0.018	0.012	0.042
A	2003	2018	A-06-05	506227	2827023	CRM	ERM	0.433	0.003	0.028	0.004
A	2003	2021	A-06-06	507215	2826006	CRM	ERM	0.385	0.007	0.014	0.031
A	2003	2018	A-06-07	508219	2828071	CM	CM	0.130	0.308	0.005	0.381
A	2003	2019	A-06-08	508131	2827035	PCM	CRM	0.055	0.299	0.003	0.293
A	2003	2021	A-06-10	509227	2826008	SCWP	RCM	0.181	0.215	0.009	0.211
A	2004	2018	A-07-01	504175	2829916	ERM	ERM	0.224	0.022	0.015	0.029
A	2004	2019	A-07-02	503219	2830950	ERM	ERM	0.137	0.324	0.009	0.310
A	2004	2018	A-07-04	505231	2831993	ERM	ERM	-0.013	0.467	-0.001	0.429
A	2004	2019	A-07-05	506192	2831975	RCM	RCM	0.260	0.089	0.014	0.122
A	2004	2019	A-07-06	506175	2832964	RCM	RCM	0.198	0.096	0.010	0.170
A	2004	2021	A-07-07	507216	2832954	RCM	ERM	0.131	0.192	0.004	0.311
A	2004	2018	A-07-08	507193	2831970	RCM	ERM	-0.033	0.407	0.003	0.387
A	2003	2021	A-08-01	503198	2833998	CRM	ERM	0.379	0.016	0.015	0.038
A	2003	2018	A-08-02	504183	2834899	RCM	ERM	0.496	0.011	0.035	0.010
A	2003	2018	A-08-03	506187	2834007	RCM	ERM	0.142	0.174	0.008	0.203
A	2003	2019	A-08-04	507197	2834010	RCM	ERM	0.328	0.050	0.023	0.027
A	2003	2019	A-08-05	507212	2834897	CM	RCM	0.251	0.131	0.013	0.183
A	2003	2018	A-08-06	507207	2835892	CRM	CRM	-0.010	0.407	-0.001	0.444
A	2003	2019	A-08-07	508180	2836880	RCM	RCM	0.067	0.231	0.002	0.353
A	2003	2021	A-08-08	507113	2836904	CRM	ERM	0.068	0.318	0.003	0.332
A	2003	2019	A-08-09	505223	2836901	CM	RCM	0.407	0.066	0.023	0.135
A	2003	2018	A-09-01	506169	2838881	CRM	CRM	0.379	0.004	0.019	0.032
A	2003	2021	A-09-02	507173	2839844	RCM	CRM	-0.114	0.110	-0.007	0.046
A	2003	2019	A-09-03	508173	2838913	CRM	CRM	0.331	0.000	0.017	0.004
A	2003	2021	A-09-04	509143	2838908	CRM	ERM	0.357	0.110	0.020	0.062
A	2003	2018	A-09-05	509217	2836866	RCM	CRM	-0.030	0.416	-0.004	0.315
A	2003	2018	A-09-06	510180	2837905	CRM	CRM	0.125	0.134	0.008	0.137
A	2003	2019	A-09-07	510174	2835906	CRM	CM	0.040	0.397	-0.002	0.410
A	2003	2021	A-09-08	511185	2835905	CWP	SCWP	0.061	0.357	-0.003	0.351
A	2003	2021	A-09-09	511196	2838896	CM	RCM	0.172	0.072	0.001	0.443
A	2003	2021	A-09-10	513152	2835885	RCM	RCM	-0.242	0.060	-0.012	0.043
A	2004	2017	A-10-01	511203	2829990	SCWP	MWP	0.271	0.092	0.019	0.120
A	2004	2017	A-10-02	512167	2831000	SCWP	SCWP	0.256	0.047	0.019	0.058
A	2004	2021	A-10-03	513091	2831909	SCWP	PCM	0.519	0.037	0.024	0.060
A	2004	2017	A-10-04	514126	2830961	CM	CM	0.125	0.176	0.008	0.206

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
A	2004	2017	A-10-07	516154	2833899	CM	CM	-0.156	0.176	-0.015	0.117
A	2004	2019	A-10-09	514158	2834463	CRM	CWP	-0.237	0.109	-0.015	0.103
A	2004	2019	A-10-10	513144	2834674	CRM	CRM	-0.387	0.122	-0.019	0.185
A	2004	2017	A-11-02	514273	2836753	CM	CM	-0.191	0.129	-0.012	0.168
A	2004	2017	A-11-03	515074	2836883	CM	CRM	-0.200	0.095	-0.014	0.116
A	2004	2017	A-11-04	516286	2836395	CM	CM	-0.285	0.022	-0.018	0.032
A	2004	2021	A-11-05	516105	2837908	CRM	CRM	0.197	0.172	0.011	0.162
A	2004	2017	A-11-06	515127	2837851	CWP	CM	-0.143	0.205	-0.013	0.172
A	2004	2017	A-11-07	514118	2837794	SCWP	MWP	0.024	0.496	0.004	0.449
A	2004	2017	A-11-08	514123	2838811	CWP	SCWP	-0.453	0.004	-0.035	0.003
A	2004	2019	A-12-01	511195	2822992	CM	CRM	0.164	0.037	0.013	0.011
A	2004	2017	A-12-05	511187	2827984	CWP	CWP	0.012	0.444	-0.001	0.480
A	2004	2017	A-12-07	513083	2826972	CM	CM	0.076	0.329	0.004	0.361
A	2004	2021	A-12-08	514248	2826938	CM	CM	0.104	0.282	0.002	0.393
A	2004	2017	A-12-09	516129	2825994	CM	CM	0.127	0.099	0.009	0.102
A	2004	2021	A-12-10	516163	2827975	CM	CM	-0.068	0.283	0.000	0.481
A	2004	2021	A-13-01	504181	2824977	CRM	CM	-0.059	0.360	0.000	0.469
A	2004	2019	A-13-03	505932	2824005	CM	CM	-0.012	0.444	0.002	0.365
A	2004	2019	A-13-05	507201	2823968	CRM	CM	0.095	0.325	0.007	0.278
A	2004	2018	A-13-09	510208	2822032	CRM	CM	-0.100	0.291	-0.016	0.100
A	2004	2019	A-13-10	512196	2822009	CM	CM	-0.019	0.427	-0.002	0.371
A	2004	2019	A-14-01	504225	2825987	RCM	RCM	0.386	0.062	0.033	0.022
A	2004	2019	A-14-02	504207	2826979	ERM	ERM	0.168	0.187	0.006	0.324
A	2004	2019	A-14-03	504225	2827957	CRM	CM	0.107	0.165	0.004	0.262
A	2004	2019	A-14-04	505224	2828001	ERM	ERM	-0.130	0.359	-0.013	0.254
A	2004	2019	A-14-05	505216	2826991	CRM	RCM	0.180	0.117	0.013	0.081
A	2004	2019	A-14-08	507222	2826980	CRM	RCM	0.184	0.084	0.017	0.026
A	2004	2019	A-14-09	507203	2827967	RCM	ERM	0.098	0.192	0.008	0.103
A	2004	2019	A-15-01	505213	2835877	CRM	CRM	0.057	0.400	0.011	0.177
A	2004	2021	A-15-02	504153	2833951	CRM	CM	-0.133	0.354	-0.016	0.144
A	2004	2018	A-15-03	503015	2832949	CRM	CRM	0.269	0.091	0.017	0.128
A	2004	2021	A-15-04	505171	2832943	CM	ERM	0.285	0.001	0.011	0.019
A	2004	2019	A-15-05	506185	2830955	RCM	RCM	0.348	0.026	0.021	0.047
A	2004	2019	A-15-06	507178	2830971	CRM	CRM	0.108	0.360	0.008	0.322
A	2004	2018	A-15-10	506122	2828979	RCM	ERM	0.299	0.002	0.023	0.003
A	2004	2018	A-16-01	509163	2837860	RCM	CRM	-0.065	0.324	-0.003	0.377
A	2004	2019	A-16-03	509181	2834862	PCM	PCM	-0.171	0.092	-0.011	0.091
A	2004	2019	A-16-04	510184	2834870	CRM	CRM	-0.183	0.059	-0.014	0.034
A	2004	2019	A-16-09	511166	2832973	CRM	CRM	-0.201	0.067	-0.013	0.070
A	2004	2019	A-16-10	512172	2832969	CRM	CRM	-0.065	0.307	-0.005	0.263
A	2004	2019	A-17-01	510176	2840851	CRM	RCM	0.197	0.038	0.016	0.021
A	2004	2018	A-17-02	510172	2839859	CM	CRM	0.131	0.146	0.012	0.086

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
A	2004	2021	A-17-03	510174	2838837	CM	RCM	-0.033	0.483	-0.003	0.463
A	2004	2019	A-17-06	513151	2838847	PCM	PCM	0.063	0.345	0.005	0.304
A	2004	2017	A-17-08	513139	2836852	PCM	SCWP	-0.210	0.192	-0.013	0.216
A	2004	2019	A-18-01	508202	2837878	RCM	RCM	-0.111	0.191	-0.006	0.218
A	2004	2018	A-18-06	504070	2841875	RCM	CRM	0.012	0.410	0.002	0.291
A	2004	2019	A-18-07	505165	2841830	RCM	CRM	-0.058	0.246	-0.004	0.244
A	2004	2019	A-18-10	507188	2842805	RCM	CM	-0.702	0.000	-0.041	0.000
A	2004	2019	A-19-01	511015	2843924	CM	CRM	-0.164	0.076	-0.013	0.040
A	2004	2021	A-19-03	512122	2842830	CM	ERM	-0.241	0.104	-0.012	0.096
A	2004	2021	A-19-04	515100	2842892	CM	CRM	0.064	0.208	0.003	0.204
A	2004	2021	A-19-06	513112	2840887	CWP	PCM	-0.118	0.269	-0.006	0.280
A	2004	2017	A-19-08	515144	2839865	SCWP	SCWP	-0.065	0.404	-0.008	0.334
A	2004	2021	A-19-09	515136	2838845	CRM	CM	0.089	0.301	0.001	0.439
A	2004	2017	A-19-10	516073	2839044	SCWP	SCWP	-0.162	0.160	-0.005	0.354
A	2004	2019	A-20-01	510343	2846852	CRM	CRM	0.070	0.175	0.005	0.158
A	2004	2019	A-20-03	511123	2845915	CM	CM	0.005	0.474	0.002	0.366
A	2004	2021	A-20-05	513181	2845696	RCM	RCM	0.199	0.163	0.005	0.322
A	2004	2021	A-20-06	516073	2845920	CM	CWP	-0.725	0.000	-0.040	0.000
A	2004	2017	A-20-07	516149	2844757	SOWP	SOWP	-0.071	0.387	-0.003	0.431
A	2005	2018	A-21-01	511191	2847210	CWP	CRM	0.300	0.060	0.026	0.032
A	2005	2021	A-21-02	510218	2845943	CRM	RCM	0.118	0.143	0.001	0.428
A	2005	2021	A-21-03	510151	2844890	CM	ERM	0.519	0.107	0.024	0.147
A	2005	2021	A-21-05	509283	2843872	CM	RCM	0.000	0.496	-0.005	0.220
A	2005	2018	A-21-06	508166	2843826	CRM	ERM	0.194	0.159	0.013	0.217
A	2005	2018	A-21-07	507169	2843834	CRM	CRM	0.069	0.390	0.008	0.375
A	2005	2018	A-21-08	510179	2842895	RCM	CRM	0.146	0.118	0.013	0.101
A	2005	2018	A-21-09	509161	2842834	CM	CM	0.022	0.422	0.002	0.399
A	2005	2017	A-22-01	516104	2846819	RCM	RCM	-0.043	0.437	-0.003	0.438
A	2005	2017	A-22-02	515118	2845783	CM	CWP	-0.261	0.042	-0.020	0.047
A	2005	2017	A-22-03	514116	2844847	CM	CWP	-0.032	0.391	-0.003	0.373
A	2005	2017	A-22-04	513113	2843822	CM	CWP	0.047	0.283	0.004	0.284
A	2005	2017	A-22-05	513134	2842827	SOWP	SOWP	-0.475	0.019	-0.038	0.024
A	2005	2021	A-22-08	514134	2842821	SCWP	SCWP	-0.274	0.114	-0.020	0.061
A	2005	2017	A-22-09	515116	2843812	CM	CWP	-0.348	0.024	-0.025	0.038
A	2005	2017	A-22-10	516024	2843849	CRM	CWP	-0.289	0.040	-0.022	0.061
A	2005	2021	A-23-01	510168	2841826	CRM	ERM	0.279	0.066	0.017	0.066
A	2005	2021	A-23-04	512252	2840716	CRM	ERM	0.070	0.314	0.004	0.321
A	2005	2021	A-23-08	513149	2839676	PCM	PCM	-0.052	0.428	-0.003	0.428
A	2005	2017	A-23-10	516135	2839836	PCM	CWP	0.024	0.453	0.000	0.488
A	2005	2018	A-24-01	506180	2841849	CRM	CRM	0.049	0.366	0.004	0.366
A	2005	2021	A-24-02	507169	2841834	RCM	ERM	0.129	0.168	0.006	0.202
A	2005	2018	A-24-03	505169	2840845	CRM	RCM	0.295	0.009	0.022	0.005

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
A	2005	2021	A-24-05	508190	2840801	ERM	ERM	-0.055	0.320	-0.010	0.215
A	2005	2018	A-25-01	504156	2838835	ERM	CRM	-0.030	0.415	-0.003	0.400
A	2005	2018	A-25-02	504185	2837840	RCM	CRM	-0.135	0.124	-0.010	0.122
A	2005	2018	A-25-03	504181	2836826	CRM	ERM	0.293	0.112	0.021	0.106
A	2005	2021	A-25-04	504188	2835849	RCM	ERM	0.314	0.038	0.011	0.120
A	2005	2021	A-25-07	506180	2836853	RCM	RCM	-0.097	0.212	-0.005	0.245
A	2005	2018	A-25-09	507158	2837840	RCM	RCM	0.304	0.008	0.022	0.011
A	2005	2021	A-26-02	506190	2834854	ERM	ERM	-0.167	0.219	-0.010	0.208
A	2005	2021	A-26-03	508179	2834854	RCM	CRM	-0.086	0.289	-0.014	0.039
A	2005	2018	A-26-04	509178	2833968	CRM	CM	0.202	0.021	0.015	0.033
A	2005	2021	A-26-05	511172	2834890	CM	CRM	-0.035	0.384	-0.004	0.286
A	2005	2018	A-26-06	509181	2835841	CRM	CRM	0.064	0.280	0.004	0.336
A	2005	2017	A-27-01	512150	2833964	CRM	CRM	0.021	0.446	0.002	0.444
A	2005	2021	A-27-02	512145	2831869	CWP	CRM	0.263	0.112	0.017	0.085
A	2005	2017	A-27-04	514096	2831997	SCWP	SCWP	0.223	0.037	0.016	0.072
A	2005	2017	A-27-05	515104	2831980	CM	CM	-0.120	0.175	-0.012	0.125
A	2005	2021	A-27-06	514137	2832972	SCWP	PCM	0.060	0.415	0.004	0.417
A	2005	2021	A-27-07	515060	2834026	CM	CRM	0.029	0.373	0.002	0.329
A	2005	2018	A-28-07	509180	2831039	CRM	CRM	0.460	0.001	0.036	0.002
A	2005	2017	A-28-10	508265	2832912	ERM	ERM	-0.069	0.274	-0.004	0.331
A	2005	2018	A-29-02	505257	2821970	CM	CM	-	-	-	-
A	2005	2018	A-29-05	508211	2823965	SOWP	CWP	0.311	0.071	0.022	0.062
A	2005	2017	A-29-07	508062	2826150	CM	CRM	0.013	0.462	-0.009	0.284
A	2005	2017	A-29-09	511189	2825973	MWP	CWP	0.325	0.035	0.025	0.058
A	2005	2017	A-29-10	511192	2824959	SCWP	CWP	0.110	0.277	0.010	0.267
A	2005	2021	A-30-01	510186	2830972	SCWP	SCWP	0.033	0.454	0.002	0.447
A	2005	2021	A-30-04	512152	2829941	CWP	CRM	0.133	0.201	0.009	0.167
A	2005	2017	A-30-05	513124	2829962	CM	CWP	0.201	0.111	0.016	0.106
A	2005	2017	A-30-06	515090	2829964	CM	CM	0.068	0.267	0.006	0.245
A	2005	2017	A-30-07	516118	2829970	CM	CM	0.240	0.012	0.020	0.013
A	2005	2017	A-30-08	515041	2828959	CM	CM	0.035	0.433	0.005	0.379
A	2005	2021	A-30-09	514119	2828965	CM	CM	0.712	0.002	0.033	0.004
B	2003	2021	B-01-01	520439	2809224	SCWP	CWP	-	-	-	-
B	2003	2021	B-01-02	521601	2809144	MWP	CWP	-	-	-	-
B	2003	2021	B-01-03	522385	2813225	CRM	RCM	0.478	0.106	0.026	0.055
B	2003	2021	B-01-04	522408	2811219	CM	CM	-	-	-	-
B	2003	2018	B-01-05	524414	2816166	CM	CM	0.380	0.000	0.023	0.002
B	2003	2018	B-01-06	524388	2815203	CM	CRM	0.338	0.016	0.022	0.020
B	2003	2018	B-01-07	524394	2812179	SCWP	CWP	-	-	-	-
B	2003	2021	B-01-08	524480	2811369	SCWP	SCWP	-	-	-	-
B	2003	2021	B-02-01	524473	2806170	MWP	MWP	-	-	-	-
B	2003	2021	B-02-02	525433	2808246	MWP	CWP	-	-	-	-

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
B	2003	2018	B-02-03	525452	2806350	MWP	MWP	0.060	0.370	0.004	0.428
B	2003	2021	B-02-04	526393	2808207	MWP	MWP	0.296	0.125	0.020	0.049
B	2003	2018	B-02-05	527489	2806438	CWP	CWP	-0.201	0.176	-0.017	0.117
B	2003	2018	B-02-06	527435	2805325	MWP	CWP	0.014	0.422	-0.003	0.323
B	2003	2021	B-02-07	528345	2807219	CWP	CM	0.123	0.201	0.008	0.131
B	2003	2018	B-02-08	528417	2806348	MWP	MWP	0.515	0.037	0.032	0.039
B	2003	2018	B-02-09	528443	2805331	MWP	MWP	0.408	0.104	0.020	0.181
B	2003	2021	B-02-10	529434	2805326	MWP	MWP	0.217	0.142	0.016	0.042
B	2003	2018	B-03-01	523480	2800352	CWP	CWP	0.079	0.268	0.005	0.241
B	2003	2018	B-03-02	524426	2801401	SCWP	SCWP	0.135	0.231	0.007	0.248
B	2003	2018	B-03-03	524439	2800361	CWP	CWP	-0.041	0.414	-0.007	0.298
B	2003	2018	B-03-04	524436	2799379	CWP	CWP	0.359	0.015	0.022	0.021
B	2003	2021	B-03-05	525424	2800358	SOWP	SOWP	0.206	0.165	0.013	0.091
B	2003	2018	B-03-06	526436	2801374	MWP	CWP	0.234	0.036	0.013	0.049
B	2003	2018	B-03-07	527362	2801328	MWP	MWP	0.104	0.261	0.006	0.288
B	2003	2018	B-03-08	527456	2799384	MWP	SOWP	0.162	0.204	0.008	0.291
B	2003	2018	B-03-09	527439	2798381	SOWP	SOWP	-	-	-	-
B	2003	2021	B-03-10	528456	2799370	SOWP	SOWP	0.285	0.076	0.013	0.092
B	2003	2021	B-04-01	524473	2796383	CWP	ERM	0.786	0.008	0.046	0.000
B	2003	2021	B-04-02	525449	2797381	MWP	CWP	0.085	0.348	0.005	0.297
B	2003	2018	B-04-03	526451	2797378	PCM	CWP	0.210	0.158	0.017	0.106
B	2003	2021	B-04-04	526445	2796391	CM	CM	0.100	0.296	0.004	0.299
B	2003	2018	B-04-05	526466	2795453	CM	ERM	0.564	0.042	0.044	0.009
B	2003	2018	B-04-06	527480	2796378	CWP	ERM	0.492	0.038	0.041	0.002
B	2003	2018	B-04-07	528432	2798371	SOWP	SOWP	-0.424	0.093	-0.030	0.079
B	2003	2018	B-04-08	528439	2797388	CWP	MWP	0.016	0.452	-0.002	0.421
B	2003	2018	B-04-09	529431	2798383	SOWP	SOWP	0.379	0.000	0.019	0.013
B	2003	2018	B-04-10	530465	2795357	RCM	ERM	0.284	0.054	0.021	0.043
B	2003	2018	B-05-01	519555	2799379	CM	ERM	0.340	0.012	0.022	0.018
B	2003	2018	B-05-02	521570	2802185	SCWP	CM	0.026	0.441	-0.004	0.387
B	2003	2018	B-05-03	521517	2800333	CWP	CWP	-0.083	0.299	-0.006	0.250
B	2003	2018	B-05-04	521530	2799348	CWP	CWP	-0.015	0.453	-0.001	0.477
B	2003	2018	B-05-05	521529	2797361	CM	CRM	0.292	0.041	0.027	0.001
B	2003	2018	B-05-06	522496	2802327	MWP	MWP	-	-	-	-
B	2003	2018	B-05-07	523462	2803358	SCWP	MWP	-	-	-	-
B	2003	2018	B-05-08	523477	2802369	CWP	CWP	-	-	-	-
B	2003	2018	B-05-09	523517	2801335	SCWP	SCWP	0.015	0.473	0.000	0.479
B	2003	2018	B-05-10	525444	2803323	SCWP	MWP	0.472	0.042	0.028	0.057
B	2003	2018	B-06-01	517488	2804319	RCM	ERM	0.199	0.060	0.015	0.031
B	2003	2018	B-06-02	517585	2802389	CWP	CWP	-	-	-	-
B	2003	2018	B-06-03	517502	2800325	CM	ERM	0.155	0.173	0.009	0.156
B	2003	2018	B-06-04	518519	2802327	MWP	CM	0.575	0.000	0.040	0.000

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
B	2003	2018	B-06-05	519370	2806264	MWP	PCM	-	-	-	-
B	2003	2018	B-06-06	519593	2800468	CWP	CWP	0.205	0.034	0.022	0.000
B	2003	2018	B-06-07	520553	2806330	SCWP	CWP	-	-	-	-
B	2003	2018	B-06-08	520492	2803321	CWP	SOWP	-	-	-	-
B	2003	2018	B-06-09	522412	2806292	MWP	CWP	-	-	-	-
B	2003	2018	B-06-10	522395	2805268	MWP	SOWP	0.118	0.223	0.007	0.241
B	2004	2018	B-07-01	523326	2814290	CM	CRM	0.038	0.349	0.004	0.290
B	2004	2018	B-07-02	524432	2814361	CM	CRM	0.302	0.006	0.022	0.007
B	2004	2021	B-07-03	523900	2813351	CRM	CRM	0.225	0.262	0.024	0.053
B	2004	2018	B-07-04	524424	2813249	CWP	CWP	0.224	0.153	0.016	0.142
B	2004	2019	B-07-05	520429	2812155	CRM	CRM	0.368	0.028	0.028	0.024
B	2004	2019	B-07-06	523397	2812236	CM	CM	-	-	-	-
B	2004	2019	B-07-09	520399	2810165	CM	CM	0.037	0.418	0.004	0.280
B	2004	2019	B-08-01	526367	2807205	PCM	PCM	0.120	0.186	0.007	0.182
B	2004	2019	B-08-02	526683	2805321	CWP	MWP	-0.026	0.428	-0.006	0.245
B	2004	2019	B-08-03	526401	2804295	SOWP	MWP	-0.042	0.419	-0.002	0.435
B	2004	2019	B-08-04	526408	2803327	SOWP	SOWP	0.305	0.154	0.015	0.202
B	2004	2019	B-08-05	527458	2804346	CM	CM	0.069	0.292	0.006	0.187
B	2004	2019	B-08-06	528412	2804346	CWP	MWP	0.266	0.132	0.021	0.080
B	2004	2019	B-08-07	528421	2803393	MWP	CWP	0.270	0.077	0.016	0.056
B	2004	2019	B-08-08	527415	2802321	SCWP	MWP	0.367	0.072	0.019	0.133
B	2004	2019	B-08-09	528382	2801360	SCWP	CWP	0.333	0.062	0.024	0.030
B	2004	2019	B-08-10	529391	2801236	SCWP	CWP	0.107	0.391	0.002	0.539
B	2004	2021	B-09-01	525374	2796260	CM	CM	0.122	0.225	0.008	0.142
B	2004	2021	B-09-02	524414	2797321	ERM	ERM	0.125	0.305	0.013	0.126
B	2004	2019	B-09-03	524437	2798345	MWP	MWP	0.128	0.224	0.009	0.214
B	2004	2019	B-09-04	525428	2798327	CWP	CWP	0.121	0.090	0.007	0.107
B	2004	2019	B-09-05	525430	2799337	MWP	SOWP	0.349	0.075	0.020	0.107
B	2004	2021	B-09-06	526419	2799325	SOWP	SOWP	0.200	0.238	0.005	0.388
B	2004	2019	B-09-07	526437	2798333	MWP	MWP	0.078	0.343	0.009	0.231
B	2004	2019	B-09-08	529363	2799438	MWP	MWP	0.317	0.048	0.021	0.035
B	2004	2021	B-09-09	529418	2797359	CRM	CRM	0.095	0.205	0.007	0.087
B	2004	2019	B-09-10	529573	2796164	CRM	CM	-0.110	0.155	-0.005	0.236
B	2004	2019	B-10-01	522469	2801346	MWP	MWP	0.298	0.015	0.020	0.011
B	2004	2021	B-10-02	521482	2803327	SOWP	SCWP	0.289	0.089	0.009	0.199
B	2004	2021	B-10-03	521451	2804319	CWP	CWP	-	-	-	-
B	2004	2019	B-10-04	523398	2806306	CWP	CWP	0.044	0.404	0.003	0.443
B	2004	2019	B-10-05	523463	2805304	MWP	MWP	-	-	-	-
B	2004	2019	B-10-07	524429	2804313	CWP	MWP	0.141	0.235	0.013	0.164
B	2004	2021	B-10-08	525407	2804310	SCWP	SCWP	-0.008	0.460	0.008	0.241
B	2004	2019	B-10-09	524434	2803412	CM	CM	-	-	-	-
B	2004	2019	B-10-10	524432	2802329	SOWP	SOWP	0.340	0.083	0.021	0.095

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
B	2004	2019	B-11-01	518358	2806241	CWP	CRM	0.224	0.039	0.018	0.018
B	2004	2021	B-11-02	517457	2805255	ERM	ERM	0.379	0.008	0.020	0.009
B	2004	2019	B-11-03	519415	2805291	MWP	PCM	-	-	-	-
B	2004	2021	B-11-04	520452	2805280	CWP	SOWP	-	-	-	-
B	2004	2019	B-11-05	520421	2804293	CWP	MWP	-	-	-	-
B	2004	2021	B-11-06	517451	2803293	CM	CM	0.292	0.004	0.018	0.000
B	2004	2019	B-11-07	518598	2803217	CWP	CM	-	-	-	-
B	2004	2019	B-11-08	518472	2801314	CM	CRM	0.265	0.077	0.021	0.031
B	2004	2019	B-11-09	518472	2800294	CRM	CM	0.041	0.457	-0.002	0.497
B	2004	2021	B-11-10	522476	2799312	SCWP	SCWP	0.167	0.090	0.016	0.003
B	2005	2019	B-12-01	524372	2817140	CWP	ERM	0.429	0.000	0.033	0.000
B	2005	2019	B-12-02	523451	2816140	CM	CM	0.126	0.093	0.011	0.053
B	2005	2019	B-12-03	523443	2815143	CM	ERM	0.588	0.023	0.042	0.023
B	2005	2018	B-12-04	522437	2815166	CM	CRM	0.281	0.042	0.023	0.048
B	2005	2019	B-12-05	522442	2814156	CM	CRM	0.472	0.017	0.035	0.033
B	2005	2020	B-12-06	522530	2812136	CM	ERM	0.377	0.006	0.026	0.005
B	2005	2021	B-12-08	520427	2811166	CM	CM	0.273	0.055	0.019	0.040
B	2005	2021	B-12-09	522421	2810163	SCWP	CM	0.233	0.150	0.012	0.188
B	2005	2020	B-13-06	519423	2808150	CWP	CM	0.077	0.260	0.007	0.192
B	2005	2020	B-13-07	519399	2807175	CM	CM	0.207	0.009	0.017	0.001
B	2005	2021	B-13-10	521440	2805254	MWP	MWP	-0.157	0.277	-0.010	0.277
B	2005	2021	B-14-01	527374	2807213	MWP	MWP	-0.160	0.323	-0.006	0.434
B	2005	2021	B-14-03	526437	2806276	CWP	MWP	-0.247	0.165	-0.016	0.151
B	2005	2021	B-14-09	525408	2802317	CWP	SCWP	-0.131	0.326	-0.004	0.444
B	2005	2020	B-15-01	518447	2805257	SCWP	CWP	0.442	0.009	0.028	0.010
B	2005	2021	B-15-02	518443	2804296	CWP	CWP	-0.136	0.165	-0.003	0.302
B	2005	2020	B-15-07	519507	2802329	CWP	CRM	0.177	0.158	0.012	0.157
B	2005	2020	B-15-08	520448	2801352	CWP	CWP	0.056	0.354	0.005	0.296
B	2005	2020	B-15-09	519446	2801343	CWP	CWP	0.202	0.106	0.008	0.222
B	2005	2020	B-15-10	517465	2801321	RCM	ERM	0.309	0.125	0.024	0.099
B	2005	2021	B-16-01	521462	2801315	CWP	MWP	0.151	0.112	0.010	0.075
B	2005	2020	B-17-01	520502	2799309	RCM	ERM	0.082	0.388	0.011	0.261
B	2005	2020	B-17-02	520511	2798160	CRM	ERM	0.614	0.001	0.048	0.000
C	2003	2021	C-01-01	535369	2812323	MWP	CWP	0.442	0.003	0.023	0.000
C	2003	2021	C-01-02	536377	2811375	MWP	SCWP	0.292	0.024	0.008	0.118
C	2003	2021	C-01-03	537345	2813237	SCWP	SCWP	0.163	0.261	0.003	0.413
C	2003	2021	C-01-04	538307	2815194	MWP	MWP	0.677	0.004	0.028	0.014
C	2003	2021	C-01-05	540298	2814227	MWP	SCWP	0.697	0.001	0.026	0.010
C	2003	2021	C-01-06	538380	2810405	MWP	CWP	0.511	0.016	0.018	0.051
C	2003	2021	C-01-07	539371	2807964	CRM	ERM	0.402	0.082	0.022	0.010
C	2003	2021	C-01-08	540341	2808244	SCWP	SCWP	0.332	0.083	0.016	0.086
C	2003	2021	C-01-09	540262	2809327	SCWP	SCWP	0.227	0.289	0.005	0.393

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
C	2003	2021	C-01-10	541130	2811251	PCM	PCM	0.181	0.183	0.009	0.174
C	2004	2019	C-02-01	538297	2811179	SCWP	MWP	0.419	0.087	0.028	0.072
C	2004	2019	C-02-02	538298	2812210	SCWP	PCM	0.172	0.196	0.009	0.237
C	2004	2019	C-02-03	538290	2813192	MWP	SCWP	0.342	0.085	0.030	0.031
C	2004	2019	C-02-04	539285	2813206	MWP	RCM	0.588	0.001	0.035	0.003
C	2004	2019	C-02-05	539235	2814197	MWP	MWP	0.199	0.138	0.016	0.073
C	2004	2019	C-02-06	539296	2815161	CWP	SCWP	0.302	0.009	0.022	0.000
C	2004	2019	C-02-07	541041	2815172	MWP	MWP	0.374	0.037	0.028	0.015
C	2004	2019	C-02-08	541130	2813219	CWP	CWP	0.066	0.364	0.012	0.145
C	2004	2019	C-02-09	541150	2812221	PCM	PCM	0.303	0.067	0.022	0.037
C	2004	2019	C-02-10	540281	2811185	MWP	MWP	0.092	0.375	0.014	0.200
C	2005	2019	C-03-01	540311	2815140	MWP	PCM	0.462	0.015	0.034	0.015
C	2005	2019	C-03-02	541061	2814191	MWP	CWP	0.399	0.003	0.033	0.001
C	2005	2019	C-03-03	540287	2813210	MWP	PCM	0.383	0.172	0.031	0.113
C	2005	2019	C-03-04	540287	2812220	MWP	PCM	-	-	-	-
C	2005	2019	C-03-05	539309	2812241	MWP	MWP	-	-	-	-
C	2005	2020	C-03-06	539293	2811200	MWP	SCWP	0.010	0.469	-0.003	0.408
C	2005	2020	C-03-07	539279	2810232	CWP	PCM	0.063	0.341	0.002	0.426
C	2005	2020	C-03-08	539305	2809190	CM	PCM	0.252	0.045	0.018	0.032
C	2005	2020	C-03-09	540310	2810188	PCM	ERM	0.459	0.010	0.033	0.002
C	2005	2020	C-03-10	541288	2810221	CWP	CWP	0.384	0.004	0.029	0.000
C	2005	2020	C-04-01	538297	2814206	MWP	MWP	0.088	0.406	0.009	0.325
C	2005	2020	C-04-02	537346	2814186	MWP	MWP	0.320	0.091	0.014	0.170
C	2005	2020	C-04-03	536331	2813196	MWP	SCWP	0.219	0.039	0.012	0.065
C	2005	2020	C-04-04	535344	2813189	MWP	SCWP	-0.042	0.422	-0.006	0.309
C	2005	2020	C-04-06	536304	2812211	SCWP	SCWP	0.139	0.248	0.008	0.263
C	2005	2020	C-04-07	537361	2812234	SCWP	SCWP	0.226	0.095	0.014	0.101
C	2005	2020	C-04-08	537337	2811189	SCWP	MWP	0.434	0.008	0.026	0.024
E	2003	2018	E-01-01	529376	2822048	CWP	CM	0.325	0.010	0.020	0.017
E	2003	2021	E-01-02	530372	2824055	CWP	CRM	0.442	0.004	0.021	0.002
E	2003	2018	E-01-03	530393	2823020	CWP	CWP	0.163	0.169	0.008	0.224
E	2003	2018	E-01-04	530350	2822044	SCWP	SCWP	0.215	0.094	0.011	0.156
E	2003	2018	E-01-05	531351	2822037	CWP	CRM	0.500	0.003	0.029	0.004
E	2003	2021	E-01-06	531320	2821059	CWP	SCWP	0.670	0.004	0.030	0.000
E	2003	2018	E-01-07	532350	2826036	CM	CRM	0.417	0.002	0.029	0.000
E	2003	2018	E-01-08	532285	2825069	CWP	CM	0.343	0.004	0.018	0.013
E	2003	2021	E-01-09	532348	2822051	CWP	CWP	0.152	0.191	0.009	0.124
E	2006	2018	E-01-10	533308	2821023	SCWP	SCWP	-	-	-	-
E	2003	2018	E-02-01	527367	2821022	CM	CRM	0.248	0.046	0.013	0.080
E	2003	2018	E-02-02	527404	2820182	CM	CM	0.279	0.001	0.015	0.005
E	2003	2018	E-02-03	527394	2819182	CWP	CWP	0.270	0.022	0.015	0.031
E	2003	2018	E-02-04	529367	2820210	CWP	CM	0.242	0.007	0.014	0.013

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
E	2003	2018	E-02-05	529373	2818187	CWP	CM	0.191	0.024	0.010	0.046
E	2003	2018	E-02-06	531403	2820153	SCWP	SCWP	0.561	0.003	0.034	0.000
E	2003	2018	E-02-07	531375	2819176	SCWP	SOWP	0.442	0.021	0.027	0.031
E	2003	2021	E-02-08	532358	2819185	CWP	CWP	0.407	0.017	0.016	0.039
E	2003	2018	E-02-09	534364	2818180	CWP	CWP	0.183	0.161	0.007	0.300
E	2003	2018	E-02-10	537394	2818253	CWP	CM	0.240	0.144	0.011	0.208
E	2003	2019	E-03-00	526356	2813208	SCWP	CWP	0.038	0.359	0.002	0.372
E	2004	2019	E-03-01	527377	2816175	CWP	SCWP	0.180	0.123	0.010	0.149
E	2004	2019	E-03-02	527397	2817139	SCWP	CWP	0.278	0.076	0.017	0.086
E	2004	2019	E-03-03	527430	2818190	CM	CM	0.225	0.040	0.014	0.046
E	2004	2021	E-03-04	528365	2819163	CWP	CRM	0.402	0.020	0.021	0.010
E	2004	2019	E-03-05	529344	2819141	CWP	CWP	0.100	0.252	0.006	0.258
E	2004	2021	E-03-06	528349	2818178	CWP	CWP	0.406	0.008	0.021	0.001
E	2004	2021	E-03-07	528348	2817156	CWP	CWP	0.154	0.223	0.009	0.206
E	2004	2019	E-03-08	528318	2816254	SCWP	SCWP	-0.061	0.342	-0.006	0.284
E	2004	2021	E-03-09	529326	2817183	CWP	SCWP	-0.123	0.281	-0.004	0.355
E	2004	2021	E-03-10	530343	2817167	SCWP	SCWP	0.098	0.295	0.005	0.245
E	2004	2019	E-04-01	531307	2824025	SCWP	SOWP	0.309	0.191	0.027	0.121
E	2004	2021	E-04-02	531299	2823022	CM	ERM	0.486	0.004	0.031	0.000
E	2004	2021	E-04-03	533230	2823053	CM	CM	0.255	0.181	0.017	0.105
E	2004	2021	E-04-04	529346	2821021	CRM	ERM	0.064	0.403	0.015	0.059
E	2004	2021	E-04-05	530351	2821046	CWP	SCWP	0.189	0.130	0.016	0.016
E	2004	2019	E-04-06	532327	2820133	SCWP	SCWP	0.241	0.125	0.013	0.166
E	2004	2021	E-04-07	533352	2819621	CWP	SCWP	0.171	0.184	0.011	0.132
E	2004	2021	E-04-08	533368	2818168	CWP	SCWP	0.209	0.102	0.010	0.096
E	2004	2019	E-04-09	532376	2818232	CWP	CWP	0.155	0.191	0.015	0.065
E	2004	2019	E-04-10	535409	2817142	CM	SCWP	-0.098	0.291	-0.008	0.251
E	2005	2019	E-05-02	529339	2823018	CWP	CRM	0.335	0.003	0.025	0.000
E	2005	2019	E-05-03	531318	2825013	CWP	CRM	-	-	-	-
E	2005	2019	E-05-04	532300	2824026	CWP	CM	-	-	-	-
E	2005	2019	E-05-05	533322	2824011	CWP	CWP	-	-	-	-
E	2005	2019	E-05-06	532314	2823016	CWP	CRM	0.256	0.085	0.019	0.071
E	2005	2019	E-05-07	533329	2821974	CM	CWP	0.236	0.049	0.018	0.036
E	2005	2019	E-05-08	532283	2821024	SCWP	SCWP	0.278	0.113	0.014	0.184
E	2005	2019	E-05-10	534342	2819154	CWP	CWP	0.357	0.034	0.028	0.012
E	2005	2020	E-06-01	528381	2820973	CM	CM	0.052	0.184	0.003	0.220
E	2005	2020	E-06-02	528372	2820118	CWP	CRM	0.439	0.001	0.033	0.000
E	2005	2020	E-06-03	530353	2820150	MWP	CWP	0.690	0.000	0.044	0.001
E	2005	2020	E-06-04	530349	2819144	CWP	CM	0.454	0.000	0.032	0.000
E	2005	2020	E-06-05	530326	2818160	CWP	CRM	0.327	0.050	0.023	0.030
E	2005	2020	E-06-06	531333	2818167	SCWP	SCWP	0.206	0.134	0.015	0.111
E	2005	2020	E-06-07	527373	2815160	SCWP	SCWP	0.095	0.243	0.003	0.352

Sub-pop	Year estd.	Samp Year	SiteID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2021)	Delta	Prob	Slope	Prob
E	2005	2020	E-06-08	527361	2814156	CWP	CWP	0.068	0.331	0.010	0.141
E	2005	2020	E-06-09	526403	2814131	SCWP	SCWP	0.131	0.209	0.008	0.219
E	2005	2020	E-06-10	526327	2815182	CWP	CWP	0.068	0.317	0.008	0.201
F	2003	2021	F-01-01	541821	2829046	MWP	SCWP	0.649	0.000	0.032	0.001
F	2003	2021	F-01-02	542251	2826192	MWP	CWP	0.859	0.000	0.035	0.001
F	2003	2021	F-01-03	540249	2827107	CWP	CM	0.324	0.008	0.017	0.003
F	2003	2021	F-01-04	539257	2825111	CM	CWP	0.353	0.018	0.015	0.027
F	2003	2021	F-01-05	539212	2822102	CM	CWP	0.522	0.009	0.029	0.002
F	2003	2021	F-01-06	540198	2822176	MWP	CRM	0.585	0.019	0.024	0.031
F	2003	2021	F-01-07	540277	2823126	CWP	CWP	0.482	0.044	0.018	0.090
F	2003	2021	F-01-08	541255	2823107	SCWP	SCWP	0.509	0.009	0.021	0.024
F	2003	2021	F-01-09	542139	2821962	MWP	SCWP	0.456	0.010	0.022	0.004
F	2003	2021	F-01-10	542267	2821167	MWP	SCWP	0.442	0.005	0.020	0.002
F	2004	2018	F-02-02	541218	2830079	CWP	CWP	0.110	0.241	0.015	0.052
F	2004	2018	F-02-03	541215	2829129	SCWP	CWP	0.435	0.018	0.036	0.005
F	2004	2018	F-02-04	541220	2828050	CWP	SCWP	0.074	0.334	0.006	0.312
F	2004	2018	F-02-05	541226	2827151	MWP	MWP	0.612	0.001	0.047	0.000
F	2004	2018	F-02-06	541225	2825084	CWP	CWP	0.137	0.198	0.014	0.094
F	2004	2018	F-02-07	542250	2825144	SCWP	SCWP	0.328	0.057	0.025	0.034
F	2004	2018	F-02-08	542239	2824082	SCWP	SCWP	0.287	0.128	0.019	0.125
F	2004	2018	F-02-09	540244	2824095	MWP	CWP	0.504	0.002	0.032	0.000
F	2004	2018	F-02-10	540163	2821056	CWP	CM	0.117	0.218	0.012	0.109
F	2005	2018	F-03-01	541200	2831069	CM	CM	0.267	0.032	0.025	0.009
F	2005	2018	F-03-02	542240	2827075	CWP	CWP	-	-	-	-
F	2005	2018	F-03-03	541228	2826091	MWP	MWP	-	-	-	-
F	2005	2018	F-03-04	540232	2826077	MWP	MWP	-	-	-	-
F	2005	2018	F-03-05	540235	2825066	CM	CM	-	-	-	-
F	2005	2018	F-03-06	539228	2824074	PCM	RCM	0.746	0.015	0.066	0.003
F	2005	2018	F-03-07	539231	2823030	CWP	RCM	0.454	0.059	0.039	0.040
F	2005	2018	F-03-08	541226	2822038	MWP	CWP	0.419	0.031	0.032	0.035
F	2005	2018	F-03-09	542213	2823068	SOWP	SOWP	0.154	0.198	0.013	0.168
F	2005	2018	F-03-10	541220	2824087	MWP	SCWP	0.640	0.001	0.049	0.000
F	2005	2018	F-04-01	539226	2821052	CWP	CRM	0.124	0.244	0.008	0.308
F	2005	2018	F-04-02	541278	2821100	CM	CM	0.158	0.125	0.012	0.125
F	2005	2018	F-04-03	542228	2831060	MWP	MWP	-	-	-	-
F	2005	2018	F-04-04	542228	2830060	MWP	MWP	0.375	0.039	0.038	0.001
F	2005	2018	F-04-05	542232	2828059	MWP	SCWP	0.188	0.083	0.015	0.067

Appendix A3: Estimate/direction and standard error for each fixed effect from General Linear Mixed Effect modeling of structural variables (total cover (%), green cover as the percent of total cover, vegetation height (cm)) and above ground biomass (g m^{-2}). Total cover and Biomass were square root transformed. Hydroperiod and Water depth are 4-year annual average prior to sampling. Survey-1 = 2003-2005; Survey-2 = 2006-2009; Survey-3 = 2017-2021. For sites that were surveyed twice over 5 years, during the 2017-2021 study, the structural values were used only from the latest survey, i.e., 2021 survey.

Sub-pop.	Fixed Effects	Cover (%)				Green Cover (%)				Veg. Height (cm)				Biomass (gm2)			
		Estimate	**Std. Er.**	**df**	**P-value**	**Estimate**	**Std. Er.**	**df**	**P-value**	**Estimate**	**Std. Er.**	**df**	**P-value**	**Estimate**	**Std. Er.**	**df**	**P-value**
	(Intercept)	5.52	0.12	448.2	**<0.001**	42.89	1.08	522.0	**<0.001**	58.59	1.47	324.8	**<0.001**	21.91	0.35	380.3	**<0.001**
	Survey-2	0.16	0.13	382.0	0.214	-8.86	1.36	383.1	**<0.001**	-1.34	1.26	379.4	0.290	0.17	0.35	380.7	0.619
A	Survey-3	0.04	0.13	384.4	0.746	-4.36	1.36	384.8	**<0.01**	10.81	1.27	383.3	**<0.001**	1.07	0.35	383.7	**<0.01**
	Hydroperiod	0.46	0.26	296.0	0.074	-4.81	2.21	257.2	**<0.05**	5.55	3.28	416.5	0.092	1.60	0.79	346.4	**<0.05**
	Water Depth	-0.41	0.27	275.8	0.131	6.70	2.34	245.6	**<0.01**	-6.28	3.57	367.2	0.079	-1.58	0.85	314.0	0.063
	(Intercept)	5.38	0.12	331.6	**<0.001**	40.82	1.28	354.2	**<0.001**	53.64	1.25	296.9	**<0.001**	22.86	0.94	65.5	**<0.001**
	Survey-2	-0.64	0.15	259.6	**<0.001**	-1.23	1.66	256.2	0.459	-1.85	1.40	260.4	0.187	0.86	0.65	72.8	0.195
B	Survey-3	0.12	0.16	303.3	0.449	-6.32	1.73	293.6	**<0.001**	11.28	1.49	312.9	**<0.001**	-0.28	0.79	102.9	0.725
	Hydroperiod	-0.23	0.26	210.6	0.363	-7.67	2.61	190.5	**<0.01**	-2.60	2.47	234.5	0.294	-2.44	1.36	76.6	0.078
	Water Depth	-0.22	0.26	204.0	0.404	8.64	2.67	185.6	**<0.01**	2.92	3.29	225.4	0.376	2.21	0.85	69.0	**<0.05**
	(Intercept)	5.61	0.20	106.0	**<0.001**	40.73	2.31	104.8	**<0.001**	59.51	1.58	98.6	**<0.001**	22.86	0.94	65.5	**<0.001**
	Survey-2	0.35	0.28	106.0	0.209	4.38	3.12	74.1	0.165	1.31	1.99	73.9	0.512	0.86	0.65	72.8	0.195
C	Survey-3	-0.44	0.33	106.0	0.187	3.38	3.73	102.2	0.367	8.62	2.48	103.8	**<0.001**	-0.28	0.79	102.9	0.725
	Hydroperiod	-0.88	0.41	106.0	**<0.05**	-10.69	4.73	72.2	**<0.05**	1.02	3.36	84.6	0.761	-2.44	1.36	76.6	0.078
	Water Depth	1.11	0.39	106.0	**<0.01**	13.95	4.43	66.1	**<0.01**	1.06	3.18	75.7	0.740	2.21	0.85	69.0	**<0.05**
	(Intercept)	5.14	0.23	118.2	**<0.001**	42.86	2.66	123.8	**<0.001**	65.18	1.90	121.1	**<0.001**	21.88	0.58	118.4	**<0.001**
	Survey-2	-0.14	0.20	124.8	0.488	-1.10	2.62	124.2	0.676	-4.48	1.76	125.1	**<0.05**	-0.79	0.51	124.6	0.124
E	Survey-3	-0.13	0.20	147.9	0.540	1.83	2.68	139.4	0.495	2.90	1.81	143.8	0.111	-0.16	0.53	146.9	0.762
	Hydroperiod	0.06	0.45	112.3	0.898	-6.35	5.17	93.1	0.223	-0.75	3.73	102.4	0.841	0.01	1.14	109.9	0.991
	Water Depth	-0.31	0.41	111.7	0.447	7.29	4.69	92.4	0.123	2.16	3.38	101.8	0.524	-0.36	1.03	109.3	0.732
	(Intercept)	5.53	0.22	89.4	**<0.001**	43.78	2.47	89.5	**<0.001**	63.35	3.04	75.2	**<0.001**	22.40	0.87	73.9	**<0.001**
	Survey-2	-0.86	0.27	73.0	**<0.01**	9.79	3.11	71.5	**<0.01**	-4.28	3.20	72.3	0.185	-2.32	0.74	72.9	**<0.01**
F	Survey-3	0.24	0.33	93.0	0.473	-6.76	3.69	92.6	0.071	10.41	4.06	92.5	**<0.05**	1.46	0.91	93.0	0.112
	Hydroperiod	0.45	0.49	77.5	0.357	-9.88	5.46	74.5	0.074	10.27	6.60	95.6	0.123	1.61	1.19	88.7	0.180
	Water Depth	-0.69	0.47	72.0	0.148	10.40	5.25	69.0	0.051	-10.08	6.48	90.5	0.123	-1.97	1.18	82.3	0.099

Appendix A4: Mean (± SD) values of vegetation structural characteristics (Total cover (%), Green cover (as the percent of Total cover), vegetation height (cm)), and biomass (g m^{-2}) at a subset of sites burned in 2005 and 2008.

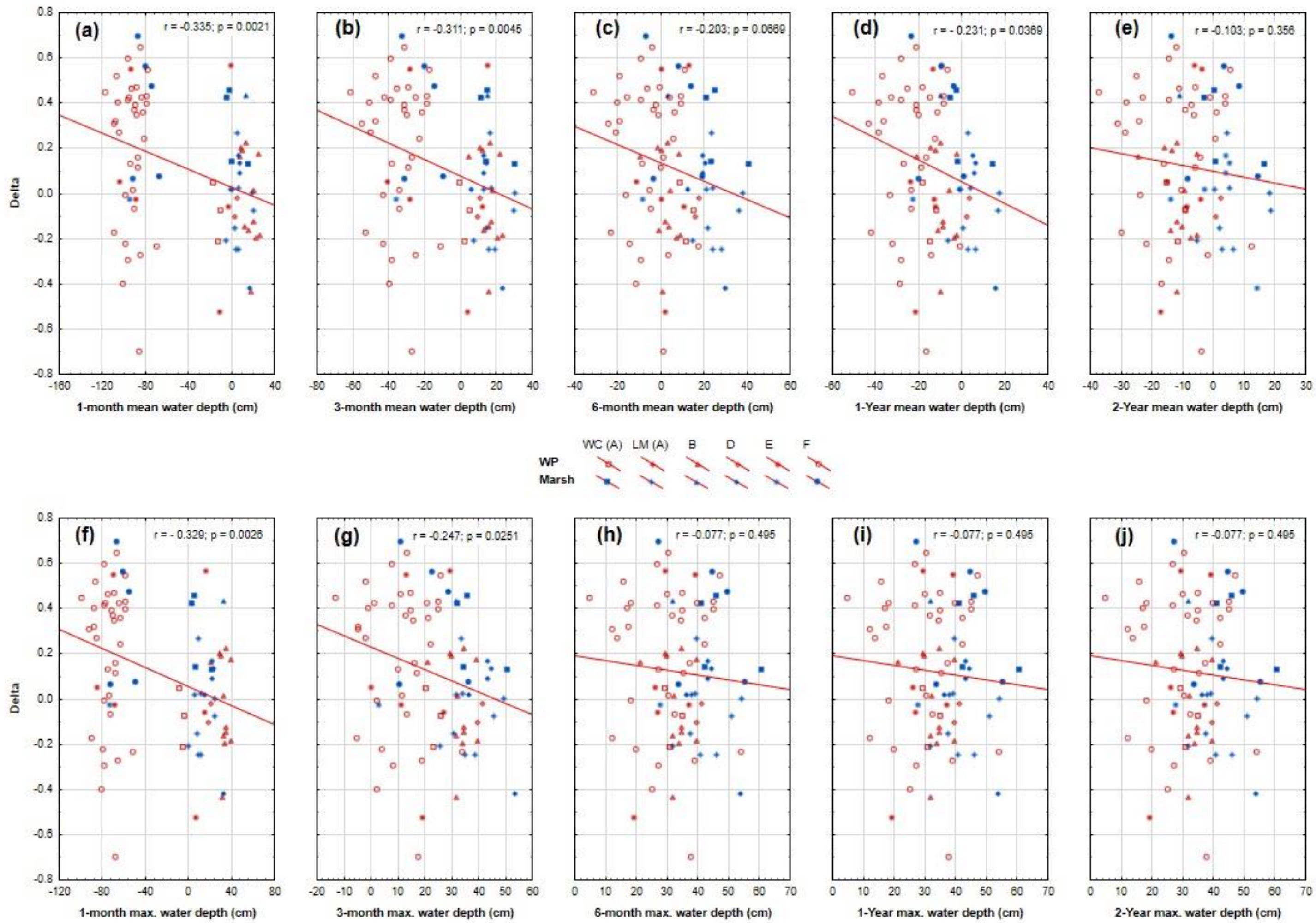
Pre- & Post-Burn Year	2005-Burn		2008-Burn	
	B (n= 12)	**A (n = 13)**	**E (n = 7)**	**F (n = 17)**
Total Cover (%)				
Pre burn	45.0 ± 11.6	33.2 ± 10.1	30.0 ± 5.6	42.4 ± 9.0
Post-Burn 01	12.9 ± 5.7	11.5 ± 5.9	13.3 ± 12.0	16.4 ± 5.1
Post-Burn 02	7.6 ± 6.3	27.6 ± 18.2	16.9 ± 6.5	36.3 ± 14.9
Post-Burn 03	13.1 ± 9.0			
Post-Burn 04	18.3 ± 13.0			
Post-Burn 05	16.8 ± 7.6			
Post-Burn 06		35.3 ± 10.3	29.9 ± 4.1	39.0 ± 13.1
Post-Burn >8	27.5 ± 10.4	38.4 ± 18.9	26.1 ± 6.8	41.1 ± 13.3
Green Cover (% of Total Cover)				
Pre burn	38.9 ± 11.2	36.5 ± 14.2	30.9 ± 10.5	36.7 ± 4.9
Post-Burn 01	40.1 ± 18.1	51.6 ± 18.2	63.0 ± 12.8	62.2 ± 4.5
Post-Burn 02	66.3 ± 13.4	51.7 ± 11.9	43.0 ± 10.2	45.0 ± 10.9
Post-Burn 03	60.9 ± 15.3			
Post-Burn 04	63.4 ± 13.5			
Post-Burn 05	50.3 ± 16.5			
Post-Burn 06		51.0 ± 6.0	50.4 ± 13	54.3 ± 10.8
Post-Burn >8	34.7 ± 11.0	37.8 ± 10.6	26.5 ± 6.4	26.8 ± 8.7
Mean height (cm)				
Pre burn	63.5 ± 14.7	60.7 ± 9.3	68.5 ± 14.1	65.5 ± 9.0
Post-Burn 01	19.1 ± 10.0	33.1 ± 16.8	44.4 ± 5.0	63.2 ± 7.4
Post-Burn 02	28.5 ± 10.8	48.9 ± 14.9	52.9 ± 7.7	52.9 ± 11.1
Post-Burn 03	34.4 ± 9.3			
Post-Burn 04	37.1 ± 11.9			
Post-Burn 05	34.0 ± 9.6			
Post-Burn 06		48.1 ± 11.0	49.7 ± 6.9	56.0 ± 8.0
Post-Burn >8	62 ± 12.7	65.8 ± 15.4	70.3 ± 5.8	86.0 ± 13.0
Biomass (g/m^{-2})				
Pre burn	625 ± 152	495 ± 99	512 ± 100	613 ± 93
Post-Burn 01	206 ± 69	234 ± 87	276 ± 95	370 ± 65
Post-Burn 02	187 ± 76	416 ± 199	337 ± 51	498 ± 118
Post-Burn 03	251 ± 93			
Post-Burn 04	302 ± 126			
Post-Burn 05	280 ± 80			
Post-Burn 06		461 ± 109	436 ± 56	536 ± 133
Post-Burn >8	462 ± 132	579 ± 212	483 ± 68	703 ± 166

Appendix A5: Delta and slope (amount and rate of change in the target direction, respectively) calculated for sites burned in 2003 (2), 2005 (21) and 2008 (63). The 2003 and 2005 burned sites were monitored for 4 and 5 years after fire, respectively. The 2008 burned sites were sampled in 1st, 2nd and 6th year after fire. Almost all those sites were again surveyed during 2017-2020 study, i.e., 9-15 years after fire. The base year for change in vegetation was the 1st year after fire, and the vector from the base year to the individual pre-burn sites in the non-metric multidimensional scaling (NMDS) ordination was the target direction. Statistical significance ($p \leq 0.1$) of delta and slope was tested using Monte Carlo's simulations with 10,000 permutations.

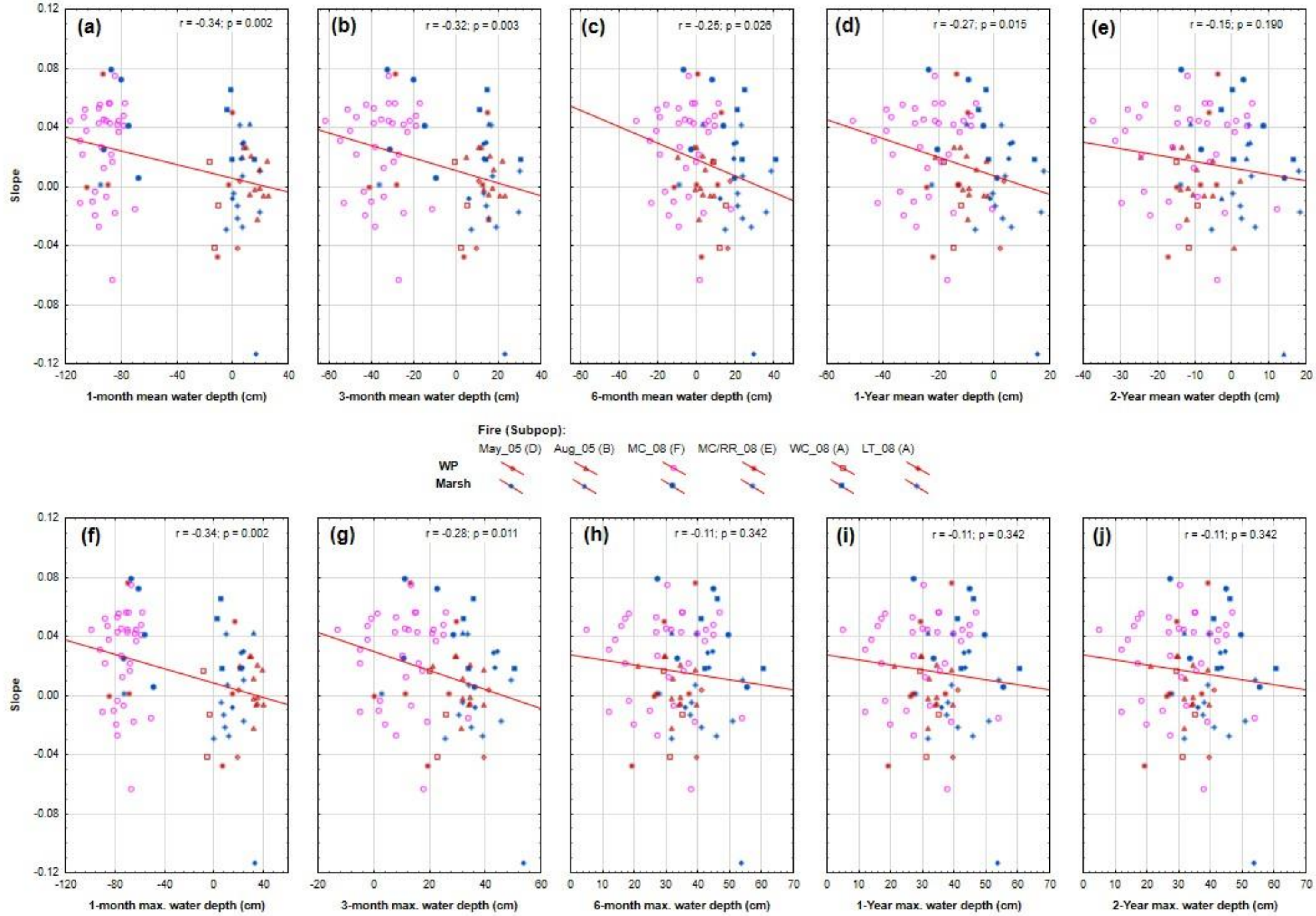
POP	FIUID	Burn Year	FIRE	Delta	Prob	Slope	Prob
A	A-09-04	2008	Lime Tree	0.005	0.469	0.010	0.379
A	A-09-06	2008	Lime Tree	-0.248	0.948	-0.027	0.960
A	A-11-05	2008	West Camp	0.129	0.167	0.018	0.107
A	A-16-01	2008	Lime Tree	-0.247	0.936	-0.021	0.903
A	A-17-01	2008	Lime Tree	-0.150	0.733	-0.013	0.711
A	A-17-02	2008	Lime Tree	-0.209	0.812	-0.029	0.881
A	A-17-03	2008	Lime Tree	0.022	0.467	-0.005	0.569
A	A-19-08	2008	West Camp	0.045	0.413	0.016	0.298
A	A-19-09	2008	West Camp	0.426	0.003	0.052	0.002
A	A-19-10	2008	West Camp	-0.072	0.669	-0.013	0.750
A	A-21-10	2008	Lime Tree	-0.076	0.717	-0.017	0.750
A	A-23-01	2008	Lime Tree	0.271	0.193	0.042	0.098
A	A-23-08	2008	West Camp	0.143	0.094	0.018	0.060
A	A-23-09	2008	West Camp	-0.214	0.909	-0.042	0.901
A	A-23-10	2008	West Camp	0.456	0.009	0.065	0.001
A	A-24-06	2008	Lime Tree	0.026	0.448	0.007	0.421
B	B-01-01	2003	Reference	0.177	0.222	0.011	0.254
B	B-01-04	2003	Reference	0.134	0.185	0.008	0.205
B	B-05-06	2005	Keyhole	-0.148	0.817	-0.005	0.669
B	B-05-07	2005	Keyhole	0.201	0.124	0.026	0.022
B	B-05-08	2005	Keyhole	0.190	0.207	0.027	0.093
B	B-06-05	2005	Sisal	-0.193	0.868	-0.006	0.676
B	B-06-07	2005	Sisal	0.161	0.129	0.020	0.047
B	B-06-08	2005	Sisal	-0.161	0.730	-0.002	0.557
B	B-10-03	2005	Sisal	-0.432	0.963	-0.022	0.932
B	B-10-05	2005	Keyhole	0.224	0.119	0.021	0.075
B	B-10-09	2005	Keyhole	0.434	0.127	0.043	0.067
B	B-11-03	2005	Sisal	0.015	0.467	0.011	0.217
B	B-11-04	2005	Sisal	-0.187	0.825	-0.006	0.661
B	B-11-05	2005	Sisal	0.177	0.185	0.017	0.112
B	B-13-10	2005	Sisal	-0.124	0.688	-0.001	0.537
D	D-01-10	2005	Aerojet	-0.228	0.842	-0.058	0.861
D	TD-1900	2005	Aerojet	-0.100	0.596	-0.042	0.682

POP	FIUID	Burn Year	FIRE	Delta	Prob	Slope	Prob
D	TD-2000	2005	Aerojet	0.018	0.486	-0.008	0.534
D	TD-2100	2005	Aerojet	0.090	0.403	0.029	0.392
D	TD-2200	2005	Aerojet	-0.020	0.503	0.004	0.456
D	TD-2300	2005	Aerojet	0.134	0.331	0.030	0.341
D	TD-2400	2005	Aerojet	0.170	0.361	0.019	0.440
D	TD-2500	2005	Aerojet	-0.417	0.673	-0.113	0.731
E	E-01-07	2008	Mustang Corner	-0.023	0.518	0.001	0.483
E	E-01-08	2008	Mustang Corner	0.551	0.099	0.076	0.023
E	E-03-02	2008	Radius Rod	0.570	0.038	0.051	0.059
E	E-03-07	2008	Radius Rod	-0.057	0.579	0.002	0.491
E	E-03-09	2008	Radius Rod	-0.523	0.931	-0.047	0.920
E	E-04-01	2008	Mustang Corner	0.055	0.412	0.000	0.518
E	E-05-03	2008	Mustang Corner	-0.026	0.547	0.002	0.466
F	F-01-01	2008	Mustang Corner	0.270	0.046	0.038	0.011
F	F-01-02	2008	Mustang Corner	0.443	0.005	0.045	0.005
F	F-01-03	2008	Mustang Corner	0.516	0.008	0.047	0.011
F	F-01-04	2008	Mustang Corner	0.065	0.422	0.025	0.256
F	F-02-02	2008	Mustang Corner	-0.010	0.514	-0.003	0.559
F	F-02-03	2008	Mustang Corner	-0.224	0.848	-0.020	0.807
F	F-02-04	2008	Mustang Corner	0.129	0.290	0.026	0.149
F	F-02-05	2008	Mustang Corner	-0.176	0.757	-0.011	0.642
F	F-02-06	2008	Mustang Corner	0.389	0.064	0.056	0.011
F	F-03-01	2008	Mustang Corner	0.694	0.001	0.078	0.001
F	F-03-02	2008	Mustang Corner	0.310	0.023	0.031	0.024
F	F-03-03	2008	Mustang Corner	0.116	0.277	0.016	0.229
F	F-03-04	2008	Mustang Corner	0.370	0.045	0.044	0.015
F	F-03-05	2008	Mustang Corner	0.563	0.008	0.072	0.001
F	F-04-03	2008	Mustang Corner	0.427	0.010	0.055	0.002
F	F-04-04	2008	Mustang Corner	0.646	0.000	0.075	0.000
F	F-04-05	2008	Mustang Corner	0.403	0.011	0.052	0.000
F	TF-0900	2008	Mustang Corner	-0.068	0.634	-0.007	0.671
F	TF-1000	2008	Mustang Corner	0.593	0.017	0.053	0.017
F	TF-1100	2008	Mustang Corner	0.414	0.015	0.043	0.012
F	TF-1200	2008	Mustang Corner	-0.297	0.936	-0.028	0.948
F	TF-1300	2008	Mustang Corner	0.462	0.043	0.046	0.031
F	TF-1400	2008	Mustang Corner	0.345	0.137	0.042	0.083
F	TF-1500	2008	Mustang Corner	0.077	0.350	0.005	0.381
F	TF-1600	2008	Mustang Corner	0.422	0.038	0.042	0.035
F	TF-1700	2008	Mustang Corner	0.013	0.490	0.013	0.342
F	TF-1900	2008	Mustang Corner	0.239	0.178	0.037	0.054
F	TF-2000	2008	Mustang Corner	-0.233	0.713	-0.016	0.641

POP	FIUID	Burn Year	FIRE	Delta	Prob	Slope	Prob
F	TF-2100	2008	Mustang Corner	-0.697	0.999	-0.063	0.999
F	TF-2200	2008	Mustang Corner	-0.274	0.677	-0.018	0.630
F	TF-2300	2008	Mustang Corner	0.398	0.223	0.048	0.177
F	TF-2400	2008	Mustang Corner	0.466	0.085	0.056	0.041
F	TF-2500	2008	Mustang Corner	0.427	0.112	0.041	0.116
F	TF-2600	2008	Mustang Corner	0.357	0.087	0.044	0.030
F	TF-2700	2008	Mustang Corner	0.160	0.259	0.021	0.184
F	TF-2800	2008	Mustang Corner	0.543	0.033	0.056	0.021
F	TF-2900	2008	Mustang Corner	0.476	0.046	0.041	0.058
F	TF-3000	2008	Mustang Corner	0.318	0.121	0.021	0.211
F	TF-3100	2008	Mustang Corner	-0.399	0.911	-0.011	0.645
F	TF-3200	2008	Mustang Corner	-0.439	0.829	-0.025	0.739



Appendix A6 - Relationship between hydrologic conditions (mean & max water depth) calculated for different periods (1, 3, 6, 12, and 24 months) and delta (**Δ**, magnitude of vegetation change) calculated using trajectory analysis. The colored symbols represent different burn groups (and sub-populations) (May_05 (D), Aug_05 (B), MC_08 (F), WC_08 (A), LT_08 (A) and MC/RR_08 (E), and two vegetation types (WP = Wet prairie, and M = Marsh).



Appendix A7 - Relationship between hydrologic conditions (mean & max water depth) calculated for different periods (1, 3, 6, 12, and 24 months) and Slope (rate of vegetation change) calculated using trajectory analysis. The colored symbols represent different burn groups (and sub-populations) (May_05 (D), Aug_05 (B), MC_08 (F), WC_08 (A), LT_08 (A) and MC/RR_08 (E), and two vegetation types (WP = Wet prairie, and M = Marsh).

Appendix A8: Number of vegetation survey sites sampled over five years (2017-2021) matched with the sparrow survey points visited during the same period (in 2017-2019, and 2021). Vegetation types are listed according to increasing wetness.

Vegetation types	**Vegetation survey sites visited for Sparrow survey**		**Vegetation survey sites with Sparrow occurrence**	
	Number (#)	**Percent (%)**	**Number (#)**	**Percent (%)**
Muhlenbergia Wet Prairie	36	11.1	14	38.9
Schizachyrium Wet Prairie	51	15.8	18	35.3
Schoenus Wet Prairie	16	5.0	12	81.3
Cladium Wet Prairie	78	24.1	28	35.9
Paspalum-Cladium Marsh	14	4.3	2	14.3
Cladium Marsh	52	16.1	15	28.8
Cladium-Rhynchospora Marsh	47	14.6	10	21.3
Rhynchospora-Cladium Marsh	10	3.1	0	0.0
Eleocharis-Rhynchospora Marsh	19	5.9	6	31.6
Total/Average	**323**	**100%**	**106**	**Average = 31.9%**