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

Ms. Sherry Whitaker
U.S. Army Engineer Research and Development Center (U.S. Army - ERDC)
3909 Halls Ferry Road, Vicksburg, MS 39081-6199
Email: Sherry.L.Whitaker@usace.army.mil

and

Tylan Dean
South Florida Natural Resources Center
Everglades and Dry Tortugas National Parks
950 N. Krome Ave., Homestead, FL 33030-4443
Email: Tylan_Dean@nps.gov

Jay P. Sah, James R. Snyder, Michael S. Ross,
Susana Stoffella, Bianca Constant, Santiago Castaneda, Carlos Pulido
Southeast Environmental Research Center
Florida International University, Miami FL 33199

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Authors' Affiliation

Jay P. Sah, Ph.D. – *Research Associate Professor*
Florida International University
Southeast Environmental Research Center
11200 SW 8th Street, Miami, FL 33199
Tel. (305).348.1658; Email: sahj@fiu.edu

Michael S. Ross, Ph.D. –*Professor*
Florida International University
Southeast Environmental Research Center/Department of Earth & Environment
11200 SW 8th Street, Miami, FL 33199
Tel. (305).348.1420; Email: rossm@fiu.edu

James R. Snyder[1], Ph. D. - *Biologist*
US Geological Survey (Retd.)
1310 15th St. SW, Naples, FL.
Tel. (239).695.1180 Email: jimsnyder_naples@yahoo.com

Susana Stoffella – *Research Analyst*
Florida International University
Southeast Environmental Research Center
11200 SW 8th Street, Miami, FL 33199
Tel. (305).348.0493; Email: stoffell@fiu.edu

Santiago Castaneda – *Sr. Field/ Lab Technician*
Florida International University
Southeast Environmental Research Center
11200 SW 8th Street, Miami, FL 33199
Tel. (305).348.6066; Email: scastane@fiu.edu

Bianca Constant – *Field/ Lab Technician*
Florida International University
Southeast Environmental Research Center
11200 SW 8th Street, Miami, FL 33199
Tel. (305).348.6066; Email: biconsta@fiu.edu

Carlos Pulido – *Grad Student*
Florida International University
Southeast Environmental Research Center
11200 SW 8th Street, Miami, FL 33199
Tel. (305).348.6066; Email: cpulido@fiu.edu

Executive Summary

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. The questions are 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, at both fine and broad scales, in newly identified sensitive areas, and to assess the changes in vegetation condition in previously surveyed part of the sub-populations A-C, E and F.

Over four years, 2017-2020, 684 plots were surveyed, including 126 along transects and 558 CSSS census points. The transect sites included both new (43) and previously surveyed sites (83). The census sites included 440 existing points that were established and surveyed for the first time in 2003-2005, and 118 new sites, i.e., surveyed for the first time in this study. In 2017, the surveyed census sites included 105 existing sites and 10 new sites only in sub-population A, most in two distinct areas (hN and hS) identified as improved potential future CSSS habitat. In contrast, over the next three years (2018-2020) the census sites in all five (A, B, C, E and F) sub-populations, as well 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 four years (2017-2020) were classified using cluster analysis, and a change in vegetation type since 2003/2005 survey was examined.

The hydrologic condition of the vegetation survey sites surveyed during 2007-2020 survey showed a distinct spatio-temporal pattern. Averaged over the sites surveyed in both 2003/2005 and 2017/2020 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

in C, E and F were wetter in 2017-2020 than previous surveys. In contrast, in the northeastern portion of A (in the hN area), the sites were drier during the 2017/2020 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 has 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 vegetation change towards a more hydric type, suggesting a continued deterioration of CSSS habitat in these areas. In the western and southern portions of sub-population B, the eastern portion of C, and throughout E and F, vegetation also shifted towards a wetter type, while composition in the central and northeastern portions of the sub-population B changed little.

These results are not unexpected, as the sites in the southwestern portion of sub-population A and southern portion of B are affected by rising ground water levels, partially caused by sea level rise, and sites in the hS area and western portions of B and E are possibly affected by a gradual increase in water flow though the Shark River Slough. This trend is likely to continue in the future, which may cause further limit the extent of suitable habitat in these areas. However, a shift in vegetation towards wetter type in C, eastern E and throughout F is possibly the results of broader restoration strategy, including the one, 'hydrating the rocky glades', where habitat deterioration was believed to have caused by 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, 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 the sub-population E and most of F do not seem to result exclusively from ongoing water management activities. The 2017/2020 surveys were done 1-4 years after the extreme event of dry season high water condition of 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. Thus, the unusually high-water conditions in the dry season of 2016, and to lesser extent in 2018, might have further enhanced the vegetation trajectory to wetter type in that region. However, at most sites, the vegetation was still wet-prairie type. The sites in these sub-populations are also affected by the increased water delivery into the Park through NESRS. Therefore, it will take time to realize the combined effects of the highwater event in the dry season of 2016 and to lesser extent in 2018, and increased water flow through NESRS in subsequent years.

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 FY 2017 and 2018 are described in Sah et al. (2018) and Sah et al. (2019), respectively. The monitoring work within the marl prairie landscape continued in FY 2019 and FY 2020.

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 four years (FY 2017-2020) 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. Over the 2017-20 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 done at a subset of previously surveyed sites. Since the vegetation characterization at new sites surveyed in 2017 and 2018 has already been described in Sah et al. (2019), this report primarily describes temporal changes in vegetation structure and composition in relation to changes in hydrologic conditions at the previously surveyed sites that were re-surveyed over four years (2017-2020) 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), 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 will affect the CSSS habitat, and how the impact on vegetation structure and composition will 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, recent 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 - followed under the operational objectives of Interim Structural and Operation Plan (ISOP)/Interim Operational Plan (IOP) (USACE 1999; USFWS 2002) - have produced consistently 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). 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, 2019, 2020), possibly 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).

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 2006, we established a network of 906 vegetation-monitoring sites in the marl prairies, most of which were congruent with sparrow census sites. 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. In 2017, we also established 19 and 24 survey sites along new transects in the 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).

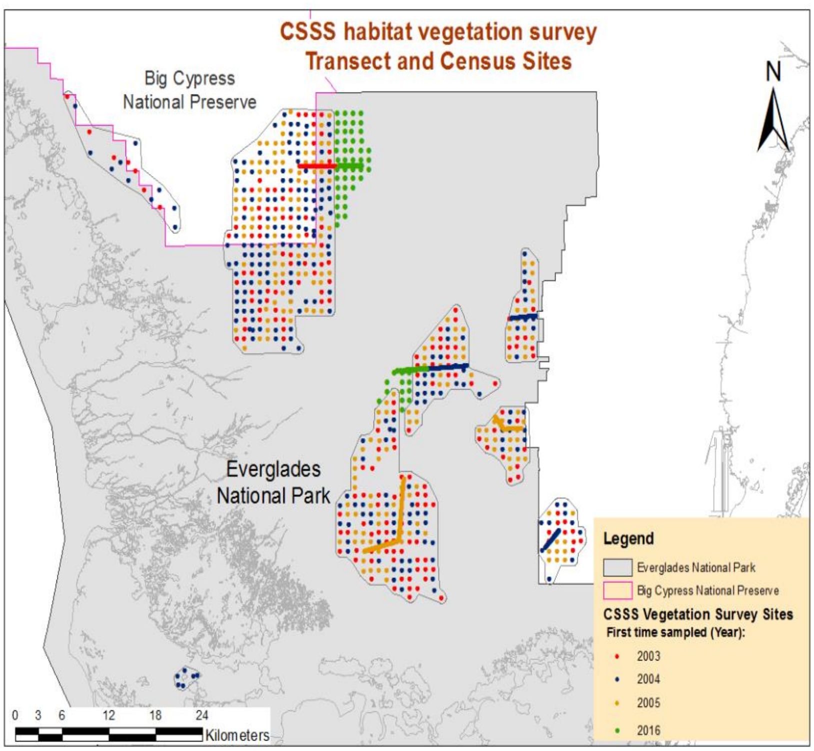

Figure 1: A network of vegetation monitoring sites that were established and surveyed for the first time before 2017-2020. In the beginning of vegetation monitoring within the CSSS habitat, 906 sites (293 transect and 613 census sites) were established over three years (2003-2005), and were surveyed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

Altogether, 684 sites, including 556 census and 126 transect sites were surveyed over four years, 2017-2020 (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 project period, 184 sites, including 131 existing and 53 new sites, were surveyed. Those included 69 transect sites and 115 census sites. In 2018, 2019 and 2020, 215, 181 and 104 sites were surveyed, respectively. In 2018, all the surveyed sites were census sites - 61 new and 154 existing sites. In 2019, only the previously surveyed sites were sampled, including 33 transect and 148 census sites.

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 2nd and 27th, we were unable to continue the field work, primarily due to stay-at-home 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.

Table 1: Sites surveyed within CSSS habitat between 2017 and 2020. * Sites were established in the area between existing boundary of sub-populations C and F, and between E and F.

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

Census sites surveyed over 2017- 2020 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 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. 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).

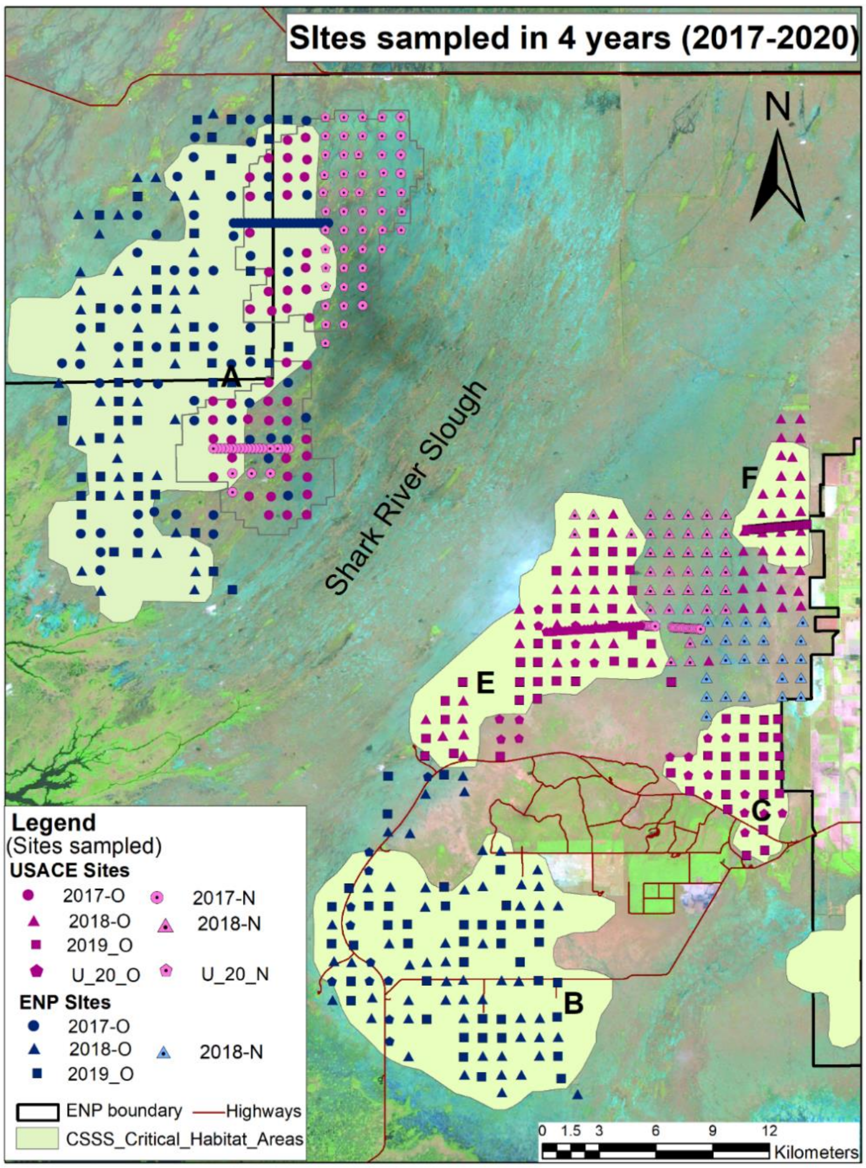

Figure 2: CSSS Vegetation Survey sites surveyed in 2017 (circle), 2018 (triangle), 2019 (square) and 2020 (pentagon). The sites surveyed in those four years included both USACE and ENP-funded sites, in pink and blue color, respectively, previously established ('O') and new (N) sites, including those surveyed for the first time in 2016.

Transect sites surveyed during the same 4-year period included 43 new sites and 85 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, 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.

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).

2.2 Data Analysis

2.2.1 Vegetation classification

We used cluster analysis to classify the 684 sites that were surveyed during the 2017/2020 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 30 years (1991-2020). 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 four years (2017-2020), 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. Biomass data were log-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 years that was done in 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), the hydrologic condition of the vegetation survey sites surveyed in four years (2017-2020) showed a distinct spatial and temporal pattern (Figures 3-5). The four-year average hydroperiod and annual mean daily water depth for the majority of sites (94.2%) were calculated using ground elevation derived from topographic surveys in combination with the field measurements of water depth or only with water depths and EDEN daily water surface elevation data. For the rest of the sites, hydrologic variables were calculated using ground elevation from the digital elevation model (DEM) database in EDEN. However, these (5.8%) sites were not included in comprehensive analysis to describe the hydrologic conditions of these areas. At the census sites (n= 405) surveyed in both 2003/2005 and 2017/2020 surveys, the hydroperiod ranged between 2 and 365 days, with a mean (± SD) of 227 (± 83) days and a median of 240 days. Similarly, the mean daily water depth ranged between -34.6 and 46.6 cm with the mean (± SD) of 3.6 (±14.1) cm and median of 2.7 cm. Both the hydroperiod and daily mean water depth at these sites significantly differed among the three surveys (Kruskal-Wallis Test: KW-$H_{(2,1213)} = 36.6$, $p < 0.001$, and KW-$H_{(2,1213)} = 21.7$, $p = 0.012$, respectively). The median hydroperiod in 2017/2020 was 22 and 33 days higher than the median values in 2003/2005 and 2006/2009, respectively. The median water depth at these sites was 2.6 and 2.8 cm higher during the recent survey than in the two previous surveys.

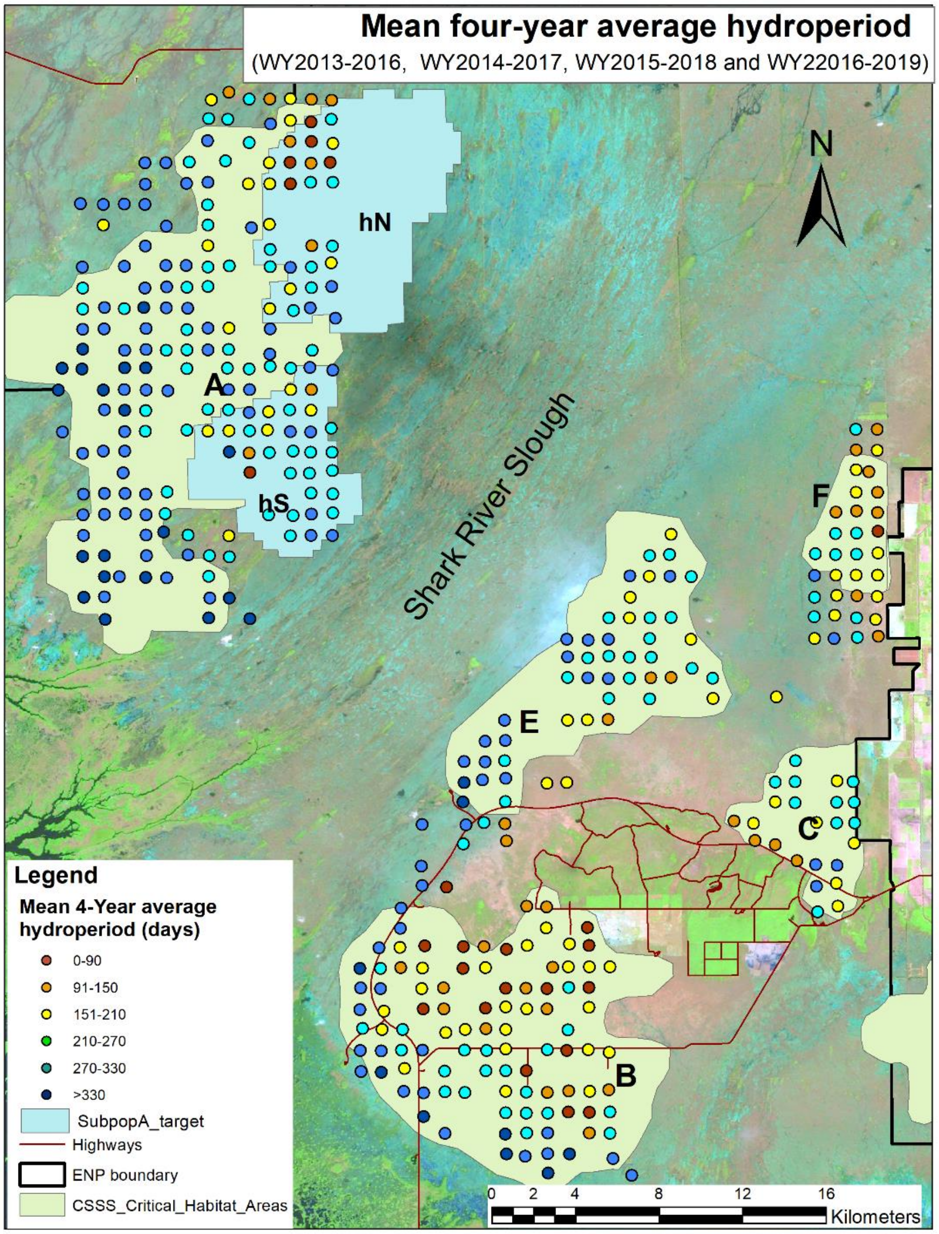

Figure 3: Four-year mean discontinuous hydroperiod at 2017/2020 vegetation survey sites in sub-populations A, B, C, E and F. The values were averaged over four years prior to the survey, and calculated only for those sites for which field measurements of water depth were available, and the sites were surveyed during both 2003/2005 and 2017/2020 surveys.

Sub-population A

During the 2017/2020 survey in sub-population A, 4-year average hydroperiod ranged between 47 and 365 days, with a mean (± SD) of 261 (± 65) days and a median of 269 days, and mean water depth ranged between -18.7 and 46.0 cm with the mean (± SD) of 10.0 (±12.2) cm and median of 9.7 cm water depth. Across all the regions, vegetation sites in sub-population A were slightly wetter in recent years (2017/2020) than during the 2003/2005 and 2006/2009 surveys, as mean hydroperiod was 13 days longer and daily mean water depth was 1.4 cm deeper in 2017/2020 than 15 years ago (Table 2). However, the hydrologic condition was not the same throughout the sub-population A (Figure 6). Sample sites in its northeastern region (hN) were much drier than the sites in other portions of the sub-population (Table 2). In the hN area, the mean hydroperiod was 188 ± 76 days (median = 203 days), and water depth was -3.0± 9.6 cm (median = -4.0 cm). In contrast, the hS area and western portion of the sub-population had mean hydroperiods of 237 ± 55 and 283 ± 50 days, and the mean water depths of 5.5 ± 9.0 and 14.1 ± 11.0 cm, respectively (Table 2). Moreover, hydrologic conditions at many sites in the hN area were drier in 2017/2020 than during previous surveys, whereas the several sites in the western and southern portions (hS) of the sub-population had become wetter over one and a half decades. For instance, mean hydroperiod at the sites in the hN area was 7 days shorter, but sites in hS and the western-A were 20 and 14 days longer in 2017/2020 than in 2003/2005 (Table 2; Figure 6).

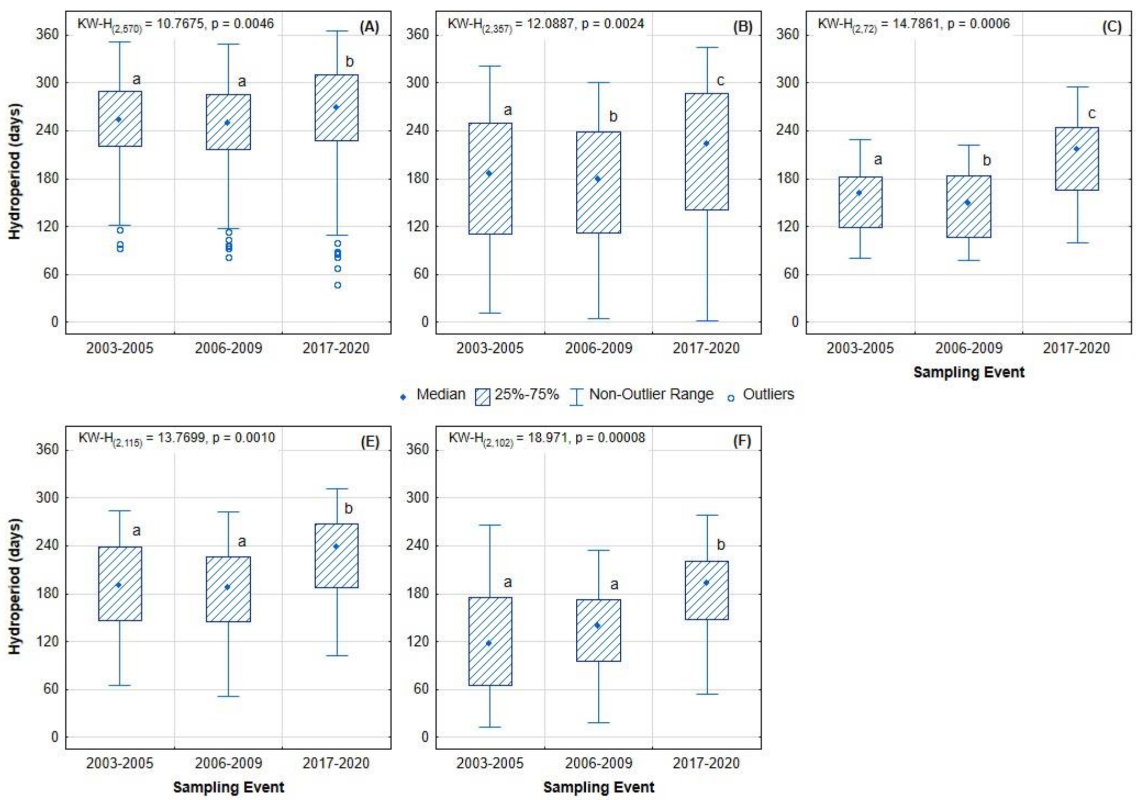

Figure 4: Box-plot showing median (box = 25-75% quartiles and whisker = non-outlier range) four-year average hydroperiod at sites that had ground elevation based on field measurements of water depth and EDEN water surface elevation, and surveyed in sub-populations A, B, C, E and F during three periods: 2003/2005, 2006/2009 and 2017/2020.

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

In comparison to sup-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 survey (Figure 4 and 5 B, C, D and E). The most distinct change in hydrologic condition was observed in sub-populations C and F, where mean hydroperiods were 50 and 64 days longer and mean water depths were 10.0 and 8.4 cm deeper during 2017/2020 than in 2003/2005, respectively. In sub-populations B and E, mean hydroperiods were 27 and 37 days longer, while mean water depths were 5.4 and 7.5 cm deeper in recent years than 15 years ago, respectively (Table 2; Figure 6).

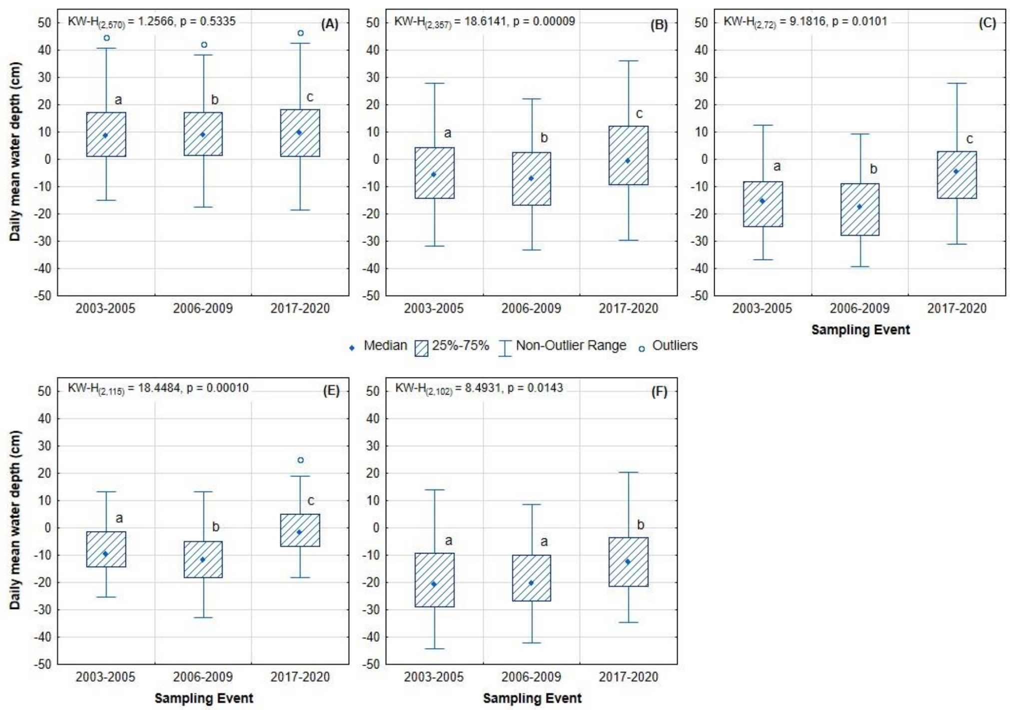

Figure 5: Box-plot showing median (box = 25-75% quartiles and whisker = non-outlier range) four-year average annual mean daily water depth at sites had ground elevation based on field measurements of water depth and EDEN water surface elevation, surveyed in sub-populations A, B, C, E and F during three periods: 2003/2005, 2006/2009 and 2017/2020.

Table 2: Four-year mean discontinuous hydroperiod and annual mean daily water depth at 2017/2020 vegetation survey sites in different regions of CSSS sub-populations A and sub-populations B, C, E and F. The values were calculated only the sites with field measurements of water depth, and surveyed during both 2003/2005 and 2017/2020 surveys. 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-population	**Region**	**N**	**4-year average hydroperiod (days)**				**4-year annual mean daily water depth (cm)**			
			2003/2005		2017/2020		2003/2005		2017/2020	
			mean (±sd)	median	mean (±sd)	median	mean (±sd)	median	mean (±sd)	median
A	hN	28	195 (±57)	201	188 (±76)	203	-1.0 (±8.4)	-1.5	-3.0 (±9.6)	-4.0
	hS	34	217 (±51)	231	237 (±55)	251	2.5 (±8.9)	4.5	5.5 (±9.0)	7.0
	W	127	269 (±45)	276	283 (±50)	297	12.4 (±9.8)	12.1	14.1 (±11.0)	14.5
B	-	119	181 (±81)	186	208 (±94)	223	-4.9 (±12.1)	-5.8	0.5 (±13.3)	-0.8
C	-	24	154 (±41)	161	204 (±55)	216	- 14.2 (±13.4)	-15.4	- 4.2 (±14.8)	-4.8
E	-	39	190 (±57)	190	227 (±50)	239	-8.2 (±9.8)	-9.5	-0.7 (±9.6)	-1.6
F	-	34	121 (±71)	118	185 (±52)	193	-19.0 (±14.0)	-20.7	-10.6 (±13.0)	-12.6

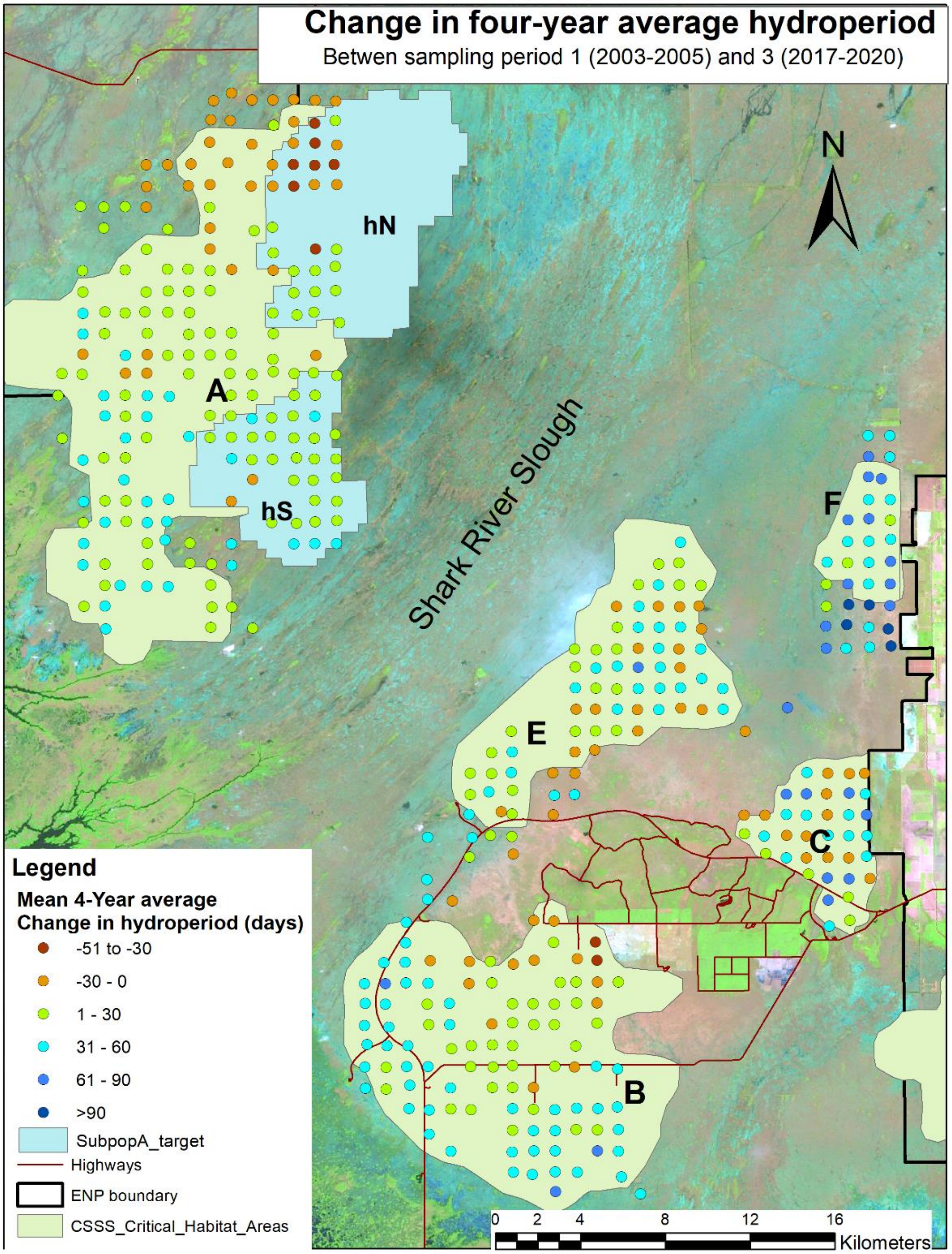

Figure 6: Change in four-year mean discontinuous hydroperiod between 2003/2005 and 2017/2020 survey periods at 2017/2020 vegetation survey sites in sub-populations A, B, C, E and F. The values were calculated only for those sites for which field measurements of water depth were available, and the sites were surveyed during both 2003/2005 and 2017/2020 surveys.

3.2 Vegetation Composition and Classification

During the 2017/2020 survey, vegetation was classified into the nine vegetation types that had been previously defined within the marl prairie landscape (Ross et al. 2006). However, some sites that were resurveyed this time were of a different vegetation type than what was present at those sites one and half decade ago, suggesting a shift in species composition in response to hydrologic changes over that period.

In sub-population A, 235 census sites and 26 transect sites were resurveyed during the period, half (55.4%) in either the hN or hS areas. Vegetation dynamics at the transect sites over 14 years (2003-2017) has been described in detail in Sah et al (2019). Resurveyed census sites also included 45 sites that were surveyed for the first time just four years ago, i.e., in 2016, and all of them were in the north-eastern portion (hN) of the sub-population. Distribution of vegetation types among the resurveyed census sites within this sub-population were not uniform (Figure 7). The western portion of the sub-population and hS area had a disproportionately high percentage (92.9% and 62.8%, respectively) of sites in one of the Marsh (M) vegetation types, which is characterized by longer hydroperiods. In hS, most (68%) sites were *Cladium* Marsh (CM), and the remaining one-third were *Cladium-Rhynchospora* Marsh (CRM), whereas in western-A, only 25% of sites were CM. Among the remaining sites, 37% were CRM, and 27% were marshes dominated by either beakrush (*Rhynchospora) or* spikerush (*Eleocharis*). Vegetation at two sites were co-dominated by *Paspalum* and *CIadium*. In contrast, in hN, almost half of the sites were wet prairie (WP) vegetation types, with shorter hydroperiods, and 60% of these were *Cladium* WP (CWP) and 32% were *Schizachyrium* WP (CWP). The *Schoenus* WP (SOWP) or *Muhlenbergia* WP types were present at three census sites.

Among the 250 resurveyed census sites in the four eastern sub-populations (B, C, E & F), 61% were wet prairie (WP) type. However, these sub-populations differed in character. For instance, at the majority (60%) of surveyed sites in sub-population E, vegetation was of the marsh type (Figure 7). In sub-population E, WP vegetation was present only at central, eastern, and southeastern sites. Among the sites with WP vegetation in these four sub-populations, 38% were *Cladium* WP. *Muhlenbergia*, *Schizachyrium* and *Schoenus* WP types were present at 29%, 22% and 11% 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 half of the marsh sites were the CM, while the rest comprised various combinations of *Cladium*, *Rhynchospora* and *Eleocharis* Marsh types.

Over the first two years (2017 and 2018) of the current survey, 114 sites were surveyed for the first time. While the vegetation types observed at these sites have been described in detail in Sah et al. (2019), a brief description of vegetation observed at census sites is mentioned here. All fourteen census sites surveyed for the first time in sub-populations A and E were marsh vegetation, specifically *Cladium* Marsh, *Cladium-Rhynchospora* Marsh and *Rhynchospora-Cladium* Marsh (Figure 7). In contrast, vegetation at the new sites in the area between sub-populations E and F (EF: 30 sites), and between C and F (CF: 27 sites) was mostly of the WP type (Figure 7). However, the sites in EF were more hydric in nature than those in CF. For instance, 61% of the sites in EF were characterized as Marsh, 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, *Schizachyrium* WP and *Cladium* WP (Figure 7).

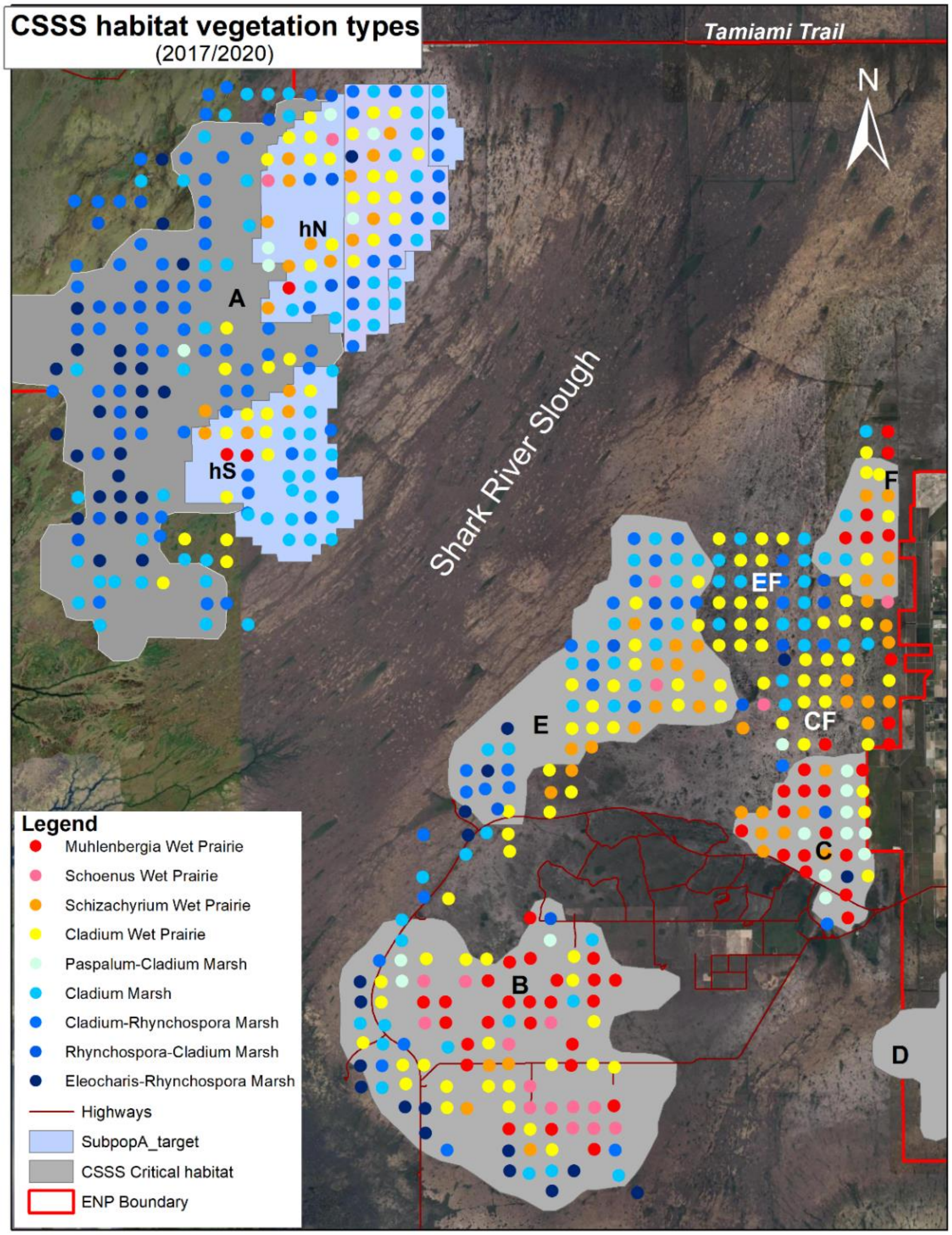

Figure 7: Spatial distribution of vegetation types at the 2017/2020 survey sites in sub-populations A, B, C, E and F. Vegetation type at each site was identified through cluster analysis of species cover values at these sites plus 608 census sites surveyed in three years (2003/2005). In the cluster analysis, 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 from the dry (red) to wet (dark blue) community types.

3.3 Vegetation Change (2003/2005 – 2017/2020)

In conjunction with hydrologic changes observed over these 17 years, a shift in vegetation composition was also detected at several sites in the surveyed sub-populations. In 2017/2020, both transect and census sites were resurveyed in sub-populations A, E and F, but only census sites in sub-population B and C. Vegetation change at Transect A sites has already been described in detail in Sah et al. (2018). Since a portion of Transect E was only recently surveyed in 2021, vegetation change in Transects E and F are not yet analyzed. Thus, the following analyses of vegetation change apply only to census sites in all five sub-populations.

In sub-populations B, C, E, and F, species composition in 2017/2020 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 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 2017/2020. Analysis was done for census sites surveyed during all three surveys.

Sub-populations/Regions (# of sites/survey)		**2003/2005 – 2006/2009**	**2006/2009 – 2017/2020**	**2003/2005 – 2017/2020**
A	**All** (184)	0.009 **(0.023)**	0.027 **(0.001)**	0.011 **(0.015)**
	hN (27)	0.036 (0.062)	0.018 **(0.023)**	0.023 (0.159)
	hS (33)	0.044 **(0.044)**	0.041 **(0.041)**	0.039 (0.058)
	W (124)	0.001 (0.353)	0.038 **(0.001)**	0.022 **(0.003)**
B (96)		0.063 **(0.002)**	0.041 **(0.002)**	0.085 **(0.001)**
C (35)		0.050 **(0.010)**	0.044 **(0.023)**	0.167 **(0.001)**
E (55)		0.073 **(0.001)**	0.077 **(0.001)**	0.239 **(0.001)**
F (29)		0.072 **(0.013)**	0.084 **(0.013)**	0.133 **(0.001)**

3.3.1 Change in vegetation-inferred hydroperiod

Across all sub-populations, vegetation-inferred hydroperiod differed significantly among the three surveys (Non-parametric Friedman ANOVA; $N = 399$, $df = 2$; $\chi2 = 53.5$; $p < 0.001$). Moreover, the change in inferred-hydroperiod was positively correlated with the change in 4-year average hydroperiod ($r = 0.29$; $p = <0.001$) and mean daily water depth ($r = 0.34$; $p = <0.001$) (**Figure 8**). However, the magnitude and direction of change in inferred-hydroperiod varied among sub-populations, and among different regions within some of these sub-populations.

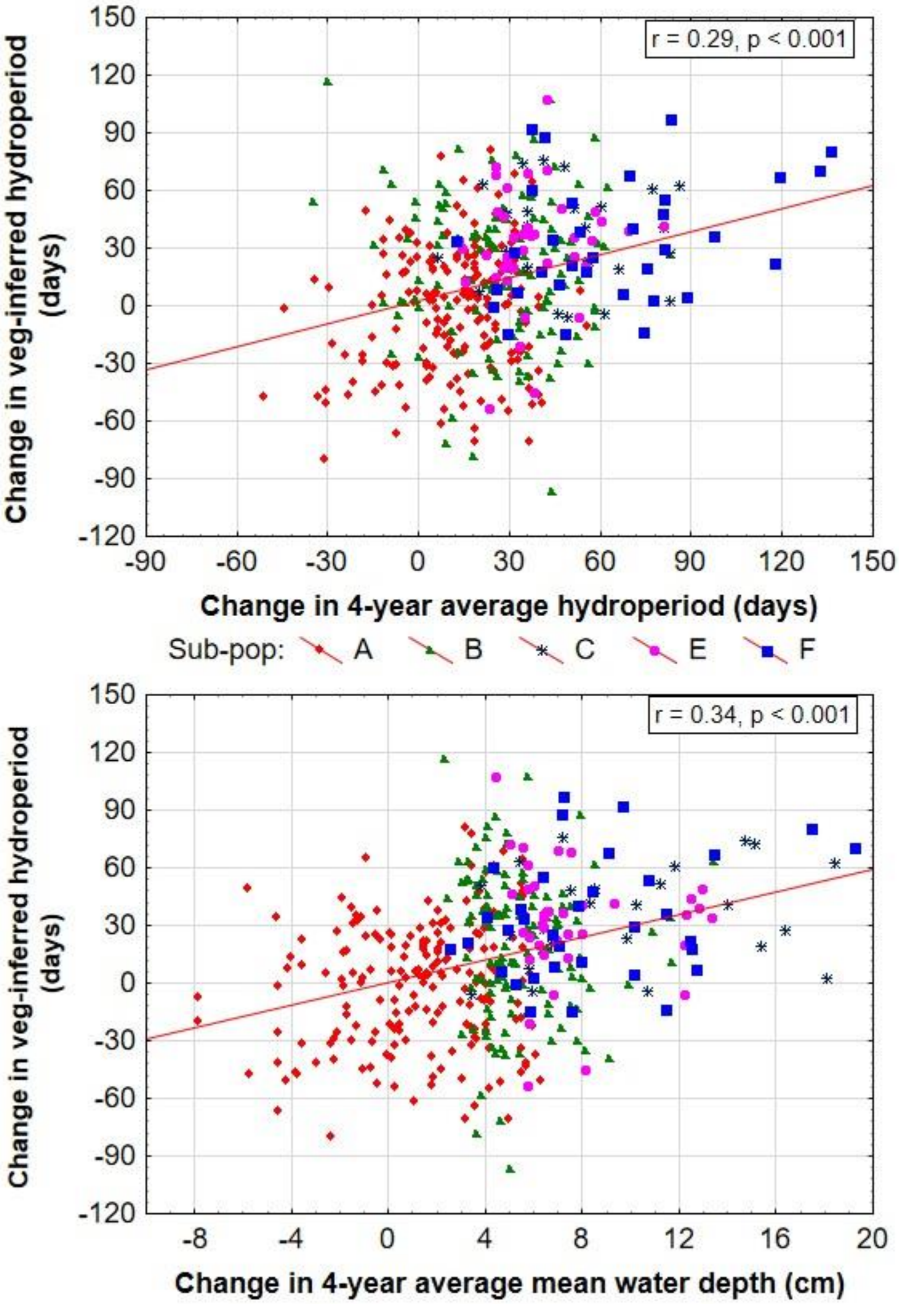

Figure 8: Relationship between change in hydrologic conditions (4-year average hydroperiod and mean water depth) and change in vegetation-inferred hydroperiod between 2003/2005 and 2017/2020 surveys at the sites surveyed in 2017/2020 in sub-population A, B, C, E and F.

3.3.1.1 Sub-population A census sites

In sub-population A, the mean (±SD) vegetation-inferred hydroperiods were 265 (±43), 270 (±46) and 264 (±40) days, and medians were 264, 274 and 270 days in 2003/2005 (E1), 2006/2009 (E2) and 2017/2020 (E3) surveys, respectively. The inferred-hydroperiod significantly differed among the three surveys, and it was significantly higher (Wilcoxon matched-pairs test: $p < 0.01$) in E2 than in both E1 and E3 surveys (Figure 9). The difference in inferred- hydroperiod between the E1 and E3 surveys was not significant. Nevertheless, the direction of change in inferred-hydroperiod varied spatially. Most (80%) of the sites in hN had shorter vegetation-inferred hydroperiod in 2017/2020 than in 2003/2005 (Figure 10). During the three surveys in hN, the mean inferred-hydroperiods were 236, 225 and 217 days, respectively. In contrast, at two-thirds of sites in hS, mean vegetation-inferred hydroperiod was higher in 2017/2020 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% sites had 2 to 64 days higher inferred-hydroperiod in 2020 than in 2016.

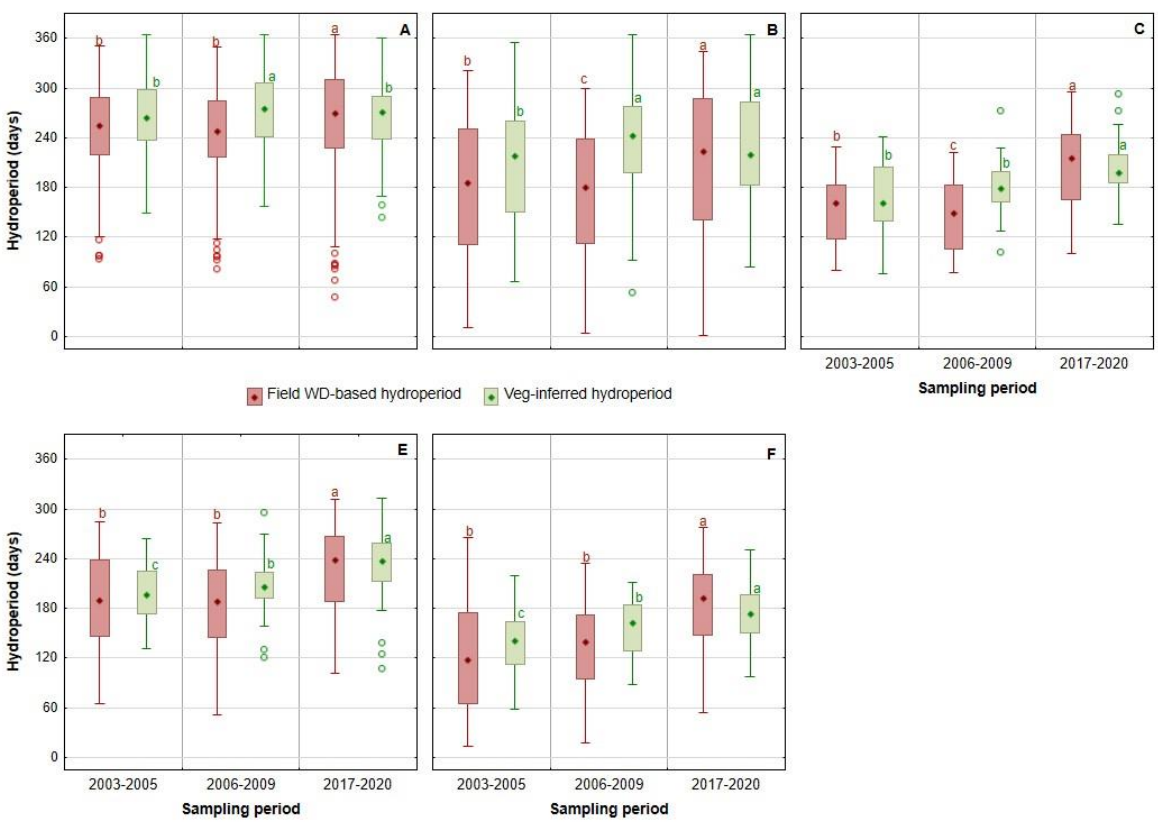

Figure 9: Box-plot showing median (box = 25-75% quartiles and whisker = non-outlier range) field water-depth hydroperiod (in red) and vegetation-inferred hydroperiod (days) (in green) averaged over census sites surveyed during 2003/2005, 2006/2009 and 2017/2020 surveys.

3.3.1.2 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 one and half decades of our study (Figure 10), the magnitude of vegetation change along the hydrologic gradient differed among these sub-populations. For instance, in sub-population B and E, mean vegetation-inferred hydroperiod increased by only 19-24 days, whereas it increased by 36 and 34 days in sub-population C and F, respectively, where the vegetation is a much drier type than in other sub-populations. Of course, changes in composition were not always spatially uniform within sub-populations. Notably, in sub-population B, increases in inferred-hydroperiod were concentrated in southern and western and some of northeastern sites, whereas inferred-hydroperiod increased more consistently throughout sub-populations C, E and F (Figure 10).

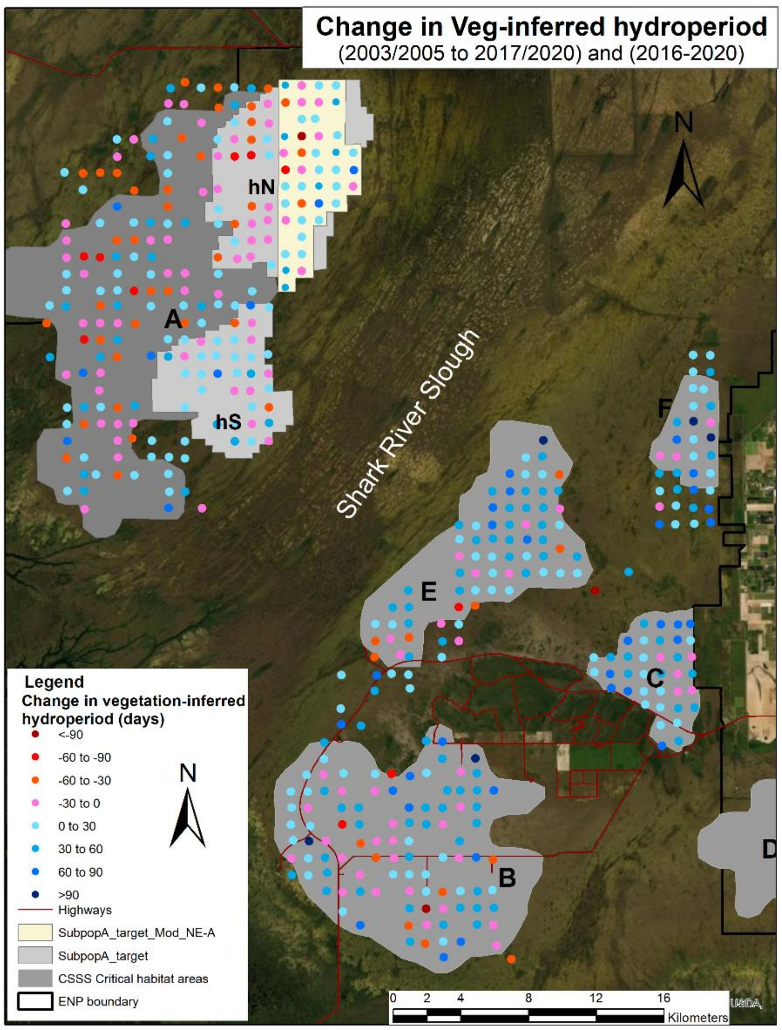

Figure 10: Map showing the spatial variation of changes in vegetation-inferred hydroperiod between 2003/2005 and 2017/2020 at the sites surveyed in both surveys in sub-populations A B, C, E, and F. In the eastern portion of hN region of sub-population A, change in vegetation-inferred hydroperiod at 45 sites are between 2016 and 2020 surveys.

3.3.2 *Change in vegetation types*

In concurrence with the significant differences described in overall species composition among survey years at census sites, vegetation type also changed at more than half (52%) of the sites during the fifteen-year period (Figure 11). However, the majority (73%) 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 167 sites that changed from one vegetation type to another, 94 remained in the marsh category. Most of these sites (M-M) were in the western portion of sub-population A, and the southwestern portion of sub-populations B and E. The 63 sites that changed from one prairie type to another (WP-WP) were mostly in the eastern portion of sub-population A, or in sub-populations B, C and F.

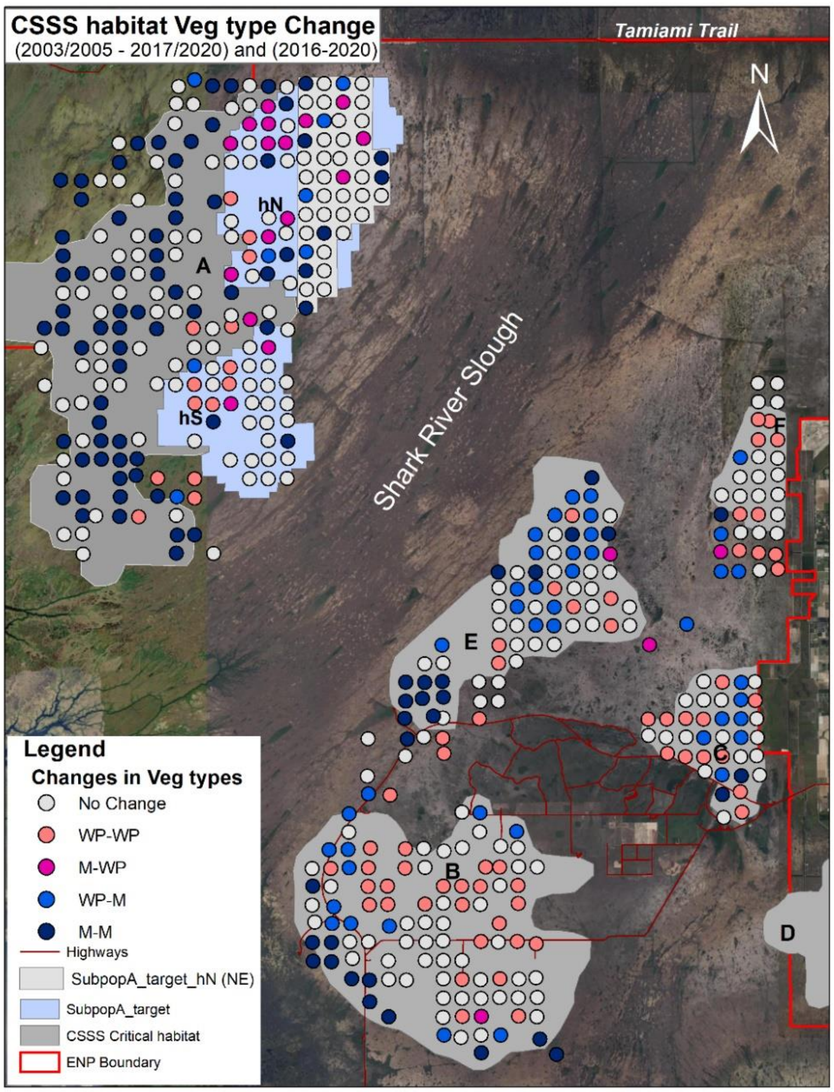

Figure 11: Change in vegetation types at the census and transect sites in sub-populations A, B, C, E and F between 2003/2005 and 2017/2020 surveys. WP-WP = One wet-prairie vegetation type to another wet-prairie type; M-WP = Marsh veg type to wet prairie type; WP-M = Wet prairie veg type to marsh type; M-M = One marsh veg type to another marsh type.

In sub-population A, vegetation at 12 sites changed from marsh to wet prairie type (M-WP) while four 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, suggesting a drying trend in those areas. In contrast, in sub-populations B, C, E and F, the majority of sites (42 of 46 sites) that showed a noticeable shift in vegetation composition between two categories changed from WP to marsh types (Figure 11), indicating the wetting trend in some portions 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 un-burned sites, i.e., for the 365 sites that did not burn between 2003 and 2008, and 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 group (Table 4). During the 2017/2020 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 4). Similarly, at sites that changed from WP to marsh type, the mean hydroperiod in the most recent survey was 237 days, i.e., 37 days higher than during 2003/2005 survey. At the sites that remained wet prairie or changed from one wet prairie type to another, the mean hydroperiods were 186 ± 64 and 181 ± 61 days, respectively, but those values were 32-36 days higher than in the 2003/2005 survey. In contrast, 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 2017/2020 survey were 175 ± 78 days and -4.7 ± 9.0 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 mean and minimum water depth at these sites were significantly lower than for the 2003/2005 survey period (Figure 12).

Table 4: Four-year mean discontinuous hydroperiod and annual mean daily water depth at 2017/2020 vegetation survey sites at which vegetation type either did not change, or changed from one type to another.

Veg change group	N	4-year average hydroperiod (days)			4-year mean daily water depth (cm)		
		2003/2005	2017/2020	p-value	2003/2005	2017/2020	p-value
No change- Wet prairie (WP)	76	154 ± 62	186 ± 64	<0.001	11.9 ± 11.0	-6.2 ± 9.9	<0.001
WP-WP	55	145 ± 66	181 ± 61	<0.001	-12.9 ± 12.1	-7.1 ± 10.2	<0.001
WP-M	33	200 ± 63	237 ± 67	<0.001	-4.6 ± 12.1	2.4 ± 12.8	<0.001
No change – Marsh (M)	97	256 ± 45	274 ± 45	<0.001	9.0 ± 9.2	11.8 ± 10.1	<0.001
M-M	90	269 ± 47	290 ± 50	<0.001	12.1 ± 10.1	15.3 ± 10.8	<0.001
M-WP	14	175 ± 52	175 ± 78	0.826	-4.8 ± 6.9	-4.7 ± 9.0	0.925

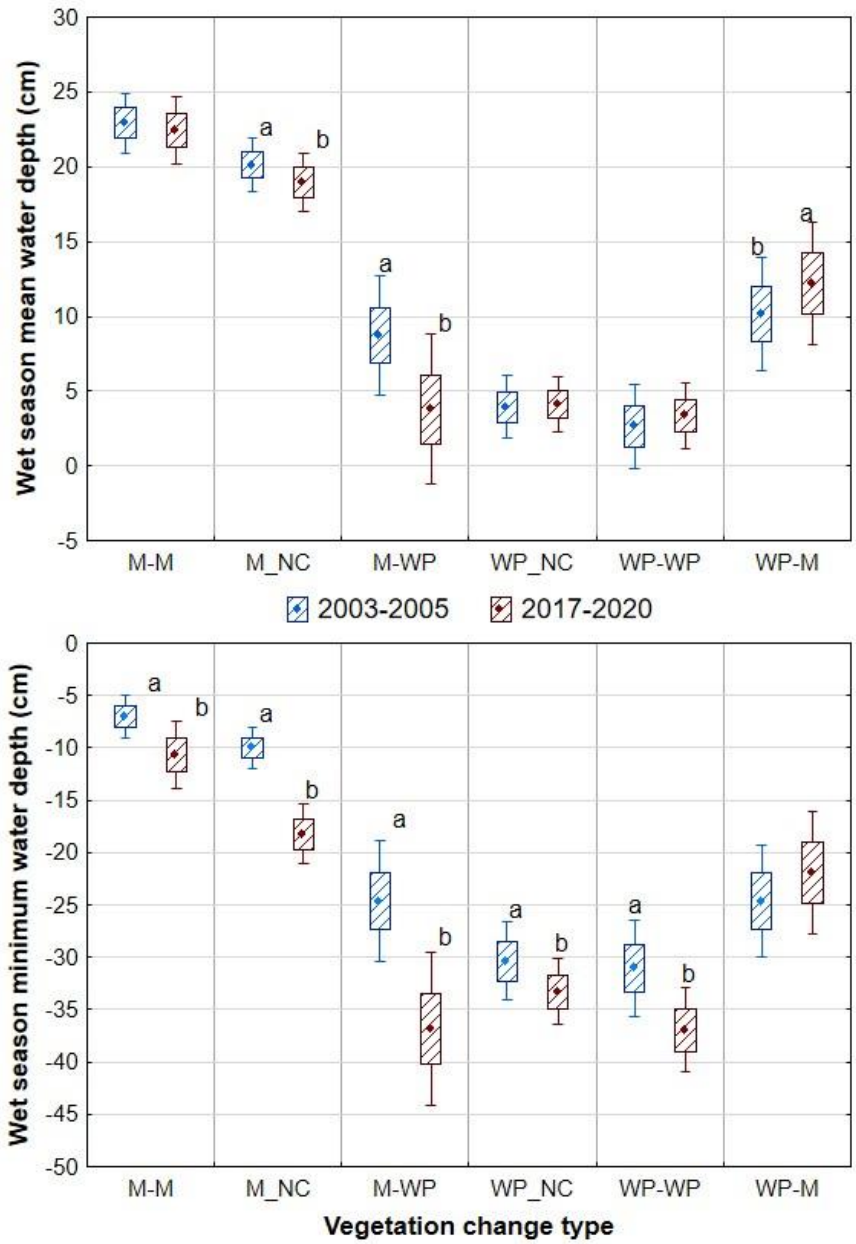

Figure 12: 4-year average wet season mean and minimum water depth (cm) during 2003/2005 and 2017/2020 surveys at the sites that changed from marsh vegetation type to wet prairie type. M= Marsh, WP = Wet prairie, NC = No change.

3.3.3 Trajectory analysis

The spatially differentiated change in vegetation-inferred hydroperiod within sub-population A was paralleled by the trajectory analysis results, which also revealed a variable direction of shift in vegetation composition. Less than half (40.7%) of census sites showed a shift in vegetation composition toward drier type. Of those sites, the magnitude (delta) and rate (slope) of trajectory shift was statistically significant at 37% of the sites, and most of these were within hN and adjacent areas (Figure 13; Appendix A1). Among the sites (59.3%), that showed a wetting trend, the trajectory shift was statistically significant at about 35% of the sites. These sites were mostly in western sub-population A and the hS area (Figure 13).

Across the four eastern sub-populations, only 12.6% 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 7% of the sites. In contrast, In contrast, among the sites that showed a shift in vegetation composition toward wetter type, the magnitude (delta) of trajectory shift was statistically significant at 55.3% of the sites.

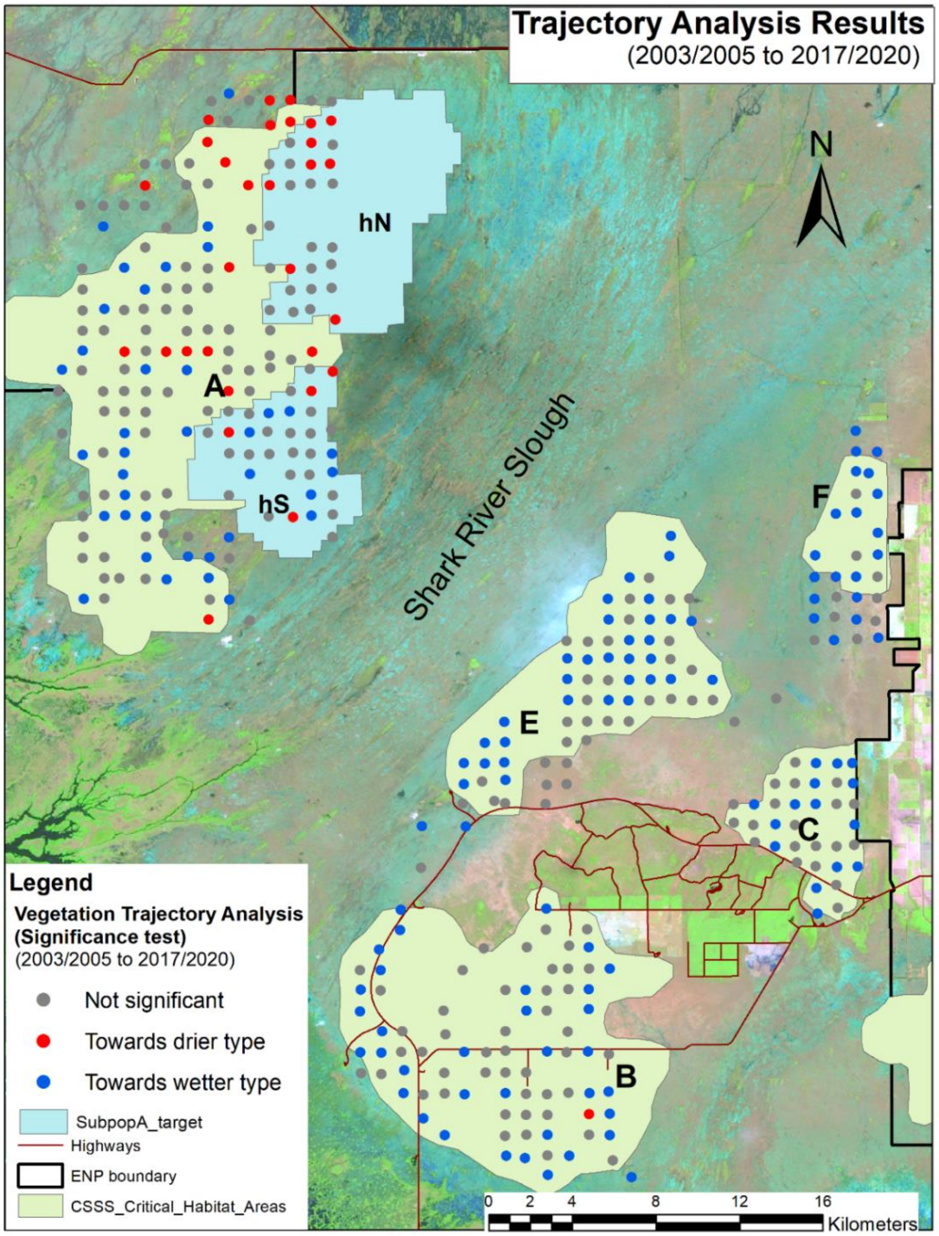

Figure 13: Sites showing a significant shift in vegetation composition between 2003/2005 and 2017/2020 surveys in sub-populations A, B, C, E and F. Significance of site trajectory was obtained by trajectory analysis. Only the sites that were not burned between 2003 and 2008 and were surveyed at least 3 times were included in trajectory analysis.

The magnitude and rate of shift in vegetation composition in trajectory analysis, represented by delta and slope, respectively, 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 reflected in the statistics produced in the trajectory analysis ($r^2 > 0.16$, $p < 0.01$) (Figure 14). Similar relationships of vegetation change to dry and wet season mean and wet season minimum water depths were observed (Figure 15 and 16d). Notably, while dry season maximum water depth had a significant relationship to vegetation shift (Figure 16a), species composition was unrelated to change in wet season maximum water depth (Figure 16b).

As expected, most of sites that changed from marsh to prairie type had negative delta values, indicating a shift toward drier vegetation type. Most of those sites were in the northeastern portion of sub-population A (Figure 17). Similarly, several sites in sub-population F experienced wetter water conditions in recent years, but the vegetation shift at those sites was minimal (Figure 17). In 2003/2005, the majority of these sites had been of the wet prairie type, and remained so in the most recent survey.

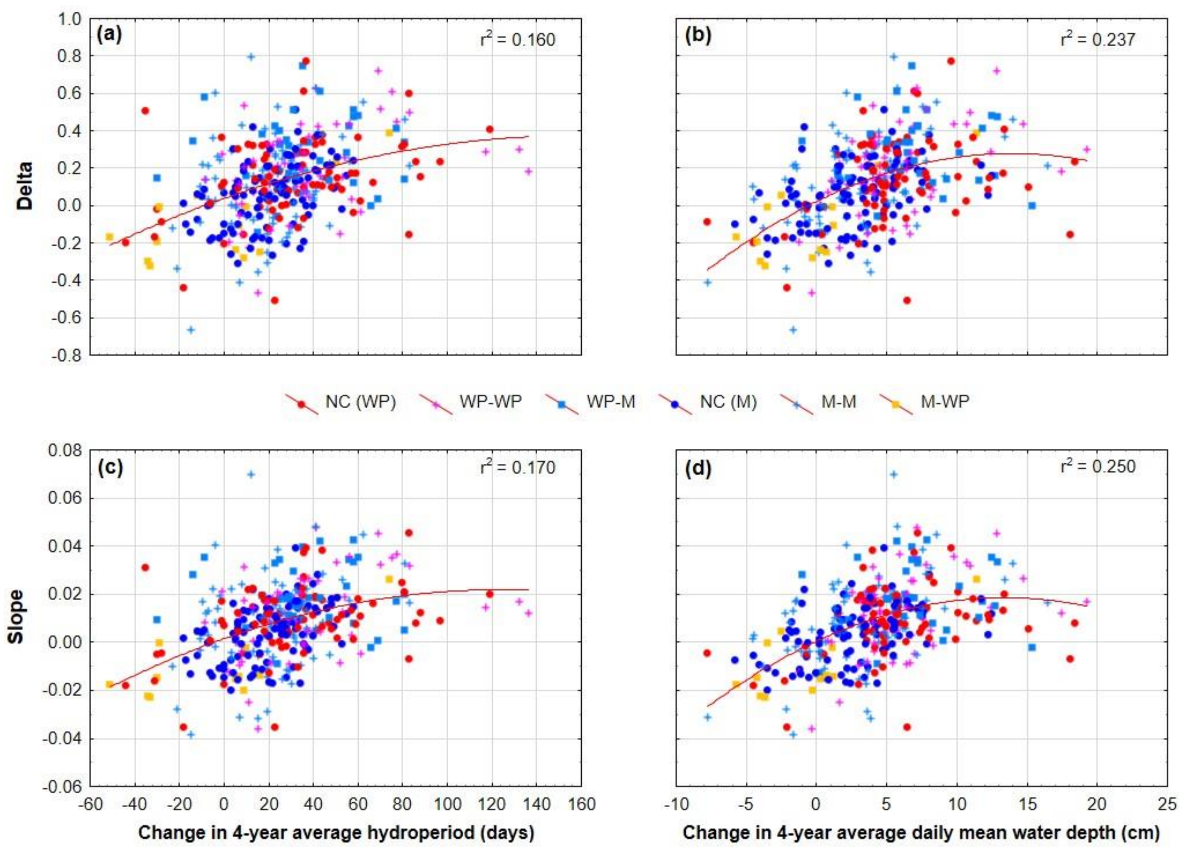

Figure 14: Relationship between change in hydrologic conditions (4-year mean hydroperiod and water depth) and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within NMDS ordination space. Color of symbols represent no change or change in vegetation types. NC = No change; M = Marsh; WP = Wet prairie.

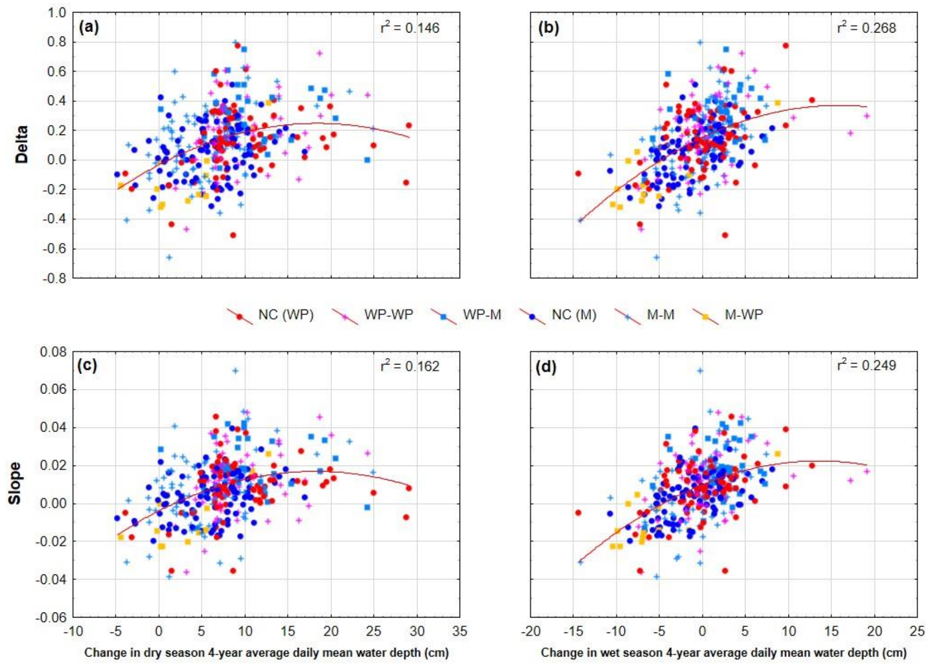

Figure 15: Relationship between change in dry and wet season mean and minimum water depth and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within ordination space. Color of symbols represent no change or change in vegetation types. NC = No change; M = Marsh; WP = Wet prairie. NC = No change; M = Marsh; WP = Wet prairie.

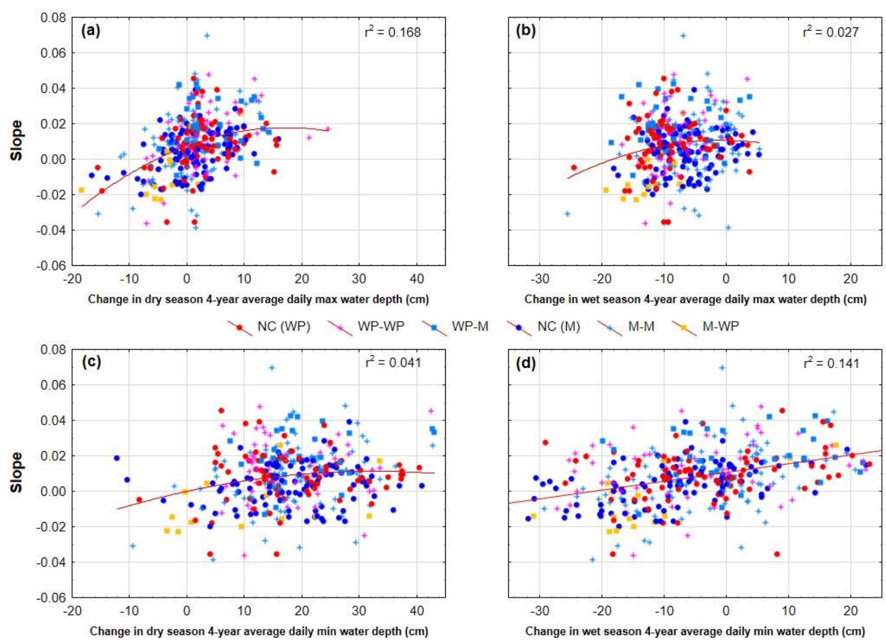

Figure 16: Relationship between change in dry and wet season maximum and minimum water depth and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within ordination space. Color of symbols represent no change or change in vegetation types. NC = No change; M = Marsh; WP = Wet prairie.

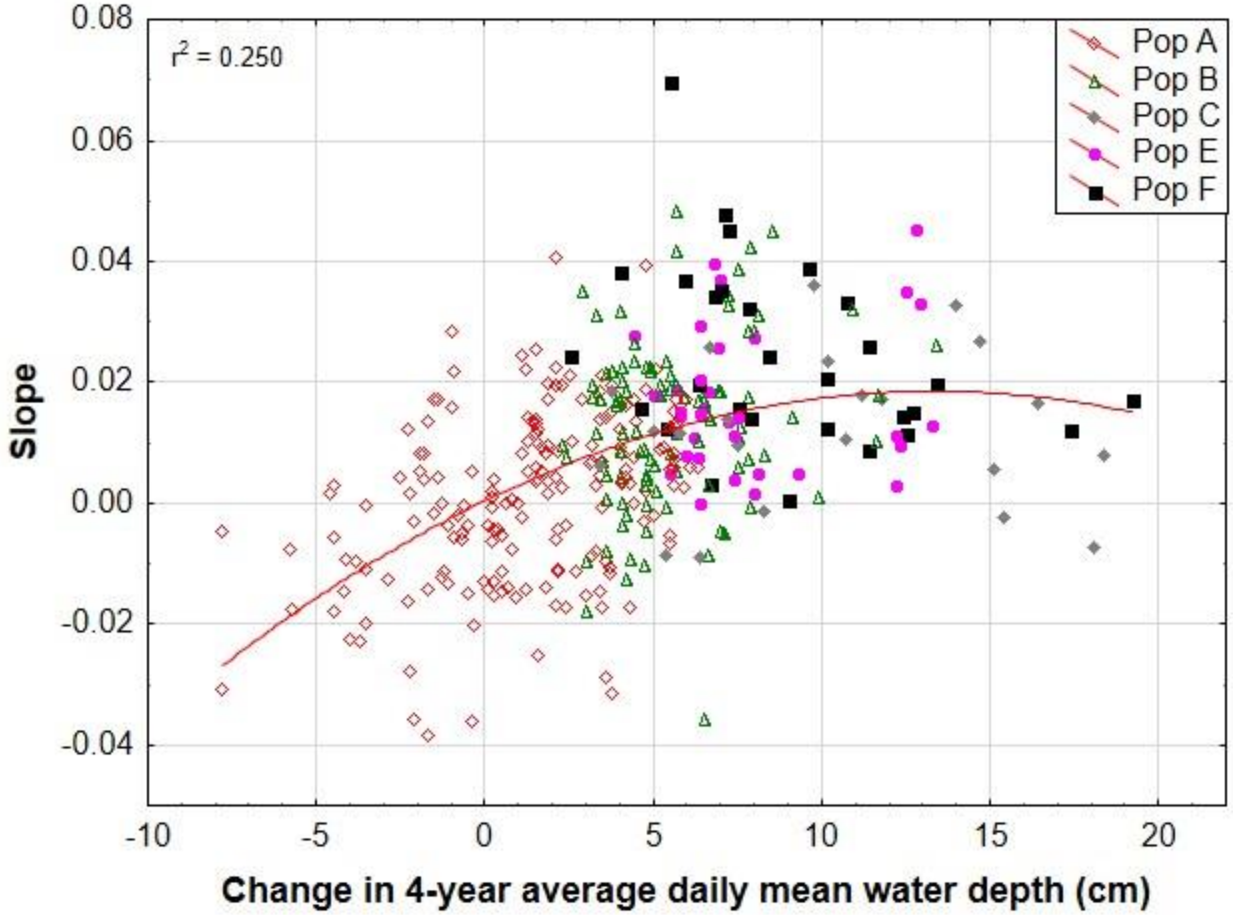

Figure 17: Relationship between change in 4-year daily mean water depth and rate (slope) of vegetation change. The slope is the statistics obtained in trajectory analysis, representing the shift in position of sites the hydrology vector within NMDS ordination space. Color of symbols represent habitat of sparrow sub-populations (A, B, C, E and F).

3.4 Vegetation Structure and Biomass

Vegetation change over fifteen years was marked also by changes in vegetation structure (vegetation total cover, green cover, and height) and aboveground biomass (Figure 18; Appendix A2). 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 was significantly higher (General linear mixed mode (GLMM)l: Tukey test, $p<0.05$) during the recent survey (2017/2020) than during the initial (2003/2005) survey, but it was not statistically different from the value during the 2006/2009 survey (Figure 18A). However, in sub-population C, the mean cover was lower during the most recent survey than during the previous surveys, possibly due to an increase in wetness at some sites. In E and F, differences in mean cover among three surveys were not statistically significant. In comparison to vegetation cover, mean vegetation height was significantly higher in 2017/2020 than in the previous two surveys in all sub-populations except E (Figure 18B); mean height during 2003/2005 and 2006/2009 did not differ.

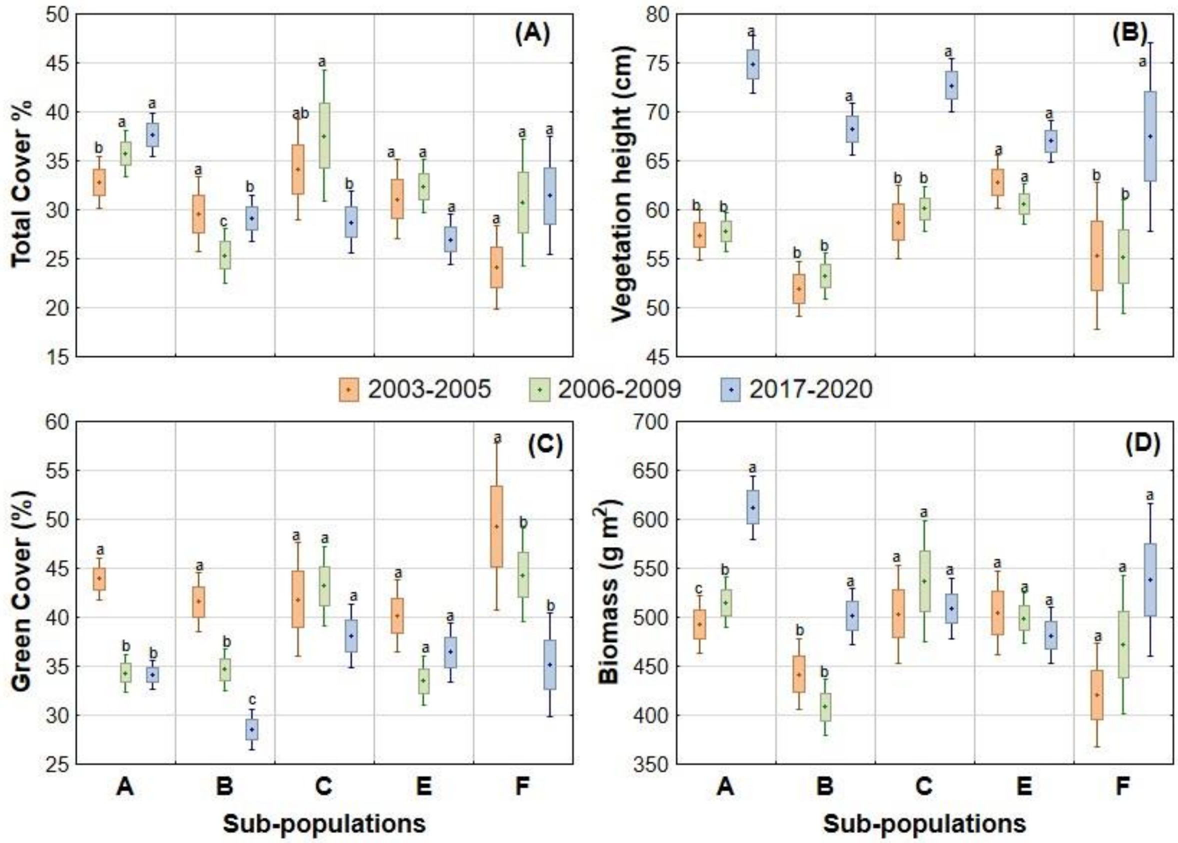

Figure 18: Box-plots (mean, SE, 95% CI) showing the vegetation structure, (A) total vegetation cover, (B) vegetation height, (C green vegetation cover (as a percent of total cover), and (D) aboveground biomass in four sub-populations within which a number of sites were surveyed during three surveys, 2003/2005, 2006/2009, and 2017/2020.

Over the full study period (2003-2020), green percent cover, expressed as a percent of total vegetation cover, decreased in all sub-populations except in E (Figure 18C), indicating the accumulation of dead materials over time. In sub-populations A and B, the increase in total cover was accompanied by an increase in mean above ground biomass (Figure 18D). In these areas, aboveground biomass in 2017/2020 was almost 25% higher than 1.5 decades earlier. However, aboveground biomass in sub-population E was slightly lower in 2017/2020 than the 2003/2005 survey, though the difference was not statistically significant. 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 the other three sub-populations were not so strong at the surveyed sites.

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 (Appendix A2).

3.5 Fire and Vegetation

Vegetation composition at the surveyed sites was also affected by fires that burned several sites between 2003 and 2019 (Table 5). 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 census sites in sub-populations A-F that were sampled for the first time in 2003/2005), 138 burned at least once in 17 years, and 21 of those sites burned two or three times during the period. Among the 138 burned sites, only 95 were resampled during the recent (2017/2020) survey (Figure 19). Moreover, while 204 sites burned in 2020 fires, only two sites, both surveyed for the first time in 2016, were resurveyed after fire in 2020. Many of those 2020 burn sites are scheduled to be surveyed between 2021-2024.

Table 5: Number of census sites that were first time surveyed during 2003/2005 survey and burned between 2003 and 2020.

Sub-Population	2003	2005	2006	2007	2008	2012	2014	2015	2017	2018	2019	2020	Total # of Sites
A	4		2	2	16		9	13			3	178	227
B	14	14		7					6	3	12	19	75
C				2		3						7	12
D	9										8		17
E	1				9								10
F	1				19	4					1		25
Total	**29**	**14**	**2**	**11**	**44**	**7**	**9**	**13**	**6**	**3**	**24**	**204**	**366**

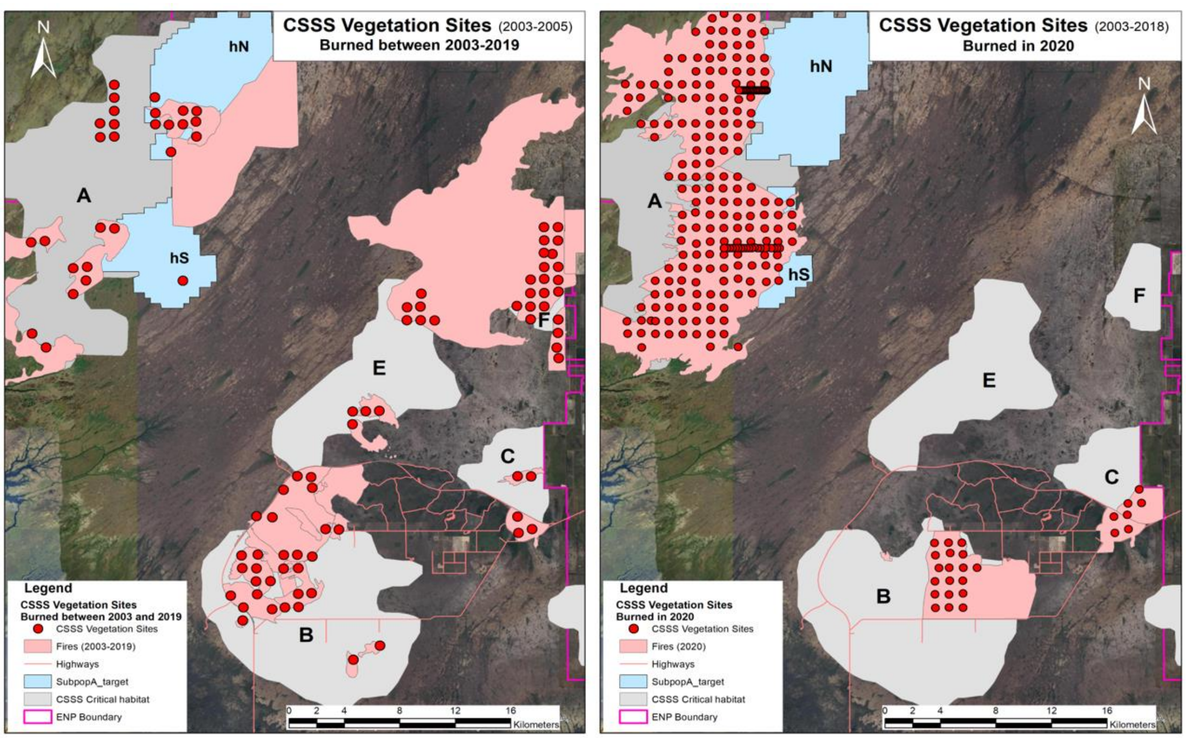

Figure 19: CSSS vegetation survey sites burned between 2003 and 2020. (A) Burned census sites that were surveyed in both 2003/2005 and 2017/2020 samplings. (B) Both transect and census vegetation sites burned in 2020.

For the sites burned between 2003 and 2008, vegetation dynamics up to six post-fire years were described in detail in previous reports (Sah et al. 2011, 2015). Twelve of those census sites burned again between 2014 and 2019. Out of 62 sites burned after 2008, post-fire survey was done for the first time at 36 sites during the recent survey. Thus, vegetation data from the 97 burned census sites surveyed between 2017 and 2020 represented a range of 0-16 years after fire. The detailed analysis of vegetation dynamics in relation to fire and pre- and post-fire hydrology will be presented in next year's report, which will include a comprehensive analysis of the five-year (2017-2021) surveys. Preliminary results from the analysis of vegetation dynamics revealed that vegetation type at 85% of the burned sites either did not change, or changed but remained within the same broad two categories, wet prairie and marsh. At 13 sites, post-fire vegetation changed from prairie to marsh type, while only at two sites was the change from marsh to prairie type.

Changes in vegetation structural characteristics are summarized here for only 2005- and 2008 burn groups, as the sites in these groups were surveyed up to 6 post-fire years, and then recently again after 9-16 years of burn. Also, the 2005-burn group primarily included the sub-population B sites 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 in sub-populations A, E and F. Analysis of structural characteristics revealed that even 13-14 years after fire, vegetation cover at the 2005-burn sites was only 61% of pre-burn, whereas at the 2008-burn sites, vegetation cover (87% - 115%) had almost fully recovered to the pre-burn level (Figure 20).

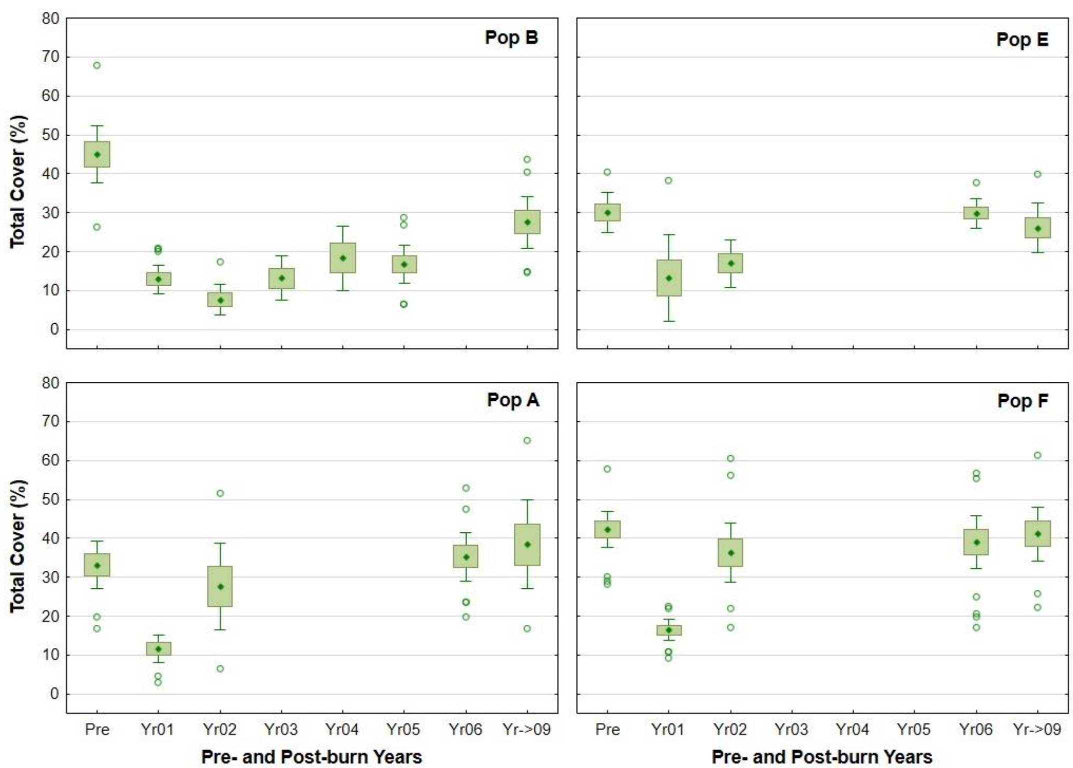

Figure 20: Box plots (Mean, ±SD and 95% CI) of vegetation cover in pre- and post-burn survey years at the sites burned in 2005 (Sub-population B), and 2008 (Sub-populations A, E and F).

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 A3). 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 21).

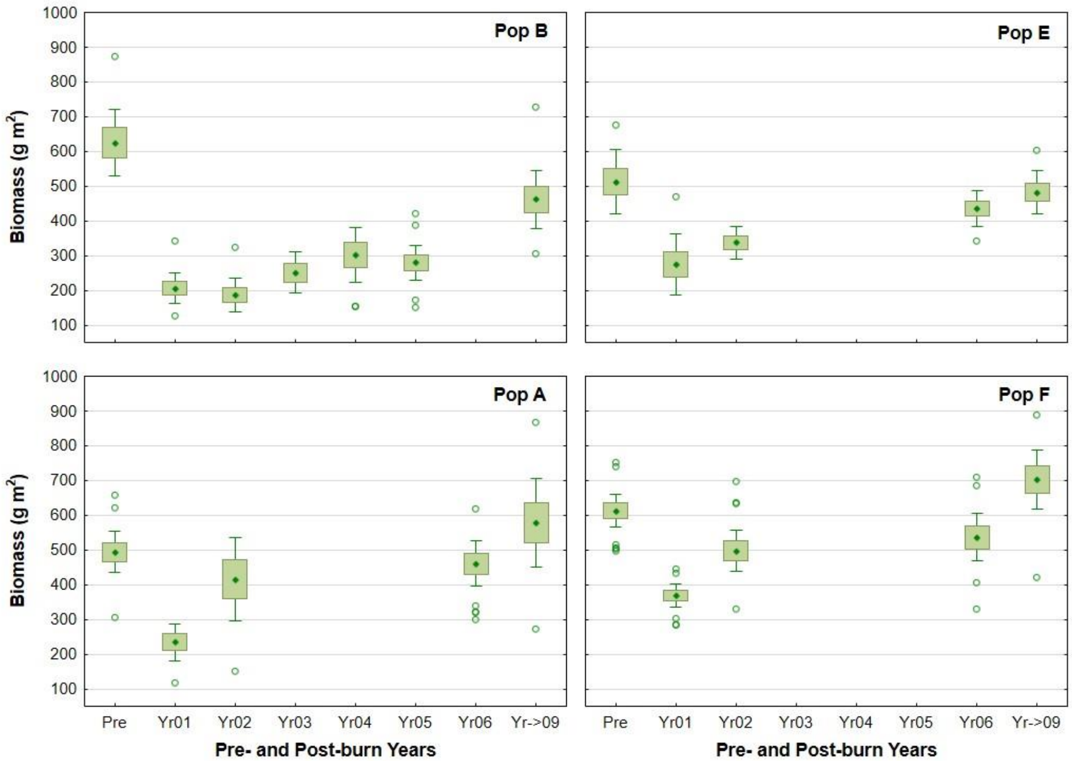

Figure 21: Box plots (Mean, ±SD and 95% CI) of aboveground plant biomass in pre- and post-burn survey years at the sites burned in 2005 (Sub-population B), and 2008 (Sub-populations A, E and F).

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 over three years, 2017-2019. In those three years, 565 sparrow census points were visited at least once in six sub-populations (A-F), while 404 points were visited all three years. Among those 565 points, 145 (25.7%) had at least one bird recorded in one of those years (Figure 22). The number of census points visited in six sub-populations ranged between 28 in sub-population F to 178 in sub-population B, whereas the percent of visited sites with sparrow records ranged from 1.3% in sub-population A to 44.4% in sub-population B (Figure 23a). 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). Sub-population D was not included in this ongoing vegetation monitoring program. 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 four years (2017-2020). Altogether, 306 vegetation survey plots coincided with sparrow census points, and sparrows were observed in 100 (32.7%) of them at least once in three years (2017-2019). The percent of vegetation sites with sparrows ranged between 1.1% in sub-population A and 61.4% in sub-population B (Figure 23a).

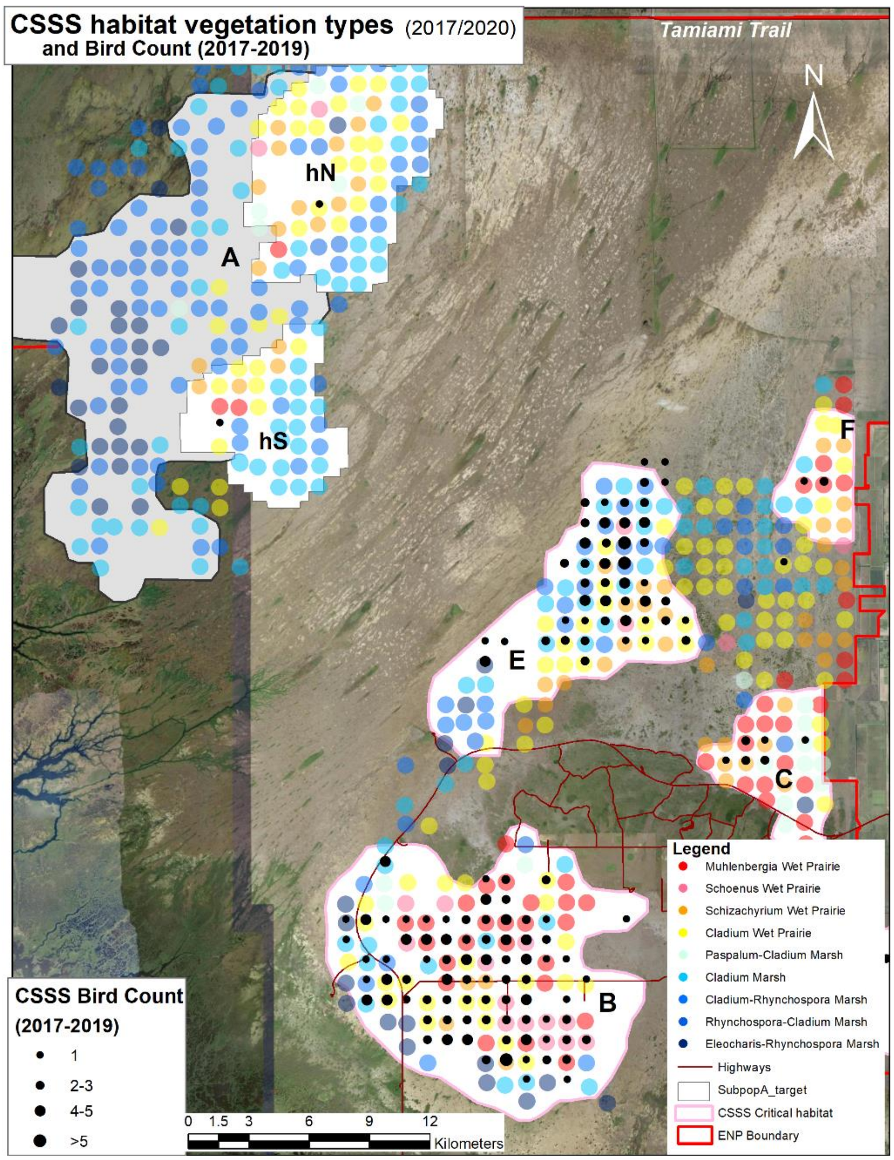

Figure 22: Map showing the vegetation types at the census sites (in background) surveyed between 2017 and 2020 and the number of birds at the sparrow census survey points with at least one bird recorded during the annual sparrow survey in any of three years (2017-2019).

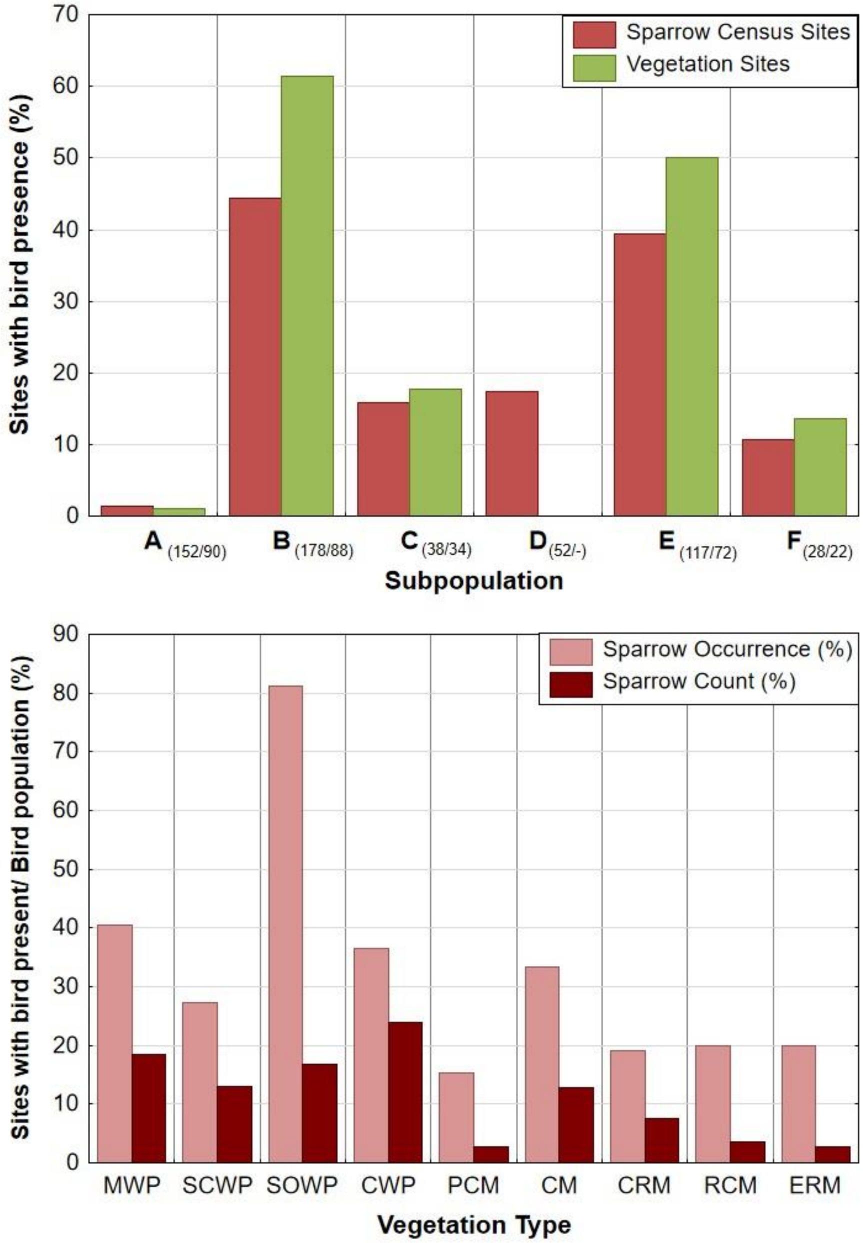

Figure 23: Percent of sites at which at least one sparrow was recorded during the annual sparrow survey in any of three years (2017-2019). Percent of sites with sparrows are by sub-populations (A) and vegetation types (B). MWP = *Muhlenbergia* Wet Prairie (WP); SCWP = *Schizachyrium* WP; SOWP = *Schoenus* WP; PCM = *Paspalum-Cladium* Marsh, CM = Cladium Marsh; CRM = *Cladium-Rhynchospora* Marsh; RCM = *Rhynchospora-Cladium* Marsh; ERM = *Eleocharis-Rhynchospora* Marsh. (A) Numbers in parenthesis represent the number of sparrow survey points and vegetation survey sites visited for bird count at least once over three years (2017-2019) and for vegetation survey over four years (2017-2020), respectively.

The vegetation survey sites represented all nine vegetation types, ranging from 10 sites of *Rhynchospora-Cladium* Marsh to 71 sites of *Cladium Wet Prairie*. However, sparrows were distributed uniformly across all vegetation types. Sparrows occurred in higher number in prairie sites than marsh sites (Figure 23b). For instance, CSSS occupied more than three-fourths of *Schoenus* Wet Prairie site (n = 13) and 41% of *Muhlenbergia* Wet Prairie, whereas only one-fifth of marsh sites, except those with *Cladium* Marsh, had sparrow records in those years. Likewise, sparrows occurred at 37% of *Cladium* Wet Prairie sites, more than the *Cladium* Marsh sites (33%). Given the differences in the number of sites visited per vegetation type, *Cladium* Wet Prairie that was present at 23% of visited vegetation sites had the highest percent of bird occurrence and nearly the same proportion of the total sparrow count over the three-year period (Appendix A4).

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 24). 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 (2016-2019), sparrow occurrence was mostly restricted to *Cladium* Wet Prairie within the hN and hS regions (Figure 25).

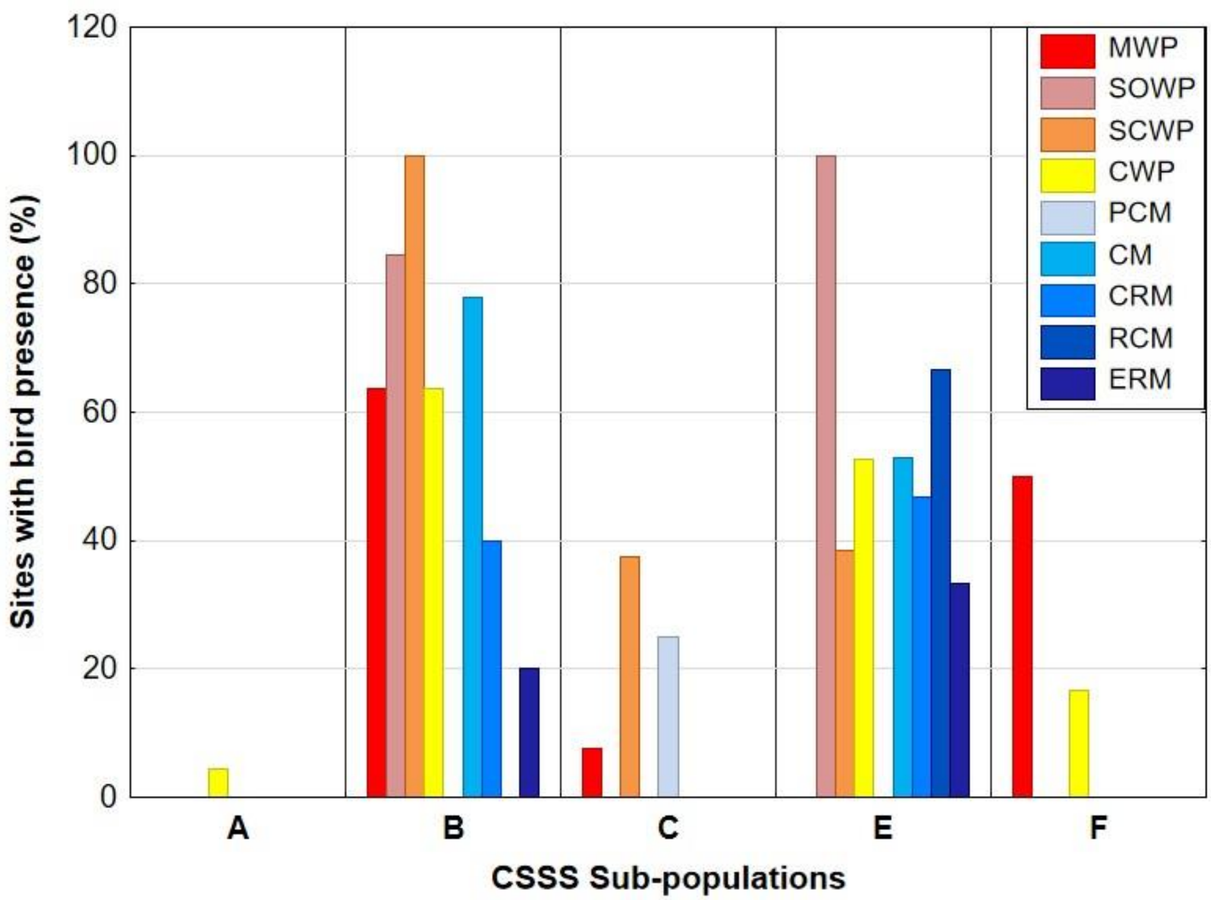

Figure 24: Percent of sites with different vegetation types separately in each of five sub-populations that had sparrows recorded during the annual sparrow survey in any of three years (2017-2019). MWP = *Muhlenbergia* Wet Prairie (WP); SCWP = *Schizachyrium* WP; SOWP = *Schoenus* WP; PCM = *Paspalum-Cladium* Marsh, CM = Cladium Marsh; CRM = *Cladium-Rhynchospora* Marsh; RCM = *Rhynchospora-Cladium* Marsh; ERM = *Eleocharis-Rhynchospora* Marsh.

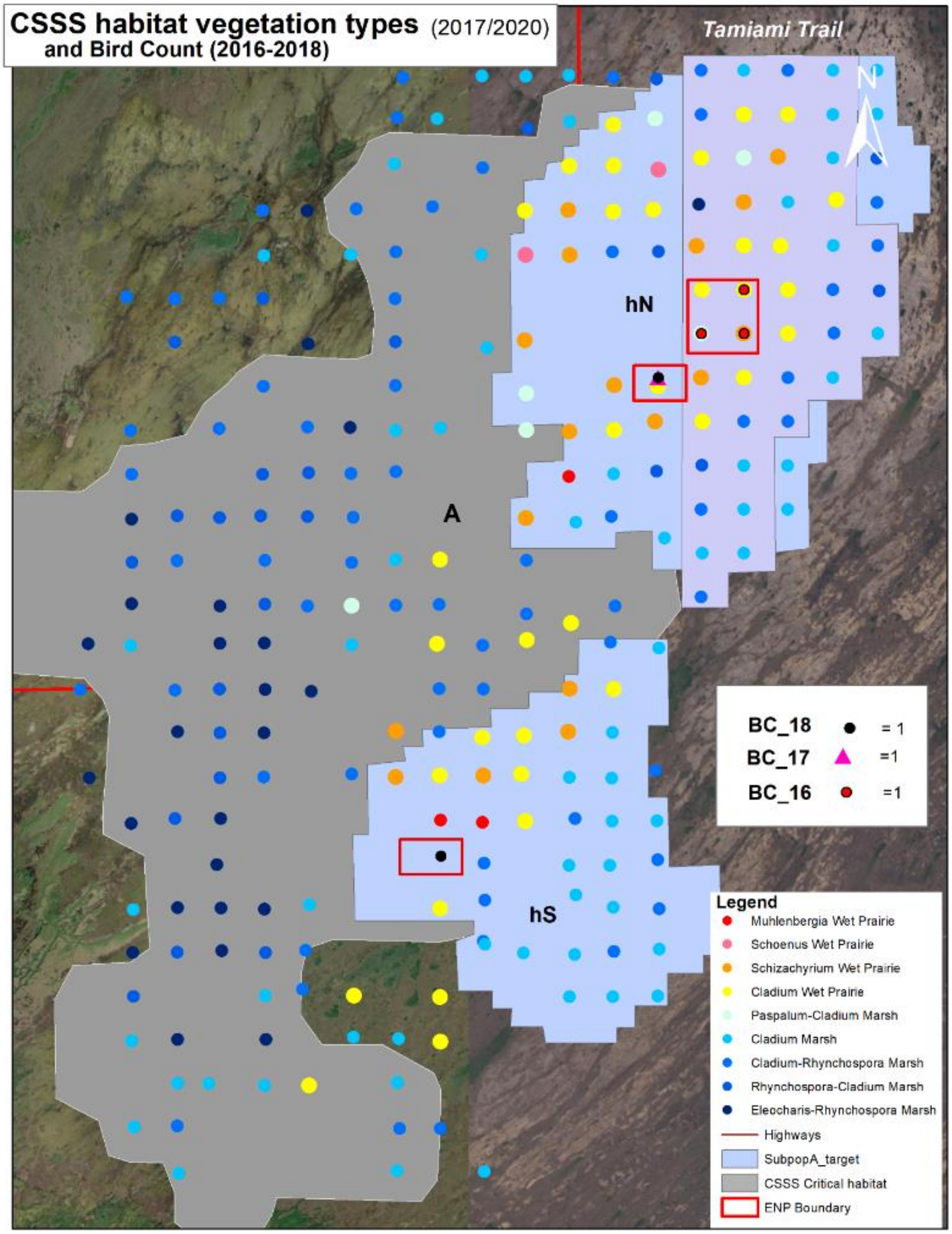

Figure 25: Distribution of vegetation types and the sites at which sparrows were recorded during the annual sparrow survey between 2016-2019. Sites where birds were recorded are marked by red rectangle.

4. Discussion

In the southern Everglades marl prairies on both sides of Shark River Slough, hydrologic conditions have changed over recent decades (2003-2020), 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 Combine 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 10), suggesting that wetting trend is not ubiquitous in that region too. 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. 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-12s structures. These regulations caused consistently low water levels at NP-205 and nearby areas for several years, resulting in a less hydric vegetation type in the northeastern part of sub-population A (Sah et al. 2011; 2016). 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 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 23; *see also* Sah et al. 2016). The improving trend in marl prairie habitat conditions is expected to continue under the planned management activities described in CEPP. 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). In this scenario, flow connectivity between Water Conservation Areas 3A and 3B will be restored and water will be allowed to flow eastward and southward to the Park (USACE 2014), 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. A thorough investigation using species indicators of sea level rise along transects in this portion of CSSS habitat could only 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 WCAs into the Park. In recent years, the NESRS region received more water delivery from the WCAs during the 2016 emergency operations (Abtew & Ciuca, 2017), and also due to implementation of the MOD Water Delivery Project components, including the Increment (Increment 1, 1.1, 1.2 and 2) Field Tests (USACE, 2020). Most of those waters flow 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 that runs through the southern SRS and south of Sub-population A along the marl-prairie slough gradients (Sah et al. 2020). 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 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), but also during the annual CSSS survey, sparrow was recorded at least at one site as recent as in 2018 (Figure 23).

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 Shark River Slough. While large portion of this sub-population has still prairie vegetation, a region 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 wetter vegetation type at most sites, and 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, completed under the C-111 South Dade Project in 2002, were earlier operated under Interim Operational Plan (IOP) until 2012, and then under ERTP between 2012 and 2015 to provide protection for the adjacent CSSS habitat by delivering sufficient water to the habitats of the CSSS-E and CSSS-F and to provide flood mitigation to agricultural lands east of C-111 Canal by controlling seepage out of ENP (USFWS 2002, 2006; USACE 2011, 2020). These pump structures are currently operated under Combined Operation Plan (COP) to continue providing the needed water to the CSSS habitats within the Park and the flood protection for the adjacent agricultural lands to the east of the canal (USACE 2020). In fact, the pumps 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 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.

Our most recent surveys were done 1-4 years after the extreme event of dry season high water condition 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 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 5; Table 2). Moreover, in sub-populations F, and some portions of C and E, we observed vegetation shift towards more mesic type, but at most of the sites, 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, that occupy predominantly prairie sites (Figure 22).

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, might have further enhanced the vegetation trajectory to wetter type in that region, but the time between such events and this study has been short (<3 years), 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 were 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. 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, and the effects of those fires in that area have not yet been assessed. In this year's analysis, we have not included vegetation trajectory in burned plots. Sah et al. (2015) described the vegetation dynamics at sites burned between 2003 and 2008 in much detail; preliminary analysis of vegetation structure and biomass suggested that the effects of post-fire flooding were much more severe in some of 2005-burned area, as previously described (Sah et al. 2016) and also observed during this study. Even 13-14 years after the 2005 fire, vegetation cover and biomass are still only 60% of pre-burn conditions (Figures 19, 20). Surprisingly, even though vegetation cover has not fully recovered at these 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 sparrow recorded in any of three years, 2017-2019. The reason could that at some of the burned sites, the change in vegetation type seems mostly driven by hydrologic changes, as the majority 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. We will have more understanding of the long-term vegetation dynamics in response to fire and flooding after detailed analysis of vegetation trajectories at burned sites in both eastern and western prairies, planned for the 2021 report, when we will present a comprehensive analysis of data from all sites surveyed over five years (2017-2021) under the current 5-year term of the ongoing study.

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 in the northeastern and central-eastern portion of sub-population A. In this connection, 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. Because of unprecedented highwater conditions in early dry season of 2020-2021, a large volume of water was delivered into the Park. 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 having 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 & 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: 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 and sampled at least three times between 2003 and 2020. Vegetation types were determined using the cluster analysis. 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. C= Census, T = Transect. E3 = Sampling event 3. 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.**	**Survey year**	**Site ID**	**X_NAD83**	**Y_NAD83**	**Vegetation type**		**Delta**	**Prob**	**Slope**	**Prob**
						(2003-2005)	**(2017-2020)**				
A	2003	2017	A-01-02	513139	2846878	CRM	CM	-0.338	**0.006**	-0.028	**0.001**
A	2003	2017	A-01-03	514119	2846904	CM	CM	-0.173	**0.037**	-0.011	**0.045**
A	2003	2017	A-01-06	515125	2844858	CRM	CWP	-0.170	0.141	-0.018	**0.057**
A	2003	2017	A-01-07	514102	2843847	SCWP	SCWP	-0.197	0.213	-0.018	0.135
A	2003	2017	A-01-08	516146	2842899	RCM	RCM	0.065	0.423	-0.009	0.271
A	2003	2017	A-03-02	513155	2834079	SCWP	CWP	0.070	0.342	0.001	0.451
A	2003	2017	A-03-04	515132	2832965	CM	CWP	-0.108	0.227	-0.014	**0.082**
A	2003	2017	A-03-05	516090	2831118	CRM	CRM	0.099	0.277	0.004	0.354
A	2003	2017	A-03-06	515089	2830946	CM	CM	0.100	**0.088**	0.005	0.144
A	2003	2017	A-03-07	513029	2831037	SCWP	CWP	0.228	**0.083**	0.012	0.146
A	2003	2017	A-03-08	511174	2831001	SCWP	CWP	-0.226	0.160	-0.025	**0.050**
A	2003	2017	A-03-09	511168	2831996	CWP	CRM	0.162	0.165	0.006	0.300
A	2003	2017	A-03-10	510182	2832018	SCWP	SCWP	0.270	0.148	0.012	0.242
A	2003	2017	A-04-02	512186	2829011	CM	CRM	0.365	**0.010**	0.022	**0.018**
A	2003	2017	A-04-03	514251	2830027	CRM	CRM	0.301	**0.047**	0.014	0.132
A	2003	2017	A-04-04	516131	2829091	CRM	CRM	0.183	0.109	0.013	**0.060**
A	2003	2017	A-04-05	515117	2828015	CM	CM	0.206	**0.008**	0.009	**0.041**
A	2003	2017	A-04-06	515133	2827012	CRM	CRM	0.068	0.228	0.010	**0.047**
A	2003	2017	A-04-07	516163	2827057	CM	CM	0.068	**0.059**	0.004	0.104
A	2006	2017	A-04-08	515108	2825981	CM	CM	-	-	-	-
A	2006	2017	A-04-09	514123	2825976	CM	CM	-	-	-	-
A	2003	2017	A-05-02	505216	2823052	CRM	CRM	0.015	0.444	-0.004	0.427
A	2003	2017	A-05-03	505226	2824020	CRM	CM	-0.169	0.185	-0.011	0.182
A	2003	2017	A-05-04	505225	2825013	CRM	ERM	0.091	0.333	0.004	0.395
A	2003	2017	A-05-05	507234	2825015	RCM	ERM	0.297	**0.017**	0.019	**0.014**
A	2003	2017	A-06-06	507215	2826006	CRM	CM	-0.062	0.290	-0.006	0.190
A	2003	2017	A-06-10	509227	2826008	SCWP	CWP	0.117	0.294	0.009	0.273
A	2004	2017	A-07-07	507216	2832954	RCM	ERM	-0.115	0.193	-0.010	0.165
A	2003	2017	A-08-01	503198	2833998	CRM	ERM	0.276	**0.049**	0.016	**0.091**
A	2003	2017	A-08-08	507113	2836904	CRM	RCM	0.095	0.206	0.005	0.247
A	2003	2017	A-09-02	507173	2839844	RCM	CRM	-0.058	0.313	-0.006	0.249

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2020)	Delta	Prob	Slope	Prob
A	2003	2017	A-09-04	509143	2838908	CRM	ERM	0.200	0.244	0.017	0.231
A	2003	2017	A-09-08	511185	2835905	CWP	CWP	-0.008	0.490	-0.005	0.312
A	2003	2017	A-09-09	511196	2838896	CM	CM	-0.100	0.123	-0.011	**0.023**
A	2003	2017	A-09-10	513152	2835885	RCM	CRM	-0.248	0.133	-0.014	0.143
A	2004	2017	A-10-01	511203	2829990	SCWP	MWP	0.266	**0.084**	0.019	0.103
A	2004	2017	A-10-02	512167	2831000	SCWP	SCWP	0.243	**0.038**	0.017	**0.040**
A	2004	2017	A-10-03	513091	2831909	SCWP	CWP	0.344	**0.023**	0.021	**0.049**
A	2004	2017	A-10-04	514126	2830961	CM	CM	0.146	0.160	0.010	0.155
A	2004	2017	A-10-07	516154	2833899	CM	CM	-0.188	0.114	-0.017	**0.065**
A	2004	2017	A-11-02	514273	2836753	CM	CM	-0.231	**0.093**	-0.015	0.145
A	2004	2017	A-11-03	515074	2836883	CM	CRM	-0.147	0.144	-0.011	0.139
A	2004	2017	A-11-04	516286	2836395	CM	CM	-0.267	**0.019**	-0.017	**0.039**
A	2004	2017	A-11-05	516105	2837908	CRM	RCM	0.128	0.271	0.008	0.270
A	2004	2017	A-11-06	515127	2837851	CWP	CM	-0.143	0.206	-0.013	0.146
A	2004	2017	A-11-07	514118	2837794	SCWP	MWP	0.007	0.508	0.002	0.462
A	2004	2017	A-11-08	514123	2838811	CWP	SCWP	-0.468	**0.000**	-0.036	**0.001**
A	2004	2017	A-12-05	511187	2827984	CWP	CWP	0.003	0.528	-0.002	0.407
A	2004	2017	A-12-07	513083	2826972	CM	CM	0.086	0.274	0.005	0.335
A	2004	2017	A-12-08	514248	2826938	CM	CM	-0.204	**0.070**	-0.015	**0.089**
A	2004	2017	A-12-09	516129	2825994	CM	CM	0.133	**0.093**	0.010	0.114
A	2004	2017	A-12-10	516163	2827975	CM	CRM	0.066	0.272	0.007	0.204
A	2004	2017	A-13-01	504181	2824977	CRM	CM	0.040	0.391	0.004	0.344
A	2004	2017	A-15-02	504153	2833951	CRM	CM	-0.357	0.132	-0.032	0.108
A	2004	2017	A-15-04	505171	2832943	CM	CRM	0.078	0.188	0.003	0.292
A	2004	2017	A-17-03	510174	2838837	CM	CM	-0.100	0.170	-0.006	0.224
A	2004	2017	A-17-08	513139	2836852	PCM	SCWP	-0.235	0.178	-0.015	0.209
A	2004	2017	A-19-03	512122	2842830	CM	CM	-0.188	**0.057**	-0.013	**0.077**
A	2004	2017	A-19-04	515100	2842892	CM	CRM	0.034	0.297	0.003	0.270
A	2004	2017	A-19-06	513112	2840887	CWP	SCWP	-0.192	0.184	-0.012	0.203
A	2004	2017	A-19-08	515144	2839865	SCWP	SCWP	-0.020	0.457	-0.005	0.369
A	2004	2017	A-19-09	515136	2838845	CRM	CWP	-0.280	**0.087**	-0.020	0.104
A	2004	2017	A-19-10	516073	2839044	SCWP	SCWP	-0.157	0.165	-0.004	0.364
A	2004	2017	A-20-05	513181	2845696	RCM	RCM	-0.262	**0.097**	-0.020	**0.069**
A	2004	2017	A-20-06	516073	2845920	CM	PCM	-0.407	**0.000**	-0.031	**0.001**
A	2004	2017	A-20-07	516149	2844757	SOWP	SOWP	-0.090	0.333	-0.005	0.369
A	2005	2017	A-21-02	510218	2845943	CRM	CRM	-0.146	**0.047**	-0.013	**0.032**
A	2005	2017	A-21-03	510151	2844890	CM	CM	-0.176	**0.008**	-0.014	**0.005**
A	2005	2017	A-21-05	509283	2843872	CM	CRM	0.031	0.385	-0.002	0.383
A	2005	2017	A-22-01	516104	2846819	RCM	RCM	-0.076	0.385	-0.006	0.371
A	2005	2017	A-22-02	515118	2845783	CM	CWP	-0.196	**0.082**	-0.015	**0.099**
A	2005	2017	A-22-03	514116	2844847	CM	CWP	-0.008	0.444	0.000	0.446
A	2005	2017	A-22-04	513113	2843822	CM	CWP	0.053	0.304	0.004	0.290

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2020)	Delta	Prob	Slope	Prob
A	2005	2017	A-22-05	513134	2842827	SOWP	SOWP	-0.439	**0.019**	-0.036	**0.022**
A	2005	2017	A-22-08	514134	2842821	SCWP	SCWP	-0.170	0.174	-0.016	0.134
A	2005	2017	A-22-09	515116	2843812	CM	CWP	-0.321	**0.028**	-0.023	**0.049**
A	2005	2017	A-22-10	516024	2843849	CRM	CWP	-0.301	**0.031**	-0.023	**0.041**
A	2005	2017	A-23-01	510168	2841826	CRM	CRM	-	-	-	-
A	2005	2017	A-23-04	512252	2840716	CRM	CM	-0.055	0.347	-0.004	0.375
A	2005	2017	A-23-08	513149	2839676	PCM	PCM	-	-	-	-
A	2005	2017	A-23-10	516135	2839836	PCM	CWP	-0.010	0.469	-0.002	0.434
A	2005	2017	A-24-02	507169	2841834	RCM	RCM	-0.002	0.522	0.000	0.505
A	2005	2017	A-24-05	508190	2840801	ERM	ERM	-0.148	0.269	-0.013	0.259
A	2005	2017	A-25-04	504188	2835849	RCM	RCM	0.136	0.240	0.008	0.318
A	2005	2017	A-25-07	506180	2836853	RCM	RCM	-0.122	0.176	-0.009	0.214
A	2005	2017	A-26-02	506190	2834854	ERM	ERM	-0.230	**0.051**	-0.017	**0.076**
A	2005	2017	A-26-03	508179	2834854	RCM	CRM	-0.305	**0.011**	-0.029	**0.003**
A	2005	2017	A-26-05	511172	2834890	CM	CRM	-0.092	0.192	-0.008	0.184
A	2005	2017	A-27-01	512150	2833964	CRM	CRM	0.034	0.417	0.003	0.402
A	2005	2017	A-27-02	512145	2831869	CWP	CWP	0.098	0.234	0.009	0.209
A	2005	2017	A-27-04	514096	2831997	SCWP	SCWP	0.214	**0.053**	0.015	**0.094**
A	2005	2017	A-27-05	515104	2831980	CM	CM	-0.103	0.204	-0.011	0.149
A	2005	2017	A-27-06	514137	2832972	SCWP	SCWP	0.086	0.255	0.007	0.267
A	2005	2017	A-27-07	515060	2834026	CM	CRM	0.089	0.274	0.007	0.285
A	2005	2017	A-28-10	508265	2832912	ERM	ERM	-0.050	0.366	-0.003	0.410
A	2005	2017	A-29-07	508062	2826150	CM	CRM	0.027	0.433	-0.007	0.371
A	2005	2017	A-29-09	511189	2825973	MWP	CWP	0.295	**0.034**	0.022	**0.058**
A	2005	2017	A-29-10	511192	2824959	SCWP	CWP	0.104	0.269	0.009	0.266
A	2005	2017	A-30-01	510186	2830972	SCWP	SCWP	0.022	0.409	0.002	0.422
A	2005	2017	A-30-04	512152	2829941	CWP	MWP	0.166	0.115	0.013	0.120
A	2005	2017	A-30-05	513124	2829962	CM	CWP	0.217	**0.096**	0.017	0.102
A	2005	2017	A-30-06	515090	2829964	CM	CM	0.098	0.209	0.008	0.202
A	2005	2017	A-30-07	516118	2829970	CM	CM	0.211	**0.026**	0.018	**0.021**
A	2005	2017	A-30-08	515041	2828959	CM	CM	0.038	0.424	0.006	0.354
A	2005	2017	A-30-09	514119	2828965	CM	CM	0.068	0.303	0.003	0.387
A	2003	2018	A-05-01	504238	2823026	CM	CM	0.028	**0.018**	0.002	**0.052**
A	2003	2018	A-05-06	509224	2825064	CRM	CM	0.153	**0.053**	0.010	**0.043**
A	2003	2018	A-05-08	510217	2824036	CM	CM	0.210	**0.024**	0.014	**0.021**
A	2003	2018	A-05-09	510265	2822985	CM	CRM	0.043	0.358	0.004	0.309
A	2003	2018	A-06-03	506201	2830025	RCM	ERM	0.262	**0.009**	0.017	**0.009**
A	2003	2018	A-06-04	506210	2827998	CRM	ERM	0.192	**0.044**	0.010	**0.073**
A	2003	2018	A-06-05	506227	2827023	CRM	ERM	0.390	**0.013**	0.025	**0.011**
A	2003	2018	A-06-07	508219	2828071	CM	CM	0.131	0.256	0.005	0.328
A	2004	2018	A-07-01	504175	2829916	ERM	ERM	0.210	**0.014**	0.014	**0.021**
A	2004	2018	A-07-04	505231	2831993	ERM	ERM	-0.002	0.483	-0.002	0.410

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2020)	Delta	Prob	Slope	Prob
A	2004	2018	A-07-08	507193	2831970	RCM	ERM	-0.058	0.364	0.000	0.450
A	2003	2018	A-08-02	504183	2834899	RCM	ERM	0.603	**0.001**	0.041	**0.001**
A	2003	2018	A-08-03	506187	2834007	RCM	ERM	0.148	0.138	0.008	0.169
A	2003	2018	A-08-06	507207	2835892	CRM	CRM	-0.014	0.382	-0.001	0.401
A	2003	2018	A-09-01	506169	2838881	CRM	CRM	0.422	**0.002**	0.022	**0.008**
A	2003	2018	A-09-05	509217	2836866	RCM	CRM	-0.022	0.424	-0.004	0.324
A	2003	2018	A-09-06	510180	2837905	CRM	CRM	0.126	0.123	0.008	0.112
A	2004	2018	A-13-09	510208	2822032	CRM	CM	-0.111	0.309	-0.017	**0.091**
A	2004	2018	A-15-03	503015	2832949	CRM	CRM	0.263	**0.099**	0.016	0.140
A	2004	2018	A-15-10	506122	2828979	RCM	ERM	0.281	**0.002**	0.021	**0.001**
A	2004	2018	A-16-01	509163	2837860	RCM	CRM	-0.078	0.305	-0.004	0.337
A	2004	2018	A-17-02	510172	2839859	CM	CRM	0.138	0.132	0.012	**0.063**
A	2004	2018	A-18-06	504070	2841875	RCM	CRM	-0.010	0.442	0.000	0.472
A	2005	2018	A-21-01	511191	2847210	CWP	CRM	0.346	**0.036**	0.028	**0.023**
A	2005	2018	A-21-06	508166	2843826	CRM	ERM	0.216	0.146	0.013	0.225
A	2005	2018	A-21-07	507169	2843834	CRM	CRM	0.063	0.396	0.004	0.430
A	2005	2018	A-21-08	510179	2842895	RCM	CRM	0.094	0.198	0.008	0.161
A	2005	2018	A-21-09	509161	2842834	CM	CM	0.003	0.478	0.000	0.478
A	2005	2018	A-24-01	506180	2841849	CRM	CRM	0.057	0.345	0.004	0.352
A	2005	2018	A-24-03	505169	2840845	CRM	RCM	0.298	**0.008**	0.022	**0.004**
A	2005	2018	A-25-01	504156	2838835	ERM	CRM	-0.191	0.158	-0.015	0.147
A	2005	2018	A-25-02	504185	2837840	RCM	CRM	-0.145	0.133	-0.012	0.113
A	2005	2018	A-25-03	504181	2836826	CRM	ERM	0.309	0.120	0.017	0.223
A	2005	2018	A-25-09	507158	2837840	RCM	RCM	0.273	**0.003**	0.020	**0.004**
A	2005	2018	A-26-04	509178	2833968	CRM	CM	0.171	**0.031**	0.012	**0.048**
A	2005	2018	A-26-06	509181	2835841	CRM	CRM	0.056	0.311	0.003	0.383
A	2005	2018	A-28-07	509180	2831039	CRM	CRM	0.510	**0.001**	0.039	**0.001**
A	2005	2018	A-29-02	505257	2821970	CM	CM	-	-	-	-
A	2005	2018	A-29-05	508211	2823965	SOWP	CWP	0.259	**0.055**	0.019	**0.067**
B	2003	2018	B-01-01	520439	2809224	SCWP	CRM	-	-	-	-
B	2003	2018	B-01-02	521601	2809144	MWP	CWP	-	-	-	-
B	2003	2018	B-01-04	522408	2811219	CM	CM	-	-	-	-
B	2003	2018	B-01-05	524414	2816166	CM	CM	0.397	**0.000**	0.023	**0.003**
B	2003	2018	B-01-06	524388	2815203	CM	CRM	0.327	**0.012**	0.021	**0.018**
B	2003	2018	B-01-07	524394	2812179	SCWP	CWP	-	-	-	-
B	2003	2018	B-01-08	524480	2811369	SCWP	CWP	-	-	-	-
B	2003	2018	B-02-01	524473	2806170	MWP	MWP	-	-	-	-
B	2003	2018	B-02-02	525433	2808246	MWP	MWP	-	-	-	-
B	2003	2018	B-02-03	525452	2806350	MWP	MWP	0.014	0.475	0.001	0.562
B	2003	2018	B-02-04	526393	2808207	MWP	RCM	0.582	**0.009**	0.035	**0.012**
B	2003	2018	B-02-05	527489	2806438	CWP	CWP	-0.204	0.180	-0.018	0.109
B	2003	2018	B-02-06	527435	2805325	MWP	CWP	0.011	0.462	-0.004	0.305

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2020)	Delta	Prob	Slope	Prob
B	2003	2018	B-02-07	528345	2807219	CWP	CM	0.148	0.138	0.010	0.135
B	2003	2018	B-02-08	528417	2806348	MWP	MWP	0.507	**0.030**	0.031	**0.039**
B	2003	2018	B-02-09	528443	2805331	MWP	MWP	0.363	0.174	0.017	0.247
B	2003	2018	B-02-10	529434	2805326	MWP	MWP	0.323	**0.024**	0.022	**0.012**
B	2003	2018	B-03-01	523480	2800352	CWP	CWP	0.061	0.336	0.003	0.361
B	2003	2018	B-03-02	524426	2801401	SCWP	SCWP	0.092	0.340	0.004	0.383
B	2003	2018	B-03-03	524439	2800361	CWP	CWP	-0.123	0.318	-0.013	0.205
B	2003	2018	B-03-04	524436	2799379	CWP	CWP	0.326	**0.042**	0.019	**0.054**
B	2003	2018	B-03-05	525424	2800358	SOWP	SOWP	0.106	0.313	0.009	0.256
B	2003	2018	B-03-06	526436	2801374	MWP	CWP	0.217	**0.050**	0.012	**0.080**
B	2003	2018	B-03-07	527362	2801328	MWP	MWP	0.121	0.241	0.007	0.260
B	2003	2018	B-03-08	527456	2799384	MWP	SOWP	0.121	0.306	0.005	0.364
B	2003	2018	B-03-09	527439	2798381	SOWP	SOWP	-	-	-	-
B	2003	2018	B-03-10	528456	2799370	SOWP	SOWP	0.340	**0.041**	0.018	**0.094**
B	2003	2018	B-04-01	524473	2796383	CWP	ERM	0.424	0.105	0.034	**0.027**
B	2003	2018	B-04-02	525449	2797381	MWP	SCWP	-0.148	0.329	-0.009	0.324
B	2003	2018	B-04-03	526451	2797378	PCM	CWP	0.234	0.105	0.019	**0.061**
B	2003	2018	B-04-04	526445	2796391	CM	CM	-0.021	0.458	-0.001	0.518
B	2003	2018	B-04-05	526466	2795453	CM	ERM	0.556	**0.052**	0.045	**0.007**
B	2003	2018	B-04-06	527480	2796378	CWP	ERM	0.509	**0.044**	0.042	**0.005**
B	2003	2018	B-04-07	528432	2798371	SOWP	SOWP	-0.510	**0.056**	-0.036	**0.056**
B	2003	2018	B-04-08	528439	2797388	CWP	MWP	-0.033	0.431	-0.005	0.308
B	2003	2018	B-04-09	529431	2798383	SOWP	SOWP	0.365	**0.006**	0.019	**0.023**
B	2003	2018	B-04-10	530465	2795357	RCM	ERM	0.238	0.107	0.017	**0.083**
B	2003	2018	B-05-01	519555	2799379	CM	ERM	0.344	**0.013**	0.023	**0.023**
B	2003	2018	B-05-02	521570	2802185	SCWP	CM	-0.056	0.389	-0.009	0.231
B	2003	2018	B-05-03	521517	2800333	CWP	CWP	-0.069	0.316	-0.005	0.312
B	2003	2018	B-05-04	521530	2799348	CWP	CWP	-0.025	0.432	-0.001	0.470
B	2003	2018	B-05-05	521529	2797361	CM	CRM	0.196	0.164	0.022	**0.029**
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	-0.004	0.481	-0.002	0.412
B	2003	2018	B-05-10	525444	2803323	SCWP	MWP	0.534	**0.034**	0.032	**0.047**
B	2003	2018	B-06-01	517488	2804319	RCM	ERM	0.226	**0.045**	0.017	**0.017**
B	2003	2018	B-06-02	517585	2802389	CWP	CWP	-	-	-	-
B	2003	2018	B-06-03	517502	2800325	CM	ERM	0.145	0.167	0.008	0.190
B	2003	2018	B-06-04	518519	2802327	MWP	CM	0.610	**0.000**	0.042	**0.000**
B	2003	2018	B-06-05	519370	2806264	MWP	PCM	-	-	-	-
B	2003	2018	B-06-06	519593	2800468	CWP	CWP	0.216	**0.041**	0.023	**0.003**
B	2003	2018	B-06-07	520553	2806330	SCWP	CWP	-	-	-	-
B	2003	2018	B-06-08	520492	2803321	CWP	SOWP	-	-	-	-

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	**Vegetation type**		Delta	Prob	Slope	Prob
						(2003-2005)	**(2017-2020)**				
B	2003	2018	B-06-09	522412	2806292	MWP	CWP	-	-	-	-
B	2003	2018	B-06-10	522395	2805268	MWP	SOWP	0.139	0.194	0.009	0.203
B	2004	2018	B-07-01	523326	2814290	CM	CRM	0.018	0.408	0.002	0.359
B	2004	2018	B-07-02	524432	2814361	CM	CRM	0.331	**0.009**	0.024	**0.011**
B	2004	2018	B-07-04	524424	2813249	CWP	CWP	0.182	0.230	0.012	0.245
B	2005	2018	B-12-04	522437	2815166	CM	CRM	0.242	**0.046**	0.020	**0.046**
E	2003	2018	E-01-01	529376	2822048	CWP	CM	0.318	**0.015**	0.019	**0.025**
E	2003	2018	E-01-02	530372	2824055	CWP	CRM	0.326	**0.014**	0.018	**0.012**
E	2003	2018	E-01-03	530393	2823020	CWP	CWP	0.111	0.266	0.005	0.337
E	2003	2018	E-01-04	530350	2822044	SCWP	SCWP	0.176	0.182	0.008	0.276
E	2003	2018	E-01-05	531351	2822037	CWP	CRM	0.512	**0.004**	0.029	**0.005**
E	2003	2018	E-01-06	531320	2821059	CWP	CM	0.746	**0.000**	0.040	**0.000**
E	2003	2018	E-01-07	532350	2826036	CM	CRM	0.396	**0.002**	0.028	**0.002**
E	2003	2018	E-01-08	532285	2825069	CWP	CM	0.349	**0.004**	0.018	**0.015**
E	2003	2018	E-01-09	532348	2822051	CWP	CM	0.337	**0.006**	0.019	**0.017**
E	2006	2018	E-01-10	533308	2821023	SCWP	SCWP	-	-	-	-
E	2003	2018	E-02-01	527367	2821022	CM	CRM	0.252	**0.043**	0.012	0.117
E	2003	2018	E-02-02	527404	2820182	CM	CM	0.271	**0.004**	0.015	**0.014**
E	2003	2018	E-02-03	527394	2819182	CWP	CWP	0.283	**0.019**	0.015	**0.029**
E	2003	2018	E-02-04	529367	2820210	CWP	CM	0.282	**0.007**	0.016	**0.011**
E	2003	2018	E-02-05	529373	2818187	CWP	CM	0.201	**0.008**	0.011	**0.021**
E	2003	2018	E-02-06	531403	2820153	SCWP	SCWP	0.612	**0.000**	0.037	**0.000**
E	2003	2018	E-02-07	531375	2819176	SCWP	SOWP	0.427	**0.029**	0.026	**0.031**
E	2003	2018	E-02-08	532358	2819185	CWP	CWP	0.280	**0.039**	0.014	**0.094**
E	2003	2018	E-02-09	534364	2818180	CWP	CWP	0.106	0.337	0.002	0.490
E	2003	2018	E-02-10	537394	2818253	CWP	CM	0.140	0.277	0.005	0.408
F	2003	2018	F-01-01	541821	2829046	MWP	CWP	0.610	**0.001**	0.036	**0.002**
F	2003	2018	F-01-02	542251	2826192	MWP	MWP	0.775	**0.000**	0.039	**0.010**
F	2003	2018	F-01-03	540249	2827107	CWP	CM	0.338	**0.003**	0.020	**0.004**
F	2003	2018	F-01-04	539257	2825111	CM	CM	0.290	**0.040**	0.016	**0.062**
F	2003	2018	F-01-05	539212	2822102	CM	CWP	0.385	**0.005**	0.026	**0.001**
F	2003	2018	F-01-06	540198	2822176	MWP	CWP	0.289	**0.063**	0.015	0.134
F	2003	2018	F-01-07	540277	2823126	CWP	CWP	0.234	0.267	0.009	0.389
F	2003	2018	F-01-08	541255	2823107	SCWP	SCWP	0.406	**0.020**	0.020	**0.046**
F	2003	2018	F-01-09	542139	2821962	MWP	SCWP	0.184	0.144	0.012	0.144
F	2003	2018	F-01-10	542267	2821167	MWP	SCWP	0.302	**0.020**	0.017	**0.028**
F	2004	2018	F-02-02	541218	2830079	CWP	CWP	0.120	0.188	0.016	**0.033**
F	2004	2018	F-02-03	541215	2829129	SCWP	CWP	0.452	**0.019**	0.037	**0.006**
F	2004	2018	F-02-04	541220	2828050	CWP	SCWP	0.033	0.461	0.003	0.449
F	2004	2018	F-02-05	541226	2827151	MWP	MWP	0.599	**0.004**	0.045	**0.001**
F	2004	2018	F-02-06	541225	2825084	CWP	CWP	0.145	0.216	0.014	0.130
F	2004	2018	F-02-07	542250	2825144	SCWP	SCWP	0.316	**0.065**	0.025	**0.041**

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2020)	Delta	Prob	Slope	Prob
F	2004	2018	F-02-08	542239	2824082	SCWP	SCWP	0.328	0.156	0.021	0.173
F	2004	2018	F-02-09	540244	2824095	MWP	CWP	0.520	**0.000**	0.033	**0.000**
F	2004	2018	F-02-10	540163	2821056	CWP	CM	0.159	0.120	0.015	**0.046**
F	2005	2018	F-03-01	541200	2831069	CM	CM	0.266	**0.016**	0.024	**0.002**
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	0.797	**0.006**	0.070	**0.002**
F	2005	2018	F-03-07	539231	2823030	CWP	RCM	0.398	**0.085**	0.034	**0.057**
F	2005	2018	F-03-08	541226	2822038	MWP	CWP	0.435	**0.032**	0.033	**0.035**
F	2005	2018	F-03-09	542213	2823068	SOWP	SOWP	0.153	0.198	0.012	0.181
F	2005	2018	F-03-10	541220	2824087	MWP	SCWP	0.629	**0.000**	0.048	**0.000**
F	2005	2018	F-04-01	539226	2821052	CWP	CRM	0.035	0.440	0.001	0.534
F	2005	2018	F-04-02	541278	2821100	CM	CM	0.158	0.117	0.012	0.119
F	2005	2018	F-04-03	542228	2831060	MWP	MWP	-	-	-	-
F	2005	2018	F-04-04	542228	2830060	MWP	MWP	0.378	**0.037**	0.038	**0.004**
F	2005	2018	F-04-05	542232	2828059	MWP	SCWP	0.150	0.120	0.013	**0.086**
A	2003	2019	A-01-01	512149	2846885	RCM	CM	-0.086	0.284	-0.003	0.318
A	2003	2019	A-01-04	515129	2846856	CM	CRM	0.102	0.217	0.002	0.454
A	2003	2019	A-01-05	514124	2845851	CM	CM	-0.098	0.162	-0.008	**0.091**
A	2006	2019	A-01-10	512155	2844803	CM	CRM	-	-	-	-
A	2003	2019	A-03-01	511118	2833996	SCWP	CWP	0.133	0.205	0.000	0.497
A	2003	2019	A-03-03	515162	2834850	CRM	CRM	-0.147	0.112	-0.015	**0.015**
A	2003	2019	A-05-07	510251	2825027	CWP	CM	0.385	**0.001**	0.020	**0.012**
A	2003	2019	A-06-02	505168	2830027	RCM	RCM	-0.036	0.450	-0.001	0.510
A	2003	2019	A-06-08	508131	2827035	PCM	CRM	0.057	0.297	0.004	0.301
A	2004	2019	A-07-02	503219	2830950	ERM	ERM	0.116	0.351	0.007	0.350
A	2004	2019	A-07-05	506192	2831975	RCM	RCM	0.234	**0.095**	0.013	0.133
A	2004	2019	A-07-06	506175	2832964	RCM	RCM	0.190	**0.093**	0.009	0.170
A	2003	2019	A-08-04	507197	2834010	RCM	ERM	0.246	0.127	0.019	**0.054**
A	2003	2019	A-08-05	507212	2834897	CM	RCM	0.264	0.117	0.014	0.177
A	2003	2019	A-08-07	508180	2836880	RCM	RCM	0.050	0.295	0.001	0.414
A	2003	2019	A-08-09	505223	2836901	CM	RCM	0.432	**0.035**	0.024	**0.086**
A	2003	2019	A-09-03	508173	2838913	CRM	CRM	0.301	**0.002**	0.016	**0.009**
A	2003	2019	A-09-07	510174	2835906	CRM	CM	0.003	0.493	-0.004	0.284
A	2004	2019	A-10-09	514158	2834463	CRM	CWP	-0.247	**0.088**	-0.014	0.115
A	2004	2019	A-10-10	513144	2834674	CRM	CRM	-0.312	0.178	-0.016	0.250
A	2004	2019	A-12-01	511195	2822992	CM	CRM	0.162	**0.037**	0.013	**0.016**
A	2004	2019	A-13-03	505932	2824005	CM	CM	-0.004	0.480	0.003	0.352
A	2004	2019	A-13-05	507201	2823968	CRM	CM	0.078	0.350	0.006	0.305
A	2004	2019	A-13-10	512196	2822009	CM	CM	-0.052	0.339	-0.005	0.257

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type		Delta	Prob	Slope	Prob
						(2003-2005)	(2017-2020)				
A	2004	2019	A-14-01	504225	2825987	RCM	RCM	0.147	0.236	0.015	0.100
A	2004	2019	A-14-02	504207	2826979	ERM	ERM	0.207	0.128	0.008	0.261
A	2004	2019	A-14-03	504225	2827957	CRM	CM	0.094	0.204	0.003	0.311
A	2004	2019	A-14-04	505224	2828001	ERM	ERM	0.138	0.282	0.006	0.352
A	2004	2019	A-14-05	505216	2826991	CRM	RCM	0.188	0.121	0.013	**0.087**
A	2004	2019	A-14-08	507222	2826980	CRM	RCM	0.187	**0.083**	0.017	**0.022**
A	2004	2019	A-14-09	507203	2827967	RCM	ERM	0.072	0.220	0.006	0.159
A	2004	2019	A-15-01	505213	2835877	CRM	CRM	0.131	0.244	0.014	0.125
A	2004	2019	A-15-05	506185	2830955	RCM	RCM	0.301	**0.037**	0.017	**0.075**
A	2004	2019	A-15-06	507178	2830971	CRM	CRM	0.093	0.376	0.006	0.360
A	2004	2019	A-16-03	509181	2834862	PCM	PCM	-0.168	0.101	-0.011	**0.095**
A	2004	2019	A-16-04	510184	2834870	CRM	CRM	-0.184	**0.058**	-0.014	**0.032**
A	2004	2019	A-16-09	511166	2832973	CRM	CRM	-0.173	**0.085**	-0.011	**0.076**
A	2004	2019	A-16-10	512172	2832969	CRM	CRM	-0.059	0.337	-0.004	0.304
A	2004	2019	A-17-01	510176	2840851	CRM	RCM	0.220	**0.044**	0.017	**0.019**
A	2004	2019	A-17-06	513151	2838847	PCM	PCM	0.049	0.346	0.004	0.313
A	2004	2019	A-18-01	508202	2837878	RCM	RCM	-0.127	0.135	-0.008	0.158
A	2004	2019	A-18-07	505165	2841830	RCM	CRM	-0.094	0.193	-0.006	0.165
A	2004	2019	A-18-10	507188	2842805	RCM	CM	-0.661	**0.001**	-0.039	**0.001**
A	2004	2019	A-19-01	511015	2843924	CM	CRM	-0.122	0.130	-0.010	**0.074**
A	2004	2019	A-20-01	510343	2846852	CRM	CRM	0.086	0.143	0.005	0.168
A	2004	2019	A-20-03	511123	2845915	CM	CM	0.010	0.462	0.002	0.377
B	2003	2019	B-01-03	522385	2813225	CRM	ERM	0.161	0.219	0.014	0.174
B	2004	2019	B-07-03	523900	2813351	CRM	RCM	0.238	0.185	0.021	0.102
B	2004	2019	B-07-05	520429	2812155	CRM	CRM	0.376	**0.017**	0.028	**0.014**
B	2004	2019	B-07-06	523397	2812236	CM	CM	-	-	-	-
B	2004	2019	B-07-09	520399	2810165	CM	CM	0.027	0.413	0.003	0.292
B	2004	2019	B-08-01	526367	2807205	PCM	PCM	0.123	0.160	0.008	0.163
B	2004	2019	B-08-02	526683	2805321	CWP	MWP	-0.053	0.361	-0.010	0.143
B	2004	2019	B-08-03	526401	2804295	SOWP	MWP	-0.152	0.239	-0.008	0.298
B	2004	2019	B-08-04	526408	2803327	SOWP	SOWP	0.329	0.132	0.017	0.189
B	2004	2019	B-08-05	527458	2804346	CM	CM	0.078	0.246	0.007	0.156
B	2004	2019	B-08-06	528412	2804346	CWP	MWP	0.279	0.118	0.021	**0.063**
B	2004	2019	B-08-07	528421	2803393	MWP	CWP	0.344	**0.061**	0.020	**0.045**
B	2004	2019	B-08-08	527415	2802321	SCWP	MWP	0.333	**0.075**	0.016	0.139
B	2004	2019	B-08-09	528382	2801360	SCWP	CWP	0.371	**0.042**	0.027	**0.011**
B	2004	2019	B-08-10	529391	2801236	SCWP	CWP	0.160	0.287	0.005	0.458
B	2004	2019	B-09-01	525374	2796260	CM	CM	0.217	**0.031**	0.014	**0.044**
B	2004	2019	B-09-02	524414	2797321	ERM	ERM	-0.194	0.238	-0.001	0.471
B	2004	2019	B-09-03	524437	2798345	MWP	MWP	0.119	0.206	0.009	0.177
B	2004	2019	B-09-04	525428	2798327	CWP	CWP	0.107	0.148	0.006	0.158
B	2004	2019	B-09-05	525430	2799337	MWP	SOWP	0.329	**0.094**	0.019	0.126

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type		Delta	Prob	Slope	Prob
						(2003-2005)	(2017-2020)				
B	2004	2019	B-09-06	526419	2799325	SOWP	SOWP	-0.118	0.361	-0.010	0.279
B	2004	2019	B-09-07	526437	2798333	MWP	MWP	0.110	0.326	0.011	0.213
B	2004	2019	B-09-08	529363	2799438	MWP	MWP	0.281	**0.081**	0.020	**0.054**
B	2004	2019	B-09-09	529418	2797359	CRM	CRM	0.240	**0.042**	0.015	**0.063**
B	2004	2019	B-09-10	529573	2796164	CRM	CM	-0.104	0.146	-0.005	0.217
B	2004	2019	B-10-01	522469	2801346	MWP	MWP	0.327	**0.020**	0.022	**0.013**
B	2004	2019	B-10-02	521482	2803327	SOWP	MWP	0.065	0.410	0.000	0.479
B	2004	2019	B-10-03	521451	2804319	CWP	MWP	-	-	-	-
B	2004	2019	B-10-04	523398	2806306	CWP	CWP	0.080	0.334	0.005	0.379
B	2004	2019	B-10-05	523463	2805304	MWP	MWP	-	-	-	-
B	2004	2019	B-10-07	524429	2804313	CWP	MWP	0.118	0.343	0.011	0.273
B	2004	2019	B-10-08	525407	2804310	SCWP	MWP	0.206	0.167	0.018	**0.097**
B	2004	2019	B-10-09	524434	2803412	CM	CM	-	-	-	-
B	2004	2019	B-10-10	524432	2802329	SOWP	SOWP	0.322	0.126	0.020	0.143
B	2004	2019	B-11-01	518358	2806241	CWP	CRM	0.240	**0.034**	0.019	**0.017**
B	2004	2019	B-11-02	517457	2805255	ERM	ERM	0.182	0.113	0.013	0.111
B	2004	2019	B-11-03	519415	2805291	MWP	PCM	-	-	-	-
B	2004	2019	B-11-04	520452	2805280	CWP	SOWP	-	-	-	-
B	2004	2019	B-11-05	520421	2804293	CWP	MWP	-	-	-	-
B	2004	2019	B-11-06	517451	2803293	CM	CM	0.210	**0.034**	0.017	**0.009**
B	2004	2019	B-11-07	518598	2803217	CWP	CM	-	-	-	-
B	2004	2019	B-11-08	518472	2801314	CM	CRM	0.199	0.113	0.018	**0.064**
B	2004	2019	B-11-09	518472	2800294	CRM	CM	0.146	0.314	0.004	0.406
B	2004	2019	B-11-10	522476	2799312	SCWP	SCWP	0.188	**0.091**	0.017	**0.032**
B	2005	2019	B-12-01	524372	2817140	CWP	ERM	0.423	**0.001**	0.033	**0.000**
B	2005	2019	B-12-02	523451	2816140	CM	CM	0.124	0.134	0.011	**0.071**
B	2005	2019	B-12-03	523443	2815143	CM	ERM	0.531	**0.039**	0.039	**0.034**
B	2005	2019	B-12-05	522442	2814156	CM	CRM	0.416	**0.052**	0.031	**0.056**
C	2003	2019	C-01-01	535369	2812323	MWP	MWP	0.151	0.163	0.012	0.105
C	2003	2019	C-01-02	536377	2811375	MWP	SCWP	-0.130	0.146	-0.009	0.111
C	2003	2019	C-01-03	537345	2813237	SCWP	MWP	0.083	0.413	-0.001	0.451
C	2003	2019	C-01-04	538307	2815194	MWP	MWP	0.361	0.108	0.018	0.155
C	2003	2019	C-01-05	540298	2814227	MWP	PCM	0.415	**0.023**	0.017	0.101
C	2003	2019	C-01-06	538380	2810405	MWP	MWP	0.301	0.159	0.012	0.281
C	2003	2019	C-01-07	539371	2807964	CRM	CRM	0.190	**0.037**	0.014	**0.015**
C	2003	2019	C-01-08	540341	2808244	SCWP	MWP	0.172	0.262	0.010	0.282
C	2003	2019	C-01-09	540262	2809327	SCWP	MWP	-0.105	0.419	-0.009	0.327
C	2003	2019	C-01-10	541130	2811251	PCM	PCM	0.092	0.304	0.006	0.262
C	2004	2019	C-02-01	538297	2811179	SCWP	MWP	0.375	0.129	0.025	0.118
C	2004	2019	C-02-02	538298	2812210	SCWP	PCM	0.129	0.256	0.006	0.328
C	2004	2019	C-02-03	538290	2813192	MWP	SCWP	0.283	0.105	0.026	**0.046**
C	2004	2019	C-02-04	539285	2813206	MWP	RCM	0.570	**0.000**	0.034	**0.002**

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2020)	Delta	Prob	Slope	Prob
C	2004	2019	C-02-05	539235	2814197	MWP	MWP	0.202	0.136	0.016	**0.075**
C	2004	2019	C-02-06	539296	2815161	CWP	SCWP	0.312	**0.005**	0.023	**0.001**
C	2004	2019	C-02-07	541041	2815172	MWP	MWP	0.384	**0.056**	0.029	**0.028**
C	2004	2019	C-02-08	541130	2813219	CWP	CWP	0.020	0.461	0.011	0.220
C	2004	2019	C-02-09	541150	2812221	PCM	PCM	0.259	0.102	0.019	**0.062**
C	2004	2019	C-02-10	540281	2811185	MWP	MWP	0.063	0.409	0.012	0.219
C	2005	2019	C-03-01	540311	2815140	MWP	PCM	0.443	**0.012**	0.032	**0.012**
C	2005	2019	C-03-02	541061	2814191	MWP	CWP	0.441	**0.003**	0.036	**0.001**
C	2005	2019	C-03-03	540287	2813210	MWP	PCM	0.284	0.231	0.024	0.179
C	2005	2019	C-03-04	540287	2812220	MWP	PCM	-	-	-	-
C	2005	2019	C-03-05	539309	2812241	MWP	MWP	-	-	-	-
E	2003	2019	E-03-00	526356	2813208	SCWP	CWP	0.055	0.343	0.003	0.375
E	2004	2019	E-03-01	527377	2816175	CWP	SCWP	0.160	0.137	0.009	0.186
E	2004	2019	E-03-02	527397	2817139	SCWP	CWP	0.237	0.131	0.015	0.109
E	2004	2019	E-03-03	527430	2818190	CM	CM	0.229	**0.049**	0.014	**0.046**
E	2004	2019	E-03-04	528365	2819163	CWP	CRM	0.169	0.168	0.011	0.160
E	2004	2019	E-03-05	529344	2819141	CWP	CWP	0.076	0.298	0.004	0.359
E	2004	2019	E-03-06	528349	2818178	CWP	CWP	0.148	0.175	0.013	0.114
E	2004	2019	E-03-07	528348	2817156	CWP	CWP	0.141	0.303	0.008	0.332
E	2004	2019	E-03-08	528318	2816254	SCWP	SCWP	-0.058	0.340	-0.006	0.255
E	2004	2019	E-03-09	529326	2817183	CWP	CWP	-0.071	0.420	0.000	0.579
E	2004	2019	E-03-10	530343	2817167	SCWP	SCWP	0.099	0.285	0.004	0.366
E	2004	2019	E-04-01	531307	2824025	SCWP	SOWP	0.194	0.295	0.021	0.206
E	2004	2019	E-04-02	531299	2823022	CM	RCM	0.382	**0.006**	0.027	**0.001**
E	2004	2019	E-04-03	533230	2823053	CM	CRM	-0.081	0.409	0.003	0.443
E	2004	2019	E-04-04	529346	2821021	CRM	RCM	0.091	0.288	0.014	0.105
E	2004	2019	E-04-05	530351	2821046	CWP	CWP	0.178	0.134	0.015	**0.057**
E	2004	2019	E-04-06	532327	2820133	SCWP	SCWP	0.198	0.187	0.010	0.258
E	2004	2019	E-04-07	533352	2819621	CWP	SCWP	0.051	0.400	0.005	0.327
E	2004	2019	E-04-08	533368	2818168	CWP	SCWP	-0.092	0.307	-0.003	0.391
E	2004	2019	E-04-09	532376	2818232	CWP	CWP	0.107	0.255	0.013	0.108
E	2004	2019	E-04-10	535409	2817142	CM	SCWP	-0.145	0.254	-0.011	0.205
E	2005	2019	E-05-02	529339	2823018	CWP	CRM	0.336	**0.004**	0.025	**0.001**
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	0.177	0.222	0.014	0.173
E	2005	2019	E-05-07	533329	2821974	CM	CWP	0.229	**0.033**	0.018	**0.011**
E	2005	2019	E-05-08	532283	2821024	SCWP	SCWP	0.193	0.239	0.007	0.348
E	2005	2019	E-05-10	534342	2819154	CWP	CWP	0.347	**0.045**	0.027	**0.017**
B	2005	2020	B-12-06	522530	2812136	CM	ERM	0.367	**0.008**	0.026	**0.005**
B	2005	2020	B-13-06	519423	2808150	CWP	CM	0.133	0.116	0.010	**0.083**

Sub-pop	Year estd.	Survey year	Site ID	X_NAD83	Y_NAD83	Vegetation type (2003-2005)	Vegetation type (2017-2020)	Delta	Prob	Slope	Prob
B	2005	2020	B-13-07	519399	2807175	CM	CM	0.213	**0.004**	0.018	**0.000**
B	2005	2020	B-15-01	518447	2805257	SCWP	CWP	0.500	**0.001**	0.032	**0.004**
B	2005	2020	B-15-02	518443	2804296	CWP	CWP	-0.039	0.401	0.001	0.426
B	2005	2020	B-15-07	519507	2802329	CWP	CRM	0.125	0.267	0.008	0.273
B	2005	2020	B-15-08	520448	2801352	CWP	CWP	0.069	0.328	0.006	0.284
B	2005	2020	B-15-09	519446	2801343	CWP	CWP	0.174	0.193	0.007	0.292
B	2005	2020	B-15-10	517465	2801321	RCM	ERM	0.384	0.104	0.028	**0.087**
B	2005	2020	B-17-01	520502	2799309	RCM	ERM	0.068	0.374	0.010	0.265
B	2005	2020	B-17-02	520511	2798160	CRM	ERM	0.627	**0.000**	0.048	**0.000**
C	2005	2020	C-03-06	539293	2811200	MWP	SCWP	-0.015	0.465	-0.005	0.367
C	2005	2020	C-03-07	539279	2810232	CWP	PCM	-0.001	0.486	-0.002	0.370
C	2005	2020	C-03-08	539305	2809190	CM	PCM	0.213	**0.066**	0.016	**0.033**
C	2005	2020	C-03-09	540310	2810188	PCM	ERM	0.465	**0.005**	0.033	**0.001**
C	2005	2020	C-03-10	541288	2810221	CWP	CWP	0.401	**0.003**	0.031	**0.000**
C	2005	2020	C-04-01	538297	2814206	MWP	MWP	-0.155	0.307	-0.007	0.356
C	2005	2020	C-04-02	537346	2814186	MWP	MWP	0.235	0.198	0.008	0.351
C	2005	2020	C-04-03	536331	2813196	MWP	SCWP	0.254	**0.026**	0.014	**0.040**
C	2005	2020	C-04-04	535344	2813189	MWP	SCWP	-0.083	0.363	-0.009	0.263
C	2005	2020	C-04-06	536304	2812211	SCWP	SCWP	0.096	0.330	0.006	0.333
C	2005	2020	C-04-07	537361	2812234	SCWP	SCWP	0.231	**0.084**	0.015	**0.082**
C	2005	2020	C-04-08	537337	2811189	SCWP	MWP	0.441	**0.019**	0.027	**0.033**
E	2005	2020	E-06-01	528381	2820973	CM	CM	0.054	0.152	0.003	0.188
E	2005	2020	E-06-02	528372	2820118	CWP	CRM	0.483	**0.000**	0.035	**0.000**
E	2005	2020	E-06-03	530353	2820150	MWP	CWP	0.722	**0.001**	0.045	**0.002**
E	2005	2020	E-06-04	530349	2819144	CWP	CM	0.473	**0.000**	0.033	**0.000**
E	2005	2020	E-06-05	530326	2818160	CWP	CRM	0.293	**0.070**	0.021	**0.056**
E	2005	2020	E-06-06	531333	2818167	SCWP	SCWP	0.169	0.188	0.013	0.149
E	2005	2020	E-06-07	527373	2815160	SCWP	SCWP	0.078	0.291	0.002	0.412
E	2005	2020	E-06-08	527361	2814156	CWP	CWP	0.083	0.308	0.011	0.128
E	2005	2020	E-06-09	526403	2814131	SCWP	SCWP	0.148	0.186	0.010	0.177
E	2005	2020	E-06-10	526327	2815182	CWP	CWP	0.125	0.201	0.012	0.116

Appendix A2: 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.

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**
A	(Intercept)	5.53	0.10	426.5	**<0.001**	44.05	0.92	499.0	**<0.001**	57.55	1.27	287.3	**<0.001**	21.82	0.30	346.2	**<0.001**
	Survey-2	0.35	0.12	352.8	**0.003**	-10.12	1.21	353.9	**<0.001**	0.52	1.14	345.3	0.648	0.73	0.31	349.9	**0.018**
	Survey-3	0.44	0.12	360.5	**<0.001**	-9.64	1.22	359.3	**<0.001**	16.96	1.16	357.6	**<0.001**	2.41	0.31	360.0	**<0.001**
	Hydroperiod	0.62	0.19	281.5	**0.001**	-5.21	1.62	238.9	**0.002**	4.10	2.46	397.2	0.096	1.86	0.59	337.6	**0.002**
	Water Depth	-0.63	0.19	265.6	**0.001**	7.53	1.62	230.6	**<0.001**	-4.34	2.51	357.6	0.085	-1.88	0.60	310.3	**0.002**
B	(Intercept)	5.10	0.14	214.5	**<0.001**	41.84	1.22	259.7	**<0.001**	51.81	1.32	172.7	**<0.001**	20.50	0.35	180.7	**<0.001**
	Survey-2	-0.38	0.16	189.0	**0.016**	-6.11	1.59	181.8	**<0.001**	1.43	1.29	190.3	0.272	-0.83	0.36	190.5	**0.021**
	Survey-3	0.39	0.16	219.9	**0.018**	-14.74	1.64	201.4	**<0.001**	16.52	1.39	234.8	**<0.001**	2.06	0.38	231.9	**<0.001**
	Hydroperiod	-0.40	0.30	162.9	0.188	-3.13	2.47	125.4	0.207	-7.48	2.91	200.9	**0.011**	-1.63	0.78	193.1	**0.038**
	Water Depth	-0.20	0.31	150.7	0.515	6.41	2.51	119.4	**0.012**	6.18	3.02	179.8	**0.042**	0.29	0.81	174.0	0.719
C	(Intercept)	5.99	0.28	61.0	**<0.001**	42.15	2.98	61.0	**<0.001**	59.47	2.16	59.9	**<0.001**	22.93	0.68	61.0	**<0.001**
	Survey-2	0.22	0.38	61.0	0.569	6.02	4.05	61.0	0.142	2.14	2.92	41.5	0.467	0.68	0.93	61.0	0.463
	Survey-3	-0.81	0.44	61.0	0.075	-2.39	4.68	61.0	0.612	11.03	3.39	57.4	**0.002**	-0.90	1.07	61.0	0.404
	Hydroperiod	0.07	0.62	61.0	0.915	-9.06	6.49	61.0	0.168	9.21	4.73	34.3	0.060	0.99	1.49	61.0	0.509
	Water Depth	0.28	0.59	61.0	0.633	12.22	6.17	61.0	0.052	-6.65	4.50	32.2	0.149	0.00	1.41	61.0	0.998
E	(Intercept)	5.49	0.19	75.7	**<0.001**	39.95	1.85	88.0	**<0.001**	62.21	1.71	79.3	**<0.001**	22.35	0.52	73.3	**<0.001**
	Survey-2	-0.07	0.24	60.4	0.766	-4.57	2.67	88.0	0.090	0.06	2.19	63.4	0.977	-0.34	0.64	61.3	0.591
	Survey-3	0.02	0.25	74.6	0.948	-6.15	2.71	88.0	**0.026**	5.29	2.28	75.6	**0.023**	0.35	0.67	76.2	0.601
	Hydroperiod	-0.17	0.42	44.8	0.682	-8.47	3.58	88.0	**0.020**	2.72	3.74	46.7	0.471	-0.26	1.17	48.0	0.822
	Water Depth	-0.21	0.43	47.0	0.622	9.43	3.66	88.0	**0.012**	-1.30	3.80	48.6	0.733	-0.39	1.19	50.5	0.745
F	(Intercept)	4.98	0.25	33.9	**<0.001**	44.05	0.92	499.0	**<0.001**	57.10	3.92	33.8	**<0.001**	20.83	0.77	31.1	**<0.001**
	Survey-2	0.44	0.24	31.6	0.075	-10.12	1.21	353.9	**<0.001**	-1.71	3.74	31.6	0.651	0.68	0.69	31.4	0.330
	Survey-3	0.41	0.34	40.9	0.229	-9.64	1.22	359.3	**<0.001**	8.46	5.25	40.9	0.115	1.63	0.98	40.9	0.106
	Hydroperiod	1.10	0.48	41.3	**0.026**	-5.21	1.62	238.9	**0.002**	10.98	7.45	41.3	0.148	3.33	1.40	39.7	**0.022**
	Water Depth	-1.29	0.48	45.9	**0.010**	7.53	1.62	230.6	**<0.001**	-11.55	7.49	45.9	0.130	-3.65	1.43	45.9	**0.014**

Appendix A3: 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 A4: Number of vegetation survey sites sampled over four years (2017-2020) matched with the sparrow survey points visited over three years (2017-2019). Vegetation types are listed according to increasing wetness.

Vegetation types	**# of Vegetation sites visited for Sparrow survey**	**% of Vegetation sites visited for Sparrow survey**	**# of Vegetation survey sites with Sparrow records**	**# of Sparrows in three years (2017-2019)**
Muhlenbergia Wet Prairie	42	13.7	17	40.5
Schizachyrium Wet Prairie	44	14.4	12	27.3
Schoenus Wet Prairie	16	5.2	13	81.3
Cladium Wet Prairie	71	23.2	26	36.6
Paspalum-Cladium Marsh	13	4.2	2	15.4
Cladium Marsh	48	15.7	16	33.3
Cladium-Rhynchospora Marsh	47	15.4	9	19.1
Rhynchospora-Cladium Marsh	10	3.3	2	20.0
Eleocharis-Rhynchospora Marsh	15	4.9	3	20.0
Total	**306**	**100.0**	**100**	**32.7**