Institute of Environment
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Status of Vegetation Structure and Composition within the Habitat of Cape Sable seaside sparrow Subpopulation D

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Eric Cline
South Florida Water Management District
3301 Gun Club Road
West Palm Beach, Fl. 33460
Tel. (561) 734-3897
Email: ecline@sfwmd.gov

Jay P. Sah[1], Carlos Pulido[1], Susana Stoffella[1],
Santiago Castaneda[1], Michael S. Ross[1, 2]
1. Southeast Environmental Research Center
2. Department of Earth and Environment

Florida International University, Miami FL 33199

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Authors' Affiliation

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

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

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

Carlos Pulido – *Research Technician*
Florida International University
Southeast Environmental Research Center
11200 SW 8th Street, Miami, FL 33199
Tel. (305) 348-6066
cpuli002@fiu.edu

Santiago Castaneda – *Research Technician*
Florida International University
Southeast Environmental Research Center
11200 SW 8th Street, Miami, FL 33199
Tel. (305) 348-6066
scastane@fiu.edu

Executive Summary

Cape Sable seaside sparrow (CSSS), a federally endangered species, and vegetation within its habitat are highly sensitive to changes in hydrologic regimes. Thus, to ensure that the impacts of Everglades restoration projects do not impede the continued existence of sparrows in their habitat, the C-111 Spreader Canal Western project embraces regular monitoring of the sparrow population and the status of its habitat. As per requirements stated in Biological Opinion issued by the US Fish and Wildlife Service (USFWS), baseline conditions of the CSSS sub-population D and its habitat were studied in 2011. A follow up study was also conducted in 2014, 2-years after the project was implemented, and again in 2016 and 2018. With funding support from SFWMD (PO # 4500117438) for FY 2020, the present study examined any vegetation shift that might have occurred since the 2011 and the subsequent surveys.

The sampling design included two groups of sites: (1) sparse vegetation sampling sites (SS sites), and (2) concentrated vegetation sampling sites (CS sites). The 44 SS sites were 500 m to 1 km apart, whereas the 36 CS sites were at the corners of each 250 x 250 m grid cell in an area of 1.25 km x 1.25 km. At each site, vegetation was sampled using a nested design: a 5 m x 5 m shrub plot was nested within a 10 m x 10 m tree plot. Within shrub plots, cover of shrubs and vines were estimated. Herbaceous plants were surveyed within five 1-m^2 subplots located within each shrub plot. In addition to species cover, a suite of structural parameters was recorded in a 0.25 m^2 quadrat in the southeast corner of each subplot. EDEN data was used to calculate annual mean daily water depth and hydroperiod for the plots. Vegetation change analysis included Analysis of Similarity (ANOSIM), change in vegetation-inferred hydroperiod, and trajectory analysis. Changes in vegetation-inferred hydroperiod between successive samplings are indicative of vegetation changes in response to hydrology of the period. The trajectory analysis method has made it possible to detect a shift in vegetation composition along a gradient representative of increasing wetness. General linear mixed models (GLMM) were used to test for differences in vegetation structural variables (vegetation cover and height), biomass, and vegetation-inferred hydroperiod among five sampling events, whereas Generalized linear mixed model was used to test for differences in species richness. Non-parametric Friedman-Test together with Wilcoxon matched-pair test was used to test differences in major species' abundance among sampling events.

Marl prairie vegetation within the habitat of sub-population D included vegetation assemblages, mainly grouped into two broad-groups: i) wet prairie and ii) marsh, and arranged along the full hydrologic gradient. Since 2011, vegetation change was marked by an increase in wetness of some sites and a consequent shift in species composition toward a vegetation type characteristic of wetter conditions. Between 2011 and 2020, vegetation at forty-four percent of marl wet prairie sites had changed to marl marsh vegetation types. However, such a shift in species composition toward a more hydric type primarily occurred between 2011 and 2014, i.e. in first 3-years after the baseline survey. Thereafter, relatively dry conditions in 2014 and 2015 might have helped in improvement of habitat condition, as evidenced by an increase in ephemeral sparrow population in those years. However, in 2016 dry season (Nov 1st – April 30th), the mean water level was unusually high, more than 14.5 cm above the 29-year average. In next four water years also, hydroperiod as well as mean annual water level was higher than the long-term (29-year) average, which have caused the vegetation shift to wetter type in comparison to baseline survey.

Since an increasing trend in wetness in marl prairies beyond 210 days hydroperiod is envisaged as gradual deterioration of sparrow breeding habitat conditions, the increase in 4-year average vegetation-inferred hydroperiods from 210 days in 2011 to 229 days in 2020 could be an indication of deteriorating habitat. However, relatively more successful sparrow nesting in breeding season in last three years (2018-2020) than previous years was in contrary to our expectation. Regardless of the early signs of recovery of sparrow population in that area, the sub-population D still remains a small and vulnerable sub-population, and is likely to be adversely impacted by increasing wetness and shift in vegetation from short-hydroperiod wet prairie to marsh types. Thus, it is important to minimize the chances of high-water condition in coming years, especially in dry season, so that observed trend of vegetation shift will not accelerate further with long-lasting adverse impact on sparrow and its habitat. This is essential especially within the sub-population D habitat, where the hydrologic conditions are likely to continue being impacted by the C-111 Spreader Canal Western Project activities.

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1. Introduction

In the Everglades, Cape Sable seaside sparrow (CSSS; *Ammodramus maritimus mirabilis*) and its habitat have been at the pivot of several water management activities for the last two decades, affecting marl prairie vegetation both sides of the Shark River Slough (SRS). The reason rests on the fact that CSSS is a federally listed endangered species endemic to the short-hydroperiod marl prairies of the Everglades, and both the sparrow and vegetation that structures its habitat are highly sensitive to changes in hydrologic regime. Unusually high-water conditions during the sparrow- breeding period can cause sharp decline of the sparrow population, either directly by inflicting mortality or impairing breeding success, or indirectly through destruction of its habitat (Pimm et al. 2002; Jenkins et al. 2003; Virzi et al. 2011). Flooding that exceedingly extends hydroperiod causes the short-hydroperiod marl prairie to change to long-hydroperiod sawgrass marsh as quickly as within 3-4 years (Armentano et al. 2006; Sah et al. 2014), resulting in the habitat to be unsuitable for sparrows (Nott et al. 1998; Jenkins et al. 2003). Thus, to ensure that impacts of Everglades restoration projects to sparrow habitat do not impede the survival and continued existence of sparrows, several water-management projects in the Southern Everglades include regular monitoring of the sparrow population and its habitat as integral components.

The C-111 Spreader Canal Western Project (C-111 SC Project or 'The Project") aims to restore the quantity, timing, and distribution of water delivered to Florida Bay via Taylor Slough and to improve hydroperiod and hydro-pattern in the area south of the C-111 canal, known as the Southern Glades and Model Lands. To ensure that the project impacts to CSSS Designated Critical Habitat Units 2 and 3 (also referred to as subpopulations C and D, respectively) do not exceed the impacts recognized in the US Fish and Wildlife Service (USFWS's) Incidental Take Statement (ITS), the SFWMD is mandated to conduct CSSS habitat monitoring in subpopulation D. As per the requirements stated in Term and Condition #6 of ITS, baseline conditions of the CSSS sub-population D and its habitat were studied with funding support from the District (SFWMD) in 2011, before project implementation (Virzi et al. 2011). The project was implemented in 2012, and a follow up study was conducted in 2014, 2016 and 2018, 2, 4 and 6 years after the implementation of the project, respectively (Sah et al. 2014, 2016, 2018). The baseline study concluded that the population had declined from a peak of 400 birds in 1981 to few pairs of birds in the mid-2000s (Virzi et al. 2011), which corresponded with a change in vegetation from short-hydroperiod prairie to the long-hydroperiod sawgrass marsh during that period (Ross et al. 2004). The study also emphasized that the population had lately (2007-2010) begun to show signs of improvement that corresponded with an enhancement in habitat conditions resulting from a drying trend in the late 2000s (Virzi et al. 2011). However, it was expected that this trend would be disrupted upon project implementation, as computer simulation modeling results indicated that operations would result in an increased hydroperiod, and thus adversely affect the habitat conditions within the CSSS subpopulation D critical habitat (USFWS 2009).

In 2014, an examination of daily stage data at EVER4, located in the center of the CSSS sub-population D habitat, revealed that the three year-period (May 1, 2011 – April 30, 2014) following the 2011 baseline survey (Project period) were slightly wetter than during the three years (May 1, 2008 – April 30, 2011) before the survey (Pre-project period). In agreement with wetter hydrologic conditions in project than pre-project period, a shift in species composition toward a vegetation composition characteristic of wetter conditions was also observed (Sah et al. 2014). However, at the time it was not clear whether the shift in habitat conditions were due to project activities or natural annual variability in hydrologic conditions, or both. The reason for uncertainty was because an analysis of stage data from other regions of the marl prairie landscape had also showed that on average the three years from 2011 to 2014 were wetter than the three years prior to 2011 sampling (Sah et al. 2014).

After 2014, a shift in vegetation composition towards wetter type continued for next four years, though with slow pace. In fact, insignificant difference in vegetation-inferred hydroperiod between 2014 and 2016 had suggested that the habitat condition did not decline any further (Sah et al. 2016) during that period. In contrast, dry conditions in 2014 and 2015 might have helped in improvement of habitat condition, as evidenced by an increase in ephemeral sparrow population in those years. A mix of both positive and negative trends in the sparrow population in subpopulation D was observed during the following two years, 2014 and 2015 (Virzi and Davis 2014; Virzi et al. 2015). In 2016 dry season, however, the water level was unusually high, more than 15 cm above the 25-year average, even limiting the scope of sparrow survey in that year (Virzi and Davis 2016). The long-term effect of unusual high-water condition on vegetation was also uncertain at that time, and was expected to depend on the hydrologic regime in subsequent years (Sah et al. 2016). In next three years, while vegetation condition was trending towards wetter type (Sah et al. 2018), the sparrow surveys had revealed mixed results. For instance, sparrow population in 2017 was moderately lower, but in 2018 and 2019, the sparrow number was higher than 2014 or 2015 (Virzi and Davis 2017; Virzi and Murphy 2018; Virzi and Tafoya 2019), suggesting that a certain level of uncertainty still persists with regard to the sparrow population and their habit in the area. Thus, it was obvious that only a regular monitoring of the vegetation could provide a conclusive assessment of the course of the sparrow habitat and its population within the sub-population D habitat where the hydrologic conditions are likely to be impacted by the project activities.

With funding support from SFWMD (PO # 4500117438) for FY 2019/2020 (hereafter FY 2020), we studied the current status of sparrow subpopulation D habitat. The specific objective of this study was to document the status of vegetation structure and composition within the habitat of CSSS sub-population D, and to analyze the magnitude and direction of any vegetation change that might have occurred since the baseline survey was performed in 2011. We hypothesized that vegetation would continue trending towards wetter types in post-project period.

2. Methods

2.1 Study design

The study area was within the critical habitat of CSSS sub-population D (Figure 1). The study was designed to incorporate sufficient spatial and temporal resolution in the vegetation monitoring that the impact of project operations on hydrology-mediated changes in vegetation structure and composition could be assessed. The survey design was the same used in the 2011 baseline and 2014 and 2016 post-project surveys, and included two groups of sites, (1) sparse vegetation survey sites (SS sites), and (2) concentrated vegetation survey sites (CS sites). Together there were 80 sites - 44 SS and 36 CS sites (Appendix 1). The SS sites included 17 previously surveyed vegetation census sites located at the corners of 1 km x 1 km grid cells (Ross et al. 2006a), and 27 sites that were established in 2011 either at the corners of additional grid cells included in the critical habitat boundary of sub-population D, or at the centers of the aforementioned grid cells. The CS sites were at the corners of each 250 x 250 m grid cell within a 1.25 km x 1.25 km area that included a set of occupied CSSS territories that had been delineated by Dr. Thomas Virzi and group (Virzi et al. 2011; Virzi and Davis 2013) at the time of project initiation.

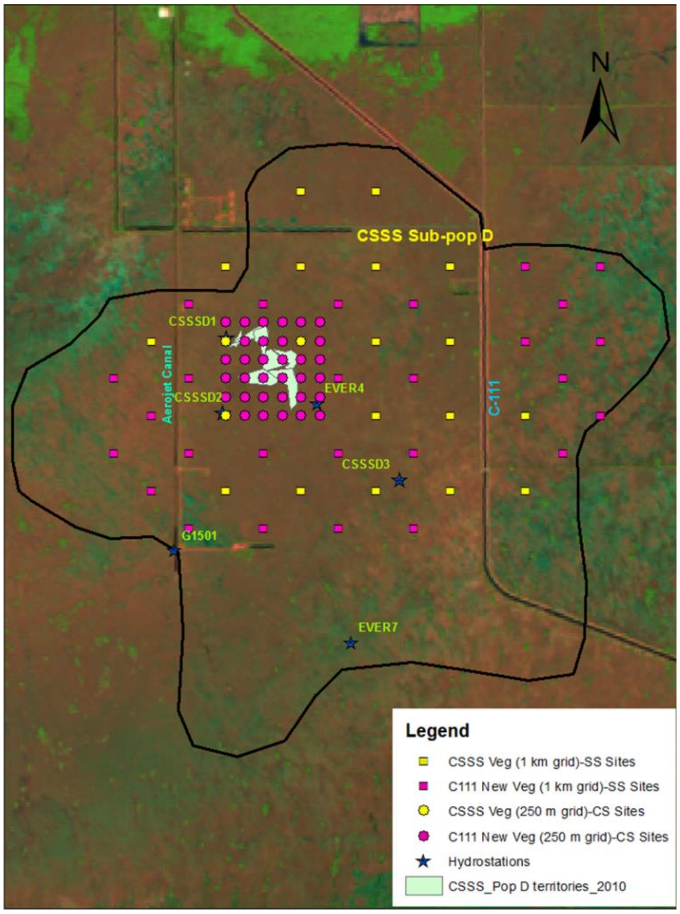

Figure 1: Vegetation survey sites within C-111 Spreader Canal Western Project – CSSS Sub-population D area.

2.2 Field Sampling

In FY 2020, we commenced vegetation survey on March 20th, and continued through April 1st, 2020. As per our schedule, we used the Float helicopter to do field surveys for four days (March 20, 25 and 30, and April 1st). Over four days, we were able to survey 48 sites, that included 40 scattered sites (SS) and 8 concentrated sites (CS). Of the 48 sites, we accessed 44 sites by the District Helicopter and 4 sites by driving to the nearest point on the Aerojet Road, and then walking to the sites (Figure 2). Following the Stay-at-Home order issued by Florida Governor that began on April 3, 2020 and the FIU's announcement of suspending all field activities, our field work was also suspended until mid-May.

After Florida Governor lifted the Stay-at-Home order in Miami-Dade on May 18 and FIU's Office of Research and Economic Development (ORED) issued 'Guidelines for Field Work Transport Using Helicopters During the Pandemic", the PI (Jay Sah) contacted the District's Flight Operations Team. We learned that the District helicopter would not be available to finish the vegetation survey at the remaining 32 sites. We then explored the possibility if we could access some of remaining sites by walking from the Aerojet road.

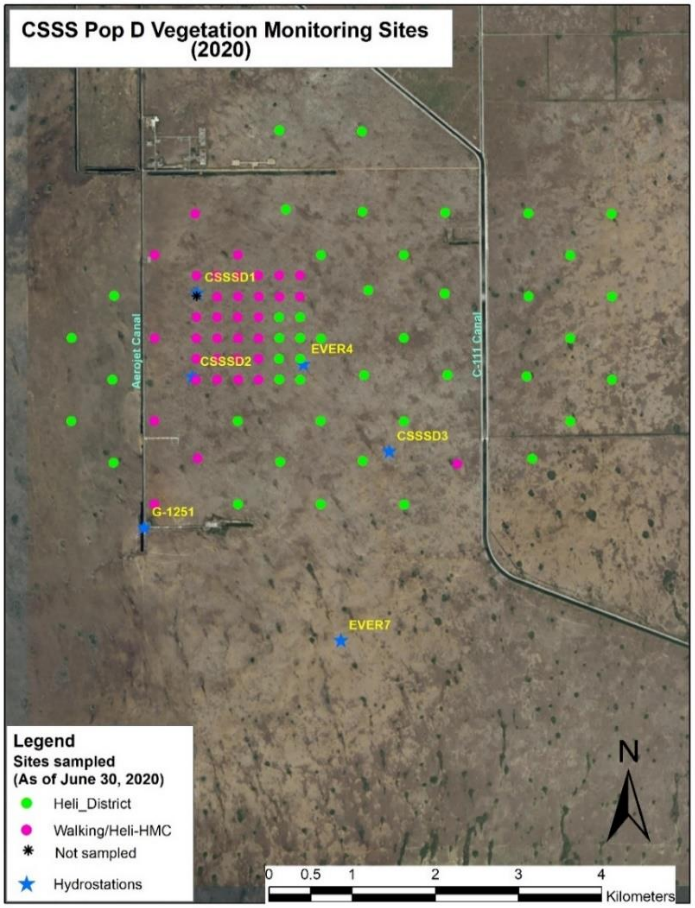

Figure 2: Location of sites within the Cape Sable seaside sparrow (CSSS) sub-population D habitat sampled for vegetation structure and composition in FY 2020.

Later, over three days, May 22, 29 and June 15, we accessed 26 sites on foot by walking from the road. Finally, we accessed five sites (3 SS and 2 CS sites) using HMC helicopter. We thus completed vegetation survey at 79 of 80 sites scheduled for the sampling in 2020.

In the field, we recorded structural and compositional vegetation parameters at the both SS and CS sites following the methods used in 2011 (Sah et al. 2011). At each sampling site, a 3-ft tall PVC pole marked the SE corner of a 10 m x 10 m tree plot. Nested within each tree plot, a 5 m x 5 m herb/shrub plot was laid out, leaving a 1-m buffer strip along the southern and eastern border of the tree plot (Figure 3).

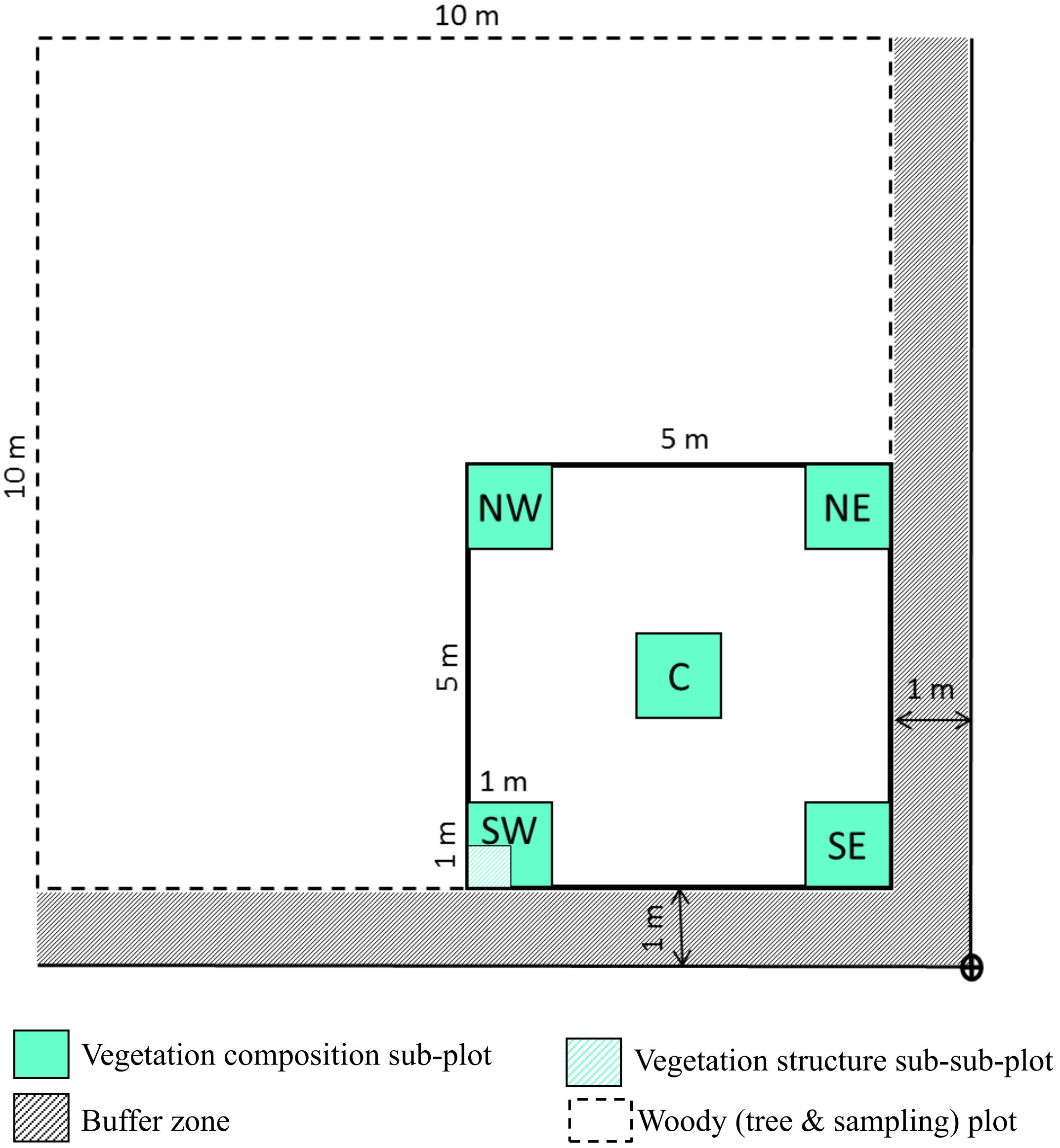

Figure 3: Vegetation sampling design at each of 80 sites sampled in 2020 to document status of vegetation structure and composition in the habitat of CSSS sub-population D within C-111 Spreader Canal Project Area.

In the tree plots, whenever there were trees present, we measured the DBH and crown length and width of any woody individuals of ≥ 5 cm DBH. Within each 5 m x 5 m herb/shrub plot, we estimated the cover class of each species of shrub (woody stems >1m height and < 5cm DBH) and woody vines, using the following categories: < 1%, 1-4%, 4-16%, 16-33%, 33-66%, and > 66%. Herbaceous plants were surveyed within five 1-m^2 subplots located at the four corners and center of each herb/shrub plot. In 1-m^2 subplots, we estimated the percent cover of each vascular plant species, using the same categories as we used for shrub cover. If an herbaceous species was present in the 5 m x 5 m herb/shrub plot but not found in any of the subplots, it was assigned a mean cover of 0.01%. In addition, a suite of structural parameters was recorded in a 0.25 m^2 quadrat in the southeast corner of each subplot. Structural measurements included the following attributes: 1) Canopy height, i.e., the tallest vegetation present within a cylinder of ~5 cm width, measured at 4 points in each 0.25 m^2 quadrat; 2) The height and species of the tallest plant in the quadrat; 3) Total vegetative cover, in percentage; and 4) Live vegetation, expressed as a percent of total cover. The number of woody individuals (height ≤ 1 m) present in the subplots was also recorded. In addition, if there was standing water in the herb/shrub plots, we also measured water depth in each subplot. We took photographs of some of survey sites to document the field conditions in the digital format (Figure 4). During our fieldwork, we took extra precaution to minimize the impact when we surveyed the sparrow-occupied area mapped by Virzi and Murphy (2018) and Virzi and Tafoya (2019).

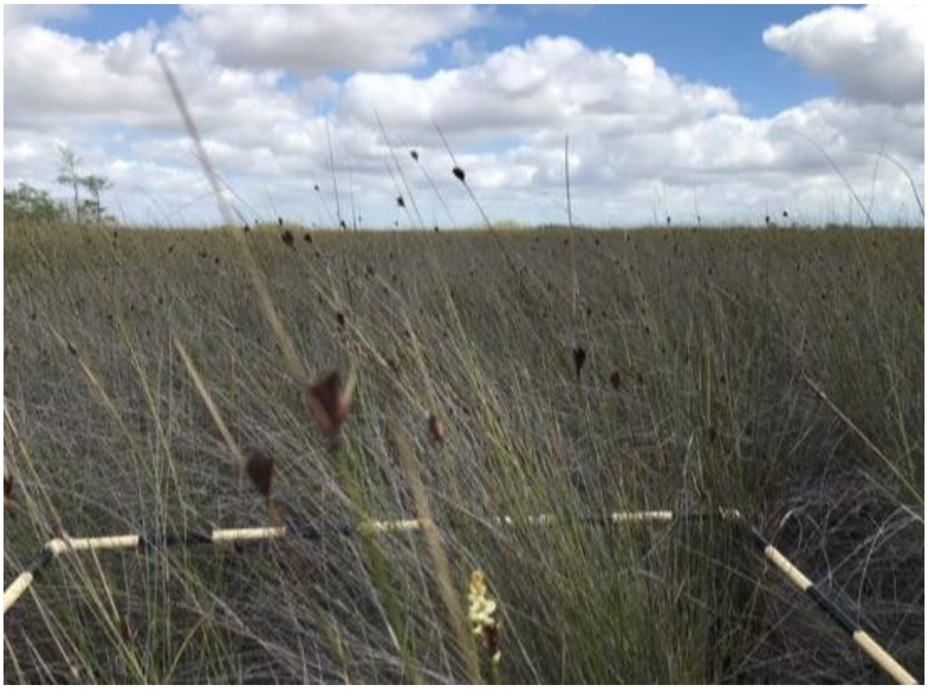

Figure 4: Black-top sedge (*Schoenus nigricans*)-dominated vegetation in C111-CSSS subpopulation D.

2.3 Data analysis

2.3.1 Hydrology

During the 2020 field survey, majority of sites were dry, except some sub-plots (26%) which has shallow (Mean ± SD: 4.3 ± 4.5 cm) standing water with high variability. Thus, for consistency in data analysis across the sampling years, we calculated hydrological variables based on elevations determined from water depths measured in 2011. In the wet season of 2011, when almost all sites in the region were inundated with standing water, we had measured water depth at three locations within each 5 m x 5 m plot: 44 and 36 plots on Aug 31 and Sept 9, respectively. Using the water surface elevations provided by available empirical models (e.g., SFWMD's Water Depth Assessment Tool (WDAT) and USGS's Everglades Depth Estimation Network (EDEN)) for the specific date, we calculated ground elevation for each plot. The EDEN water surface elevation data were not available for 10 sites east of the C-111canal, and at the time of field measurement of water depth, standing water was not present at one site. Thus, the analysis of hydrology data was mainly based on the 69 sites. Across all the sites (n = 69), ground elevations based on both the WDAT and EDEN water surface data were strongly correlated (r = 0.89), though the WDAT-based mean ground elevation was 2.12 cm higher than the EDEN-based elevation (Sah et al. 2011, 2014). A similar finding was observed in a separate study when both EDEN and WDAT data for several sites within the habitat of sparrow sub-populations A-F and in nine tree islands were compared (Sah et al. 2015). Because of their readily availability, we used EDEN data (http://sofia.usgs.gov/eden/models/watersurfacemod_download.php) to calculate annual mean daily water depth and hydroperiod for each of the 69 plots. Hydroperiod was defined as the discontinuous number of days in a water year (WY: May 1 - April 30) when water level was above the ground surface.

2.3.2 Vegetation classification and change

The hierarchical agglomerative cluster analysis was performed using PCORD version 6.0 (McCune and Mefford 2011) to classify the vegetation survey-sites based on the vegetation data collected in 2020. However, to keep the vegetation 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 surveyed 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. (2006a), i.e. we used species cover percent data, eliminated the species that were present in less than 12 sites, and relativized the species cover 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. 2006a).

To examine changes in vegetation composition over time, the vegetation data was summarized using a non-metric multidimensional scaling (NMDS) ordination. Prior to NMDS, we pre-processed the species cover data. We first transformed the species' cover categorical data to percent species cover by taking mid-value of the range that each category represents. We then calculated relative frequency (%) and relative cover (%)of each species for each site. Thereafter, we calculated species' importance value (IV) as follows:

Importance Value (IV) = (Relative Frequency (%) + Relative Cover (%))/2

Species IV data was then standardized by species' maximum i.e., all IV values for a species were divided by the maximum IV attained by that species to reduce excessive influence of any dominant species in the calculation of dissimilarities (Faith et al., 1987). The site x species matrix used for the ordination had 398 sites (80 sites per survey for three surveys, 2011, 2014 and 2018, and 79 sites per survey for 2016 and 2020) and 91 species. In the analysis, the species that had minimum three occurrence across all surveys were only retained. Thus, the final site x species matrix used for ordination had 398 sites and 61 species. In the ordination, vector fitting technique was used to find the best fit of environmental and community variables to the species composition data (Kantvilas and Minchin, 1989). Analysis of Similarity (ANOSIM), a nonparametric multivariate analytical procedure, was used to examine the differences in vegetation composition among the survey years (Clarke et al. 2014).

Vegetation change analysis included calculation of vegetation-inferred hydroperiod, the hydroperiod for a site indicated from its vegetation composition using a Weighted Averaging regression model (see Armentano et al. 2006 for details). The analysis was performed using C^2 program, version 1.7.6 (Juggins 2014). 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 changes was also analyzed with trajectory analysis (Minchin et al. 2005; Sah et al. 2014b), which uses a change in community composition along a vector representing hydrologic condition. In species' IV-based NMDS ordination space, the reference vector for the hydrologic gradient was defined by the 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. 2014b). 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. The NMDS and trajectory analysis were performed using DECODA (Kantvilas and Minchin 1989; Minchin 1998).

2.3.3 Vegetation 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 = Crown cover (%), and Ht = Mean crown height (cm).

Friedman-ANOVA (Non-parametric test for multiple dependent variables) was used to test differences in cover of major species among five sampling events. To account for the variability caused by the repeated measures of vegetation structural variables (vegetation height, cover and biomass) and vegetation-inferred hydroperiod, Linear Mixed Models were used. General Liner Mixed Models (GLMM) were used to examine differences in structural variables between WP and M sites and among survey years, whereas Generalized Linear Mixed Models (GLMMs) were used to examine differences in species richness, a count variable. Biomass and vegetation inferred hydroperiod data were log-transferred to approximate normality. Models were run in R v.3.5.2 (R core team, 2018) using the *lmer* (for general linear mixed model) and *glmer* (for generalized linear mixed model) functions 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, biomass and species richness among survey years that was done in post hoc test using *glht* function implemented in 'multcomp' package. Spatio-temporal variation in hydrological and vegetation structural parameters was illustrated on the map using ArcGIS 10.5.

3. Results

3.1 Hydrologic condition

In this study, analysis of hydrologic conditions of the vegetation survey sites revealed that in post-project period (since 2012), seven out of eight years had mean water level higher than long-term (29-year) average (the period for which EDEN data are available). In contrast, before the baseline survey in 2011, the mean annual water level was below average for several years, except the water year 2009/2010 (Figure 5). When averaged over four year-period prior to vegetation survey, the mean annual hydroperiod and water depth in 2011 were 220 ± 33 days and -0.02 ± 4.75 cm, respectively. However, both hydroperiod and mean annual water depth were consistently higher in post-project survey years than in 2011. The 4-year mean annual hydroperiods were 22, 47, 42 and 56 days longer, and mean annual water depths were 2.93, 5.70, 2.23 and 3.87 cm higher during the 2014, 2016, 2018 and 2020 surveys, respectively than the pre-project period, i.e. before baseline survey in 2011 (Figure 6).

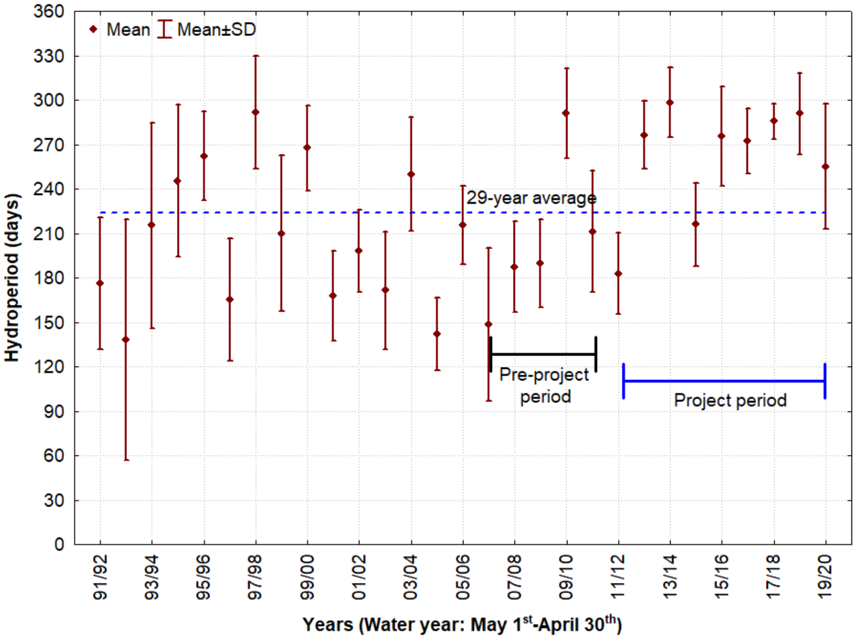

Figure 5: Annual mean hydroperiod at the vegetation survey sites (n = 69) for 29 years (1991/92-2019/20 water years: May 1 – April 30). Dashed line is the 29-year (WY) average value. Hydroperiod for each site was calculated using field water depth-based ground elevation and EDEN water surface time-series data.

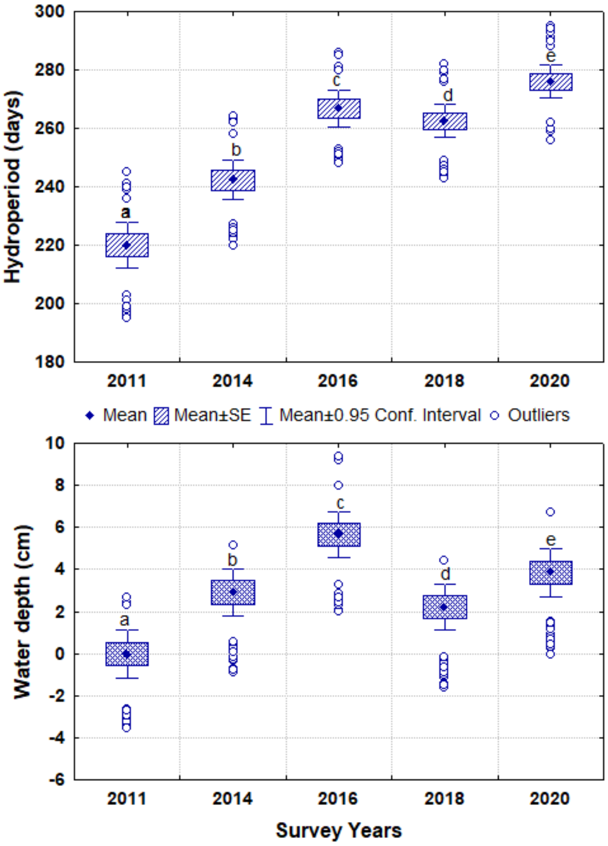

Figure 6: Four-year average hydroperiod and mean annual water depth at the vegetation survey sites (n = 69) surveyed during the base year (2011) and in post-project survey years (2014, 2016, 2018 and 2020). Different letters in superscript represent the significant difference as determined in non-parametric, Wilcoxon-matched-pair test.

3.2 Vegetation composition

As in 2011, marl prairie vegetation within the habitat of sub-population D in 2020 also were broadly categorized into two groups, ‘wet prairies’ and ‘marsh’. Wet prairie (WP) vegetation mainly included mixed dominance of sawgrass (*Cladium jamaicense*) and/or blacktop sedge (*Schoenus nigricans*), and they were prevalent at the CS sites (Figure 7).

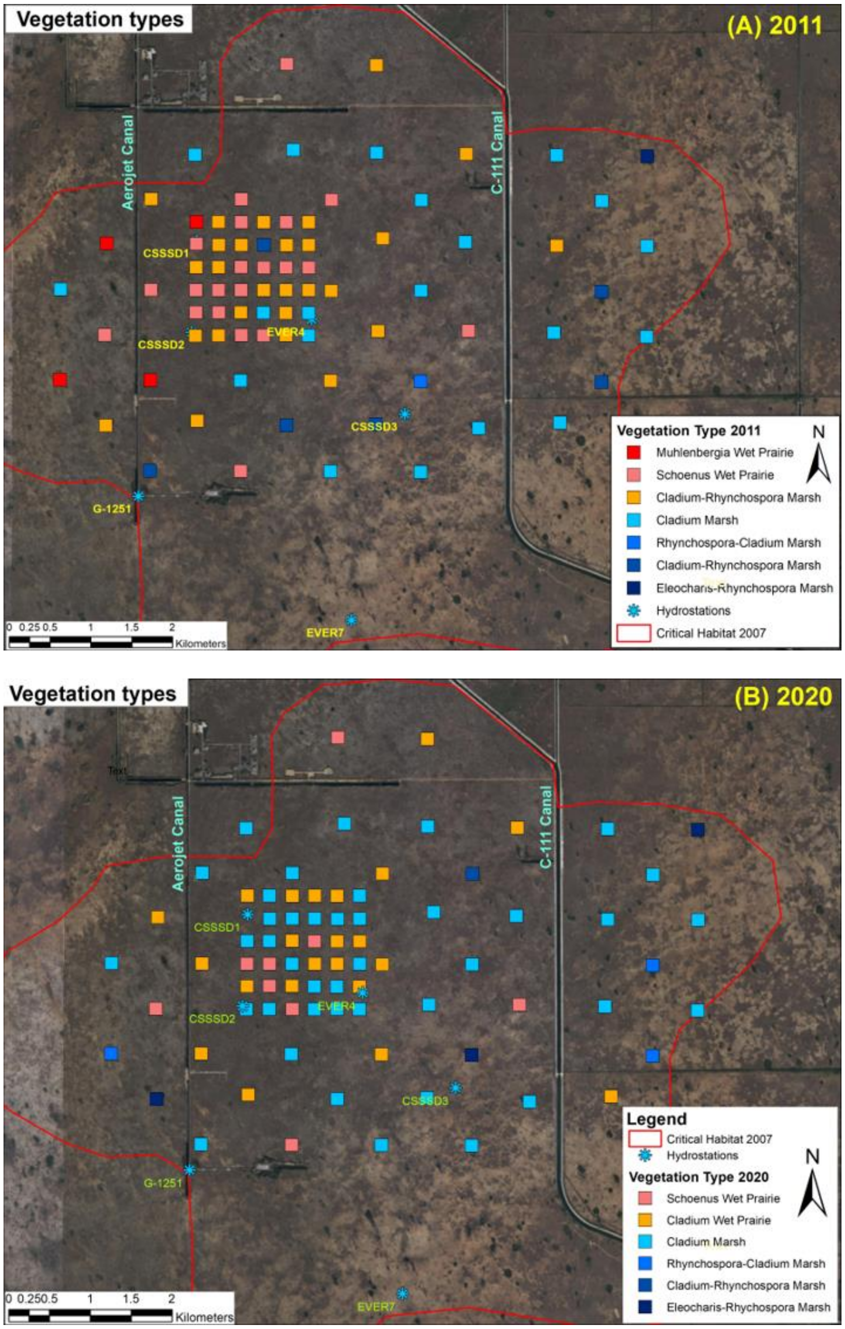

Figure 7: Vegetation types at 80 sites in the habitat of CSSS sub-population D within C-111 Spreader Canal Western Project Area. Vegetation type at each site was identified through cluster analysis of species cover values at 688 sites, including 608 census sites sampled in three years (2003-05). Vegetation types represent from dry (red) to wet (dark blue) community types and are based on (A) 2011, and (B) 2018 vegetation composition data.

In 2011, there were four sites classified as the *Muhlenbergia* WP (Figure 7A), however, none of the wet prairie sites in 2020 had dominance of muhly grass (*Muhlenbergia capillaris*) to be classified as *Muhlenbergia* WP (Figure 7B). Across all the sites, mean cover of muhly grass decreased from 3.25% in 2011 to 0.79% in 2020. Marsh (M) sites had hydroperiods generally greater than 210 days, and the vegetation assemblages at the sites were mainly sawgrass (*C. jamaicense*), sawgrass-beakrush sedge (*Cladium-Rhynchospora*) and beakrush-sawgrass (*Rhynchospora-Cladium*) marsh. Three sites had the vegetation assemblage of spikerush-beakrush (*Eleocharis-Rhynchospora*) marsh (Figure 7B).

In NMDS ordination, the first axis, which was aligned to parallel the fitted vector of 4-year average mean annual water depth, separates the marsh sites from wet prairie sites, suggesting that species composition along the gradient is primarily influenced by hydrology (hydroperiod - $r = 0.73$, $p < 0.001$; mean annual water depth $r = 0.74$, $p < 0.001$) (Table 1).Soil depth as well as three community characteristics variables were also significantly correlated.

The species composition in all post-project survey years was significantly different (ANOSIM: p-value < 0.001) from that in 2011 (Table 2). While vegetation composition in 2020 differed from that in 2014 and 2016, ANOSIM results suggests that the difference in vegetation composition between 2018 and 2020 was not statistically significant.

Table 1: Maximum correlations (r) of significant environmental and community characteristic vectors fitted in NMDS ordination space for plant species' importance value (IV) data. Probabilities (P) were calculated using 10,000 random permutations.

Environment and Community Variables	N	r	p-value
Soil Depth (cm)	17	0.576	0.013
4-Yr average Hydroperiod (Days)	343	0.726	<0.001
4-Yr average water depth (cm)	343	0.740	<0.001
Species richness	398	0.768	<0.001
Vegetation Cover (%)	398	0.301	<0.001
Above ground biomass (g/m^2)	398	0.394	<0.001

Table 2: Global R and *p*-values from analysis of similarity (ANOSIM) testing for among-year differences in vegetation composition before (2011) and after (2014, 2016, 2018 and 2020) the operation of the C-111 spreader canal western project began in 2012.

Sampling event	2011 (base line survey)	2014	2016	2018
2014	0.077***			
2016	0.200***	0.125***		
2018	0.212***	0.096***	0.100***	
2020	0.186***	0.106***	0.090***	0.185

*p-value: * <0.5, ** < 0.01, *** <0.001*

Vegetation change over nine years, since the base line survey in 2011, was marked by an increase in wetness of some sites and a consequent shift in species composition toward the wetter type. Twenty-three (44%) wet-prairie sites of 2011 were classified as marsh sites based on species abundance data collected in 2020 (Appendix 1). In contrast, almost all the 2011 marsh sites (89%) still had the marsh vegetation in 2020. Trajectory analysis results also revealed that between 2011 and 2020, vegetation composition at 67 (83.75%) sites had shifted toward relatively wetter type (represented by positive delta and slope), and such a shift towards wetter type was statistically significant (p = < 0.1) at 40 sites – 33 wet prairie and 7 marsh sites (Appendix 2). In contrast, only two marsh sites located east of C111 canal showed significant drying trend. In general, while 2011 wet prairie sites showed a noticeable shift in position towards increasing wetness in an ordination space, marsh sites did not show much shift in species composition over nine years along hydrologic gradient (Figure 8).

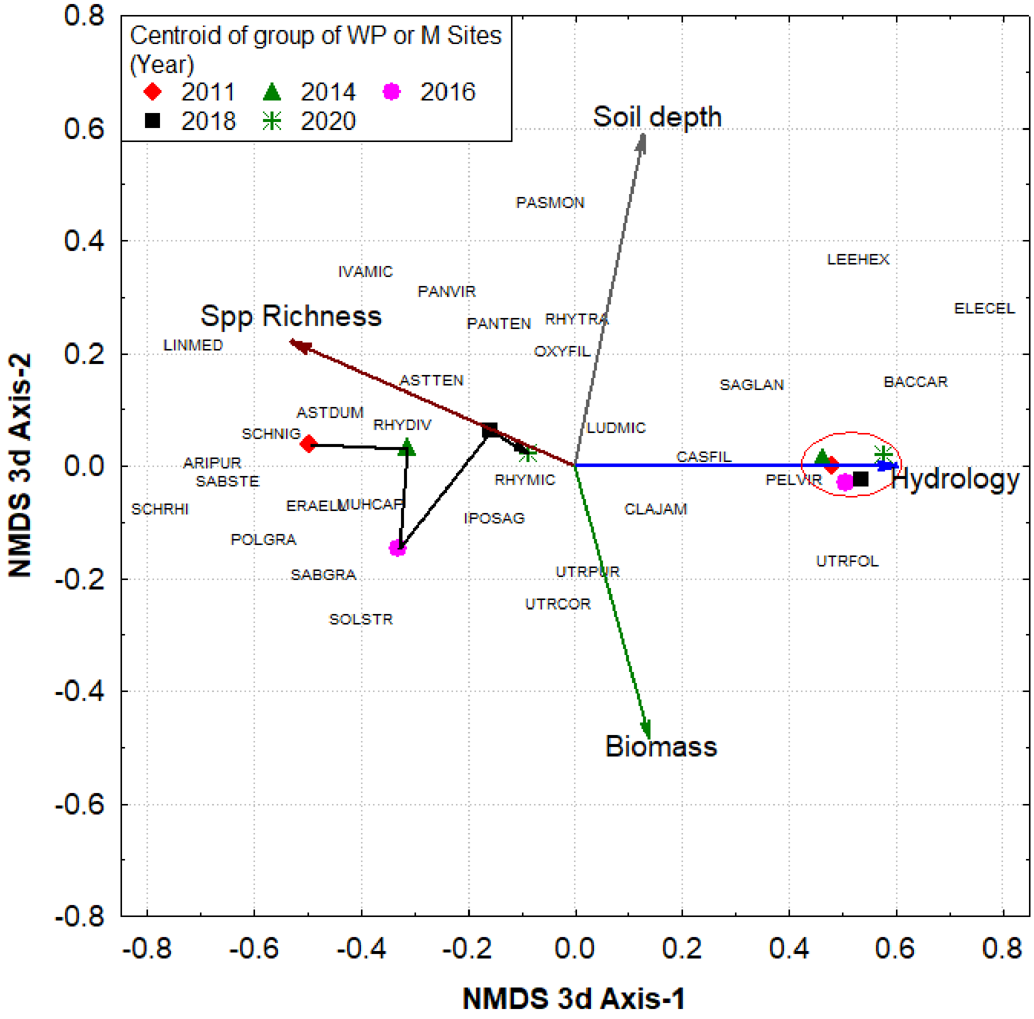

Figure 8: Site scores from species' importance value (IV)based non-metric multidimensional scaling (NMDS) 3-D Ordination Axis-1 and 2. Points in ordination space represent centroids of sites grouped by major vegetation category (Wetpraire (WP) and Marsh (M)) and sampling year (2011, 2014, 2016, 2018 and 2020). Centroids of Marsh sites are circled by an oval. Only selected species are plotted to reduce the overlap. Full name of species are given in Appendix 2.

Over nine years (2011-2020), the cover value of major species (*Muhlebergia capillaris* ssp. *filipes*, *Schoenus nigricans* and *Rhynchospora microcarpa*) that are characteristics of marl wet prairie sites, i.e. dry end of the marl prairie hydrologic gradient, significantly declined. The mean cover of muhly grass and black-top sedge in 2020 was only one-fourth of their cover values in 2011. In contrast, the difference in spikerush (*Eleocharis cellulosa*), which was most abundant at the wet end of the marl prairie gradient (Ross et al. 2006a; Sah et al. 2011a), was not statistically significant (Table 2). Mean cover of sawgrass (*Cladium jamaicense*) decreased by one-third in 2014, three years after the base surveyed year, b cover then remained same in next four years. Sawgrass cover value again increased between 2018 and 2020 surveys. The cover beakrush sedge (*Rhynchospora tracyi*) varied greatly over time. In 2020, its cover was lower than in 2011, but same as in 2018.

Together with the cover value, the importance value (IV) of the species that are characteristic relatively dry community, also decreased over time. However, the importance values of marsh species were either same, e.g. spikerush, or increase as were the IV of *C. jamaicense* and *R. tracyi*, suggesting a shift in species composition at sites toward wetter type.

Table 3: Mean (± 1 S.D.) value of percent cover and importance value (IV) of major species averaged over all sites (n = 80) surveyed in 2011, 2014, 2016, 2018 and 2020 within the CSSS sub-population D habitat region. P-values are from non-parametric test, Friedman Analysis of Variance for multiple dependent samples. Different letters in superscript represent the significant difference as determined in non-parametric, Wilcoxon matched-pair test.

Plant species	**Sampling years**					**Friedman Test p-value**
	2011	**2014**	**2016**	**2018**	**2020**	
Mean Cover						
Cladium jamaicense	33.3±18.9^{a}	21.9±14.0^{b}	22.7±14.5^{b}	23.9±14.1^{b}	27.9±16.6 ^{c}	<0.001
Schoenus nigricans	11.1±17.8^{a}	6.0±10.5^{b}	5.2±9.5^{bc}	4.0±6.7^{c}	2.8±6.3^{d}	<0.001
Muhlenbergia capillaris ssp. *filipes*	3.2±6.9^{a}	1.7±2.7^{b}	1.0±1.8^{c}	0.5±1.1^{d}	0.8±1.7^{c}	<0.001
Rhynchospora microcarpa	3.3±5.0^{a}	1.5±1.9^{b}	0.6±1.5^{c}	0.4±0.9 ^{d}	0.3±0.6^{d}	<0.001
Rhynchospora tracyi	4.5±6.5^{a}	3.5±3.7^{a}	1.7±3.3^{bc}	3.0±4.2 ^{ac}	2.8±4.8^{c}	<0.001
Eleocharis cellulosa	3.2±10.0	2.3±7.0	1.2±4.7	1.0±5.4	0.8±2.1	0.236
Importance Value (IV)						
Cladium jamaicense	40.6±20.6^{a}	42.0±19.2^{a}	48.6±20.5^{b}	50.0±19.2^{bc}	52.2±19.0^{c}	<0.001
Schoenus nigricans	11.2±15.3^{a}	10.0±14.1^{ab}	10.7±15.4^{ab}	10.0±14.4^{b}	7.0±11.9^{c}	<0.001
Muhlenbergia capillaris ssp. *filipes*	4.8±7.6^{a}	4.5±6.3^{a}	4.1±6.2^{a}	2.3±4.0^{b}	3.5±5.3^{a}	0.005
Rhynchospora microcarpa	6.0±6.4^{a}	6.2±6.0^{ab}	5.0±4.6^{ac}	2.9±3.4^{d}	3.4±3.9^{d}	<0.001
Rhynchospora tracyi	7.3±7.8^{a}	10.1±8.9^{b}	8.5±11.0^{a}	12.8±9.7^{c}	10.6±9.8^{bd}	<0.001
Eleocharis cellulosa	4.2±11.4	5.1±13.3	3.6±9.9	3.3±9.2	4.0±9.2	0.393

3.3 Vegetation-inferred hydroperiod

Observed- and vegetation-inferred hydroperiods were well correlated even when data were pooled for all five sampling years ($r = 0.71$, $p < 0.001$). In concurrence with the wetter conditions during the four project-period surveys than base line survey, the mean (± SD) vegetation-inferred hydroperiod was significantly (General Linear Mixed Model: Tukey's test, $p < 0.05$) higher in all four post-project surveys than in 2011 (210 ± 47 days) (Figure 9). However, there was no significant difference in vegetation-inferred hydroperiod between 2014 and 2016 or 2018, suggesting that a prevalence of wet conditions during the project period caused a shift in species composition toward a more hydric type, primarily in first 3-years after the baseline survey. The trend in vegetation change towards more hydric type continued for next two years, but with slower pace. Though the wetting trend again accelerated after 2018. In concurrence with the 4-year average hydroperiod (Figure 6), the mean vegetation-inferred hydroperiod also was higher in 2020 (229 ± 38 days) than in any other survey years (Figure 9).

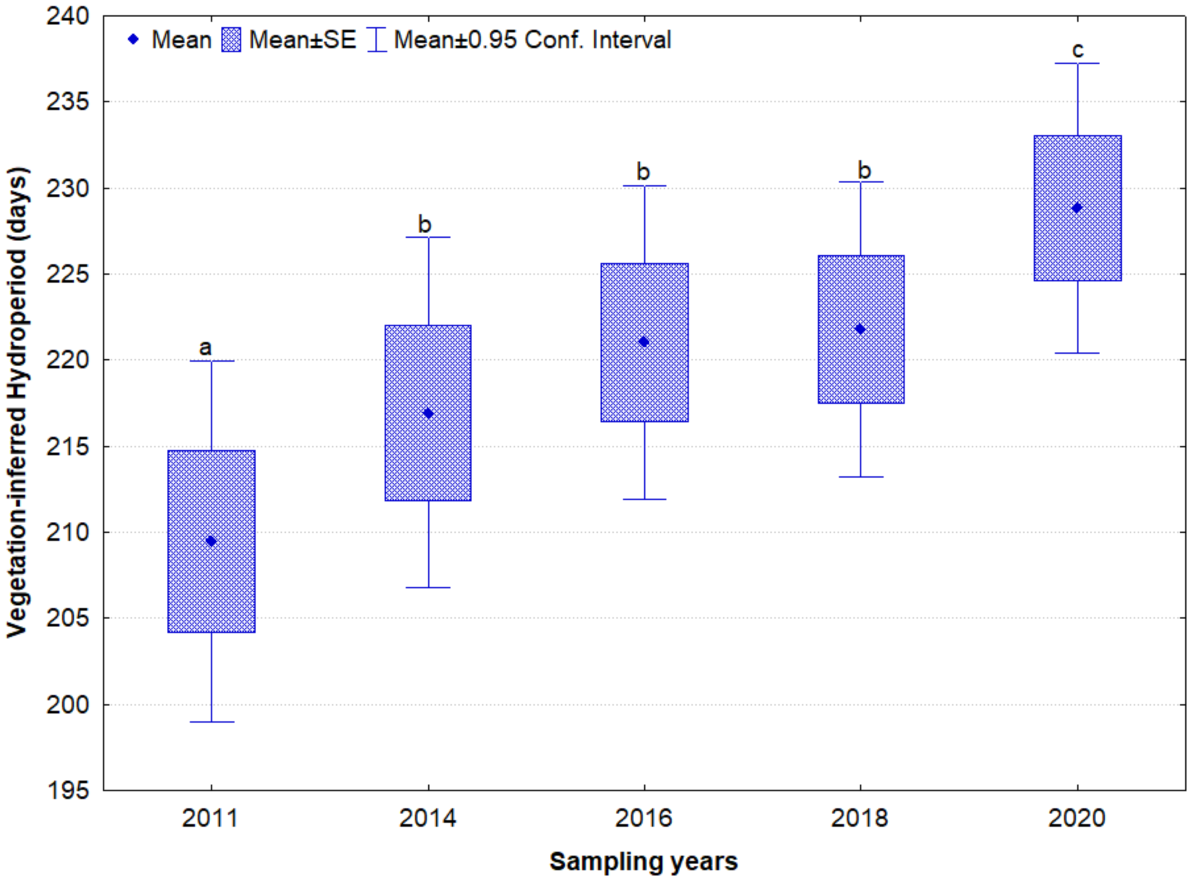

Figure 9: Box-plots (Mean, SE, and mean±1.96*SE) showing vegetation-inferred hydroperiod in different survey years within the habitat of CSSS sub-population D. Vegetation-inferred hydroperiod values were predicted from vegetation composition using Weighted Averaging regression model developed from the vegetation and hydrology data from CSSS vegetation transect D (Ross et al. 2006). Different letters above the whisker represent significant difference (General Linear Mixed Model – Tukey's test, $p < 0.05$)

3.4 Vegetation structure and biomass

Vegetation change over five years was also marked by changes in vegetation structure (vegetation cover and height), species richness and aboveground biomass (Figure 10). Mean (±SD) vegetation cover was significantly lower (General Linear Mixed Model: Tukey's test, $p < 0.05$) during all four post-project surveys, 2014 (32.6 ± 12.7%), 2016 (34.1 ± 13.7%), 2018 (29.0 ± 11.8%) and 2020 (32.0 ± 15.1%) than in 2011 (39.3 ± 17.2%) (Figure 10a). The vegetation cover did not differ among all four post-project surveys. In comparison to reduced cover, vegetation height increased over nine years. The mean vegetation height was significantly higher in 2018 (61.0 ± 15.5 cm) and 2020 (69.4 ± 14.7 cm) than in 2011 (52.9 ± 14.1 cm), whereas vegetation height in 2014 (57.2 ± 11.4) and 2016 (56.4 ± 12.5 cm) were intermediate (Figure 10b). The increase in vegetation height in post-project period was primarily at only marl wet prairie sites, whereas at the marsh sites, the mean vegetation height was the same until 2016, but it was significantly higher in 2018 and 2020 than previous three samplings (Table 3). In general, vegetation height in the marl prairies is maximum in sawgrass dominated marsh, and the height decreases towards both dry and wet end of the gradient (Ross et al. 2006a). Thus, during the post-project period an increase in mean vegetation height with an increase in wetness at the relatively dry sites was normal.

Mean plant species richness was significantly lower in 2014 (8.7 ± 3.1 species/plot) and 2018 (8.0 ± 3.3) than in 2011 (10.0 ± 3.8), however the mean richness in 2016 (10.4 ± 4.3) was almost the same as it was in 2011 (Figure 10c). The mean species richness did not differ from the richness in any previous survey years. The aboveground biomass was relatively low in 2014 through 2018 (480±137, 490±149, and 466.8±140 g m^{-1} in 2014, 2016 and 2018, respectively), but the difference between post-project period and base line survey 520±176 g m^{-1}) was not statistically significant (Figure 10d). The aboveground biomass was the highest (533 ± 192) in 2020. The observed changes in vegetation structure (cover and height), species richness and aboveground biomass over nine years (2011-2020) spatially varied in the study area (Appendix 3). Sites in the central portion of study area (CS), where marl wet prairie vegetation types are dominant, usually had high species richness, medium cover and biomass. In contrast, the sparse sites (SS), especially those located east of C111, had lower species cover, biomass and species richness than resto of the area.

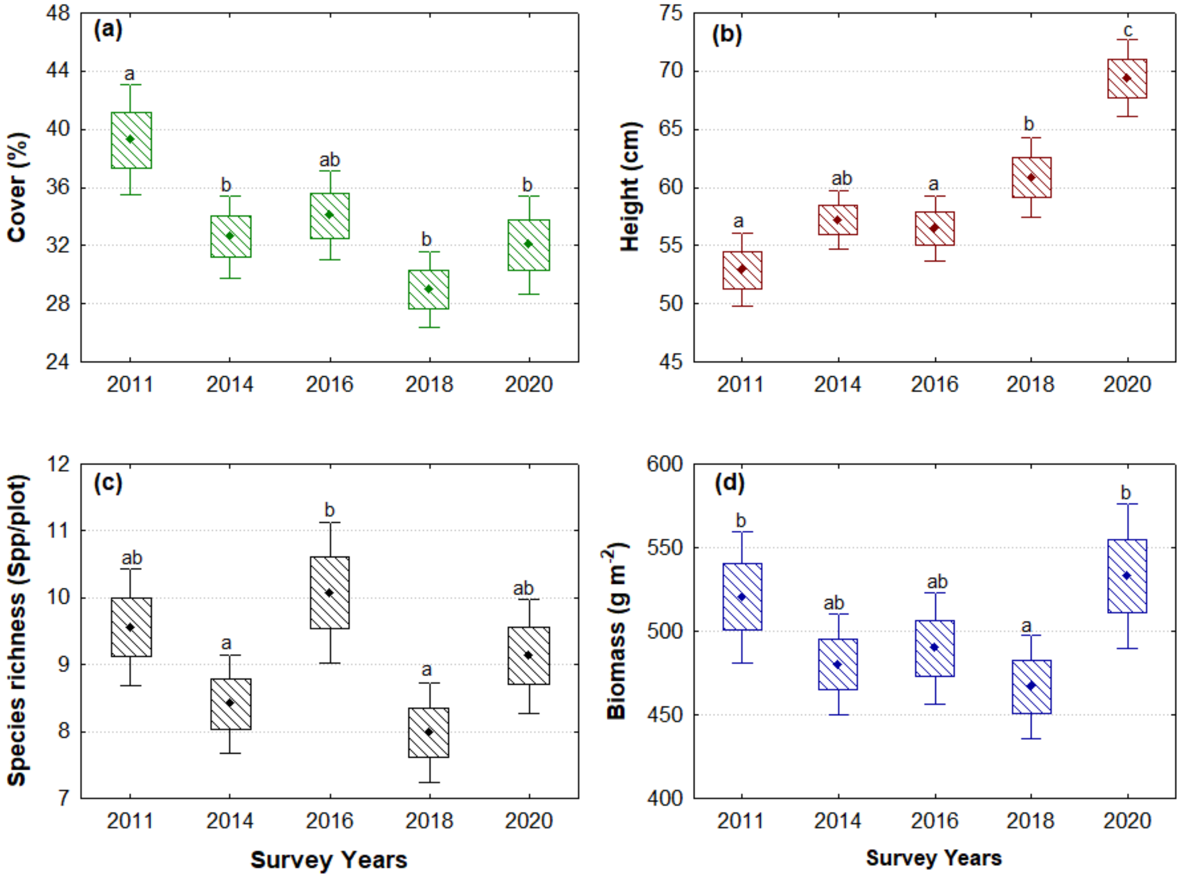

Figure 10: Box-plots (mean, SE, 95% CI) showing the vegetation structure, (a) vegetation cover, (b) vegetation height, (c) species richness, and (d) aboveground biomass in 2011 baseline survey, and 2014, 2016, 2018 and 2020 post-project period surveys. For 2011, 2014 and 2018, n = 80, and for 2016 and 2020, n = 79. Different letters represent the significant difference as determined in post-hoc (Tukey's) test using "multcomp" package in R.

Table 4: Mean (± 1 S.D.) value of vegetation structural measurements and species richness for two groups of sites, wet prairie (WP) vs marsh (M) surveyed in 2011, 2014, 2016 and 2018 within the CSSS sub-population D habitat region. Grouping of sites as WP and M is based on the 2011 site classification. Different letters in superscript represent the significant difference as determined in post-hoc (Tukey's) test using "multcomp" package in R.

Vegetation structural variables	**Vegetation type (2011)**	**Sampling years**				
		2011	**2014**	**2016**	**2018**	**2020**
Vegetation cover (%)	WP	38.9±16.0^{a}	32.4±12.1^{b}	34.3±12.6^{ab}	28.8±12.0^{b}	31.4±13.4^{b}
	M	40.0±19.4^{a}	33.0±14.0^{ab}	33.7±15.6^{ab}	29.4±11.6^{b}	33.2±18.1^{ab}
Vegetation height (cm)	WP	51.5±13.1^{a}	58.0±11.0^{b}	56.8±12.3^{ab}	60.2±13.9^{b}	67.0±13.6^{c}
	M	55.6±15.8^{a}	55.6±11.2^{a}	55.8±13.1^{a}	62.1±18.2^{ab}	73.7±15.9^{c}
Species richness (species/plot)	WP	11.4±3.0^{ab}	9.8±2.4^{a}	12.2±3.9^{b}	9.5±2.5^{a}	10.8±6.1^{ab}
	M	6.1±3.1^{a}	5.9±3.3^{a}	6.2±3.4^{a}	5.2±2.9^{a}	5.2±2.9^{a}
Aboveground plant biomass (g m^{-1})	WP	509±150	483±133	493±142	463±140	516±173
	M	542±218	476±145	484±164	474±141	565±221

4. Discussion

In the Everglades, the marl prairie is a dynamic landscape system where hydrology and fire are important drivers. In this system, vegetation responses to hydrologic alterations may occur rapidly (Armentano et al. 2006), consequently affecting the quality of CSSS habitat and the sparrow population (Nott et al. 1999; Jenkins et al. 2003). Within the habitat of sub-population D, vegetation has gone through different episodes of change over the past three decades, primarily in response to the natural and anthropogenic alterations in hydrologic regimes. In 1981, the vegetation was mostly the marl wet prairie type, and the sparrow population at the time was about 400 individuals (Pimm et al. 2002). During the early 1990s, however, the vegetation changed to a sawgrass-dominated marsh type, primarily in response to prolonged hydroperiod and high-water conditions in the area (Ross et al. 2004). These conditions resulted from both high rainfall during the mid-1990s and an increased water delivery into Taylor Slough through the operations of S-332 pump station (Ross et al. 2004; Armentano et al. 2006). Consequently, the sparrow population sharply declined (Pimm et al. 2002). Marsh vegetation prevailed until the early 2000s, and the sparrow population dropped from sight, as no sparrow was recorded for three consecutive years (2002-2004). Later, in the second half of the last decade (2005-2010), the vegetation within the region showed a drying trend, primarily in response to several drought years (Sah et al. 2011a). Consequently, the wet prairie vegetation was more widely spread in 2011 than it was during the period of 2003-2006 when a detailed systematic vegetation survey was first conducted at a network of sites located 1 km apart (Ross et al. 2006a; Sah et al. 2011a). Since the baseline survey in 2011, vegetation composition has shifted back toward a wetter type, a trajectory that might have implications on sparrow occupancy within the area. Forty-four percent of 2011 marl wet prairie sites have changed to relatively wet marl marsh vegetation types in 2020.

In the marl prairies, species richness is negatively correlated with hydroperiod (Ross et al. 2006a). Thus, a low species richness in two of four sampling years after the baseline survey was not a surprise, especially when vegetation composition has shifted towards wetter type in nine years. However, species richness in 2016 and 2020 similar to 2011 were unexpected. The reason for high species richness in 2016 could be due to prolonged dry period in 2014 and early 2015, one year prior to 2016 sampling. In 2016, there was also high variation in occurrence of species at the wet prairie sites (Table 3). Many of the sites in that particular year had characteristic species from both marl wet prairie and marsh vegetation types, especially due to relatively high-water conditions in dry season that occurred after a prolonged dry period in 2014-2015. Many species that are usually found at the marl marsh sites, such as *Eleocharis interstincta*, *Ludwigia alata*, *L. curtissii*, *L. repens*, *Utricularia purpurea, U. resupinata,* and U. *subulata*, were first time recorded in 2016. Nonetheless, by 2018, in conjunction with a change in vegetation composition from wet prairie to marsh types, species richness also declined. In 2018, maidencane (*Panicum hemitomon*), a characteristic species of wet conditions in Everglades was first time recorded. Increase in species richness between 2018 and 2020 was possibly the result of alternating dry and wet conditions. While wet conditions observed in 2016 and 2018 continued until 2019, the WY 2019/2020, that included early part of 2020 survey, was relatively dry. In addition, couple of sites burned in early 2020 where some ephemeral marsh species were recorded. For instance, Piedmont marshelder (*Iva microcephala*) was first time recorded in 2020 from the vegetation survey sites in Pop D. Despite the fact that the plant species richness has shown high variability during the study period (2011-2020), if the marl wet prairie vegetation composition continues to shift towards wetter type, it is likely that plant species richness in subpopulation D will also decline over time.

A shift in marl prairie vegetation towards wetter type is perceived as the deterioration in the available sparrow habitat quality. The foundation for this belief lies in the fact that sparrow occurrence is usually highest in muhly-dominated wet prairie with hydroperiods ranging between 90 and 210 days; concurrently, CSSS occurrence is less frequent in wetter vegetation types ranging from sawgrass-dominated prairie and marsh to beakrush sedge (*Rhynchospora tracyi*) and spikerush (*Eleocharis* sp.) marsh (Nott et al. 1998; Ross et al. 2006a). In sub-population A, west of Shark River Slough, researchers had also attributed a sharp decline in sparrow population to severe and prolonged flooding in the mid-1990s and the consequent change in vegetation to sawgrass marsh (Nott et al. 1998; Pimm et al. 2002; Jenkins et al. 2003). In Sub-population D too, sparrow population has sharply declined since the 1980s, probably for the same reason (Pimm et al. 2002). However, within this sub-population, a small breeding population of sparrows has consistently been recorded since 2006 by Julie Lockwood (2006-2010) and Tom Virzi (2011-2019) from Rutgers University (Lockwood et al. 2006, 2010; Virzi et al. 2011, 2015; Virzi and Davis 2013, 2014, 2016, 2017; Virzi and Murphy 2018). The bird nests were generally found within an area of high ground in northwest-central region of subpopulation D (Virzi and Davis 2013, 2014, 2016; Virzi et al. 2015), where ground elevation is relatively high and WP vegetation is dominant (Figure 7a, b).

In 2013, Virzi and Davis reported that the total extent of occupied habitat was found shrinking each year, and they wondered if the decline was in response to changes in vegetation conditions. An analysis of 2014 data had also shown that the increase in mean vegetation-inferred hydroperiod between 2011 and 2014 was disproportionately higher at WP or CS sites than the M or SS sites (Sah et al. 2014). At the WP and CS sites, inferred hydroperiod had increased by 11 and 13 days, respectively. In contrast, inferred hydroperiod had increased by only 1-3 days at the M or SS sites. The results had also showed that vegetation at the existing WP or CS sites shifted towards wetter types, likely causing the sites to be less suitable CSSS habitat. Between 2014 and 2018, however, there was no significant change in vegetation-inferred hydroperiod (Figure 9), suggesting that after 2014, the habitat condition showed wetting trend but much slower pace during that period. In fact, WY 2014-2015 was drier than average (Figure 5), and total rainfall during 2015 wet season was also 15.5% less than average. This prolonged dry condition might have temporarily reversed the trend of change in vegetation composition and helped in improvement in habitat conditions. This was evident by an increase in ephemeral sparrow population in both 2014 and 2015, which was attributed to the extended favorable breeding season (Virzi and Davis, 2014; Virzi et al. 2015). The sparrow data from 2016 was incomplete, but in 2017, sparrow population was slightly lower than 2014 and 2015 (Virzi and Davis 2017).

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; Copeland et al. 2016), including those in South Florida (Ross et al. 2006b; Miao et al. 2009; Ross et al. 2009). In South Florida, rain events are closely associated with El Nino-Southern Oscillation (ENSO) (Moses et al. 2013). In the winter of 2016, strong El Nino caused much higher rainfall than average, resulting in unusual high-water level in southern Everglades. In a normal year, water level in eastern marl prairies drops up to 100 cm below the ground in every dry season (Sah et al. 2011b). However, in the dry season (Nov 1 – April 30) of 2016, mean water level at the vegetation survey transects in CSSS sub-population C, E and F was 17.5 cm above the ground, which was 33.5 cm higher than 27-year average. However, within the habitat of CSSS sub-population D, the condition was not so extreme. In the 2016 dry season, the mean water level at vegetation survey sites was 11.9 cm above the ground, which was 15.4 cm higher than the 27-year average. The water level in 2016 dry season was high enough to shorten sparrow study period in that subpopulation (Virzi and Davis 2016).

In the past, unusual high water condition in the breeding season of sparrow had not only caused crash of sparrow populations, e.g. sub-population A, but had also contributed to the vegetation shift from muhly- or bluestem-dominated marl wet prairies to sawgrass-dominated marsh within the habitat (Pimm et al. 2002; Nott et al. 1998). At that time, however, high water condition in that area continued for next 2-3 years, due to both high rainfall and water deliveries through S12s. Thus, unusual dry season flooding followed by higher water level than normal for multiple years was the major cause of habitat degradation within the western marl prairies (Nott et al. 1998; Jenkins et al. 2003). Due to similar reasons, decline in sparrow population and a shift in vegetation composition had also occurred in sub-population D (Pimm et al 2002; Ross et al. 2004; Virzi et al. 2011). In this area, the mean annual water depth for next three water years (2016-2018) was higher than 29-year average. In addition, the 4-year average hydroperiod before 2020 survey was significantly higher than in any previous surveys. That might have accelerated the vegetation composition to shift towards wetter type than it was in 2018 and before. In fact, in 2020, the vegetation-inferred hydroperiod, a matrix that has been used to track the shift in vegetation composition in response to hydrologic changes, was significantly higher than any previous surveys. If the trend continues, that will have adverse impact on the quality of habitat, and ultimately the sparrow population in this area.

Prior to the implementation of the C111-SC project, a simulation model to assess the potential impacts of the project on habitat conditions had indicated that the operations would result in an increased hydroperiod, and might have adverse effects on the habitat conditions within the CSSS subpopulation D critical habitat (USFWS 2009). Thus, during the eight years of post-project period, a shift in vegetation composition in response to hydrologic changes towards wetter types that we observed in sub-population D area is in consistent with our expectation. In general, an increasing trend in wetness in marl prairies beyond 210 days hydroperiod is envisaged as gradual deterioration of sparrow breeding habitat conditions (USACE 2016). Thus, the increase in 4-year average vegetation-inferred hydroperiods from 210 days in 2011 to 229 days in 2020 (Figures 6, 9) observed during the post-project period could be an indication deteriorating habitat condition. However, relatively more successful sparrow nesting during the breeding season in last three years (2018-2020) than previous years (Virzi and Murphy 2018; Virzi and Tofoya 2019, 2020) could be envisaged as contrary to our expectation. In 2020, almost all sparrows' nests and majority of sparrows were observed within the core area where prairie vegetation is still dominant (Appendix 3: Figure A.3). However, eleven pairs were detected outside the core area, designated during the baseline survey. While several factors, including the favorable dry seasons, low dispersal barrier, effect of Hurricane Irma on dispersal patterns and habitat quality, etc. might have played important role in successful breeding and relative high number of sparrows in sub-population D in those years, the subpopulation still remains small and vulnerable (Virzi and Tofaya 2020).

Within the habitat of sub-population D, ongoing wetting trend together with the shift in vegetation from short-hydroperiod marl wet prairies to marsh types eventually may have adverse effects on sparrow success. Thus, it is important to minimize the chances of high-water condition in coming years, especially in dry season, so that observed trend of vegetation shift will not accelerate further with long-lasting adverse impact on sparrow and its habitat. Only a continued monitoring of the vegetation as well as sparrow population dynamics can provide a conclusive assessment of ongoing trend of vegetation shift, probably caused by the synergistic effects of high rainfall and the project activities on the future fate of the existing CSSS population and its habitat. Moreover, the trajectory analysis method used in this study has made it possible to detect a shift in vegetation composition along a vector representative of increasing wetness. This demonstrates that a more sensitive tool based on plant assemblages is available for tracking the outcome of water management decisions on sparrow habitat quality in this sub-population.

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APPENDIX

Appendix 1: List of CSSS sub-population D habitat vegetation monitoring sites sampled in 2020. Vegetation types are based on 2011 and 2020 species composition data. MWP = *Muhlenbergia* Wet Prairie; SOWP = *Schoenus* Wet Prairie; COWP = *Cladium* Wet Prairie; CM = *Cladium* Marsh; CRM = *Cladium-Rhynchospora* Marsh; RCM = *Rhynchospora-Cladium* Marsh; ERM = *Eleocharis-Rhynchospora* Marsh. Delta and slope (amount and rate of change in the target direction, respectively) were obtained for each sites from trajectory analysis in which the base year for vegetation change was 2011 and statistical significance ($p < 0.1$) of delta and slope was tested using Monte Carlo's simulations with 1,000 permutations.

PLOT	X_UTM83	Y_UTM83	Veg. type (2011)	Veg. type (2018)	delta (Δ)	p-value (delta)	slope	p-value (slope)
D-01-02	544353	2801406	CWP	CWP	0.275	0.200	0.030	0.154
D-01-03	545411	2804404	CM	CM	0.173	0.217	0.020	0.200
D-01-05	546405	2803430	CWP	CM	0.565	0.011	0.058	0.003
D-01-06	546354	2802406	CWP	CM	0.455	0.048	0.037	0.078
D-01-07	547357	2802410	SOWP	SOWP	0.062	0.396	0.021	0.186
D-01-08	547475	2801337	CM	CM	-0.274	0.077	-0.022	0.155
D-01-10	548377	2801401	CM	CWP	-0.395	0.029	-0.045	0.014
D-02-01	545335	2805354	SOWP	SOWP	0.070	0.392	0.009	0.358
D-02-02	546327	2805342	CWP	CWP	-0.010	0.475	0.005	0.417
D-02-03	546334	2804375	CM	CM	0.256	0.015	0.030	0.007
D-02-04	543345	2803363	MWP	CWP	0.588	0.007	0.071	0.004
D-02-06	547321	2803391	CM	CM	0.000	1.000	0.000	1.000
D-02-07	548307	2802395	CM	CM	-0.062	0.282	-0.010	0.176
D-03-01	547329	2804365	CWP	CWP	-0.066	0.392	-0.013	0.307
D-03-02	544322	2804348	CM	CM	0.276	0.063	0.038	0.019
D-03-03	546337	2801375	CRM	CM	0.085	0.296	0.007	0.309
D-03-04	545343	2801363	CRM	CM	0.320	0.064	0.032	0.068
D-04-01	542834	2802855	CM	CM	0.228	0.156	0.032	0.077
D-04-02	542831	2801856	MWP	RCM	0.253	0.165	0.024	0.183
D-04-03	543326	2802353	SOWP	SOWP	0.130	0.265	0.000	0.501
D-04-04	543338	2801354	CWP	ERM	0.490	0.007	0.045	0.010
D-04-05	543835	2803855	CWP	CM	0.377	0.090	0.058	0.024
D-04-06	543835	2802853	SOWP	CWP	0.685	0.011	0.094	0.001
D-04-07	543832	2801857	MWP	CWP	0.506	0.078	0.074	0.013
D-04-08	543832	2800854	CRM	CM	0.442	0.012	0.054	0.000
D-04-09	544836	2803855	SOWP	CM	0.759	0.003	0.082	0.001
D-04-10	544832	2801855	CM	CM	0.254	0.299	0.042	0.182
D-05-01	544836	2800854	SOWP	SOWP	0.349	0.045	0.042	0.030
D-05-02	545835	2803854	SOWP	CWP	0.554	0.030	0.071	0.003
D-05-03	545835	2802849	CWP	CWP	-0.125	0.276	-0.009	0.346
D-05-04	545831	2801855	CWP	CWP	0.065	0.404	0.033	0.074
D-05-05	545833	2800854	CM	CM	-0.072	0.304	0.004	0.396
D-05-06	546832	2803854	CM	CRM	0.321	0.067	0.025	0.121
D-05-07	546833	2802854	CM	CM	-0.049	0.390	0.002	0.470
D-05-08	546830	2801851	RCM	ERM	0.692	0.028	0.029	0.232
D-05-09	546834	2800850	CM	CM	0.082	0.361	0.014	0.252
D-06-01	548330	2804355	CM	CM	0.133	0.284	0.012	0.297

PLOT	**X_UTM83**	**Y_UTM83**	**Veg. type (2011)**	**Veg. type (2018)**	**delta (Δ)**	**p-value (delta)**	**slope**	**p-value (slope)**
D-06-02	548333	2803356	CWP	CM	0.143	0.098	0.020	0.047
D-06-03	548832	2803849	CM	CM	0.001	0.511	0.001	0.499
D-06-04	548834	2802850	CRM	RCM	0.191	0.053	0.027	0.011
D-06-05	548834	2801851	CRM	RCM	0.060	0.340	0.005	0.378
D-06-06	549331	2804349	ERM	ERM	0.042	0.470	-0.008	0.434
D-06-07	549336	2803354	CM	CM	-0.222	0.034	-0.027	0.015
D-06-08	549334	2802353	CM	CM	-0.159	0.103	-0.024	0.036
TD-01-01	544337	2803605	MWP	CWP	0.623	0.005	0.066	0.003
TD-01-02	544583	2803606	CWP	CM	0.426	0.085	0.045	0.064
TD-01-03	544835	2803604	SOWP	CWP	0.537	0.019	0.059	0.012
TD-01-04	545084	2803606	CWP	CWP	0.320	0.061	0.025	0.129
TD-01-05	545333	2803606	SOWP	CWP	0.514	0.007	0.061	0.003
TD-01-06	545582	2803607	CWP	CM	0.270	0.152	0.025	0.173
TD-02-01	544339	2803363	SOWP	-	0.416	0.038	0.043	0.100
TD-02-02	544585	2803351	CWP	CM	0.536	0.016	0.051	0.018
TD-02-03	544837	2803353	CWP	CM	0.650	0.003	0.057	0.013
TD-02-04	545086	2803354	CRM	CM	0.329	0.081	0.042	0.045
TD-02-05	545337	2803351	CWP	CM	0.480	0.019	0.041	0.039
TD-02-06	545583	2803353	CWP	CM	0.819	0.030	0.091	0.010
TD-03-01	544337	2803104	CWP	CM	0.689	0.006	0.081	0.001
TD-03-02	544584	2803105	CWP	CM	0.212	0.117	0.034	0.033
TD-03-03	544834	2803107	SOWP	CWP	0.102	0.351	0.024	0.190
TD-03-04	545084	2803104	SOWP	SOWP	0.340	0.056	0.044	0.019
TD-03-05	545332	2803104	SOWP	CWP	0.370	0.051	0.038	0.043
TD-03-06	545584	2803105	SOWP	CWP	0.413	0.075	0.036	0.107
TD-04-01	544335	2802852	SOWP	SOWP	0.456	0.008	0.046	0.008
TD-04-02	544585	2802853	SOWP	SOWP	0.480	0.022	0.042	0.047
TD-04-03	544835	2802853	SOWP	CM	0.664	0.000	0.064	0.000
TD-04-04	545085	2802853	CWP	CWP	0.340	0.055	0.024	0.153
TD-04-05	545334	2802854	CWP	CWP	0.151	0.178	0.015	0.188
TD-04-06	545584	2802856	CWP	CM	0.476	0.030	0.049	0.021
TD-05-01	544334	2802604	SOWP	CWP	0.690	0.000	0.057	0.007
TD-05-02	544587	2802607	SOWP	SOWP	0.208	0.214	0.024	0.170
TD-05-03	544833	2802608	CWP	CWP	0.467	0.010	0.060	0.001
TD-05-04	545085	2802605	CM	CM	0.103	0.225	0.022	0.054
TD-05-05	545332	2802603	CWP	CM	0.875	0.001	0.101	0.000
TD-05-06	545584	2802603	CM	CWP	0.275	0.066	0.035	0.026
TD-06-01	544330	2802349	CWP	CM	0.448	0.017	0.045	0.008
TD-06-02	544585	2802352	CWP	CM	0.726	0.000	0.081	0.000
TD-06-03	544839	2802354	SOWP	SOWP	0.333	0.066	0.036	0.055
TD-06-04	545084	2802353	SOWP	CM	0.640	0.006	0.058	0.014
TD-06-05	545335	2802356	CWP	CM	0.229	0.081	0.018	0.143
TD-06-06	545585	2802355	CM	CM	-0.296	0.061	-0.015	0.232

Appendix 2: List of species recorded during vegetation samplings in CSSS Subpopulation D within C-111 Spreader Canal West Project area. Species name in parenthesis are the current name of species accepted by ITIS (Integrated Taxonomic Information System).

SPCODE	Species	Species_2011	Species_2014	Species_2016	Species_2018	Species_2020
AGALIN	*Agalinis linifolia*	*	*	*	*	*
ALEBRA	*Aletris bracteata*	*		*		*
AMBART	*Ambrosia artemisiifolia*	*				
ANNGLA	*Annona glabra*			*	*	*
ARIPUR	*Aristida purpurascens*	*		*	*	*
ASCLAN	*Asclepias lanceolata*	*	*	*	*	*
ASTADN	*Aster adnatum (Symphyotrichum adnatum)*		*			
ASTBRA	*Aster bracei (Symphyotrichum bracei)*			*		
ASTDUM	*Aster dumosus (Symphyotrichum dumosum)*	*		*	*	
ASTSPP	*Aster* sp.		*			
ASTTEN	*Aster tenuifolium (Symphyotrichum tenuifolium)*	*	*	*	*	*
BACCAR	*Bacopa caroliniana*	*	*	*	*	*
CALTUB	*Calopogon tuberosus*	*	*	*	*	*
CARSCA	*Carolina scalystem (Elytraria caroliniensis)*				*	
CASFIL	*Cassytha filiformis*	*	*	*	*	*
CENASI	*Centella asiatica*	*	*	*	*	*
CHIALB	*Chiococca alba*	*	*	*		*
CHRICA	*Chrysobalanus icaco*		*		*	
CLAJAM	*Cladium jamaicense*	*	*	*	*	*
CONERE	*Conocarpus erectus*		*	*		*
CRIAME	*Crinum americanum*	*	*	*	*	*
CYPHAS	*Cyperus haspan*		*			
DICDIC	*Dichanthelium dichotomum*			*		
DYSANG	*Dyschoriste angusta*	*				
ELEBAL	*Eleocharis baldwinii*	*	*			*
ELECEL	*Eleocharis cellulosa*	*	*	*	*	*
ELEINT	*Eleocharis interstincta*			*		
ERAELL	*Eragrostis elliottii*	*		*	*	*
FUIBRE	*Fuirena breviseta*			*		
HELPIN	*Helenium pinnatifidum*			*		*
HYMPAL	*Hymenocallis palmeri*	*	*	*	*	*
HYPCIS	*Hypericum cistifolium*			*		
ILECAS	*Ilex cassine*	*	*	*	*	*
IPOSAG	*Ipomoea sagittata*	*	*	*	*	*

SPCODE	**Species**	**Species _2011**	**Species_ 2014**	**Species _2016**	**Species_ 2018**	**Species_ 2020**
IVAMIC	*Iva microcephala*					*
JUSANG	*Justicia angusta*		*	*	*	*
LEEHEX	*Leersia hexandra*	*	*	*		*
LINMED	*Linum medium* var. *texanum*	*	*	*		*
LOBGLA	*Lobelia glandulosa*				*	
LUDALA	*Ludwigia alata*			*		
LUDCUR	*Ludwigia curtissii*			*		
LUDMIC	*Ludwigia microcarpa*	*	*	*	*	*
LUDREP	*Ludwigia repens*			*		
MAGVIR	*Magnolia virginiana*			*	*	
MIKSCA	*Mikania scandens*	*		*	*	
MITPET	*Mitreola petiolata*	*	*	*		*
MORCER	*Morella cerifera*	*	*	*	*	*
MUHCAP	*Muhlenbergia capillaris*	*	*	*	*	*
OXYFIL	*Oxypolis filiformis*	*	*	*	*	*
PANHEM	*Panicum hemitomon*				*	
PANTEN	*Panicum tenerum*	*	*	*	*	*
PANVIR	*Panicum virgatum*	*	*	*	*	*
PASMON	*Paspalum monostachyum*	*		*		*
PELVIR	*Peltandra virginica*	*	*	*	*	*
PERBOR	*Persea borbonia*		*			
PHYNOD	*Phyla nodiflora*	*	*	*	*	
PHYSTO	*Phyla stoechadifolia*	*				
PLUROS	*Pluchea rosea*	*	*	*	*	*
POLGRA	*Polygala grandiflora*	*	*	*		*
PROPAL	*Proserpinaca palustris*	*				
RHYDIV	*Rhynchospora divergens*	*	*	*	*	*
RHYINU	*Rhynchospora inundata*	*		*		
RHYMIC	*Rhynchospora microcarpa*	*	*	*	*	*
RHYSPP	*Rhynchospora* sp.			*		
RHYTRA	*Rhynchospora tracyi*	*	*	*	*	*
SABGRA	*Sabatia grandiflora*			*		*
SABSTE	*Sabatia stellaris*	*	*			*
SAGLAN	*Sagittaria lancifolia*	*	*	*	*	*
SALCAR	*Salix caroliniana*			*		
SAMEBR	*Samolus ebracteatus*	*		*		
SARCLA	*Sarcostemma clausum (Funastrum clausum)*	*				
SCHNIG	*Schoenus nigricans*	*	*	*	*	*
SCHRHI	*Schizachyrium rhizomatum*	*	*	*	*	*

SPCODE	**Species**	**Species _2011**	**Species_ 2014**	**Species _2016**	**Species_ 2018**	**Species_ 2020**
SETPAR	*Setaria parviflora*	*				
SOLSTR	*Solidago stricta*	*	*	*	*	*
TAXDIS	*Taxodium distichum*		*	*	*	*
TEUCAN	*Teucrium canadense*		*			
TYPDOM	*Typha domingensis*	*	*	*	*	*
UNKD21	Unknown D02-01			*		
UNKSEED	Unknown seedling					*
UNKTD25	Unknown TD02-05	*				
UNKTD56	Unknown TD05-06		*			
UNKWP16	Unknown WP16					*
UTRCOR	*Utricularia cornuta*	*	*	*	*	*
UTRFOL	*Utricularia foliosa*	*		*	*	*
UTRGIB	*Utricularia gibba*	*		*	*	
UTRPUR	*Utricularia purpurea*			*	*	*
UTRRES	*Utricularia resupinata*			*		
UTRSPP	*Utricularia* sp.			*		*
UTRSUB	*Utricularia subulata*			*		*
VICACU	*Vicia acutifolia*	*				

Appendix 3

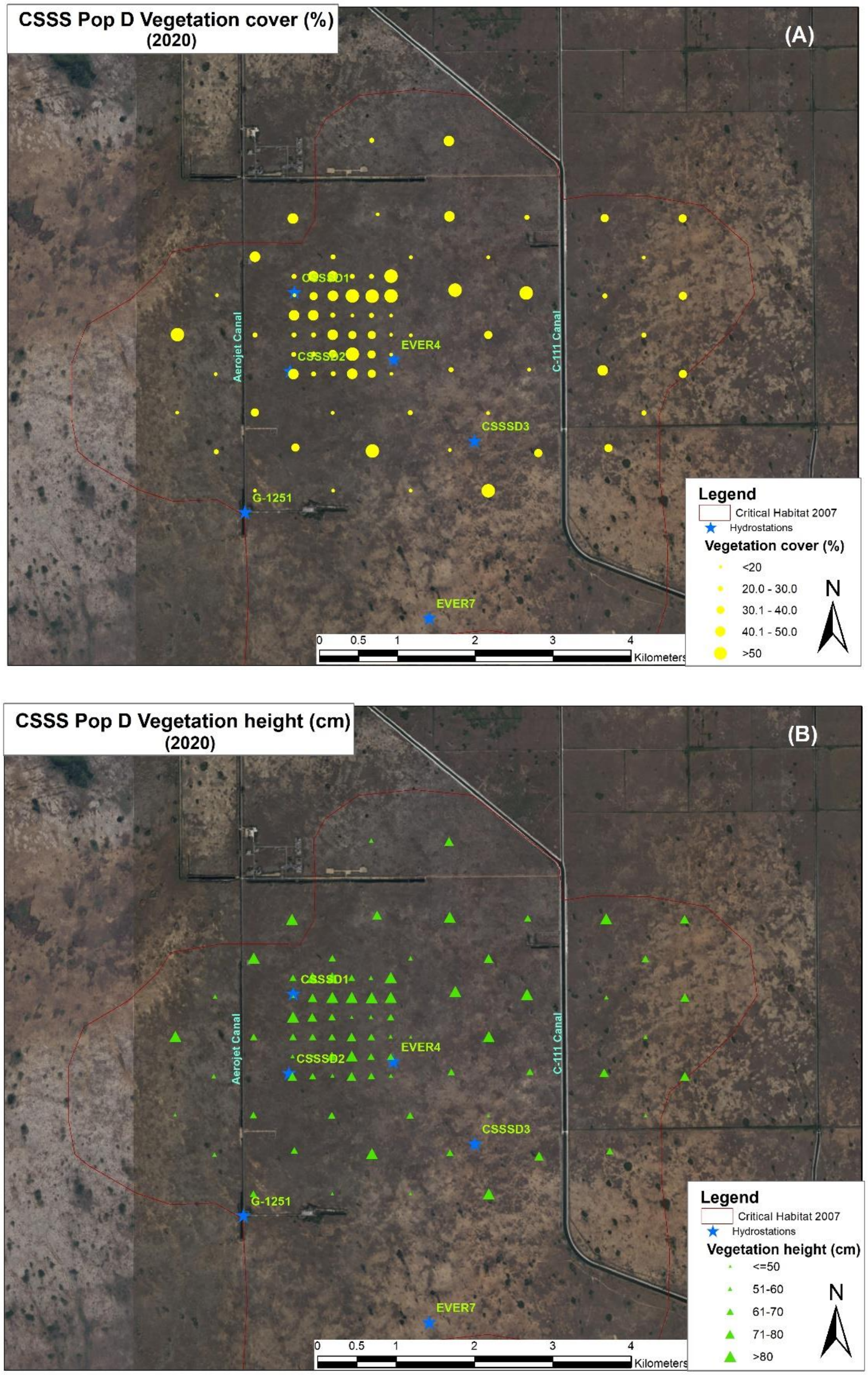

Figure A-1: Mean total vegetation cover and height at 79 sites surveyed during 2020 in CSSS Sub-population D habitat within C-111 Spreader Canal Western Project area.

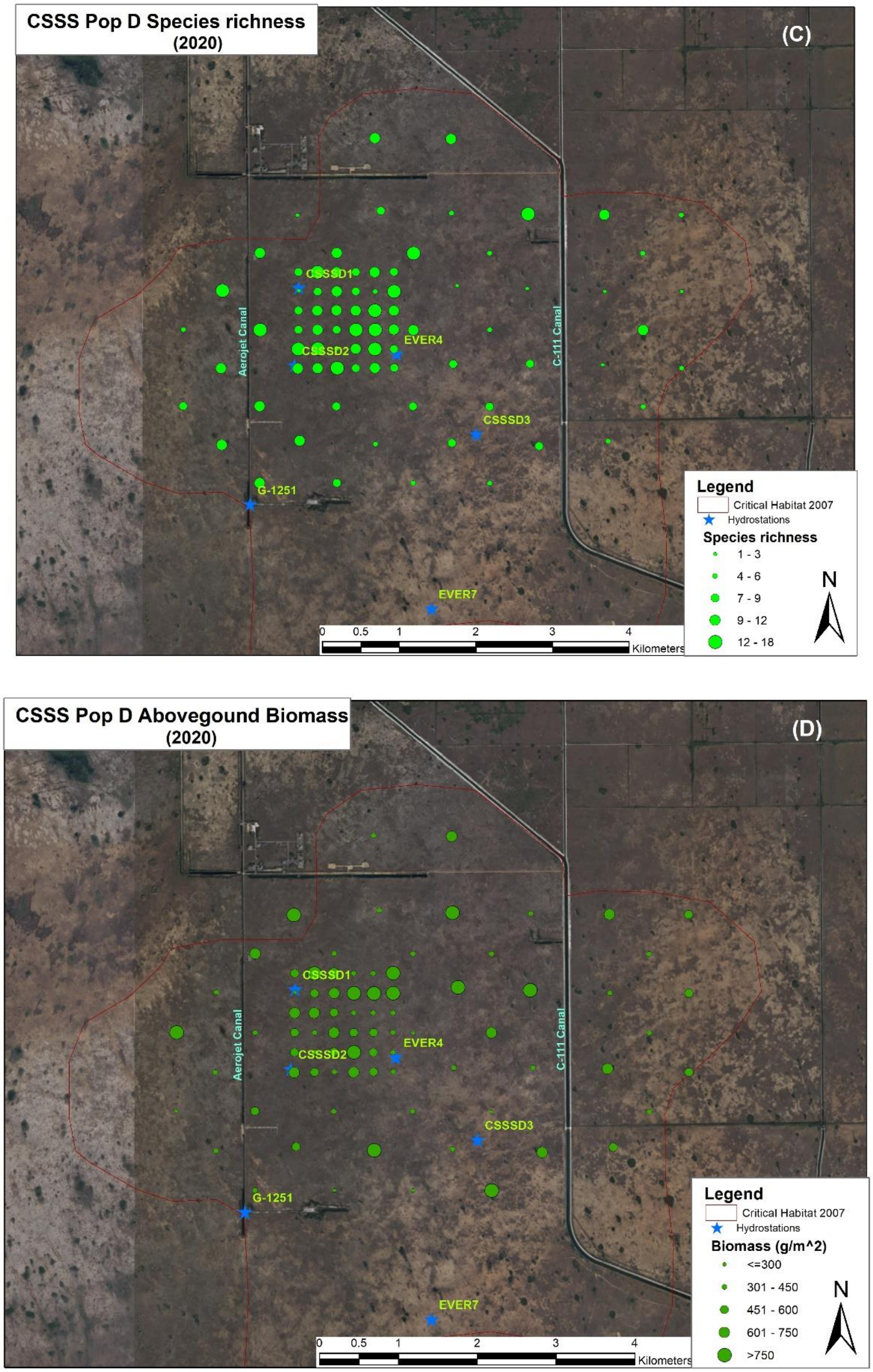

Figure A-2: Mean species richness and aboveground biomass at 79 sites surveyed during 2020 in CSSS Sub-population D habitat within C-111 Spreader Canal Western Project area.

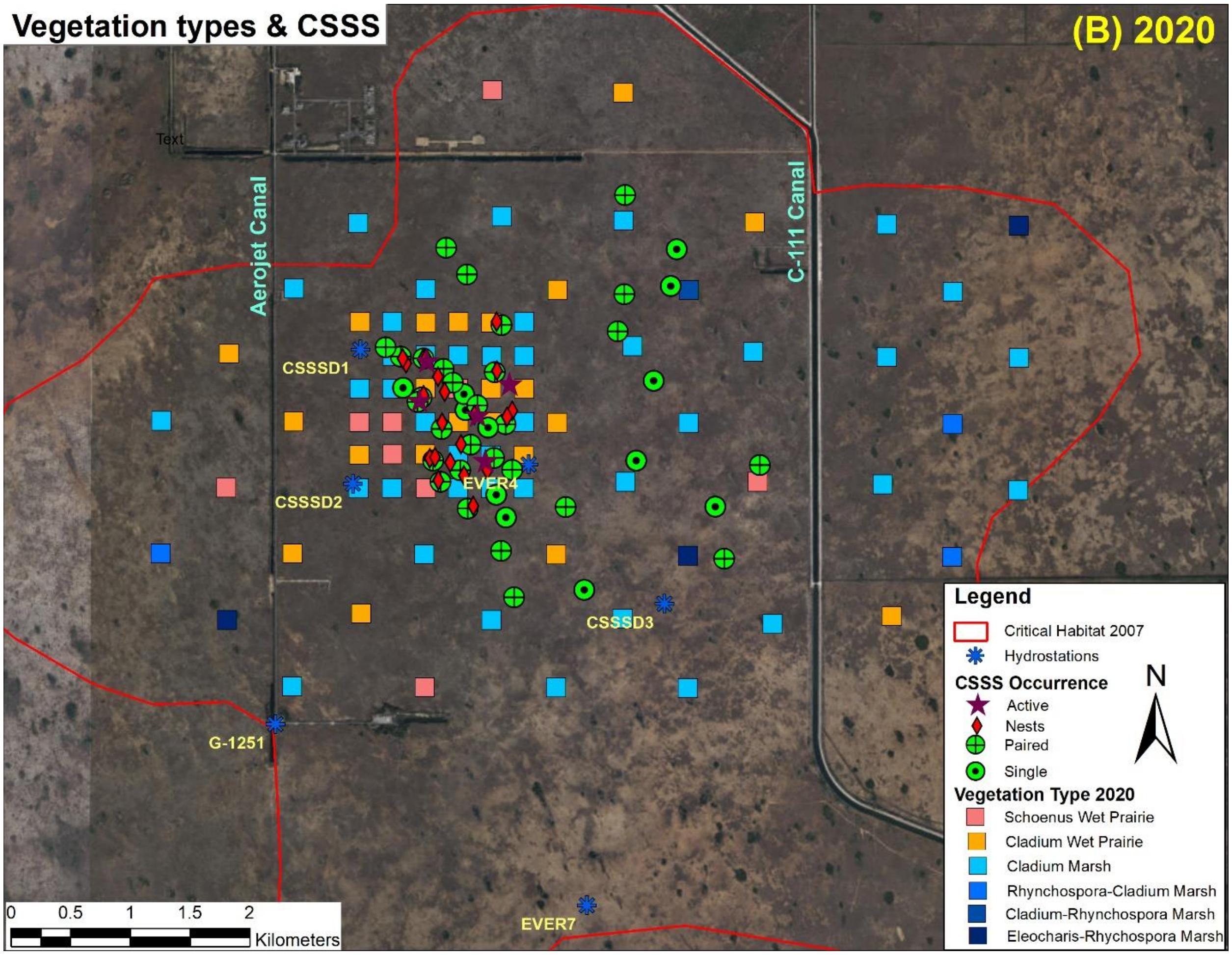

Figure A-3: Vegetation types at 79 sites surveyed during 2020 study and sparrow occurrence, as recorded by Virzi and Tofoya (2020) within the habitat of CSSS sub-population D within C-111 Spreader Canal Western Project Area