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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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Executive Summary

Cape Sable seaside sparrow (CSSS), a federally endangered species, and vegetation within its habitat are highly sensitive to changes in hydrologic regimes. 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, B, E and F.

Over two years, 2017 and 2018, 399 sites, including 69 transects and 330 census sites, were sampled. Among them, 184 sites (69 transect and 115 census sites) were sampled in 2017, while 215 census sites were sampled in 2018. The transect sites included 26 sites on Transect A established in 2003, 19 new sites on newly established transect (TAS) in the southeastern portion of the subpopulation A, and 24 sites east of sub-population E. The census sites included 259 existing sites that were established and sampled for the first time in 2003/2005, and 71 new sites. In 2017, the sampled census sites included 105 existing sites and 10 new sites, most in two distinct areas (hN and hS) identified as improved potential future CSSS habitat. In contrast, in 2018, the sampled census sites were in four sub-populations, A, B, E and F. Vegetation sampling was done following the method described in Ross et al. (2006). Vegetation change analysis included calculation of changes in vegetation-inferred hydroperiod, and use of 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 sampled over two years (2017/2018) were classified using cluster analysis, and a change in vegetation type (if any) since 2003/2005 survey was examined.

The hydrologic condition of the vegetation survey sites sampled during 2007/2018 survey showed a distinct spatio-temporal pattern. Averaged over the sites sampled in both 2003/2005 and 2017/2018 surveys, the four-year average hydroperiod and annual mean water depth differed significantly among sampling periods in all four sub-populations, and they also varied spatially. The vegetation sites in southern and southwestern portions of sub-populations A and B, and throughout in E and F were wetter in 2017/2018 than previous surveys. In the contrast, in the northeastern portion of A (in the hN area), the sites were drier during the 2017/2018 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 the composition that was indicative of relatively dry conditions. Several sites in this area changed from marsh to wet prairie vegetation type. In contrast, majority of the sites in the southern and western portion of this sub-population experienced a vegetation change towards wetter type, suggesting a continued deterioration of CSSS habitat in these areas. In western and southern portions of sub-population B and throughout the sub-populations E and F, vegetation shifted towards 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 gradual increase in water flow though the Shark River Slough. This trend is likely to continue in the future, which may cause further limitation in the extent of suitable habitat in these areas. However, a shift in vegetation towards wetter type in 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 the CSSS habitat. However, the shift in vegetation composition was expected to be of greater magnitude close to the eastern Park boundary driven by the seepage from retention ponds 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 2017/2018 surveys were done 1 and 2 years after the extreme event of dry season high water condition that occurred in spring 2016, when marl prairies in those two 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 were still wet-prairie type. Since, the time between such events and this study was short (<3 years), the actual effects of such a high water conditions might not have been realized yet. Therefore, it is important to minimize the chances of high water condition at least in next two years, so that the effects of the 2016 and 2018 high water level events followed by two years of wet conditions will not trigger the change of wet prairie vegetation to marsh type vegetation and have a long-lasting adverse impact on sparrow habitat.

Finally, if maintaining the exiting 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 are the objective, 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) and other components of CERP.

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General Background

The Cape Sable seaside sparrow (CSSS) as well as the vegetation within its range are highly sensitive to natural and management-caused changes in both hydrologic 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 CSSS habitat 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 six sparrow sub-populations (A-F) were re-visited annually to assess vegetation dynamics over space and time (2007, 2008, 2009 and 2010). The subset sampled each year included both unburned and burned sites (Sah et al. 2011). After a three-year interruption, the vegetation study was resumed in FY 2014 with funding from Everglades National Park (ENP). In FY 2014, 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 first time sampled in northeastern portion of sub-population A and western portion of sub-population E (Sah et al. 2017a)

The hydrologic modelling carried out using the Regional Simulation Model (RSM) tool to evaluate the potential impact of Everglades Restoration Transition Project (ERTP) predicts that habitat in the eastern portion of CSSS sub-population A will 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 habitat suitability modeling approach, suggests that some additional areas northeast of currently occupied habitat in sub-population A will 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 are also projected to improve. In contrast, the areas in the western portion of sub-populations B and E will 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 WY 2017 with the 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). Sah et al. (2018) describes the vegetation monitoring results for the sites sampled in WY 2017. The monitoring work within the marl prairie landscape continued in the following year, i.e. in WY 2018. In the field, when vegetation sampling was done under these two separate funding sources, we ensured that the sites to be sampled under each were complementary, but not duplicative. However, when we were in the field, and the sites to be sampled under these projects were within the same vicinity, we sampled them together in-group 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, sampled together in WY 2017 and 2018 under both projects.

In 2017, the study focused on the establishment and vegetation survey on two new transects, one in the southeastern portion of sub-population A and the other east of sub-population

E. In addition, a subset of existing transect and census sites was also sampled 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 subpopulations of E and F (hereafter called EF). In addition, a subset of existing census sites also was sampled within sub-population A, B, E and F. Vegetation sampling was done in spring 2018, followed by water depth measurement at the new sites in the wet season of the same year. The report describes temporal changes in vegetation structure and composition in relation to hydrologic conditions at the previously sampled sites, and characterization of vegetation pattern at the new census sites in CF and EF areas. While the account of temporal change in vegetation composition at previously sampled census sites will include the sites from both 2017 and 2018 surveys, the vegetation characterization at new sites is described only for those sampled in 2018.

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, the sparrow 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), 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 (CSSS), originally described from brackish coastal marsh habitat, 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 caused 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). 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, 2016, 2017b), possibly improving the CSSS habitat, as these areas were considered over-drained followed frequent fires that adversely impacted the habitat resulting in reduced sparrow numbers (Pimm et al. 2002). These vegetation shifts are subject to change due to future restoration activities associated with Comprehensive Everglades Restoration Plan (CERP) and its recently outlined components, such as Everglades Restoration Transition Plan (ERTP) and Central Everglades Planning Project (CEPP) (USACE 2011; USACE 2014; 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 under the latter, some areas of sparrow habitat within both western (sub-population A) and eastern (B, E and F) sub-populations will become wetter, and thus possibly less suitable than at present (Pearlstine et al. 2014). 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 Slough (USACE 2014). In contrast, the model also predicts that some additional suitable habitat may become available outside the recent range of CSSS occurrence. In particular, adjoining areas to the northeast of currently occupied habitat boundary of sub-population A are expected to exhibit improved condition (Pearlstine et al. 2014, 2016). The results of hydrologic modelling associated with Everglades Restoration Transition Plan (ERTP) and Central Everglades Planning Project (CEPP) have also suggested an improvement in habitat condition east of sub-population A (USACE 2011, 2014).

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. 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. Likewise, to the east of sub-population E, where the area is expected to improve, there was a need to establish new sites. Thus, the major objectives of the study we initiated in 2016 are 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-E) within the marl prairie landscape.

2. Methodology

2.1 Data Collection

2.1.1 Study area

The study area included the portion of 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-sampling 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 (NE-A), 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 up to the transition with the ridge-and-slough landscape. In 2017, we also established 19 and 24 sampling 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 in southeastern portion of sub-population A and east of sub-population E that will possibly be impacted by the hydrological changes caused by ongoing and planned restoration activities (USCACE 2014; USFWS 2016).

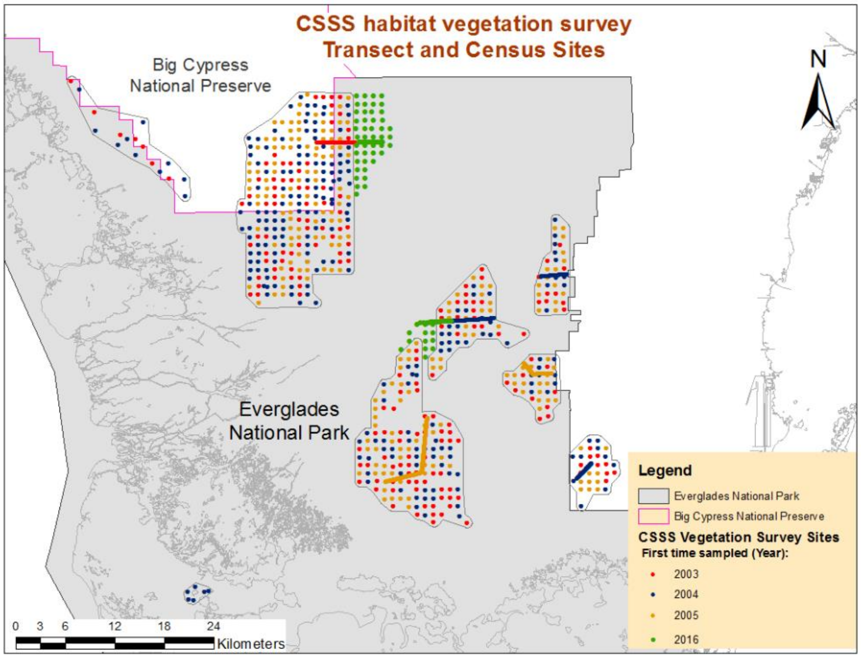

Figure 1: A network of vegetation monitoring sites that were established and first time sampled before 2017/2018 sampling. In the beginning of vegetation monitoring within the CSSS habitat, 906 sites (293 transect and 613 census sites) were established over three years (2003-2005), and were sampled at least twice in 7-year period (2003-2009). In 2016, additional 103 sites (45 transect and 58 census sites) were established and first time sampled.

Census sites sampled in 2017 included 10 new sites and a subset of 105 sites from the previously sampled sites in subpopulation A. Most of census sites were in the eastern portion of CSSS sub-population A and the areas adjacent to it, where two distinct areas (hN and hS) have been identified as improved potential future CSSS habitat (USCACE 2014; USFWS 2016). All the new sites were established within hN and hS, especially in the gaps between existing vegetation survey sites in the CSSS monitoring network. In total, we sampled 34 census and 23 transect sites within hN, and 41 census and 19 transect sites within hS (Figure 2). The transect sites sampled within the hN habitat area were established in 2003 and sampled three times (2003, 2006 and 2010) prior to 2017 sampling, while all transect sites within hS were established and sampled for the first time in 2017.

In 2018, we sampled 215 census sites, including 61 new sites and a subset of 154 sites from the previously sampled sites in subpopulation A, B, E and F (Figure 2). Among the 61 new sites, 27 were between sub-populations C and F (hereafter, called 'CF), 30 were between subpopulations of E and F (hereafter, called EF), and four sites were in subpopulation E. Re-sampled sites included 39 sites in sub-population A, 61 sites in B, 20 sites in E, and 34 sites in F. The list of sites sampled in 2017/2018 is given in Appendix 1.

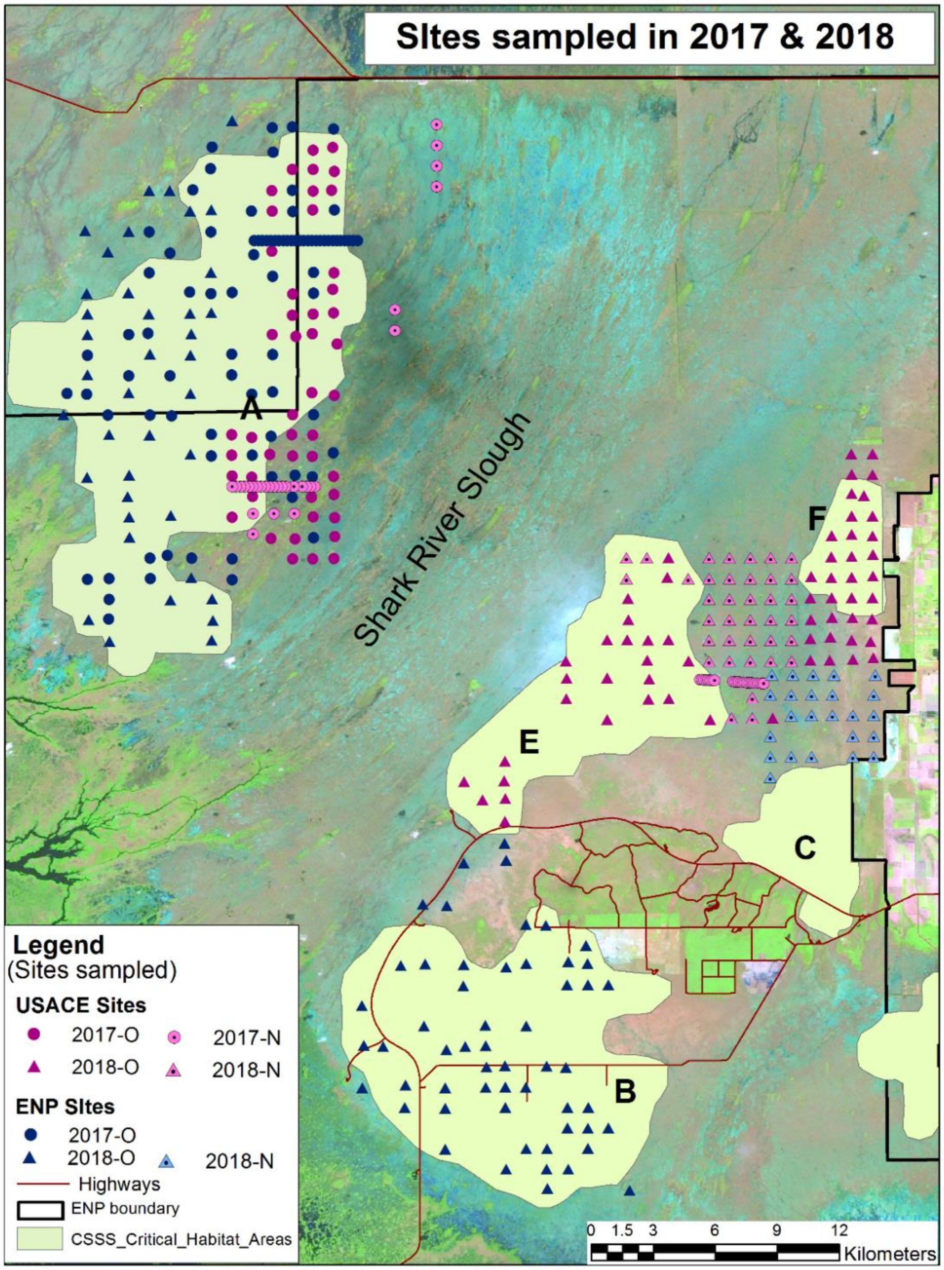

Figure 2: CSSS Vegetation Survey sites sampled in 2017 (circle) and 2018 (triangle). The sites sampled in those two years included old (O) and new sites (N) both USACE and ENP-funded sites, in pink and blue color, respectively. Old sites were established during 2003-2005 sampling, and new sites were established during the current (2018) sampling.

2.1.2 Vegetation sampling

At each sampling site, vegetation was sampled in a N-S oriented, 1 x 60 m rectangular plot beginning 3 m south of a rebar established to permanently mark the sampling 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 recorded our 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 every two meters beginning at Meter 1. Structural sampling 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 surveys in combination with water depth measured in the field (for transect sites) or only measured water depths (for census sites). If there was standing water at the time of sampling, 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 autolevel at the time of vegetation sampling.

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 the wetland marshes, 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 399 sites that were sampled in 2017 and 2018 and included both new and previously sampled sites, examined the spatial distribution of vegetation types, and noted any temporal change in vegetation types at previously sampled sites. However, to keep the vegetation type identified at those sites in coherence with the classification adapted for the marl prairie vegetation encompassing all the subpopulations, the analysis also included vegetation data collected at 608 census sites sampled in 2003-2005 within both historical (Cape Sable) and recent range (six subpopulations) of CSSS habitat. We followed the 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 initially recognized based on data only from the 608 census sites (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 site total. The hydrology vector was derived by calculating plot level hydroperiod, using mean plot elevation obtained using field measurements of water depths and EDEN daily water surface elevation data. In ordination space, the vectors for the hydrologic gradient were defined by the 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 scores of the sampling 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 the 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 sampled for three times or more. In two years, 2017 and 2018, 26 transect sites were sampled for the 4th time, whereas 200 census sites were sampled for the third time since the initial survey in 2003-2005. Likewise, 42 census sites that were burned at least once over 15 years, 2003-2018, were sampled for >4 times.

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 ordination space, the reference vector for the hydrologic gradient was defined by a vector fitting technique in which a gradient is defined in the direction through ordination that produces maximum correlation between the measured environmental attribute and the scores of the sampling units along the vector (Minchin 1998). The orientation of the ordination was then 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 (Minchin et al. 2005; Sah et al. 2014). In this analysis, the slope was calculated as the linear regression coefficient of projected scores on the target vector in sampling 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 caused by the repeated measurement of vegetation structural variables (vegetation height, total cover and green cover) and above ground biomass, Linear Mixed Models were used. General Liner Mixed Models were used to examine differences in structural variables between WP and M sites and among sampling years. Biomass data were log-transformed to approximate normality. Models were run in R v.3.5.0 (R Core Team, 2018) 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 posthoc test using *glht* function implemented in 'multicomp' package.

3. Results

3.1 Hydrologic Conditions

Across the four sub-populations (A, B, E and F), the hydrologic condition of the vegetation survey sites sampled in 2017/2018 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 (87.6%) were calculated using ground elevation derived from the field measurements of water depth and EDEN daily water surface elevation data. For the rest of sites, hydrologic variables were calculated using ground elevation from digital elevation model (DEM) database in EDEN. However, these (12.4%) sites were not included in comprehensive analysis to describe the hydrologic conditions of these areas. At the census sites sampled in both 2003/2005 and 2017/2018 surveys, the hydroperiod ranged between 2 and 365 days, with a mean (± SD) of 227 (± 83) days and a median of 239 days. Similarly, the mean daily water depth ranged between -32.9 and 42.1 cm with the mean (± SD) of 2.5 (±13.9) cm and median of 1.6 cm. Both the hydroperiod and daily mean water depth at these sites significantly differed among the three sampling events (Kruskal-Wallis Test: KW-$H_{(2,681)} = 16.3$, $p < 0.001$, and KW-$H_{(2,681)} = 8.8$, p =

0.012, respectively). The median hydroperiod in 2017/18 was 19 and 27 days higher than the median values in 2003/2005 and 2006/2009, respectively. The median water depth at these sites was 2.8 and 2.2 cm higher than two previous sampling events.

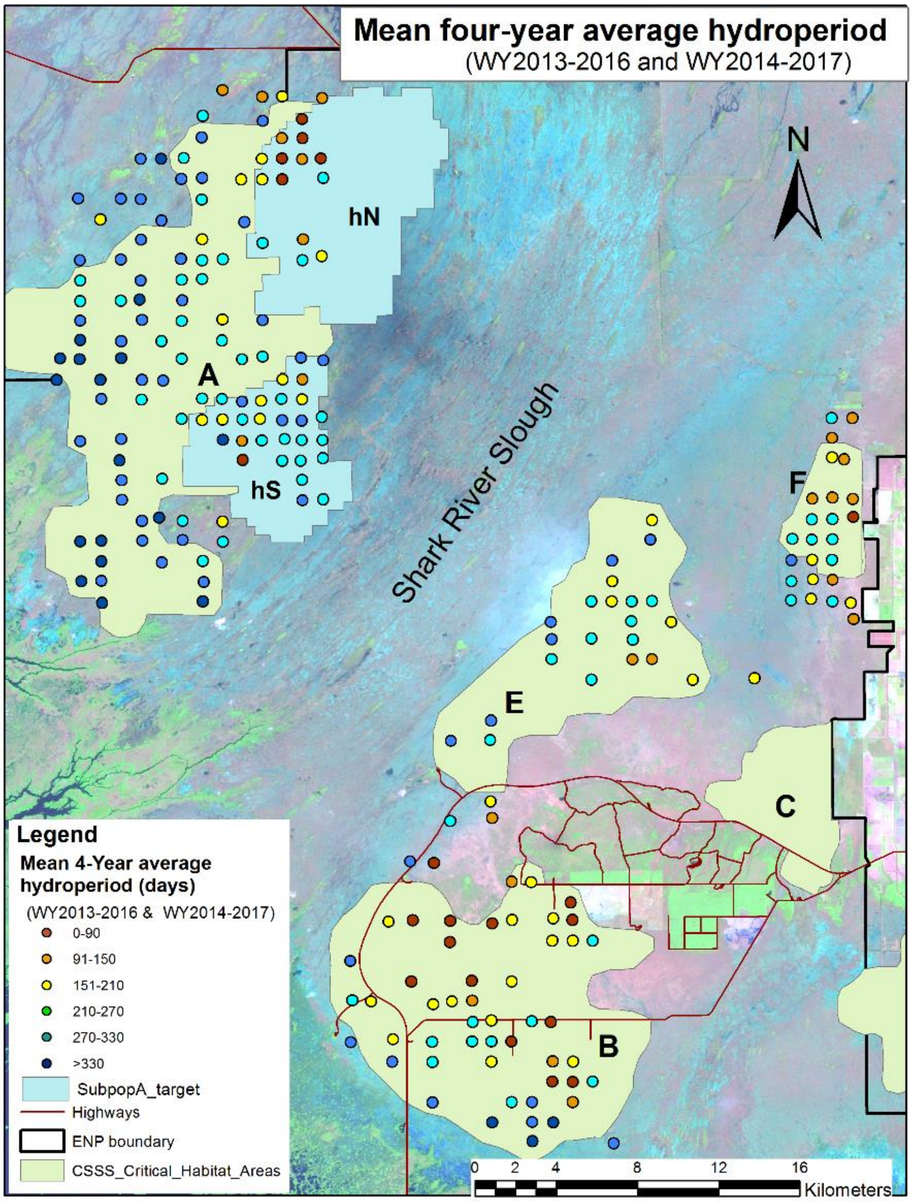

Figure 3: Four-year mean discontinuous hydroperiod at 2017/2018 vegetation survey sites in sub-populations A, B, E and F. The values were calculated only for those sites for which field measurements of water depth were available, and the sites were sampled during both 2003/2005 and 2017/2018 surveys.

Sub-population A

During 2017/2018 sampling in sub-population A, 4-year average hydroperiod ranged between 47 and 365 days, with a mean (± SD) of 255 (± 73) days and a median of 262 days, and mean water depth ranged between -18.7 and 42.0 cm with the mean (± SD) of 8.6 (±12.2) cm and median of 8.6 cm water depth. Across all the regions, vegetation sites in sub-population A were slightly wetter in recent years (2017/2018) than during 2003/2005 and 2006/2009 samplings, as mean hydroperiod was 12 days longer and daily mean water depth was 1.3 cm deeper in 2017/2018 than 15 years ago (Figures 4A and 5A). However, the hydrologic condition was not the same throughout the subpopulation A (Figure 6). The vegetation sites in the northeastern portion (hN) were much drier than the sites in other portions of the sub-population (Table 1). In the hN area, the mean hydroperiod was 141 ± 67 days (median = 133 days), and water depth was -8.7± 6.6 cm (median = -7.8 cm). In contrast, the hS area and western portion of the sub-population had mean hydroperiods of 232 ± 57 and 281 ± 53 days, and the mean water depths of 4.5 ± 9.4 and 13.2 ± 10.5 cm, respectively (Table 1). Moreover, the hydrologic condition at many sites in the hN area was drier in 2017/2018 than the previous samplings, whereas the sites in the western and southern portion (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 20 days shorter, but at the sites in hS and the western-A were 20 and 14 days longer in 2017/2018 than in 2003/2005 (Table 1; Figure 6).

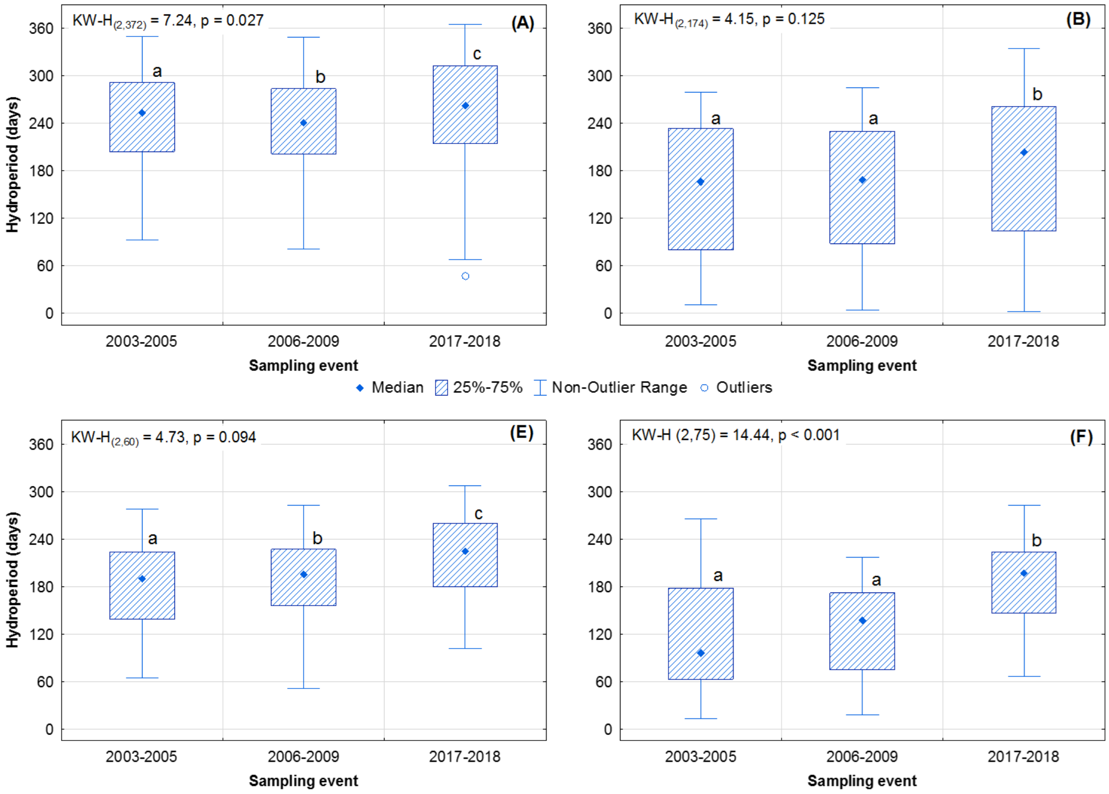

Figure 4: Box-plot showing median (box = 25% and whisker = 75% quartiles) four-year average hydroperiod at a subset of sites sampled in sub-populations A, B, E and F over two years, 2017 and 2018 that had field measurements of water depth. The sites were sampled three times: during 2003/2005, 2006/2009 and 2017/2018 sampling events.

Eastern sub-populations (B, E and F)

In comparison to sup-population A, vegetation sampling sites in sub-population B, E and F are relatively dry, but in recent years they have become wetter than what they were during 2003/2005 sampling (Figure 4 and 5 B,C,D). The most distinct change in hydrologic condition was observed in sub-population F, where mean hydroperiod was 68 days longer and mean water depth was 9 cm deeper during 2017/2018 than in 2003/2005. In sub-populations B and E, mean hydroperiods were 28 and 39 days longer, while mean water depths were 5.8 and 6.5 cm deeper in recent years than 15 years ago, respectively (Table 1; Figure 6).

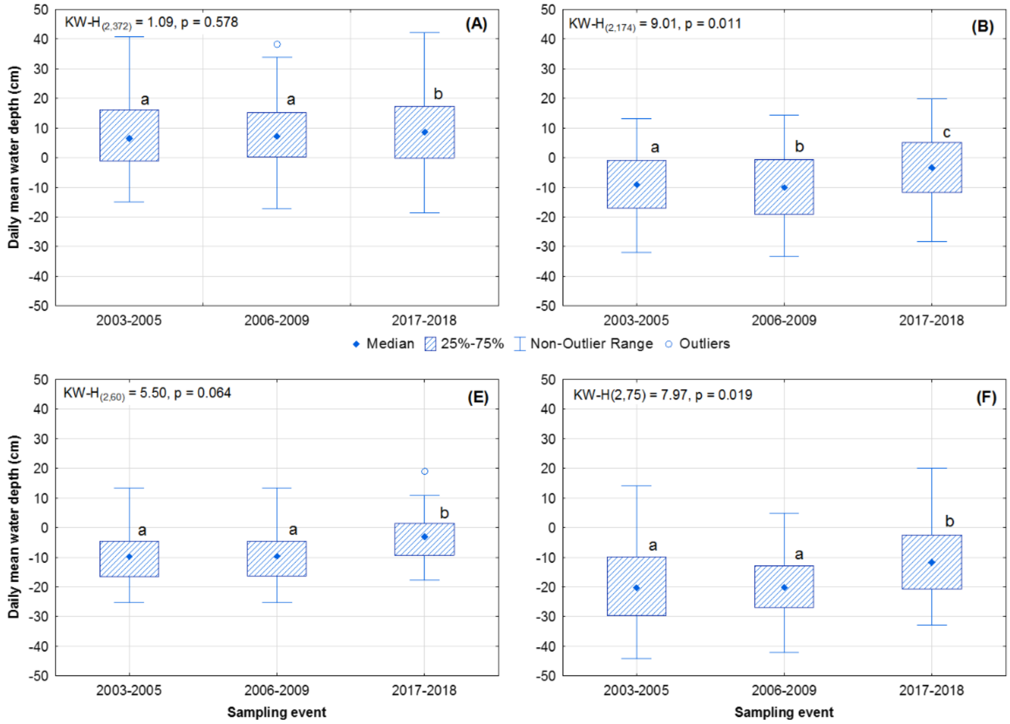

Figure 5: Box-plot showing median (box = 25% and whisker = 75% quartiles) four-year average annual mean daily water depth at a subset of sites sampled in sub-populations A, B, E and F over two years, 2017 and 2018 that had field measurements of water depth. The sites were sampled three times: during 2003/2005, 2006/2009 and 2017/2018 sampling events.

Table 1: Four-year mean discontinuous hydroperiod and annual mean daily water depth at 2017/2018 vegetation survey sites in different regions of CSSS sub-populations A and sub-populations B, E and F. The values were calculated only for those sites for which field measurements of water depth were available, and the sites were sampled during both 2003/2005 and 2017/2018 sampling events. The hydroperiod and daily water depth values were calculated using the ground elevation derived from the field measurements of water depth and EDEN daily water surface elevation data.

Sub-pop	**Region**	**N**	**4-year average hydroperiod (days)**				**4-year annual mean daily water depth (cm)**			
			2003/2005		2017/2018		2003/2005		2017/2018	
			mean (±sd)	median	mean (±sd)	median	mean (±sd)	median	mean (±sd)	median
Sub-pop. A	hN	15	161 (±51)	145	141 (±67)	133	-5.9 (±6.0)	-7.5	-8.7 (±6.6)	-7.8
Sub-pop. A	hS	28	212 (±55)	216	231 (±58)	232	1.6 (±9.5)	0.8	4.5 (±9.4)	4.0
Sub-pop. A	W	81	268 (±47)	277	284 (±52)	298	11.6 (±9.9)	11.8	13.2 (±10.5)	13.2
Sub-pop. B	-	58	159 (±83)	166	187 (±99)	203	-8.8 (±11.7)	-9.1	-3.0 (±12.5)	-3.4
Sub-pop. E	-	20	182 (±61)	190	221 (±55)	225	-9.5 (±10.0)	-9.75	-3.0 (±9.3)	-3.1
Sub-pop. F	-	25	118 (±76)	96	186 (±54)	197	-19.3 (±14.9)	-20.3	-10.2 (12.8)	-11.7

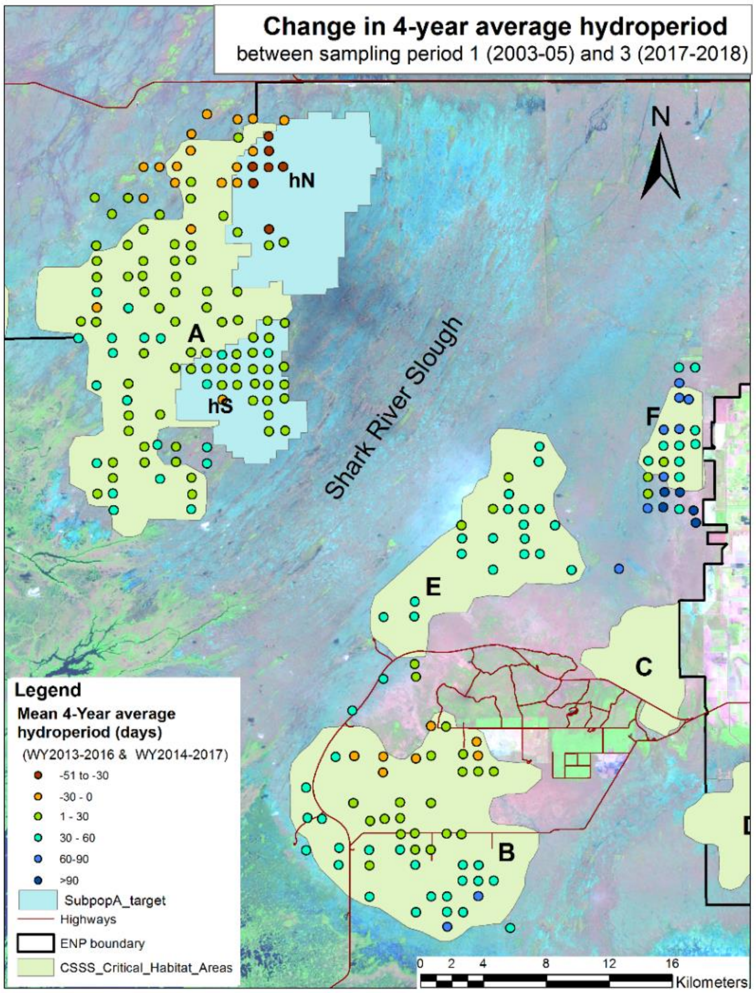

Figure 6: Change in four-year mean discontinuous hydroperiod between 2003/2005 and 2017/2018 sampling periods at 2017/2018 vegetation survey sites in sub-populations A, B, E and F. The values were calculated only for those sites for which field measurements of water depth were available, and the sites were sampled during both 2003/2005 and 2017/2018 sampling events.

3.2 Vegetation Composition and Classification

In general, during 2017/2018 sampling, vegetation was classified into the nine of same ten vegetation types that had been previously defined within the marl prairie landscape (Ross et al. 2006). The 10th vegetation type, *Spartina* Marsh, was not present at any site sampled in 2017/2018. However, some sites that were resampled this time were of a different vegetation type than what was present at those sites 15 years earlier, suggesting a shift in species composition in response to hydrologic changes over that period.

In sub-population A, 170 sites were resampled during the period, half (52.3%) in either the hN or hS areas. Distribution of vegetation types among the resampled sites within this sub-population were not uniform (**Figure 7**). The western portion of the subpopulation and hS area had a disproportionately high percentage (91.3% and 60.5%, respectively) of sites in one of the Marsh (M) vegetation types. In hS, most (69%) sites were *Cladium* Marsh (CM), and the remaining one-third were *Cladium-Rhynchospora* Marsh (CRM), whereas in western-A, only 23% of sites were CM. Among the remaining sites, 36% were CRM, and 30% were marshes dominated by either beakrush (*Rhynchospora) or* spikerush (*Eleocharis*). In contrast, in hN, two-third of the sites were wet prairie (WP) vegetation types, and 50% of these were *Schizachyrium* WP (SCWP) and 32% were *Cladium* WP (CWP). The *Schoenus* WP (SOWP) type was present at only three transect and two census sites.

Across all three eastern sub-populations, of the 115 resampled sites, 64% were wet prairie (WP) type. However, these three sub-populations differed in character. For instance, at the majority (60%) of sampled sites in sub-population E, vegetation was of the marsh type (**Figure 7**). In sub-population E, WP vegetation was present only at a few eastern sites. Among the sites with WP vegetation in these three sub-populations, 44% were *Cladium* WP. *Muhlenbergia*, *Schizachyrium* and *Schoenus* WP types were present at 23%, 19% and 14% of sites, respectively. Marsh vegetation was prevalent also in the western and southern portions of B, and a very few locations in F. About half of the marsh sites were the CM, while the rest were either *Cladium*, *Rhynchospora* or *Eleocharis* Marsh.

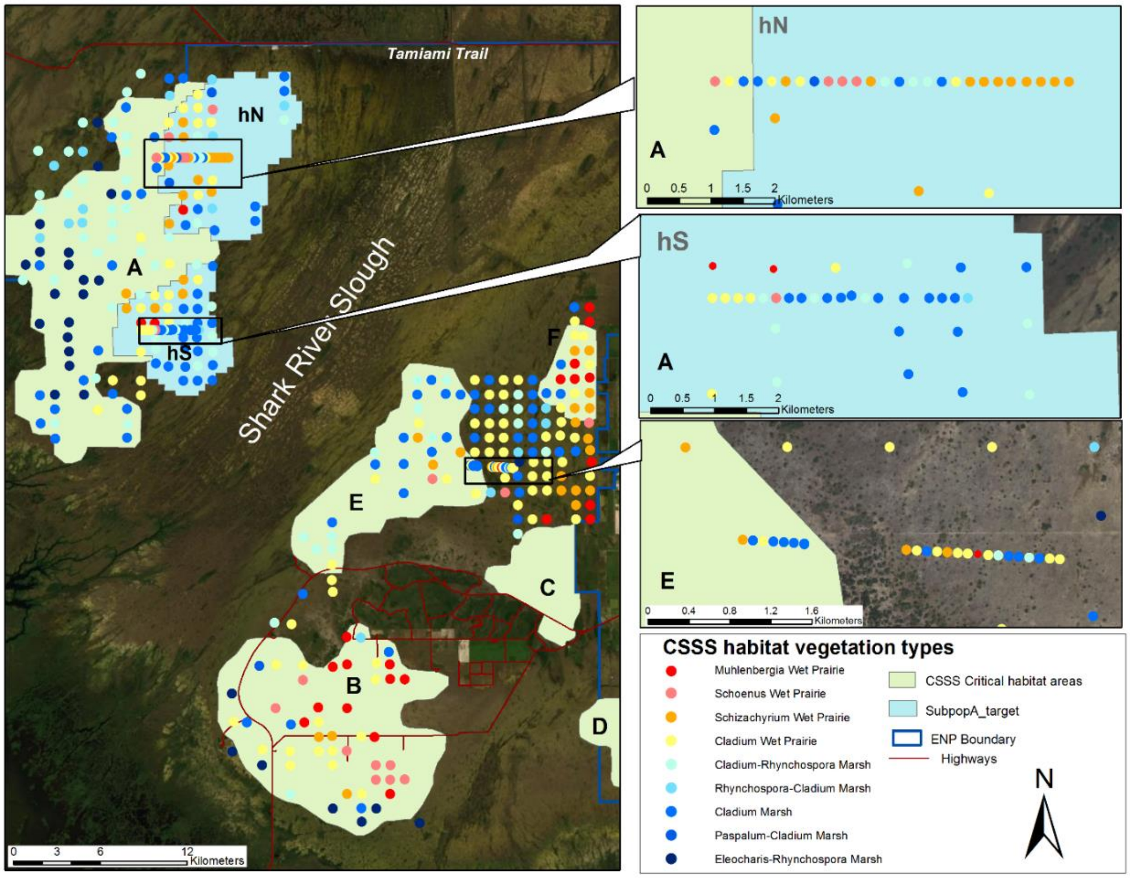

Figure 7: Spatial distribution of vegetation types at the 2017/2018 sampling sites in subpopulations A, B, E and F. Vegetation type at each site was identified through cluster analysis of species cover values at these sites plus 608 census sites sampled in three years (2003/2005). In the cluster analysis, cluster diagram was cut in the 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.

Over the two years (2017 and 2018), 114 sites were sampled for the first time. 29 (10 census and 19 transect) sites were in sub-population A, and 28 (4 census and 24 transect) sites in sub-population E. In sub-population A, a majority (83%) of these new sites had marsh vegetation, including *Cladium* Marsh, *Cladium-Rhynchospora* Marsh and *Rhynchospora-Cladium* Marsh (Figure 7). In contrast, at the newly established sites on the extended part of Transect E, half of the sites were of WP type, mainly *Cladium* WP and *Schizachyrium* WP, and most of the other sites were *Cladium* Marsh (Figure 7).

In comparison to sub-population A, the vegetation in the new sites sampled 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 the sites in CF. For instance, in the EF area, 61% of the sites had marsh vegetation, mostly *Cladium* Marsh and *Cladium-Rhynchospora* Marsh. The remaining 39% had WP vegetation of a single type, *Cladium* WP. In contrast, vegetation at 81% of the sites in the CF area were WP types, including *Muhlenbergia* WP, *Schizachyrium* WP and *Cladium* WP (Figure 7).

3.3 Vegetation Change (2003/2005 – 2017/2018)

In correspondence with hydrologic changes observed over these 15 years, a shift in vegetation composition was also detected at several sites in sub-populations A, B, E and F. In 2017/18, both transect and census sites were resampled in sub-population A, but only census sites in sub-population B, E and F. Vegetation change at Transect A sites has already been described in detail in Sah et al. (2018). Thus, the following sections describe vegetation change at only census sites in all four sub-populations resampled in (2017/2018).

In sub-populations B, E, and F, species composition in 2017/2018 was significantly different (ANOSIM: $p<0.05$) from previous surveys (Table 2). However, in Sub-population A, the difference in species composition was significant only between two most recent samplings (2006/2009 and 2017/2018). Though, 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 sampling was significant, and in this region the difference between two most recent samplings was also much stronger than in other two regions (hN and hS).

Table 2: Global R and *p*-values (in parenthesis) from analysis of similarity (ANOSIM) testing differences in vegetation composition among three sampling events: 2003/2005, 2006/2009 and 2017/2018.

Sub-populations		**2003/2005 – 2006/2009**	**2006/2009 – 2017/2018**	**2003/2005 – 2017/2018**
A	**All**	0.010 **(0.034)**	0.019 **(0.006)**	0.008 (0.067)
	hN	0.033 (0.075)	0.049 **(0.039)**	0.016 (0.197)
	hS	0.053 **(0.028)**	0.040 **(0.048)**	0.036 (0.056)
	W	0.002 (0.559)	0.021 **(0.017)**	0.015 **(0.003)**
B		0.107 **(0.001)**	0.138 **(0.001)**	0.144 **(0.001)**
E		0.260 **(0.001)**	0.246 **(0.002)**	0.408 **(0.001)**
F		0.072 **(0.014)**	0.121 **(0.001)**	0.227 **(0.001)**

3.3.1 Change in vegetation-inferred hydroperiod

Across all sub-populations, vegetation-inferred hydroperiod was significantly different (Non-parametric Friedman ANOVA; N =232, df = 2; $p < 0.001$) among three sampling events. Moreover, the change in inferred-hydroperiod was positively correlated with the change in 4-year average hydroperiod and mean daily water depth (**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.

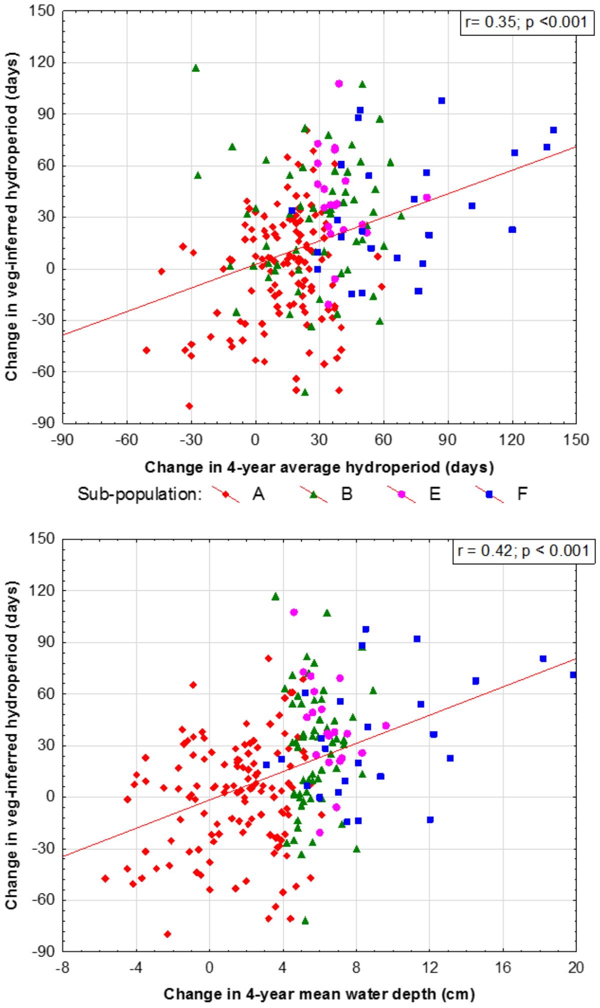

Figure 8: Relationship between change in hydrologic conditions (4-year average hydroperiod and mean water depth) and change in vegetation-inferred hydroperiod between 2003/2005 and 2017/2018 samplings at the sites sampled in 2017/2018 in sub-population A, B, E and F.

3.3.1.1 Sub-population A census sites

In sub-population A, the mean (±SD) vegetation-inferred hydroperiods were 262 (±44), 269 (±49) and 260 (±44) days, and medians were 261, 272 and 266 days in 2003/2005, 2006/2009 and 2017/2018 sampling events, respectively. The inferred-hydroperiod significantly differed among the three sampling events, and it was significantly higher (Wilcoxon matched-pairs test: $p < 0.001$) in 2006/2009 than in both 2003/2005 and 2017/2018 samplings (Figure 9). Nevertheless, the direction of change in inferred-hydroperiod varied spatially. Most (75%) of the sites in hN had shorter vegetation-inferred hydroperiod in 2017/2018 than in 2003/2005 (Figure 10). During the three samplings in hN, the mean inferred-hydroperiods were 236, 224 and 216 days, respectively. In contrast, mean vegetation-inferred hydroperiod at the two-third of sites in hS was higher in 2017/2018 than previous two sampling events. Surprisingly, the sites in the western portion of sub-population showed mixed results. More than half (57%) of the sites had 1 to 69 days higher vegetation-inferred hydroperiod in the third sampling than in previous two samplings, but rest had low inferred-hydroperiod than previous surveys.

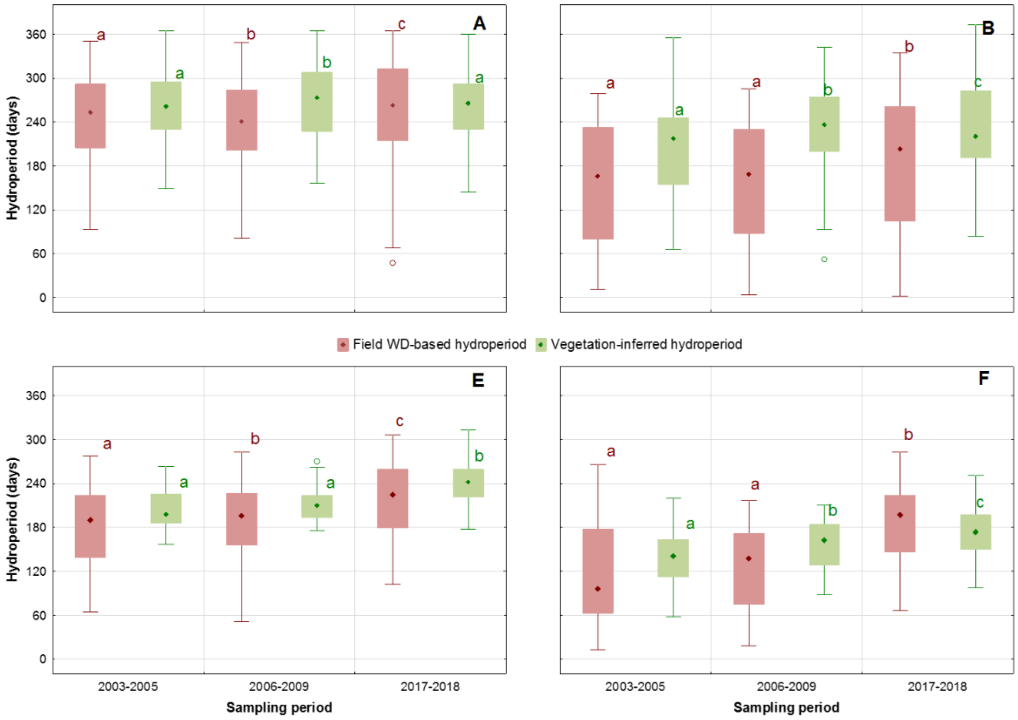

Figure 9: Box-plot showing median (box = 25% and whisker = 75% quartiles) field water-depth hydroperiod (in red) and vegetation-inferred hydroperiod (days) (in green) averaged over census sites sampled during 2003/2005, 2006/2009 and 2017/2018 samplings.

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

While the vegetation composition in three sub-populations (B, E and F) has shifted towards a more hydric type over the one and half decades of our study (Figure 9), the magnitude of vegetation change along the hydrologic gradient differed among these sub-populations. For instance, in sub-population B, mean vegetation-inferred hydroperiod increased by only 24 days, while it increased by 40 days in E. In sub-population F, where the vegetation is a much drier type, mean inferred-hydroperiod increased by 34 days: from 140 days in 2003/2005 to 174 days in 2017/2018. Even within each sub-population, the change in vegetation composition was not uniform. In sub-population B, increase in inferred-hydroperiod were mostly on the southern and western sites, whereas inferred-hydroperiod increased throughout the sub-populations E and F (Figure 10).

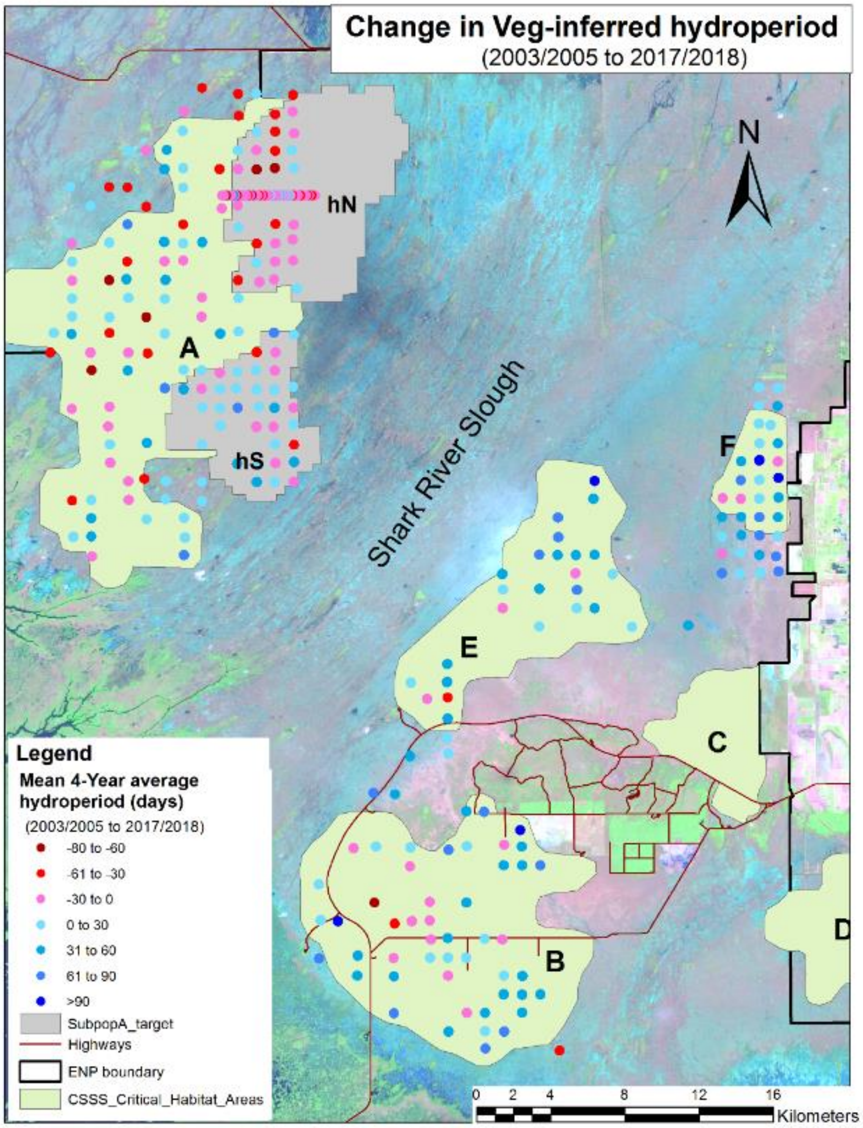

Figure 10: Map showing the spatial variation in a change in vegetation-inferred hydroperiod between 2003/2005 and 2017/2018 samplings at the sites sampled in 2017/2018 in sub-populations A B, E, and F.

3.3.2 Change in vegetation types

In concurrence with the significant differences described in overall species composition among sampling years at both census (259) and transect (26) sites, vegetation type also changed at almost half (49%) of the sites during the fourteen-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: marsh or wet prairie vegetation. For instance, among the 103 sites that changed from one vegetation type to another, 63 remained in the marsh category. Most of these sites were in the western portion of sub-populations A and E, and the southwestern portion of sub-population B. The sites that changed from one prairie type to another were mostly in the eastern portion of sub-population A, or in sub-populations B and F.

In sub-population A, while vegetation at 12 sites changed from marsh to wet prairie type, vegetation at only three sites changed from a wet prairie to a marsh type. 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, E and F, the majority of sites (21 of 23 sites) that showed a noticeable shift in vegetation composition changed from WP to marsh types (Figure 11), indicating the wetting trend in some portions of those sub-populations.

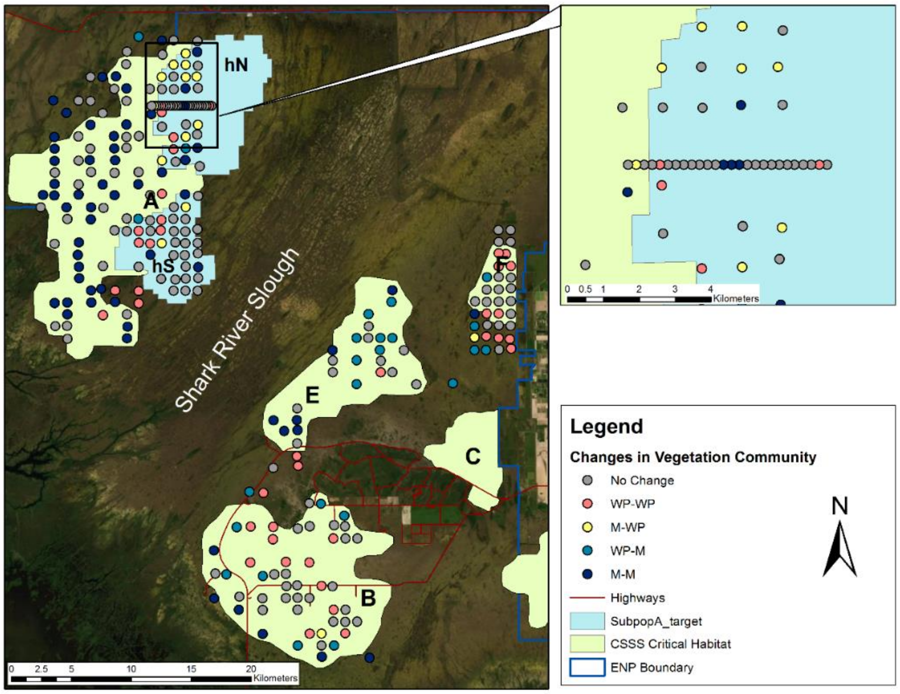

Figure 11: Change in vegetation types at the census and transect sites in sub-populations A, B, E and F between first sampling (2003/2005) and 2017/2008 sampling. WP-WP = One wet-prairie vegetation type to another wet-prairie type; M-WP = Marsh veg type to wet prairie type; WP-M = Wet prairie veg type to marsh type; M-M = One marsh veg type to another marsh type.

Hydrologic conditions at the sites that showed either no change or a change in vegetation type differed significantly. Our analysis of differences in hydrologic conditions among sites showing different trends in vegetation was restricted to un-burned sites, i.e. for the sites that were not burned between 2003 and 2018. Over the study period, for most of sites, including the prairie sites that either changed from one prairie type to another or remained in the same type, mean hydroperiod significantly increased (Table 3). During the 2017/2018 sampling 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 265 days, a flooding duration that was approximately 20 days higher than in 2003/2005 (Table 3). Similarly, at the sites that changed from WP to marsh type, the mean hydroperiod in the most recent sampling was 225 days, i.e. 34 days higher than during 2003/2005 sampling. The sites that remained wet prairie or changed from one wet prairie type to another, the mean hydroperiods were 170 ± 67 and 166 ± 82 days, respectively, but those values were 30 to 40 days higher than in the 2003/2005 sampling. In contrast, mean hydroperiod decreased slightly or remained the same at sites that showed a change from marsh to wet prairie type. At these sites, the mean hydroperiod and water depth during 2017/2018 sampling were 163 ± 83 days and -6.1 ±

7.0 cm, well within the range at other prairie sites. However, for the same period, wet season mean and minimum water depth at these sites were significantly lower than for the 2003/2005 sampling period (Figure 12).

Table 3: Four-year mean discontinuous hydroperiod and annual mean daily water depth at 2017-2018 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	2017/2018	p-value	2003-2005	2017/2018	p-value
No change-Wet prairie (WP)	53	141 (±64)	170 (±67)	<0.001	-13.1 (±10.5)	-7.9 (±9.3)	<0.001
WP-WP	33	126 (±80)	166 (±82)	<0.001	-14.2 (±13.8)	-7.8 (±11.6)	<0.001
WP-M	21	191 (±70)	225 (±78)	<0.001	-5.8 (±12.3)	-0.1 (±12.5)	<0.001
No change – Marsh (M)	56	252 (±43)	270 (±44)	<0.001	7.4 (±8.0)	9.3 (±8.2)	<0.001
M-M	53	270 (±50)	292 (±55)	<0.001	12.3 (±10.9)	15.0 (±10.9)	<0.001
M-WP	11	165 (±54)	163 (±83)	<872	-6.1 (±7.0)	-6.0 (9.7)	0.958

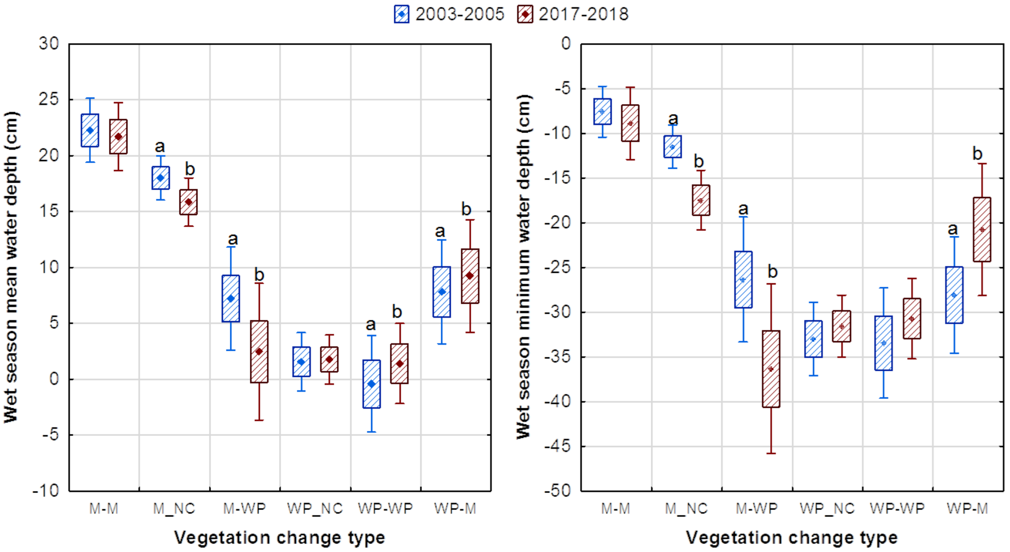

Figure 12: 4-year average wet season mean and minimum water depth (cm) during 2003/05 and 2017/18 samplings at the sites that changed from marsh vegetation type to wet prairie type. M= Marsh, WP = Wet prairie, NC = No change.

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. Whereas 90% of the transect sites showed a drying trend (Sah et al. 2018), only about half (52.4%) of census sites showed a shift in vegetation composition toward drier type. Among the latter, the magnitude (delta) and rate (slope) of trajectory shift was statistically significant at 35% of the sites, and most of these were within hN and adjacent areas (Figure 13; Appendix 2). Among the sites (47.6%), that showed a wetting trend, the trajectory shift was statistically significant at only 30% of the sites. These sites were mostly in hS area (Figure 13)

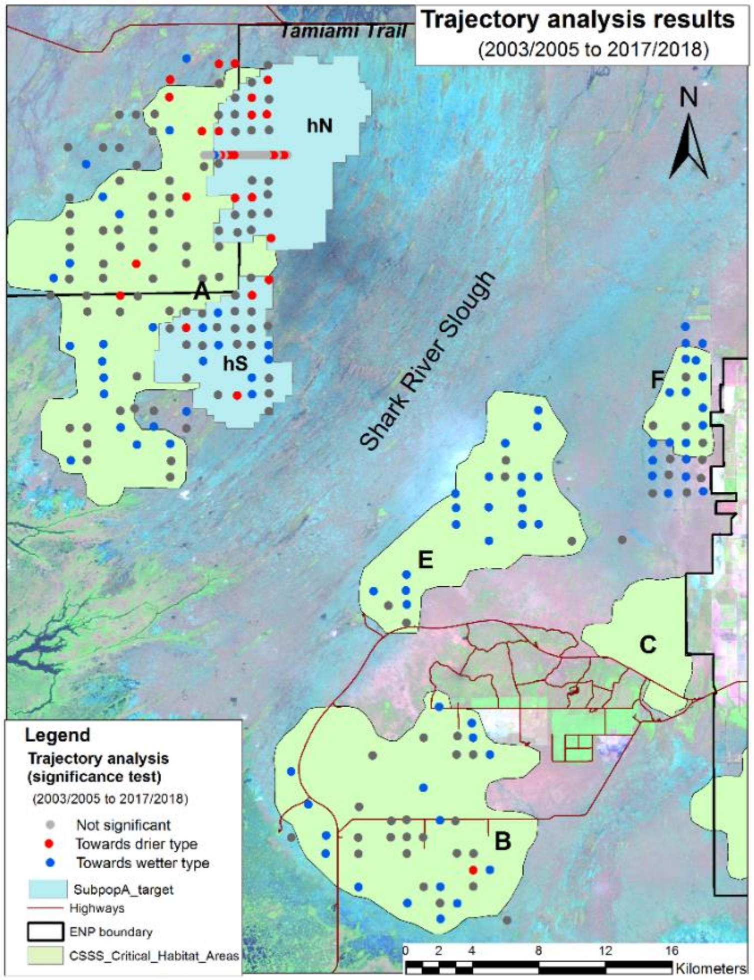

Figure 13: Sites showing a significant shift in vegetation composition between 2003/2005 and 2017/2018 samplings in sub-populations A, B, E and F. Significance of site trajectory was obtained by trajectory analysis. Only the sites that were not burned until 2008 and were sampled at least 3 times were 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 ($r^2 > 0.18$, $p < 0.01$) (Figure 14). Similar relationships were observed between changes in dry and wet season mean and minimum water depths and vegetation shift (Figure 15). Notably, while dry season maximum water depth had a significant effect on vegetation shift, species composition was little affected by a change in wet season maximum water depth (Figure 16).

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 sampling.

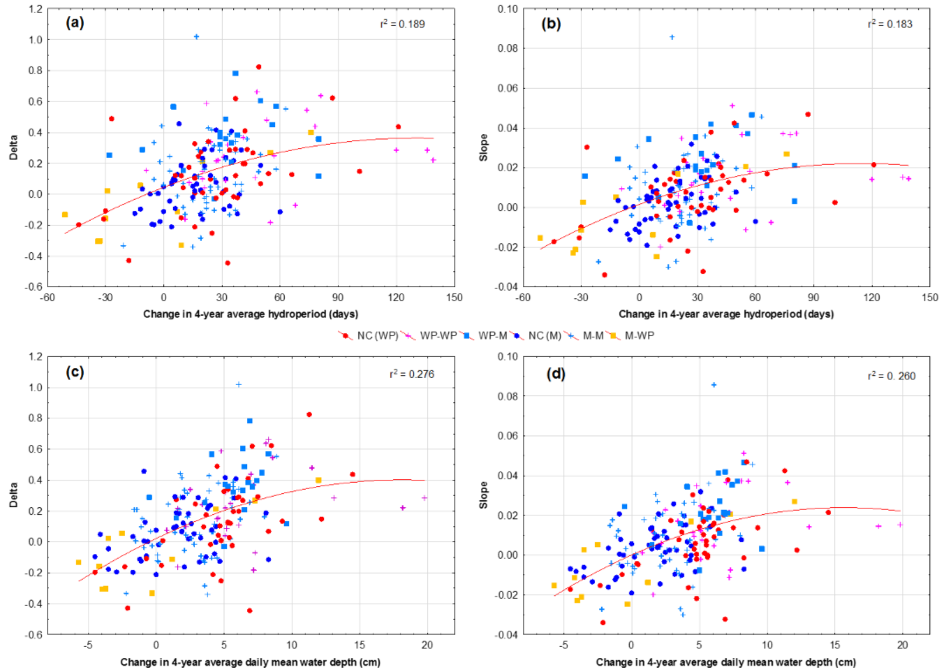

Figure 14: Relationship between change in hydrologic conditions (4-year mean hydroperiod and water depth) and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology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

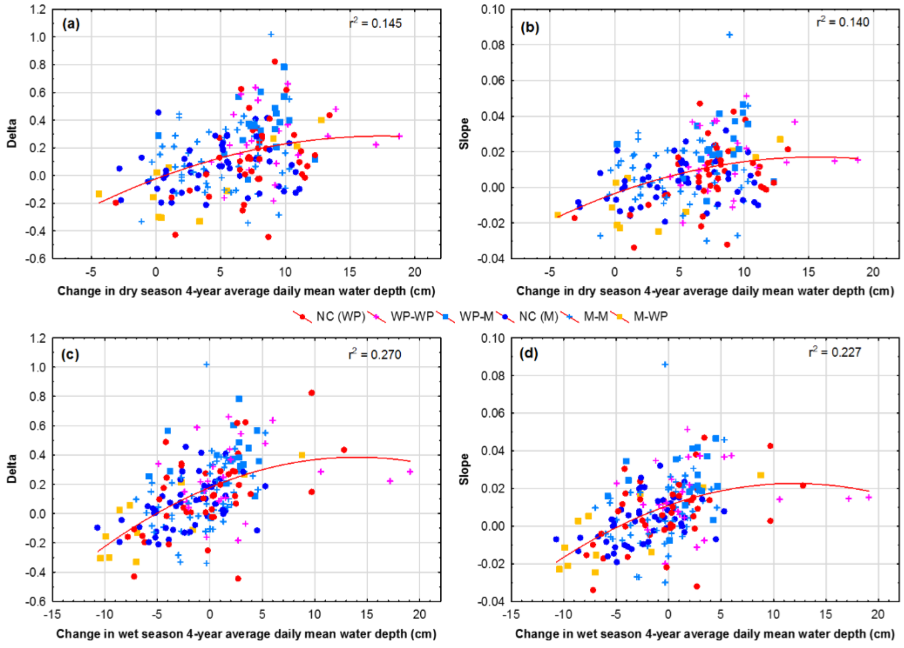

Figure 15: Relationship between change in dry and wet season mean and minimum water depth and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within 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.

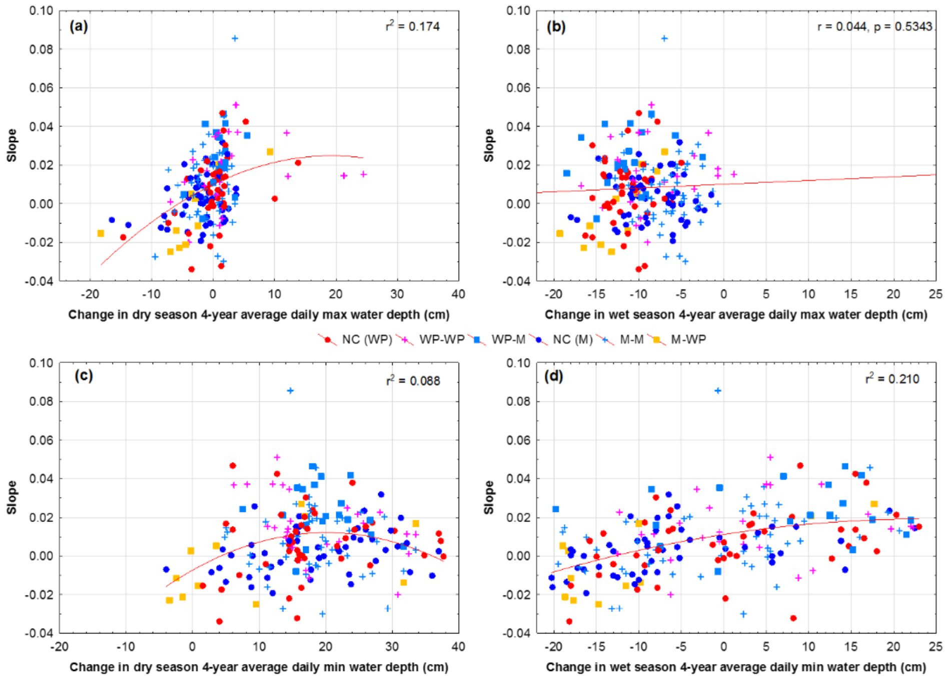

Figure 16: Relationship between change in dry and wet season maximum and minimum water depth and magnitude (delta) and rate (slope) of vegetation change. Both delta and slope are the statistics obtained in trajectory analysis, representing the shift in position of sites along the hydrology vector within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

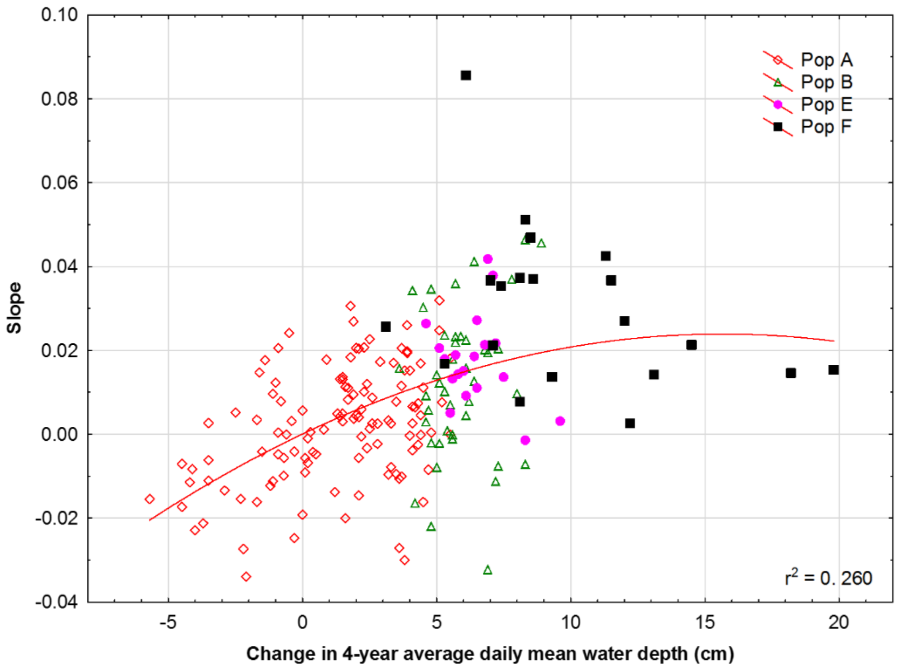

Figure 17: Relationship between change in 4-year daily mean water depth and rate (slope) of vegetation change. The slope is the statistics obtained in trajectory analysis, representing the shift in position of sites the hydrology vector within NMDS ordination space. Color of symbols represent habitat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

3.4 Vegetation Structure and Biomass

Vegetation change over fourteen years was marked also by changes in vegetation structure (vegetation total cover, green cover and height) and aboveground biomass (Figure 18). These structural changes reflected the differences in hydrologic conditions and vegetation composition among different sub-populations described above.

In sub-populations A and F, mean vegetation cover was significantly higher (General linear mixed model: Tukey test, $p<0.05$) during the recent sampling (2017/18) than during the initial (2003/2005) sampling, but were not statistically different from the value 2006/2009 sampling (Figure 18A). However, in sub-populations B and F, the mean cover was lower during both surveys after 2003/2005. In comparison to vegetation cover, mean vegetation height was significantly higher in 2017/2018 than in the previous two surveys in all four sub-populations (Figure 18B); mean height during 2003/2005 and 2006/2009 did not differ. In sub-populations A and F, the increase in total cover was accompanied by an increase in mean above ground biomass (Figure 18D). In these areas, aboveground biomass in 2017/2018 was almost 25% higher than 1.5 decade earlier. However, aboveground biomass in sub-populations B and F were similar in both 2003/2005 and 2017/2018 surveys, though biomass during the interim (2006/2009) survey was relatively low. Over the full study period (2003-2018), green percent cover, expressed as the percent of total vegetation cover, has decreased in all four sub-populations (Figure 18C).

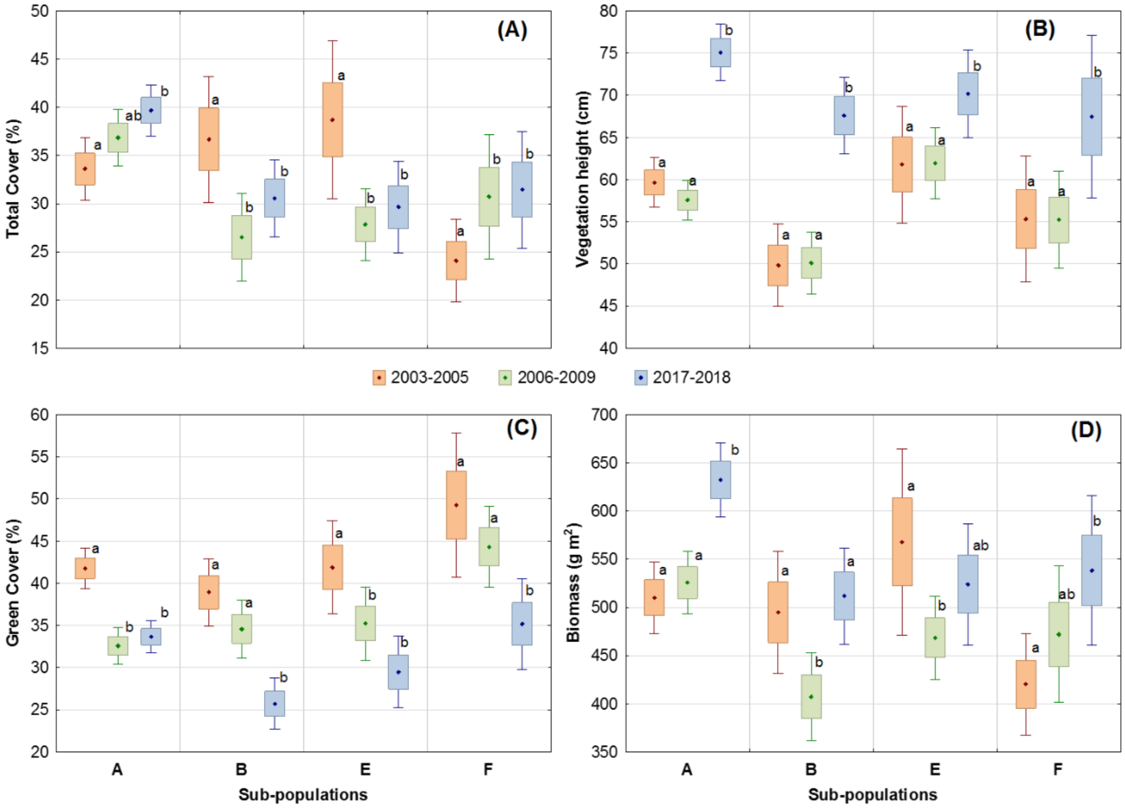

Figure 18: Box-plots (mean, SE, 95% CI) showing the vegetation structure, (A) total vegetation cover, (B) vegetation height, (C green vegetation cover (as a percent of total cover), and (D) aboveground biomass in four sub-populations within which a number of sites were sampled during three sampling events, 2003/2005, 2006/2009, and 2017/2018.

4. Discussion

In the southern Everglades marl prairies on both sides of Shark River Slough, hydrologic conditions have changed over one and a half decades (2003-2018), 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 and B, 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) and Central Everglades Planning Project (CEPP) (USACE 2011; USACE 2014). Vegetation change pattern observed in marl prairie landscape during this study suggests changes, including improvements, in the sparrow habitat conditions in both sides of the Shark River Slough.

This study shows that the vegetation composition in 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. In contrast, vegetation in the northeastern portion of this subpopulation has shifted towards a drier type, indicating an improvement in habitat conditions in this area. This improvement is possibly the result of 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; 2017a). 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. Such changes in the vegetation composition was probably the primary reason that sparrows have continued to occupy that part of sub-population A in recent years, though still in low numbers. 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 areas in the southern and western portion of this sub-population experienced a wetter hydrologic regime than eight years earlier. In this area, vegetation change towards a wetter type in response to more hydric conditions in recent years 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. In an analysis of the flow data in relation to rainfall, Kotun et al. (2009) showed that mean annual runoff per unit rainfall in the FMB-Monroe sub-basin increased by a factor of two during 1992-2008 in comparison to three earlier periods (1941-1952, 1953-1963 and 1964-1991). They attributed the increased runoff to high stage level in WCA-3A, which resulted in a backwater effect in Mullet Slough, causing water to flow southwest towards Big Cypress National Preserve, and ultimately ending up in increased flow across the Tamiami Trail, apparently contributing to high water levels in the western part of sub-population A. Vegetation in coastal Florida, including the southwestern part of sup-population A, is also influenced by the sea level rise, but the extent of that influence is uncertain. A thorough investigation using species indicators of sea level rise along transects in this portion of CSSS habitat can only help to answer this question. The more hydric condition than previous sampling events in hS, the southeastern portion of subpopulation A, was unexpected. More than two thirds of sites sampled 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. 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; USFWS 2016).

Vegetation change in sub-population B was also spatially variable. In western and southern portions of this sub-population, vegetation shifted towards 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 subpopulation 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. This trend is likely to continue in the future, which may cause further limitation in the extent of suitable habitat for this sparrow sub-population.

In E and F, the other two eastern sub-populations, we observed a shift towards wetter vegetation type at most sites. 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, operated under Interim Operation Plan (IOP) to provide protection for the adjacent CSSS habitat (USFWS 2002), 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, as these areas were considered over-drained, resulting in frequent fires that adversely impacted the habitat and reduced 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 (Sah et al. 2011, 2016, 2017a). 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 2017/2018 surveys were done 1 and 2 years after the extreme event of dry season high water condition that occurred in spring 2016, when marl prairies in those two sub-populations were flooded for an extended period (Sah et al. 2017a, b). At the sampled sites in sub-populations E and F, the mean hydroperiods in 2016 were 352 and 290 days, respectively, which were 134 and 181 days higher than mean hydroperiods averaged over 24-years (1991-2015) prior to that extreme event. In a normal year, water level in eastern marl prairies drops up to 100 cm below the ground surface in the dry season (Sah et al. 2011). But in these two sub-populations, dry season mean daily water depth in WY 2015/2016 were 13.1 and 9.6 cm, while the 24-year average values were -19.9 and -15.1 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 sampling much higher (6-8 cm) than during previous surveys (Figure 5; Table 1). Moreover, in sub-populations F, and some portions of E, we observed vegetation shift towards more mesic type, but at most of the sites vegetation type have not changed from WP type to marsh type, despite a very wet dry season in 2016 and 2018.

In the Everglades marl prairies and ridge & slough landscapes, the hydrology-mediated change in vegetation composition is usually visible in 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, the unusual extreme hydrologic condition may also disrupt the 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 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, but the time between such events and this study was short (<3 years), and thus the actual effects of such a high water conditions 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 total aboveground biomass and a decrease in green cover (i.e. live biomass) over one and a half decades. Since the current analysis of vegetation structure was based on only unburned sites, the increase in biomass at those 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, have not burned in >30 years. Therefore, the increase in dead biomass in such areas may require immediate attention. 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, and the next phase of analysis is planned for 2020 report, when we will present a comprehensive analysis of data from all sites sampled over four years (2017-2020) in both western and eastern marl prairies.

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 small population of sparrows in sub-population A 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 prescribed burn (ROG NW RX) was executed in this area in 2014. Similarly, the western part of this sub-population was planned to burn (River of Grass West RX) in September 2019. These fires are expected to contribute in the habitat improvement.

In the eastern populations, where habitat degradation is thought to have resulted from over drainage and frequent fires, the areas would 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, and to some extent in 2018, can affect the restoration goal. Thus, a compensatory strategy to offset the negative consequences of such events 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 exiting 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 objective, 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) and other components of CERP.

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Appendices

Appendix A1: List of vegetation survey sites sampled in 2017 and 2018. C= Census; T = Transect. Coordinates are in UTM NAD 1983.

2017						2018					
Sub pop.	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**	**Sub pop.**	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**
A	C	A-01-02	513139	2846878	ENP	A	C	A-05-01	504238	2823026	ENP
A	C	A-01-03	514119	2846904	ENP	A	C	A-05-06	509224	2825064	ENP
A	C	A-01-06	515125	2844858	USACE	A	C	A-05-08	510217	2824036	ENP
A	C	A-01-07	514102	2843847	ENP	A	C	A-05-09	510265	2822985	ENP
A	C	A-01-08	516146	2842899	ENP	A	C	A-06-03	506201	2830025	ENP
A	C	A-03-02	513155	2834079	ENP	A	C	A-06-04	506210	2827998	ENP
A	C	A-03-04	515132	2832965	ENP	A	C	A-06-05	506227	2827023	ENP
A	C	A-03-05	516090	2831118	ENP	A	C	A-06-07	508219	2828071	ENP
A	C	A-03-06	515089	2830946	USACE	A	C	A-07-01	504175	2829916	ENP
A	C	A-03-07	513029	2831037	USACE	A	C	A-07-04	505231	2831993	ENP
A	C	A-03-08	511174	2831001	USACE	A	C	A-07-08	507193	2831970	ENP
A	C	A-03-09	511168	2831996	USACE	A	C	A-08-02	504183	2834899	ENP
A	C	A-03-10	510182	2832018	ENP	A	C	A-08-03	506187	2834007	ENP
A	C	A-04-02	512186	2829011	USACE	A	C	A-08-06	507207	2835892	ENP
A	C	A-04-03	514251	2830027	ENP	A	C	A-09-01	506169	2838881	ENP
A	C	A-04-04	516131	2829091	USACE	A	C	A-09-05	509217	2836866	ENP
A	C	A-04-05	515117	2828015	USACE	A	C	A-09-06	510180	2837905	ENP
A	C	A-04-06	515133	2827012	ENP	A	C	A-13-09	510208	2822032	ENP
A	C	A-04-07	516163	2827057	USACE	A	C	A-15-03	503015	2832949	ENP
A	C	A-04-08	515108	2825981	USACE	A	C	A-15-10	506122	2828979	ENP
A	C	A-04-09	514123	2825976	USACE	A	C	A-16-01	509163	2837860	ENP
A	C	A-05-02	505216	2823052	ENP	A	C	A-17-02	510172	2839859	ENP
A	C	A-05-03	505226	2824020	ENP	A	C	A-18-06	504070	2841875	ENP
A	C	A-05-04	505225	2825013	ENP	A	C	A-21-01	511191	2847210	ENP
A	C	A-05-05	507234	2825015	ENP	A	C	A-21-06	508166	2843826	ENP
A	C	A-06-06	507215	2826006	ENP	A	C	A-21-07	507169	2843834	ENP
A	C	A-06-10	509227	2826008	ENP	A	C	A-21-08	510179	2842895	ENP
A	C	A-07-07	507216	2832954	ENP	A	C	A-21-09	509161	2842834	ENP
A	C	A-08-01	503198	2833998	ENP	A	C	A-24-01	506180	2841849	ENP
A	C	A-08-08	507113	2836904	ENP	A	C	A-24-03	505169	2840845	ENP
A	C	A-09-02	507173	2839844	ENP	A	C	A-25-01	504156	2838835	ENP
A	C	A-09-04	509143	2838908	ENP	A	C	A-25-02	504185	2837840	ENP
A	C	A-09-08	511185	2835905	ENP	A	C	A-25-03	504181	2836826	ENP
A	C	A-09-09	511196	2838896	ENP	A	C	A-25-09	507158	2837840	ENP
A	C	A-09-10	513152	2835885	ENP	A	C	A-26-04	509178	2833968	ENP
A	C	A-10-01	511203	2829990	USACE	A	C	A-26-06	509181	2835841	ENP

2017						2018					
Sub pop.	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**	**Sub pop.**	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**
A	C	A-10-02	512167	2831000	ENP	A	C	A-28-07	509180	2831039	ENP
A	C	A-10-03	513091	2831909	ENP	A	C	A-29-02	505257	2821970	ENP
A	C	A-10-04	514126	2830961	USACE	A	C	A-29-05	508211	2823965	ENP
A	C	A-10-07	516154	2833899	USACE	B	C	B-01-01	520439	2809224	ENP
A	C	A-11-02	514273	2836753	USACE	B	C	B-01-02	521601	2809144	ENP
A	C	A-11-03	515074	2836883	USACE	B	C	B-01-04	522408	2811219	ENP
A	C	A-11-04	516286	2836395	USACE	B	C	B-01-05	524414	2816166	USACE
A	C	A-11-05	516105	2837908	USACE	B	C	B-01-06	524388	2815203	USACE
A	C	A-11-06	515127	2837851	USACE	B	C	B-01-07	524394	2812179	ENP
A	C	A-11-07	514118	2837794	USACE	B	C	B-01-08	524480	2811369	ENP
A	C	A-11-08	514123	2838811	USACE	B	C	B-02-01	524473	2806170	ENP
A	C	A-12-05	511187	2827984	USACE	B	C	B-02-02	525433	2808246	ENP
A	C	A-12-07	513083	2826972	USACE	B	C	B-02-03	525452	2806350	ENP
A	C	A-12-08	514248	2826938	USACE	B	C	B-02-04	526393	2808207	ENP
A	C	A-12-09	516129	2825994	USACE	B	C	B-02-05	527489	2806438	ENP
A	C	A-12-10	516163	2827975	USACE	B	C	B-02-06	527435	2805325	ENP
A	C	A-13-01	504181	2824977	ENP	B	C	B-02-07	528345	2807219	ENP
A	C	A-15-02	504153	2833951	ENP	B	C	B-02-08	528417	2806348	ENP
A	C	A-15-04	505171	2832943	ENP	B	C	B-02-09	528443	2805331	ENP
A	C	A-17-03	510174	2838837	ENP	B	C	B-02-10	529434	2805326	ENP
A	C	A-17-08	513139	2836852	USACE	B	C	B-03-01	523480	2800352	ENP
A	C	A-19-03	512122	2842830	ENP	B	C	B-03-02	524426	2801401	ENP
A	C	A-19-04	515100	2842892	USACE	B	C	B-03-03	524439	2800361	ENP
A	C	A-19-06	513112	2840887	USACE	B	C	B-03-04	524436	2799379	ENP
A	C	A-19-08	515144	2839865	ENP	B	C	B-03-05	525424	2800358	ENP
A	C	A-19-09	515136	2838845	ENP	B	C	B-03-06	526436	2801374	ENP
A	C	A-19-10	516073	2839044	USACE	B	C	B-03-07	527362	2801328	ENP
A	C	A-20-05	513181	2845696	ENP	B	C	B-03-08	527456	2799384	ENP
A	C	A-20-06	516073	2845920	USACE	B	C	B-03-09	527439	2798381	ENP
A	C	A-20-07	516149	2844757	USACE	B	C	B-03-10	528456	2799370	ENP
A	C	A-21-02	510218	2845943	ENP	B	C	B-04-01	524473	2796383	ENP
A	C	A-21-03	510151	2844890	ENP	B	C	B-04-02	525449	2797381	ENP
A	C	A-21-05	509283	2843872	ENP	B	C	B-04-03	526451	2797378	ENP
A	C	A-22-01	516104	2846819	ENP	B	C	B-04-04	526445	2796391	ENP
A	C	A-22-02	515118	2845783	USACE	B	C	B-04-05	526466	2795453	ENP
A	C	A-22-03	514116	2844847	USACE	B	C	B-04-06	527480	2796378	ENP
A	C	A-22-04	513113	2843822	USACE	B	C	B-04-07	528432	2798371	ENP
A	C	A-22-05	513134	2842827	USACE	B	C	B-04-08	528439	2797388	ENP
A	C	A-22-08	514134	2842821	ENP	B	C	B-04-09	529431	2798383	ENP
A	C	A-22-09	515116	2843812	USACE	B	C	B-04-10	530465	2795357	ENP

2017						2018					
Sub pop.	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**	**Sub pop.**	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**
A	C	A-22-10	516024	2843849	USACE	B	C	B-05-01	519555	2799379	ENP
A	C	A-23-01	510168	2841826	ENP	B	C	B-05-02	521570	2802185	ENP
A	C	A-23-04	512252	2840716	ENP	B	C	B-05-03	521517	2800333	ENP
A	C	A-23-08	513149	2839676	ENP	B	C	B-05-04	521530	2799348	ENP
A	C	A-23-10	516135	2839836	USACE	B	C	B-05-05	521529	2797361	ENP
A	C	A-24-02	507169	2841834	ENP	B	C	B-05-06	522496	2802327	ENP
A	C	A-24-05	508190	2840801	ENP	B	C	B-05-07	523462	2803358	ENP
A	C	A-25-04	504188	2835849	ENP	B	C	B-05-08	523477	2802369	ENP
A	C	A-25-07	506180	2836853	ENP	B	C	B-05-09	523517	2801335	ENP
A	C	A-26-02	506190	2834854	ENP	B	C	B-05-10	525444	2803323	ENP
A	C	A-26-03	508179	2834854	ENP	B	C	B-06-01	517488	2804319	ENP
A	C	A-26-05	511172	2834890	ENP	B	C	B-06-02	517585	2802389	ENP
A	C	A-27-01	512150	2833964	ENP	B	C	B-06-03	517502	2800325	ENP
A	C	A-27-02	512145	2831869	USACE	B	C	B-06-04	518519	2802327	ENP
A	C	A-27-04	514096	2831997	USACE	B	C	B-06-05	519370	2806264	ENP
A	C	A-27-05	515104	2831980	USACE	B	C	B-06-06	519593	2800468	ENP
A	C	A-27-06	514137	2832972	USACE	B	C	B-06-07	520553	2806330	ENP
A	C	A-27-07	515060	2834026	USACE	B	C	B-06-08	520492	2803321	ENP
A	C	A-28-10	508265	2832912	ENP	B	C	B-06-09	522412	2806292	ENP
A	C	A-29-07	508062	2826150	ENP	B	C	B-06-10	522395	2805268	ENP
A	C	A-29-09	511189	2825973	ENP	B	C	B-07-01	523326	2814290	USACE
A	C	A-29-10	511192	2824959	ENP	B	C	B-07-02	524432	2814361	USACE
A	C	A-30-01	510186	2830972	ENP	B	C	B-07-04	524424	2813249	USACE
A	C	A-30-04	512152	2829941	USACE	B	C	B-12-04	522437	2815166	USACE
A	C	A-30-05	513124	2829962	ENP	E	C	E-01-01	529376	2822048	USACE
A	C	A-30-06	515090	2829964	ENP	E	C	E-01-02	530372	2824055	USACE
A	C	A-30-07	516118	2829970	USACE	E	C	E-01-03	530393	2823020	USACE
A	C	A-30-08	515041	2828959	USACE	E	C	E-01-04	530350	2822044	USACE
A	C	A-30-09	514119	2828965	ENP	E	C	E-01-05	531351	2822037	USACE
A	T	TA-0000	517265	2841401	ENP	E	C	E-01-06	531320	2821059	USACE
A	T	TA-0200	517065	2841401	ENP	E	C	E-01-07	532350	2826036	USACE
A	T	TA-0400	516865	2841401	ENP	E	C	E-01-08	532285	2825069	USACE
A	T	TA-0600	516665	2841401	ENP	E	C	E-01-09	532348	2822051	USACE
A	T	TA-0800	516446	2841401	ENP	E	C	E-01-10	533308	2821023	USACE
A	T	TA-1000	516265	2841401	ENP	E	C	E-02-01	527367	2821022	USACE
A	T	TA-1200	516065	2841401	ENP	E	C	E-02-02	527404	2820182	USACE
A	T	TA-1400	515865	2841401	ENP	E	C	E-02-03	527394	2819182	USACE
A	T	TA-1600	515665	2841401	ENP	E	C	E-02-04	529367	2820210	USACE
A	T	TA-1800	515465	2841401	ENP	E	C	E-02-05	529373	2818187	USACE
A	T	TA-2000	515265	2841401	ENP	E	C	E-02-06	531403	2820153	USACE

2017						2018					
Sub pop.	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**	**Sub pop.**	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**
A	T	TA-2200	515065	2841401	ENP	E	C	E-02-07	531375	2819176	USACE
A	T	TA-2380	514865	2841401	ENP	E	C	E-02-08	532358	2819185	USACE
A	T	TA-2600	514665	2841401	ENP	E	C	E-02-09	534364	2818180	USACE
A	T	TA-2800	514465	2841401	ENP	E	C	E-02-10	537394	2818253	USACE
A	T	TA-3000	514264	2841401	ENP	F	C	F-01-01	541821	2829046	USACE
A	T	TA-3200	514065	2841401	ENP	F	C	F-01-02	542251	2826192	USACE
A	T	TA-3400	513865	2841401	ENP	F	C	F-01-03	540249	2827107	USACE
A	T	TA-3600	513665	2841401	ENP	F	C	F-01-04	539257	2825111	USACE
A	T	TA-3800	513465	2841401	ENP	F	C	F-01-05	539212	2822102	USACE
A	T	TA-4000	513265	2841401	ENP	F	C	F-01-06	540198	2822176	USACE
A	T	TA-4200	513064	2841401	ENP	F	C	F-01-07	540277	2823126	USACE
A	T	TA-4400	512865	2841401	ENP	F	C	F-01-08	541255	2823107	USACE
A	T	TA-4600	512665	2841401	ENP	F	C	F-01-09	542139	2821962	USACE
A	T	TA-4800	512465	2841401	ENP	F	C	F-01-10	542267	2821167	USACE
A	T	TA-5000	512265	2841401	ENP	F	C	F-02-02	541218	2830079	USACE
A	C	A-35-06	521110	2847017	USACE	F	C	F-02-03	541215	2829129	USACE
A	C	A-35-07	521109	2846017	USACE	F	C	F-02-04	541220	2828050	USACE
A	C	A-35-08	521109	2845017	USACE	F	C	F-02-05	541226	2827151	USACE
A	C	A-35-09	521109	2844017	USACE	F	C	F-02-06	541225	2825084	USACE
A	C	A-35-10	519084	2838044	USACE	F	C	F-02-07	542250	2825144	USACE
A	C	A-36-01	519084	2837044	USACE	F	C	F-02-08	542239	2824082	USACE
A	C	A-36-02	514268	2828296	USACE	F	C	F-02-09	540244	2824095	USACE
A	C	A-36-03	512172	2827242	USACE	F	C	F-02-10	540163	2821056	USACE
A	C	A-36-04	512207	2828170	USACE	F	C	F-03-01	541200	2831069	USACE
A	C	A-36-05	512207	2827170	USACE	F	C	F-03-02	542240	2827075	USACE
A	T	TAS-1000	515195	2829486	USACE	F	C	F-03-03	541228	2826091	USACE
A	T	TAS-1200	514995	2829486	USACE	F	C	F-03-04	540232	2826077	USACE
A	T	TAS-1400	514795	2829486	USACE	F	C	F-03-05	540235	2825066	USACE
A	T	TAS-1600	514595	2829486	USACE	F	C	F-03-06	539228	2824074	USACE
A	T	TAS-2000	514195	2829486	USACE	F	C	F-03-07	539231	2823030	USACE
A	T	TAS-2400	513795	2829486	USACE	F	C	F-03-08	541226	2822038	USACE
A	T	TAS-2600	513595	2829486	USACE	F	C	F-03-09	542213	2823068	USACE
A	T	TAS-2800	513377	2829523	USACE	F	C	F-03-10	541220	2824087	USACE
A	T	TAS-3000	513213	2829491	USACE	F	C	F-04-01	539226	2821052	USACE
A	T	TAS-3200	512995	2829486	USACE	F	C	F-04-02	541278	2821100	USACE
A	T	TAS-3400	512795	2829486	USACE	F	C	F-04-03	542228	2831060	USACE
A	T	TAS-3600	512595	2829486	USACE	F	C	F-04-04	542228	2830060	USACE
A	T	TAS-3800	512395	2829486	USACE	F	C	F-04-05	542232	2828059	USACE
A	T	TAS-4000	512195	2829486	USACE	CF	C	CF-001	542363	2820357	ENP
A	T	TAS-4200	511995	2829486	USACE	CF	C	CF-003	540363	2820357	ENP

2017						**2018**					
Sub pop.	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**	**Sub pop.**	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**
A	T	TAS-4400	511795	2829486	USACE	CF	C	CF-004	539363	2820357	ENP
A	T	TAS-4600	511595	2829486	USACE	CF	C	CF-005	538363	2820357	ENP
A	T	TAS-4800	511395	2829486	USACE	CF	C	CF-006	537363	2820357	ENP
A	T	TAS-5000	511195	2829486	USACE	CF	C	CF-007	537284	2819378	ENP
E	T	TE-90100	533865	2820122	USACE	CF	C	CF-008	538284	2819378	ENP
E	T	TE-90200	533965	2820116	USACE	CF	C	CF-009	539284	2819378	ENP
E	T	TE-90300	534065	2820110	USACE	CF	C	CF-010	540289	2819381	ENP
E	T	TE-90400	534165	2820104	USACE	CF	C	CF-012	542281	2819388	ENP
E	T	TE-90500	534265	2820098	USACE	CF	C	CF-013	542281	2818388	ENP
E	T	TE-90600	534364	2820092	USACE	CF	C	CF-014	541281	2818388	ENP
E	T	TE-90700	534464	2820086	USACE	CF	C	CF-015	540289	2818388	ENP
E	T	TE-90800	534464	2820079	USACE	CF	C	CF-016	539284	2818388	ENP
E	T	TE-91700	535462	2820024	USACE	CF	C	CF-017	538284	2818378	ENP
E	T	TE-91800	535562	2820018	USACE	CF	C	CF-019	537281	2817388	ENP
E	T	TE-91900	535662	2820012	USACE	CF	C	CF-023	541281	2817388	ENP
E	T	TE-92000	535762	2820005	USACE	CF	C	CF-024	542281	2817388	ENP
E	T	TE-92100	535862	2819999	USACE	CF	C	CF-025	542281	2816388	ENP
E	T	TE-92200	535961	2819993	USACE	CF	C	CF-026	541281	2816388	ENP
E	T	TE-92300	536061	2819987	USACE	CF	C	CF-028	539281	2816388	ENP
E	T	TE-92400	536161	2819981	USACE	CF	C	CF-029	538281	2816388	ENP
E	T	TE-92500	536261	2819975	USACE	CF	C	CF-030	537281	2816388	ENP
E	T	TE-92600	536361	2819969	USACE	CF	C	CF-031	537281	2815388	ENP
E	T	TE-92700	536460	2819962	USACE	CF	C	CF-032	536394	2818253	USACE
E	T	TE-92800	536560	2819956	USACE	CF	C	CF-033	535394	2818253	USACE
E	T	TE-92900	536660	2819950	USACE	CF	C	CF-034	536394	2819253	USACE
E	T	TE-93000	536760	2819944	USACE	E	C	E-09-01	533299	2825028	USACE
E	T	TE-93100	536860	2819938	USACE	E	C	E-09-02	530299	2825028	USACE
E	T	TE-93200	536960	2819932	USACE	E	C	E-09-03	530299	2826028	USACE
						E	C	E-09-04	531299	2826028	USACE
						EF	C	EF-01	534299	2821028	USACE
						EF	C	EF-02	534299	2822028	USACE
						EF	C	EF-03	534299	2823028	USACE
						EF	C	EF-04	534299	2824028	USACE
						EF	C	EF-05	534299	2825028	USACE
						EF	C	EF-06	534299	2826028	USACE
						EF	C	EF-07	535299	2821028	USACE
						EF	C	EF-08	535299	2822028	USACE
						EF	C	EF-09	535299	2823028	USACE
						EF	C	EF-10	535299	2824028	USACE
						EF	C	EF-11	535299	2825028	USACE

2017						2018					
Sub pop.	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**	**Sub pop.**	**C_T**	**Site ID**	**X**	**Y**	**Funding Source**
						EF	C	EF-12	535299	2826028	USACE
						EF	C	EF-13	536299	2821028	USACE
						EF	C	EF-14	536299	2822028	USACE
						EF	C	EF-15	536299	2823028	USACE
						EF	C	EF-16	536299	2824028	USACE
						EF	C	EF-17	536299	2825028	USACE
						EF	C	EF-18	536299	2826028	USACE
						EF	C	EF-19	537299	2821028	USACE
						EF	C	EF-20	537299	2822028	USACE
						EF	C	EF-21	537299	2823028	USACE
						EF	C	EF-22	537299	2824028	USACE
						EF	C	EF-23	537299	2825028	USACE
						EF	C	EF-24	537299	2826028	USACE
						EF	C	EF-25	538299	2821028	USACE
						EF	C	EF-26	538299	2822028	USACE
						EF	C	EF-27	538299	2823028	USACE
						EF	C	EF-28	538299	2824028	USACE
						EF	C	EF-29	538299	2825028	USACE
						EF	C	EF-30	538299	2826028	USACE

Appendix A2: Vegetation type for all sites, and delta and slope (amount and rate of change in the target direction, respectively) for sites that were not burned and sampled at least three times between 2003 and 2018. 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.	**C_T**	**Year estd.**	**Samp-YearE3**	**Field ID**	**Vegetation type**		**Delta**	**Prob**	**Slope**	**Prob**
					(2003-2005)	**(2017/2018)**				
A	C	2003	2017	A-01-02	*CRM*	*CM*	-0.333	**0.009**	-0.027	**0.002**
A	C	2003	2017	A-01-03	*CM*	*CM*	-0.178	**0.058**	-0.011	**0.066**
A	C	2003	2017	A-01-06	*CRM*	*CWP*	-0.133	0.196	-0.015	**0.078**
A	C	2003	2017	A-01-07	*SCWP*	*SCWP*	-0.197	0.208	-0.017	0.142
A	C	2003	2017	A-01-08	*SCWP*	*RCM*	0.049	0.405	-0.008	0.319
A	C	2003	2017	A-03-02	*SCWP*	*CWP*	0.075	0.317	0.001	0.448
A	C	2003	2017	A-03-04	*CM*	*CWP*	-0.111	0.201	-0.014	**0.075**
A	C	2003	2017	A-03-05	*CRM*	*CRM*	0.100	0.281	0.003	0.365
A	C	2003	2017	A-03-06	*CM*	*CM*	0.090	**0.088**	0.005	0.132
A	C	2003	2017	A-03-07	*SCWP*	*CWP*	0.216	**0.065**	0.011	0.121
A	C	2003	2017	A-03-08	*SCWP*	*CWP*	-0.162	0.235	-0.020	**0.088**
A	C	2003	2017	A-03-09	*CWP*	*CRM*	0.154	0.149	0.005	0.312
A	C	2003	2017	A-03-10	*SCWP*	*SCWP*	0.273	0.142	0.013	0.206
A	C	2003	2017	A-04-02	*CM*	*CRM*	0.334	**0.012**	0.020	**0.019**
A	C	2003	2017	A-04-03	*CRM*	*CRM*	0.291	**0.028**	0.013	0.101
A	C	2003	2017	A-04-04	*CRM*	*CRM*	0.188	0.117	0.014	**0.088**
A	C	2003	2017	A-04-05	*CM*	*CM*	0.184	**0.014**	0.008	**0.075**
A	C	2003	2017	A-04-06	*CRM*	*CRM*	0.066	0.247	0.010	**0.070**
A	C	2003	2017	A-04-07	*CM*	*CM*	0.068	**0.059**	0.004	0.104
A	C	2003	2017	A-05-02	*CRM*	*CRM*	0.020	0.424	-0.003	0.431
A	C	2003	2017	A-05-03	*CRM*	*CM*	0.044	0.385	-0.001	0.511
A	C	2003	2017	A-05-04	*CRM*	*ERM*	0.099	0.327	0.004	0.399
A	C	2003	2017	A-05-05	*RCM*	*ERM*	0.314	**0.007**	0.021	**0.006**
A	C	2003	2017	A-06-06	*CRM*	*CM*	-0.056	0.296	-0.006	0.203
A	C	2003	2017	A-06-10	*SCWP*	*CWP*	0.099	0.275	0.006	0.295
A	C	2004	2017	A-07-07	*RCM*	*ERM*	-0.133	0.111	-0.011	**0.099**
A	C	2003	2017	A-08-01	*CRM*	*ERM*	0.428	**0.010**	0.026	**0.022**
A	C	2003	2017	A-08-08	*CRM*	*RCM*	0.068	0.260	0.003	0.319
A	C	2003	2017	A-09-02	*RCM*	*CRM*	-0.037	0.380	-0.005	0.289
A	C	2003	2017	A-09-04	*CRM*	*ERM*	0.208	0.232	0.018	0.215
A	C	2003	2017	A-09-08	*CWP*	*CWP*	0.006	0.476	-0.005	0.314
A	C	2003	2017	A-09-09	*CM*	*CM*	-0.112	0.116	-0.012	**0.032**
A	C	2003	2017	A-09-10	*RCM*	*CRM*	-0.123	0.184	-0.009	0.162

Sub-pop.	**C_T**	**Year estd.**	**Samp-YearE3**	**Field ID**	**Vegetation type**		**Delta**	**Prob**	**Slope**	**Prob**
					(2003-2005)	**(2017/2018)**				
A	C	2004	2017	A-10-01	*SCWP*	*PCM*	0.241	**0.099**	0.017	0.116
A	C	2004	2017	A-10-02	*SCWP*	*SCWP*	0.244	**0.049**	0.017	**0.061**
A	C	2004	2017	A-10-03	*SCWP*	*CWP*	0.338	**0.029**	0.023	**0.046**
A	C	2004	2017	A-10-04	*CM*	*CM*	0.117	0.191	0.009	0.191
A	C	2004	2017	A-10-07	*CM*	*CM*	-0.164	0.128	-0.015	**0.081**
A	C	2004	2017	A-11-02	*CM*	*CM*	-0.189	0.129	-0.012	0.167
A	C	2004	2017	A-11-03	*CM*	*CRM*	-0.149	0.141	-0.011	0.158
A	C	2004	2017	A-11-04	*CM*	*CM*	-0.294	**0.007**	-0.019	**0.021**
A	C	2004	2017	A-11-05	*CRM*	*RCM*	0.105	0.296	0.009	0.282
A	C	2004	2017	A-11-06	*CWP*	*CM*	-0.148	0.193	-0.013	0.142
A	C	2004	2017	A-11-07	*SCWP*	*MWP*	0.032	0.485	0.005	0.432
A	C	2004	2017	A-11-08	*CWP*	*SCWP*	-0.425	**0.003**	-0.033	**0.005**
A	C	2004	2017	A-12-05	*CWP*	*CWP*	-0.014	0.481	-0.003	0.394
A	C	2004	2017	A-12-07	*CM*	*CM*	0.088	0.300	0.005	0.344
A	C	2004	2017	A-12-08	*CM*	*CM*	-0.264	**0.028**	-0.019	**0.033**
A	C	2004	2017	A-12-09	*CM*	*CM*	0.121	0.115	0.009	0.122
A	C	2004	2017	A-12-10	*CM*	*CRM*	0.065	0.288	0.007	0.194
A	C	2004	2017	A-13-01	*CRM*	*CM*	0.064	0.351	0.007	0.307
A	C	2004	2017	A-15-02	*CRM*	*CM*	-0.342	0.135	-0.030	0.117
A	C	2004	2017	A-15-04	*CM*	*CRM*	0.065	0.241	0.003	0.338
A	C	2004	2017	A-17-03	*CM*	*CM*	-0.093	0.289	-0.006	0.373
A	C	2004	2017	A-17-08	*PCM*	*SCWP*	-0.178	0.247	-0.011	0.282
A	C	2004	2017	A-19-03	*CM*	*CM*	-0.195	**0.028**	-0.013	**0.050**
A	C	2004	2017	A-19-04	*CM*	*CRM*	0.024	0.343	0.002	0.297
A	C	2004	2017	A-19-06	*CWP*	*SCWP*	-0.157	0.202	-0.009	0.254
A	C	2004	2017	A-19-08	*SCWP*	*SCWP*	-0.108	0.284	-0.010	0.247
A	C	2004	2017	A-19-09	*CRM*	*CWP*	-0.331	**0.060**	-0.025	**0.068**
A	C	2004	2017	A-19-10	*SCWP*	*SCWP*	-0.152	0.196	-0.004	0.377
A	C	2004	2017	A-20-05	*RCM*	*RCM*	-0.046	0.418	-0.006	0.348
A	C	2004	2017	A-20-06	*CM*	*PCM*	-0.444	**0.004**	-0.033	**0.006**
A	C	2004	2017	A-20-07	*SOWP*	*SOWP*	-0.081	0.325	-0.004	0.391
A	C	2005	2017	A-21-02	*CRM*	*CRM*	-0.125	**0.078**	-0.011	**0.053**
A	C	2005	2017	A-21-03	*CM*	*CM*	-0.197	**0.006**	-0.016	**0.006**
A	C	2005	2017	A-21-05	*CM*	*CRM*	0.005	0.468	-0.004	0.306
A	C	2005	2017	A-22-01	*RCM*	*RCM*	-0.097	0.420	-0.007	0.392
A	C	2005	2017	A-22-02	*CM*	*CWP*	-0.158	0.121	-0.011	0.148
A	C	2005	2017	A-22-03	*CM*	*CWP*	0.022	0.424	0.003	0.398
A	C	2005	2017	A-22-04	*CM*	*CWP*	0.056	0.255	0.005	0.227
A	C	2005	2017	A-22-05	*SOWP*	*SOWP*	-0.429	**0.020**	-0.034	**0.031**
A	C	2005	2017	A-22-08	*SCWP*	*SCWP*	-0.160	0.199	-0.015	0.162

Sub-pop.	**C_T**	**Year estd.**	**Samp-YearE3**	**Field ID**	**Vegetation type**		**Delta**	**Prob**	**Slope**	**Prob**
					(2003-2005)	**(2017/2018)**				
A	C	2005	2017	A-22-09	*CM*	*CWP*	-0.302	**0.012**	-0.021	**0.024**
A	C	2005	2017	A-22-10	*CRM*	*CWP*	-0.305	**0.021**	-0.023	**0.037**
A	C	2005	2017	A-23-04	*CRM*	*CM*	-0.085	0.256	-0.006	0.306
A	C	2005	2017	A-23-10	*PCM*	*CWP*	-0.017	0.451	-0.002	0.417
A	C	2005	2017	A-24-02	*RCM*	*RCM*	0.002	0.505	0.000	0.478
A	C	2005	2017	A-24-05	*MWP*	*ERM*	-0.211	0.187	-0.019	0.172
A	C	2005	2017	A-25-04	*RCM*	*RCM*	0.100	0.284	0.005	0.366
A	C	2005	2017	A-25-07	*RCM*	*RCM*	-0.130	0.126	-0.010	0.154
A	C	2005	2017	A-26-02	*ERM*	*ERM*	-0.078	0.360	-0.003	0.425
A	C	2005	2017	A-26-03	*RCM*	*CRM*	-0.285	**0.016**	-0.027	**0.008**
A	C	2005	2017	A-26-05	*CM*	*CRM*	-0.093	0.173	-0.008	0.159
A	C	2005	2017	A-27-01	*CRM*	*CRM*	0.025	0.388	0.003	0.365
A	C	2005	2017	A-27-02	*CWP*	*CWP*	-0.017	0.494	0.000	0.524
A	C	2005	2017	A-27-04	*SCWP*	*SCWP*	0.174	**0.061**	0.012	0.104
A	C	2005	2017	A-27-05	*CM*	*CM*	-0.098	0.228	-0.010	0.165
A	C	2005	2017	A-27-06	*SCWP*	*SCWP*	0.096	0.213	0.008	0.213
A	C	2005	2017	A-27-07	*CM*	*CRM*	0.045	0.375	0.003	0.385
A	C	2005	2017	A-28-10	*ERM*	*ERM*	-0.126	0.165	-0.008	0.218
A	C	2005	2017	A-29-07	*CM*	*CRM*	0.019	0.442	0.000	0.530
A	C	2005	2017	A-29-09	*MWP*	*CWP*	0.320	**0.015**	0.025	**0.025**
A	C	2005	2017	A-29-10	*SCWP*	*CWP*	0.087	0.300	0.008	0.298
A	C	2005	2017	A-30-01	*SCWP*	*SCWP*	0.010	0.476	0.000	0.476
A	C	2005	2017	A-30-04	*CWP*	*MWP*	0.147	0.153	0.011	0.172
A	C	2005	2017	A-30-05	*CM*	*CWP*	0.211	**0.094**	0.017	**0.091**
A	C	2005	2017	A-30-06	*CM*	*CM*	0.077	0.263	0.007	0.253
A	C	2005	2017	A-30-07	*CM*	*CM*	0.233	**0.010**	0.020	**0.009**
A	C	2003	2018	A-05-01	CM	*CM*	0.023	**0.022**	0.001	**0.053**
A	C	2003	2018	A-05-06	CRM	*CM*	0.161	**0.042**	0.010	**0.031**
A	C	2003	2018	A-05-08	CM	*CM*	0.182	**0.038**	0.012	**0.027**
A	C	2003	2018	A-05-09	CM	*CRM*	0.024	0.437	0.003	0.416
A	C	2003	2018	A-06-03	RCM	*ERM*	0.288	**0.006**	0.018	**0.010**
A	C	2003	2018	A-06-04	CRM	*ERM*	0.208	**0.042**	0.011	**0.062**
A	C	2003	2018	A-06-05	CRM	*ERM*	0.416	**0.002**	0.027	**0.000**
A	C	2003	2018	A-06-07	CM	*CM*	0.121	0.243	0.005	0.330
A	C	2004	2018	A-07-01	ERM	*ERM*	0.217	**0.015**	0.015	**0.020**
A	C	2004	2018	A-07-04	ERM	*ERM*	-0.004	0.463	0.000	0.450
A	C	2004	2018	A-07-08	RCM	*ERM*	-0.106	0.304	-0.004	0.429
A	C	2003	2018	A-08-02	RCM	*ERM*	0.443	**0.007**	0.031	**0.007**
A	C	2003	2018	A-08-03	RCM	*ERM*	0.061	0.321	0.004	0.288
A	C	2003	2018	A-08-06	CRM	*CRM*	-0.019	0.349	-0.001	0.430

Sub-pop.	C_T	Year estd.	Samp-YearE3	Field ID	Vegetation type		Delta	Prob	Slope	Prob
					(2003-2005)	(2017/2018)				
A	C	2003	2018	A-09-01	CRM	*CRM*	0.455	**0.000**	0.021	**0.008**
A	C	2003	2018	A-09-05	RCM	*CRM*	-0.026	0.380	-0.004	0.293
A	C	2003	2018	A-09-06	CRM	*CRM*	0.128	0.112	0.008	0.118
A	C	2004	2018	A-13-09	CRM	*CM*	-0.105	0.294	-0.016	0.118
A	C	2004	2018	A-15-03	CRM	*CRM*	0.237	0.150	0.015	0.176
A	C	2004	2018	A-15-10	RCM	*ERM*	0.272	**0.005**	0.021	**0.003**
A	C	2004	2018	A-16-01	RCM	*CRM*	-0.128	0.194	-0.007	0.249
A	C	2004	2018	A-17-02	CM	*CRM*	0.097	0.181	0.010	0.108
A	C	2004	2018	A-18-06	RCM	*CRM*	-0.012	0.397	0.001	0.429
A	C	2005	2018	A-21-01	CWP	*CRM*	0.288	**0.049**	0.024	**0.035**
A	C	2005	2018	A-21-06	CRM	*ERM*	0.209	0.130	0.015	0.180
A	C	2005	2018	A-21-07	CRM	*CRM*	0.035	0.446	0.004	0.434
A	C	2005	2018	A-21-08	RCM	*CRM*	0.149	**0.070**	0.012	**0.064**
A	C	2005	2018	A-21-09	CM	*CM*	0.005	0.456	0.000	0.443
A	C	2005	2018	A-24-01	CRM	*CRM*	0.074	0.307	0.006	0.278
A	C	2005	2018	A-24-03	CRM	*RCM*	0.244	**0.018**	0.018	**0.017**
A	C	2005	2018	A-25-01	ERM	*CRM*	-0.017	0.448	-0.002	0.423
A	C	2005	2018	A-25-02	RCM	*CRM*	-0.122	0.162	-0.010	0.160
A	C	2005	2018	A-25-03	CRM	*ERM*	0.328	**0.086**	0.019	0.150
A	C	2005	2018	A-25-09	RCM	*RCM*	0.288	**0.004**	0.021	**0.007**
A	C	2005	2018	A-26-04	CRM	*CM*	0.115	0.150	0.007	0.176
A	C	2005	2018	A-26-06	CRM	*CRM*	0.051	0.306	0.003	0.388
A	C	2005	2018	A-28-07	CRM	*CRM*	0.415	**0.000**	0.032	**0.000**
A	C	2005	2018	A-29-05	SOWP	*CWP*	0.249	**0.067**	0.018	**0.071**
B	C	2003	2018	B-01-05	CM	*CM*	0.408	**0.000**	0.024	**0.000**
B	C	2003	2018	B-01-06	CM	*CRM*	0.341	**0.008**	0.023	**0.011**
B	C	2003	2018	B-02-03	MWP	*MWP*	0.041	0.416	0.003	0.486
B	C	2003	2018	B-02-04	MWP	*RCM*	0.566	**0.009**	0.034	**0.011**
B	C	2003	2018	B-02-05	CWP	*CWP*	-0.212	0.173	-0.016	0.129
B	C	2003	2018	B-02-06	MWP	*CWP*	0.040	0.370	-0.002	0.367
B	C	2003	2018	B-02-07	CWP	*CM*	0.253	**0.032**	0.016	**0.035**
B	C	2003	2018	B-02-08	MWP	*MWP*	0.488	**0.042**	0.030	**0.039**
B	C	2003	2018	B-02-09	MWP	*MWP*	0.327	0.172	0.014	0.287
B	C	2003	2018	B-02-10	MWP	*MWP*	0.342	**0.022**	0.024	**0.013**
B	C	2003	2018	B-03-01	CWP	*CWP*	0.029	0.403	0.001	0.447
B	C	2003	2018	B-03-02	SCWP	*SCWP*	0.103	0.302	0.006	0.321
B	C	2003	2018	B-03-03	CWP	*CWP*	-0.253	0.205	-0.022	0.139
B	C	2003	2018	B-03-04	CWP	*CWP*	0.289	0.119	0.016	0.153
B	C	2003	2018	B-03-05	SOWP	*SOWP*	0.122	0.276	0.010	0.215
B	C	2003	2018	B-03-06	MWP	*CWP*	0.219	**0.068**	0.012	**0.091**

Sub-pop.	**C_T**	**Year estd.**	**Samp-YearE3**	**Field ID**	**Vegetation type**		**Delta**	**Prob**	**Slope**	**Prob**
					(2003-2005)	**(2017/2018)**				
B	C	2003	2018	B-03-07	MWP	*MWP*	0.119	0.255	0.007	0.267
B	C	2003	2018	B-03-08	MWP	*SOWP*	0.107	0.311	0.005	0.378
B	C	2003	2018	B-03-10	SOWP	*SOWP*	0.268	**0.082**	0.013	0.150
B	C	2003	2018	B-04-01	CWP	*ERM*	0.447	0.111	0.037	**0.033**
B	C	2003	2018	B-04-02	MWP	*SCWP*	-0.184	0.281	-0.011	0.296
B	C	2003	2018	B-04-03	PCM	*CWP*	0.267	0.120	0.021	**0.082**
B	C	2003	2018	B-04-04	CM	*CM*	-0.115	0.228	-0.007	0.230
B	C	2003	2018	B-04-05	CM	*ERM*	0.551	**0.079**	0.046	**0.011**
B	C	2003	2018	B-04-06	CWP	*ERM*	0.567	**0.042**	0.047	**0.003**
B	C	2003	2018	B-04-07	SOWP	*SOWP*	-0.444	0.115	-0.032	**0.098**
B	C	2003	2018	B-04-08	CWP	*MWP*	-0.071	0.350	-0.008	0.263
B	C	2003	2018	B-04-09	SOWP	*SOWP*	0.410	**0.007**	0.020	**0.036**
B	C	2003	2018	B-04-10	RCM	*ERM*	0.162	0.245	0.010	0.240
B	C	2003	2018	B-05-01	CM	*ERM*	0.356	**0.015**	0.023	**0.027**
B	C	2003	2018	B-05-02	SCWP	*CM*	-0.030	0.425	-0.008	0.265
B	C	2003	2018	B-05-03	CWP	*CWP*	-0.024	0.455	-0.001	0.442
B	C	2003	2018	B-05-04	CWP	*CWP*	-0.025	0.437	0.000	0.495
B	C	2003	2018	B-05-05	CM	*CRM*	0.387	0.143	0.036	**0.049**
B	C	2003	2018	B-05-09	SCWP	*SCWP*	0.007	0.486	-0.002	0.413
B	C	2003	2018	B-05-10	SCWP	*MWP*	0.586	**0.015**	0.035	**0.028**
B	C	2003	2018	B-06-01	RCM	*ERM*	0.255	**0.019**	0.020	**0.006**
B	C	2003	2018	B-06-03	CM	*ERM*	0.145	0.156	0.008	0.177
B	C	2003	2018	B-06-04	MWP	*CM*	0.603	**0.000**	0.041	**0.000**
B	C	2003	2018	B-06-06	CWP	*CWP*	0.197	**0.064**	0.022	**0.002**
B	C	2003	2018	B-06-10	MWP	*SOWP*	0.153	0.169	0.009	0.172
B	C	2004	2018	B-07-01	CM	*CRM*	0.024	0.427	0.002	0.369
B	C	2004	2018	B-07-02	CM	*CRM*	0.370	**0.007**	0.026	**0.010**
B	C	2004	2018	B-07-04	CWP	*CWP*	0.124	0.338	0.008	0.386
B	C	2005	2018	B-12-04	CM	*CRM*	0.223	**0.052**	0.018	**0.050**
E	C	2003	2018	E-01-01	CWP	*CM*	0.322	**0.008**	0.019	**0.022**
E	C	2003	2018	E-01-02	CWP	*CRM*	0.373	**0.027**	0.021	**0.033**
E	C	2003	2018	E-01-03	CWP	*CWP*	0.120	0.231	0.005	0.343
E	C	2003	2018	E-01-04	SCWP	*SCWP*	0.196	0.155	0.009	0.231
E	C	2003	2018	E-01-05	CWP	*CRM*	0.487	**0.003**	0.027	**0.003**
E	C	2003	2018	E-01-06	CWP	*CM*	0.782	**0.000**	0.042	**0.003**
E	C	2003	2018	E-01-07	CM	*CRM*	0.380	**0.002**	0.027	**0.001**
E	C	2003	2018	E-01-08	CWP	*CM*	0.358	**0.007**	0.018	**0.032**
E	C	2003	2018	E-01-09	CWP	*CM*	0.383	**0.007**	0.021	**0.010**
E	C	2003	2018	E-02-01	CM	*CRM*	0.283	**0.034**	0.013	**0.081**
E	C	2003	2018	E-02-02	CM	*CM*	0.284	**0.004**	0.014	**0.016**

Sub-pop.	**C_T**	**Year estd.**	**Samp-YearE3**	**Field ID**	**Vegetation type**		**Delta**	**Prob**	**Slope**	**Prob**
					(2003-2005)	**(2017/2018)**				
E	C	2003	2018	E-02-03	CWP	*CWP*	0.287	**0.011**	0.015	**0.015**
E	C	2003	2018	E-02-04	CWP	*CM*	0.333	**0.002**	0.019	**0.006**
E	C	2003	2018	E-02-05	CWP	*CM*	0.206	**0.018**	0.011	**0.032**
E	C	2003	2018	E-02-06	SCWP	*SCWP*	0.618	**0.001**	0.038	**0.000**
E	C	2003	2018	E-02-07	SCWP	*SOWP*	0.367	**0.068**	0.022	**0.088**
E	C	2003	2018	E-02-08	CWP	*CWP*	0.291	**0.041**	0.014	**0.089**
E	C	2003	2018	E-02-09	CWP	*CWP*	0.068	0.356	-0.001	0.441
E	C	2003	2018	E-02-10	CWP	*CM*	0.118	0.327	0.003	0.481
F	C	2003	2018	F-01-01	MWP	*CWP*	0.636	**0.001**	0.037	**0.001**
F	C	2003	2018	F-01-02	MWP	*MWP*	0.823	**0.000**	0.043	**0.005**
F	C	2003	2018	F-01-03	CWP	*CM*	0.356	**0.001**	0.021	**0.003**
F	C	2003	2018	F-01-04	CM	*CM*	0.187	0.135	0.008	0.230
F	C	2003	2018	F-01-05	CM	*CWP*	0.399	**0.008**	0.027	**0.005**
F	C	2003	2018	F-01-06	MWP	*CWP*	0.283	**0.086**	0.014	0.154
F	C	2003	2018	F-01-07	CWP	*CWP*	0.147	0.356	0.003	0.475
F	C	2003	2018	F-01-08	SCWP	*SCWP*	0.435	**0.012**	0.021	**0.056**
F	C	2003	2018	F-01-09	MWP	*SCWP*	0.222	0.108	0.015	0.113
F	C	2003	2018	F-01-10	MWP	*SCWP*	0.283	**0.024**	0.015	**0.052**
F	C	2004	2018	F-02-02	CWP	*CWP*	0.128	0.190	0.017	**0.045**
F	C	2004	2018	F-02-03	SCWP	*CWP*	0.438	**0.022**	0.037	**0.010**
F	C	2004	2018	F-02-04	CWP	*SCWP*	0.006	0.474	0.001	0.474
F	C	2004	2018	F-02-05	MWP	*MWP*	0.623	**0.002**	0.047	**0.001**
F	C	2004	2018	F-02-06	CWP	*CWP*	0.133	0.244	0.014	0.139
F	C	2004	2018	F-02-07	SCWP	*SCWP*	0.322	**0.052**	0.025	**0.037**
F	C	2004	2018	F-02-08	SCWP	*SCWP*	0.348	**0.098**	0.022	0.124
F	C	2004	2018	F-02-09	MWP	*CWP*	0.543	**0.007**	0.037	**0.001**
F	C	2004	2018	F-02-10	CWP	*CM*	0.220	**0.085**	0.021	**0.028**
F	C	2005	2018	F-03-01	CM	*CM*	0.285	**0.013**	0.026	**0.002**
F	C	2005	2018	F-03-06	PCM	*RCM*	1.018	**0.000**	0.086	**0.000**
F	C	2005	2018	F-03-07	CWP	*RCM*	0.398	0.121	0.035	**0.069**
F	C	2005	2018	F-03-08	MWP	*CWP*	0.478	**0.009**	0.037	**0.006**
F	C	2005	2018	F-03-09	SOWP	*SOWP*	0.182	0.125	0.014	0.121
F	C	2005	2018	F-03-10	MWP	*SCWP*	0.662	**0.000**	0.051	**0.000**
F	C	2005	2018	F-04-01	CWP	*CRM*	0.026	0.450	0.000	0.555
F	C	2005	2018	F-04-02	CM	*CM*	0.128	0.195	0.009	0.193
F	C	2005	2018	F-04-04	MWP	*MWP*	0.401	**0.038**	0.040	**0.005**
F	C	2005	2018	F-04-05	MWP	*SCWP*	0.216	**0.053**	0.016	**0.049**