Southeast Environmental Research Center
FLORIDA INTERNATIONAL UNIVERSITY

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

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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. 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 # 4500104597) for FY 2018, the present study examined any vegetation shift that might have occurred since the 2011, 2014, and 2016 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 were used to test for differences in vegetation structural variables, biomass, and vegetation-inferred hydroperiod among four sampling events, whereas Generalized linear mixed model was used to test for differences in species richness.

Marl prairie vegetation within the habitat of sub-population D included vegetation assemblages 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. 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, the water level was unusually high, more than 15 cm above the 27-year average. In next two water years also, mean annual water level was higher than the long-term average, which has caused the vegetation shift to wetter type in comparison to baseline survey. Thus, it is important to minimize the chances of high water condition at least in next two years (2019 & 2020), so that the observed shift towards wetter type vegetation composition, primarily caused by the synergistic effects of the 2016 dry-season high water level followed by two years of wet conditions, will not have a long-lasting adverse impact on sparrow habitat. This is essential especially within the sub-population D habitat, where the hydrologic conditions are likely to be 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), causing 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 is designed 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. The project was implemented in 2012, and a follow up study was conducted in 2014 and 2016, 2 and 4 years after the implementation of the project, respectively. 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).

Between 2014 and 2016, there was no significant change in vegetation-inferred hydroperiod, suggesting that after 2014, the habitat condition did not decline any further (Sah et al. 2016). In fact, 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. 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). 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 # 4500104597) for FY 2017/2018, 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.

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 sampling 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 sampling sites (SS sites), and (2) concentrated vegetation sampling sites (CS sites). Together there were 80 sites - 44 SS and 36 CS sites (Appendix 1). The SS sites included 17 previously sampled 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 (Rutgers University) and group (Virzi et al. 2011; Virzi and Davis 2013) at the time of project initiation.

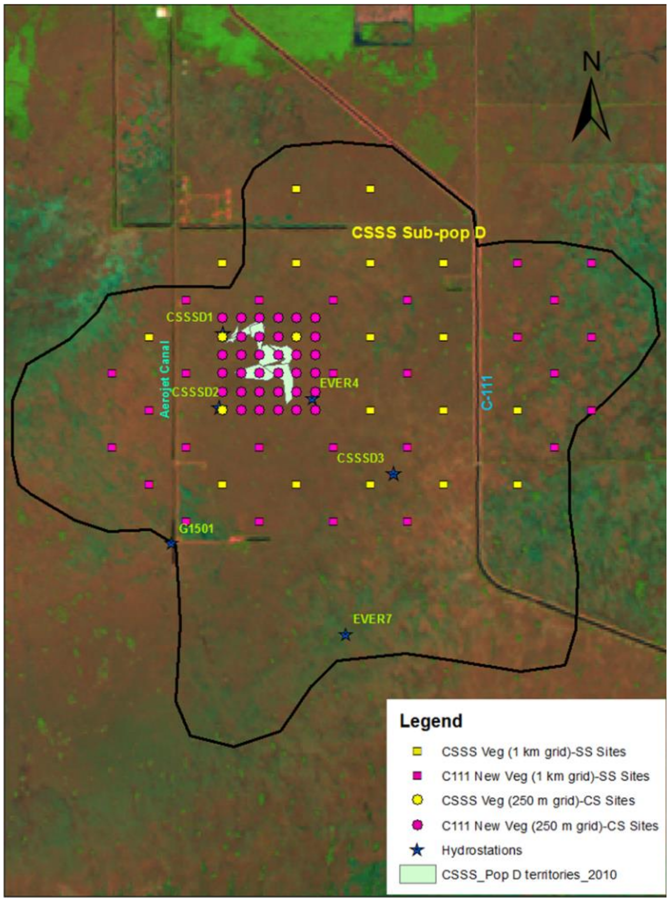

Figure 1: Vegetation survey sites within C-111 Spreader Canal Western Project – CSSS Sub-population D area.

2.2 Field Sampling

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 2). 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 sampling 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. Figure 3 shows photo of research team members taking vegetation structural and compositional measurements in the field. Field sites were accessed by helicopter or by walking from the Aerojet road.

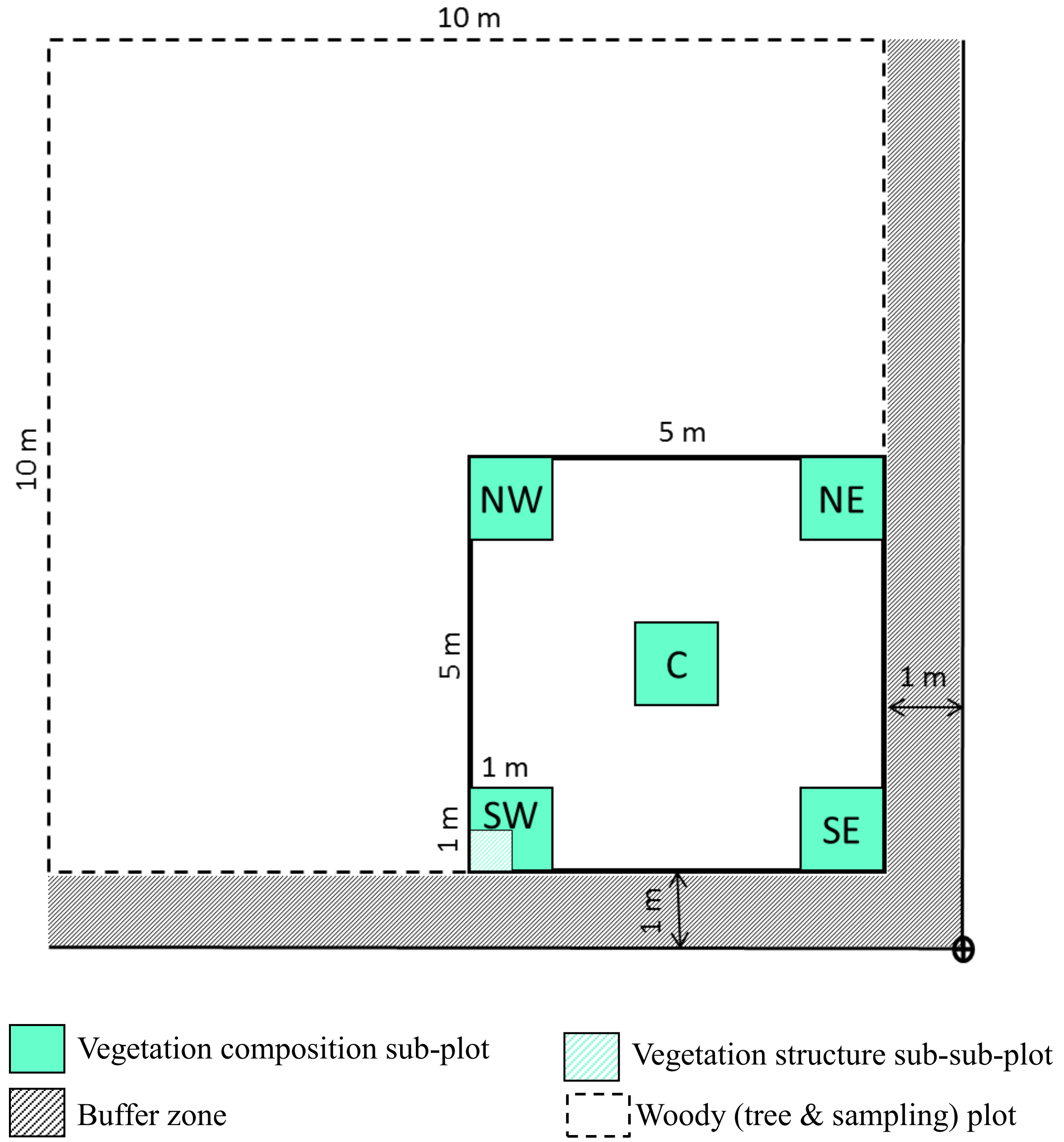

Figure 2: Vegetation sampling design at each of 80 sites sampled in 2018 to document status of vegetation structure and composition in the habitat of CSSS sub-population D within C-111 Spreader Canal Project Area.

Figure 3: Field crew member taking vegetation measurements in the field.

2.3 Data analysis

2.3.1 Hydrology

During the 2018 field survey, majority of sites were dry, except some sub-plots (25%) which has shallow (Mean ± SD: 7.2 ± 3.3 cm) standing water. 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 EDEV 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 (Figure 4). 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.

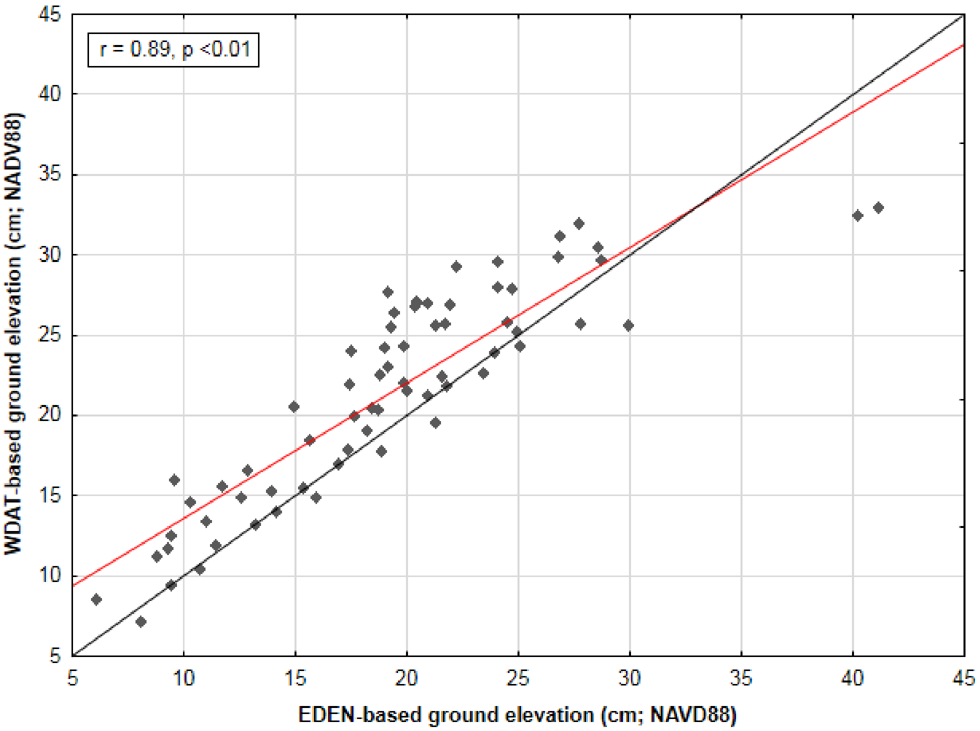

Figure 4: Scatterplot showing the relationship between EDEN (Everglades Depth Estimation Network)- and WDAT (Water Depth Assessment Tools)-based ground elevation of 69 vegetation survey sites within the habitat of CSSS sub-population D.

2.3.2 Vegetation classification and change

The hierarchical agglomerative cluster analysis was used to classify the vegetation survey-sites based on the vegetation data collected 2018. 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 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. (2006a), i.e. we eliminated the 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. 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, 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. Analysis of Similarity (ANOSIM), a nonparametric multivariate analytical procedure, was used to examine the differences in vegetation composition among the sampling years (McCune and Grace 2002). 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). A change in vegetation-inferred hydroperiod between successive samplings 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. 2014), which uses a change in community composition along a vector representing hydrologic condition. In 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. 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 10,000 permutations.

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 three 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 were used to examine differences in structural variables between WP and M sites and among sampling 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.3.5.0 (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 sampling years that was done in posthoc test using *glht* function implemented in 'multicomp' 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), five out of six years had mean water level higher than 27-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 2009/10 (Figure 5). When averaged over four year-period prior to vegetation sampling, the mean annual hydroperiod and water depth were consistently higher in post-project sampling years (2014, 2016 and 2018) than 2011. The 4-year mean annual hydroperiods were 22, 47 and 44 days longer, and mean annual water depths were 2.93, 5.70 and 2.23 cm higher during the 2014, 2016 and 2018 samplings, respectively than the pre-project period, i.e. before baseline survey in 2011.

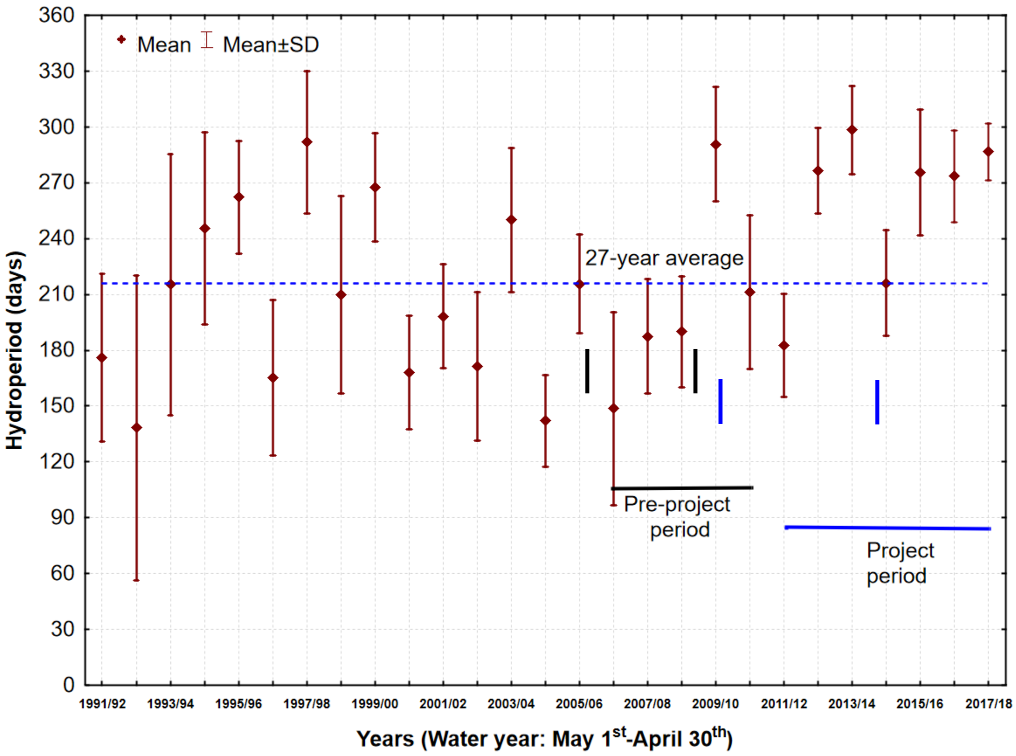

Figure 5: Annual mean hydroperiod at the vegetation survey sites (n = 69) for 27 years (1991/92-2017/18 water years: May 1 – April 30). Dashed line is the 27-year (WY) average value. Hydroperiod for each site was calculated using field water depth-based ground elevation and EDEN water surface time-series data.

3.2 Vegetation composition

As in 2011, marl prairie vegetation within the habitat of sub-population D in 2018 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, near recently occupied portion of sparrow habitat (Figure 6). In 2011, there were four sites classified as the *Muhlenbergia* WP (Figure 6a), however, none of the wet prairie sites in 2018 had dominance of muhly grass (*Muhlenbergia capillaris*) (Figure 6b). 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. One site had the vegetation assemblage of spikerush-beakrush (*Eleocharis-Rhynchospora*) marsh (Figure 6b).

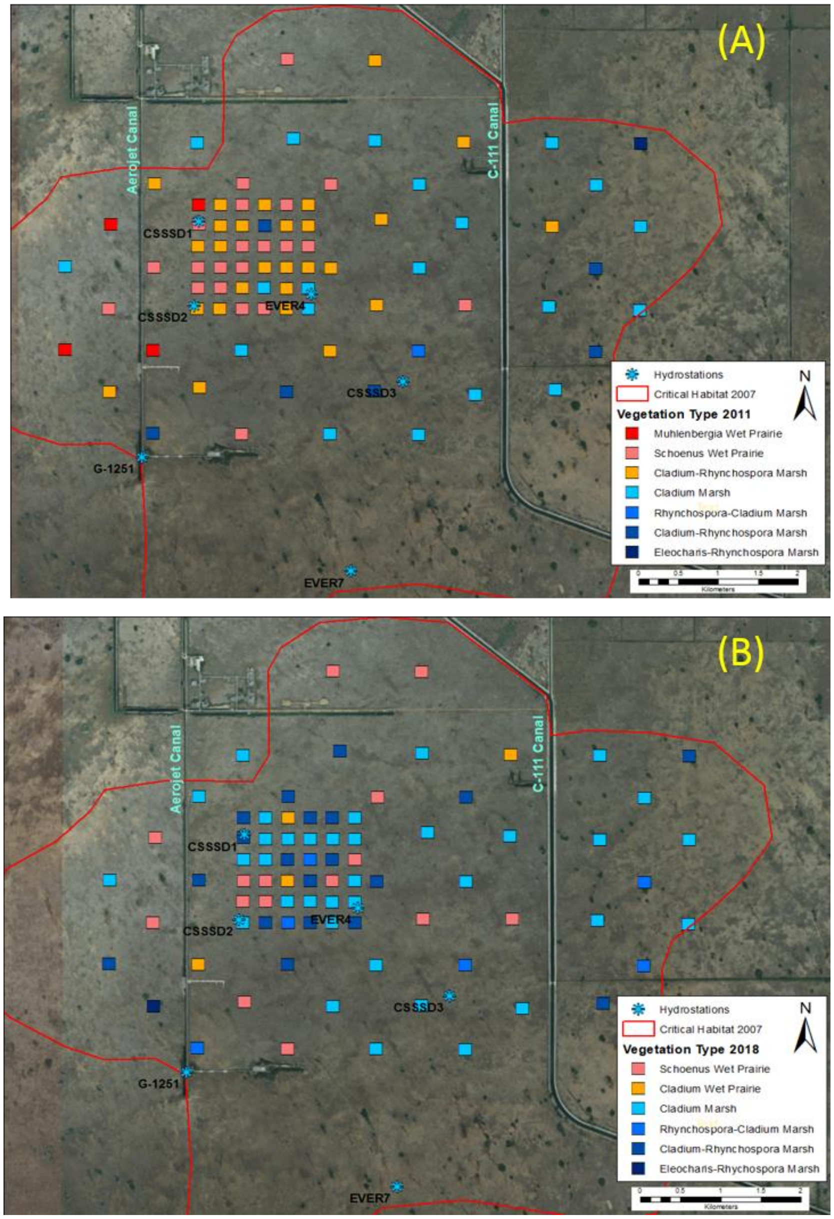

Figure 6: Vegetation types at 80 sites in the habitat of CSSS sub-population D within C-111 Spreader Canal Western Project Area. Vegetation type at each site was identified through cluster analysis of species cover values at 688 sites, including 608 census sites sampled in three years (2003-05). Vegetation types are based on (A) 2011, and (B) 2018 vegetion composition data. Vegetation types represent from the dry (red) to wet (dark blue) community types

The species composition in all post-project sampling years was significantly different (ANOSIM: p-value < 0.001) from that in 2011 (Table 1). Vegetation change over seven 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. Thirty-three wet-prairie sites of 2011 were classified as marsh sites based on species abundance data collected in 2018 (Appendix 1). In contrast, all the 2011 marsh sites still had the marsh vegetation in 2018. Trajectory analysis results revealed that vegetation composition at 61 (76%) sites had shifted toward relatively wetter type in 2018 than in 2011, and such a shift towards wetter type was statistically significant at 29 sites – 23 wet prairie and 6 marsh sites (Appendix 2). In general, while 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 seven years along hydrologic gradient (Figure 7).

Table 1: Global R and *p*-values from analysis of similarity (ANOSIM) testing for among-year differences in vegetation composition before (2011) and after (2014, 2016 and 2018) the operation of the C-111 spreader canal western project began in 2012.

Sampling event	**2011 (base line survey)**	**2014**	**2016**
2014	0.082***		
2016	0.205***	0.139***	
2018	0.211***	0.095***	0.106***

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

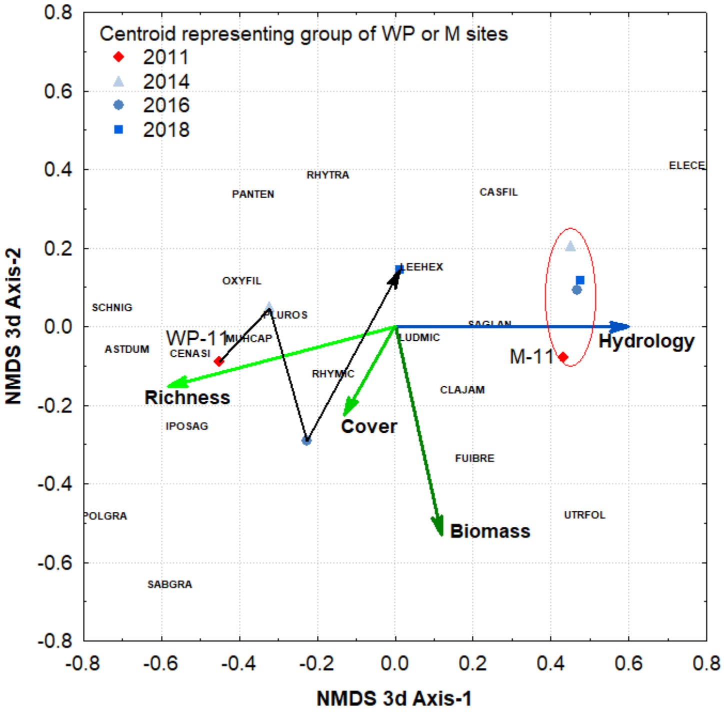

Figure 7: Site scores non-metric multidimensional scaling (NMDS) 3-D Ordination Axis-1 and 2. Points in ordination space represent centroids of sites grouped by major vegetation category (Wetpraire (WP) and Marsh (M)) and sampling year (2011, 2014, 2016 and 2018). Only selected species are plotted to reduce the overlap. Full name of species are given in Appendix 2.

Over seven years (2011-2018), the cover value of major species (*Muhlebergia capillaris* ssp. *filipes*, *Schoenus nigricans* and *Rhyncohospora microcarpa*) that are characteristics of marl wet prairie sites, i.e. dry end of the marl prairie hydrologic gradient, significantly declined. 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 first three years, but then remained same in next two years, whereas the cover of beakrush sedge (*Rhynchospora tracyi*) did not change much in first three years and then significantly declined in 2016, but later increased in 2018.

Table 2: Mean (± 1 S.D.) value of percent cover of major species averaged over all sites (n = 80) surveyed in 2011, 2014 and 2016 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**	
Cladium jamaicense	33.3±18.9^{a}	21.9±14.0^{b}	22.5±14.6^{b}	23.9±14.1^{b}	<0.001
Schoenus nigricans	11.1±17.8^{a}	6.0±10.5^{b}	5.2±9.5^{bc}	4.0±6.7^{c}	<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}	<0.001
Rhynchospora microcarpa	3.3±5.0^{a}	1.5±1.9^{b}	0.6±1.5^{c}	0.4±0.9^{d}	<0.001
Rhynchospora trayci	4.5±6.5^{a}	3.5±3.7^{a}	1.7±3.3^{b}	3.0±4.2^{a}	<0.001
Eleocharis cellulosa	3.2±10.0	2.3±7.0	1.2±4.7	1.0±5.4	0.222

3.3 Vegetation-inferred hydroperiod

Observed- and vegetation-inferred hydroperiods were well correlated even when data were pooled for all four sampling years (r = 0.71, p <0.001). In concurrence with the wetter conditions during the three project-period samplings than base line survey, the mean (± SD) vegetation-inferred hydroperiod was significantly (General Linear Mixed Model: Tukey's test, p < 0.05) higher in 2014 (217 ± 46 days), 2016 (221 ± 40 days) and 2018 (222 ± 38) than in 2011 (210 ± 47 days) (Figure 8). However, there was no significant difference in vegetation-inferred hydroperiod between 2014 and 2016, 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.

3.4 Vegetation structure and biomass

Vegetation change over five years was marked also by changes in vegetation structure (vegetation cover and height), species richness and aboveground biomass (Figure 9). Mean (±SD) vegetation cover was significantly lower (General Linear Mixed Model: Tukey's test, p < 0.05) during all three post-project samplings, 2014 (32.6 ± 12.7%), 2016 (34.1 ± 13.7%), and 2018 (29.0 ± 11.8%) than in 2011 (39.3 ± 17.2%) (Figure 9a). In comparison to reduced cover, vegetation height increased over seven years. The mean vegetation height was significantly higher in 2018 (61.0 ± 15.5 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 9b). 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 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.

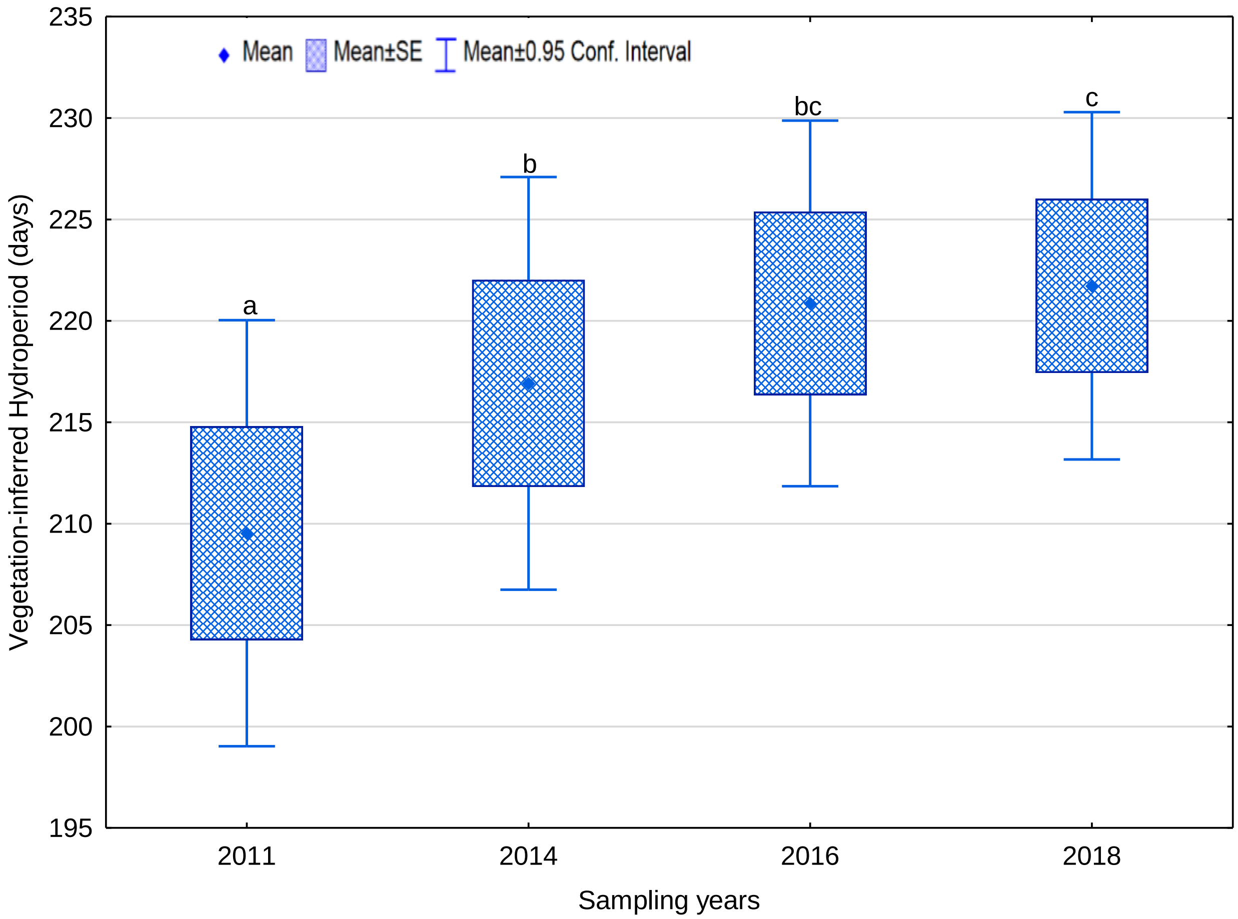

Figure 8: Box-plots (Mean, SE, and mean±1.96*SE) showing vegetation-inferred hydroperiod at the 80 sites within the habitat of CSSS sub-population D. Vegetation-inferred hydroperiod values were predicted from vegetation composition using Weighted Averaging regression model developed from the vegetation 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, $p < 0.05$)

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 9c). The lowest richness in 2018 is in concurrence with the wettest vegetation in that year. 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 9d). The observed changes in vegetation structure (cover and height), species richness and aboveground biomass over seven years (2011-2018) spatially varied in the study area. (Appendices 3, 4).

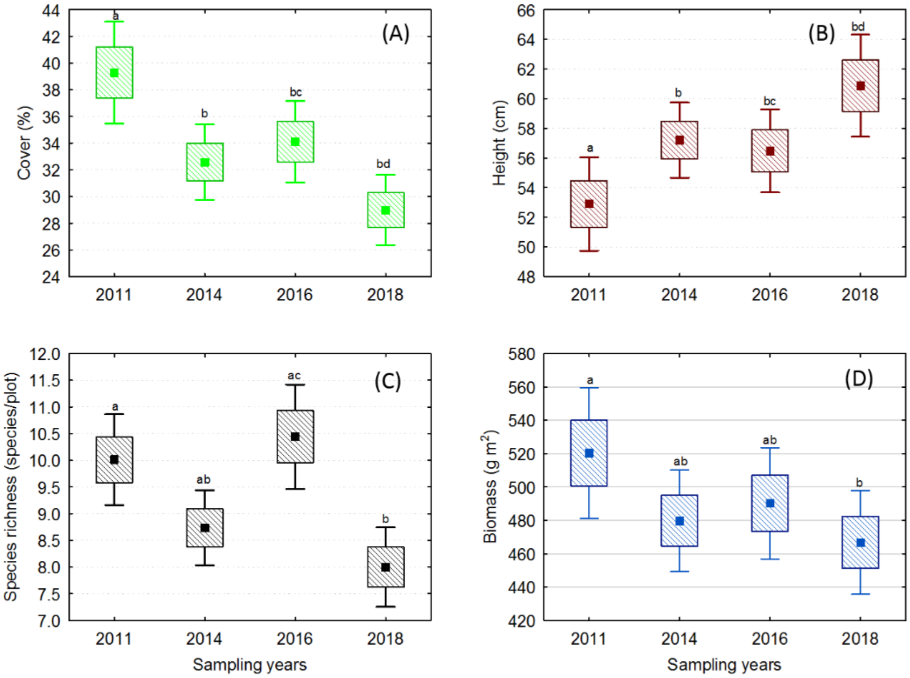

Figure 9: Box-plots (mean, SE, 95% CI) showing the vegetation structure, (a) vegetation cover, (b) vegetation height, (c) species richness, and (d) aboveground biomass in 2011 baseline survey, and 2014, 2016, and 2018 post-project period samplings (n = 80).

Table 3: 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 "multcom" package in R.

Vegetation structural variables	**Vegetation type**	**Sampling years**			
		2011	**2014**	**2016**	**2018**
Vegetation cover (%)	WP	38.9±16.0^{a}	32.4±12.1^{b}	34.3±12.6^{ab}	28.8±12.0^{b}
	M	40.0±19.4^{a}	33.0±14.0^{ab}	33.7±15.6^{ab}	29.4±11.6^{b}
Vegetation height (cm)	WP	51.5±13.1^{a}	58.0±11.0^{b}	56.8±12.3^{b}	60.2±13.9^{b}
	M	55.6±15.8^{a}	55.6±11.2^{a}	55.8±13.1^{a}	62.1±18.2^{b}
Species richness (species/plot)	WP	11.4±3.0^{a}	9.8±2.4^{b}	12.0±4.3^{a}	9.5±2.5^{b}
	M	6.1±3.1^{a}	5.9±3.3^{a}	6.2±3.4^{a}	5.2±2.9^{a}
Aboveground plant biomass (g m^{-1})	WP	509±150	483±133	493±142	463±140
	M	542±218	476±145	484±164	474±141

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. These conditions resulted from both high rainfall during the mid-1990s and an increased water delivery into Taylor Slough since 1993 (Ross et al. 2004). 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. Sixty-three percent of 2011 marl wet prairie sites have changed to relatively wet marl marsh vegetation types in 2018.

In the marl prairies, species richness is negatively correlated with hydroperiod (Ross et al. 2006a). Thus, a low species richness in two of three sampling years after the baseline survey was not a surprise, especially when vegetation composition has shifted towards wetter type in seven years. However, species richness in 2016 similar to 2011 was 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. Despite the fact that the plant species richness has shown high variability during the study period (2011-2018), 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 180 days; concurrently, CSSS occurrence is less frequent in wetter vegetation types ranging from sawgrass-dominated prairie and marsh to beakrush sedge (*Rhyncospora tracyi*) and spikerush

(*Eleocharis* sp.) marsh (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 (2011-2016) from Rutgers University (Lockwood et al. 2006, 2010; Virzi et al. 2011, 2015; Virzi and Davis 2013, 2014, 2016). 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 relative high and WP vegetation is dominant (Figure 6a, 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 2016, however, there was no significant change in vegetation-inferred hydroperiod (Figure 8), suggesting that after 2014, the habitat condition did not change much 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).

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 Ketches 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 (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). 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). The mean annual mean water for next two water years (2016-2018) was higher than 27-year average. That might have accelerated the vegetation composition to shift towards wetter type than it was in 2016 and before. If the trend continues, that will have adverse impact on the quality of habitat, and ultimately the sparrow population in this area. Thus, it is important to minimize the chances of high water condition for at least next two years, 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, 2016-dry season flooding, 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 2018. Vegetation types are based on 2011 and 2018 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 10,000 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	SOWP	-0.238	0.364	-0.024	0.383
D-01-03	545411	2804404	CM	CRM	0.033	0.439	0.000	0.537
D-01-05	546405	2803430	CWP	CM	0.283	0.022	0.045	0.008
D-01-06	546354	2802406	CWP	SOWP	0.092	0.401	0.027	0.314
D-01-07	547357	2802410	SOWP	SOWP	0.277	0.295	0.030	0.331
D-01-08	547475	2801337	CM	CM	0.039	0.341	0.007	0.285
D-01-10	548377	2801401	CM	CRM	-0.312	0.063	-0.044	0.079
D-02-01	545335	2805354	SOWP	SOWP	0.378	0.154	0.030	0.277
D-02-02	546327	2805342	CWP	SOWP	0.157	0.400	-0.017	0.462
D-02-03	546334	2804375	CM	CM	0.231	0.129	0.043	0.055
D-02-04	543345	2803363	MWP	SOWP	0.756	0.085	0.095	0.099
D-02-06	547321	2803391	CM	CM	-0.075	0.253	-0.011	0.230
D-02-07	548307	2802395	CM	CM	-0.079	0.340	-0.016	0.280
D-03-01	547329	2804365	CWP	CWP	-0.024	0.465	-0.004	0.488
D-03-02	544322	2804348	CM	CM	0.007	0.506	-0.004	0.403
D-03-03	546337	2801375	CRM	CM	0.267	0.025	0.049	0.001
D-03-04	545343	2801363	CRM	CM	0.206	0.265	0.028	0.300
D-04-01	542834	2802855	CM	CM	0.263	0.074	0.040	0.066
D-04-02	542831	2801856	MWP	CRM	-0.155	0.384	-0.015	0.436
D-04-03	543326	2802353	SOWP	SOWP	0.214	0.387	0.009	0.475
D-04-04	543338	2801354	CWP	ERM	0.562	0.092	0.076	0.092
D-04-05	543835	2803855	CWP	CM	0.551	0.014	0.085	0.008
D-04-06	543835	2802853	SOWP	CRM	1.674	0.000	0.227	0.000
D-04-07	543832	2801857	MWP	CWP	0.462	0.190	0.050	0.255
D-04-08	543832	2800854	CRM	RCM	0.372	0.060	0.043	0.122
D-04-09	544836	2803855	SOWP	CRM	0.470	0.068	0.058	0.109
D-04-10	544832	2801855	CM	CRM	0.164	0.307	0.018	0.345
D-05-01	544836	2800854	SOWP	SOWP	-0.063	0.441	-0.015	0.402
D-05-02	545835	2803854	SOWP	SOWP	0.717	0.092	0.103	0.085
D-05-03	545835	2802849	CWP	CRM	-0.040	0.468	0.000	0.476
D-05-04	545831	2801855	CWP	CM	0.520	0.224	0.098	0.125
D-05-05	545833	2800854	CM	CM	0.050	0.387	0.008	0.375
D-05-06	546832	2803854	CM	CRM	-0.111	0.408	-0.013	0.416
D-05-07	546833	2802854	CM	CM	-0.029	0.425	-0.001	0.467
D-05-08	546830	2801851	RCM	RCM	0.223	0.395	0.034	0.375
D-05-09	546834	2800850	CM	CM	-0.010	0.452	0.005	0.431
D-06-01	548330	2804355	CM	CM	-0.064	0.452	-0.013	0.416

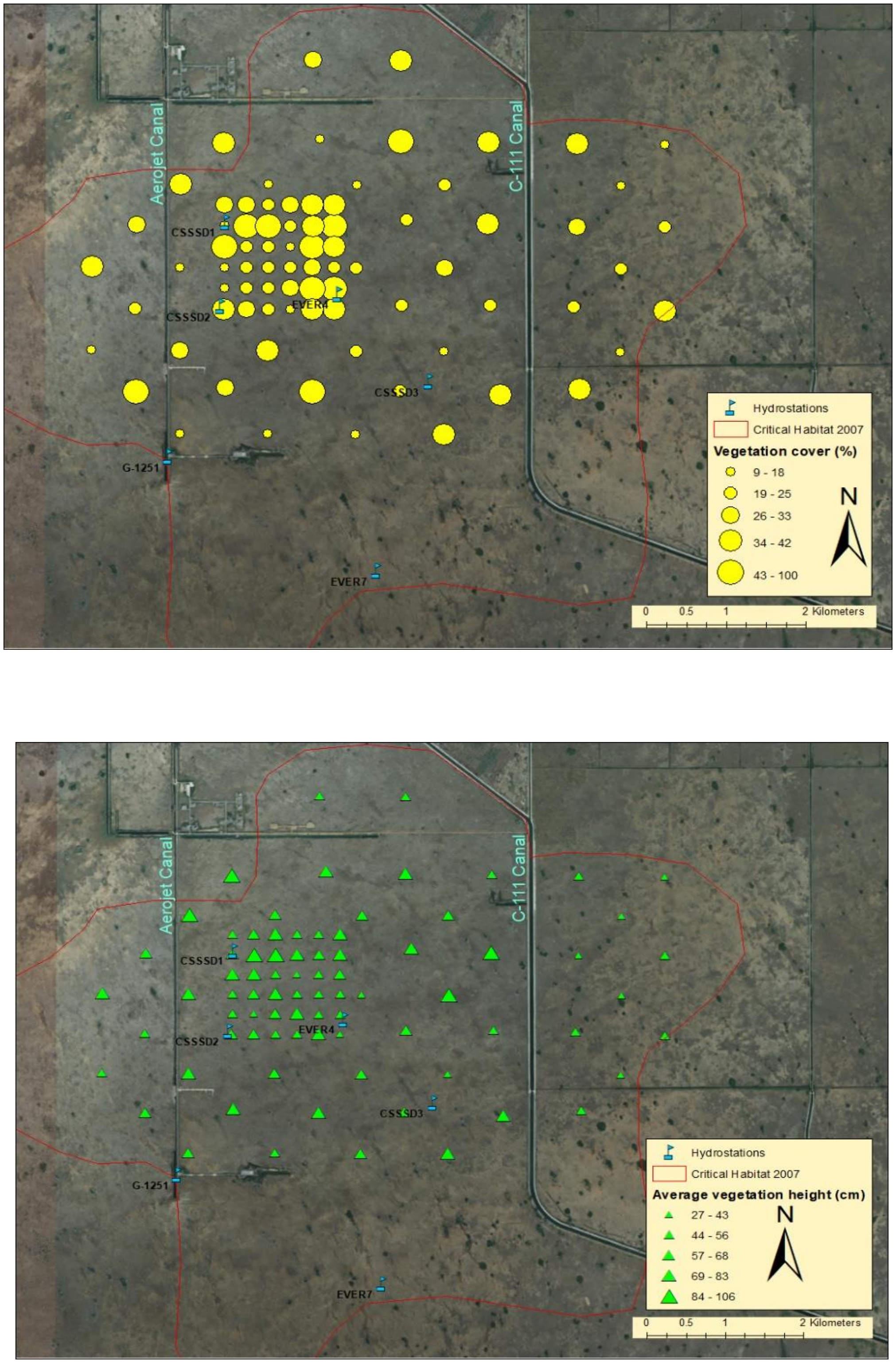
PLOT	X_UTM83	Y_UTM83	Veg. type (2011)	Veg. type (2018)	delta (Δ)	p-value (delta)	slope	p-value (slope)
D-06-02	548333	2803356	CWP	CM	0.113	0.315	-0.004	0.551
D-06-03	548832	2803849	CM	CM	-0.155	0.181	-0.027	0.133
D-06-04	548834	2802850	CRM	RCM	-0.174	0.260	-0.012	0.371
D-06-05	548834	2801851	CRM	RCM	-0.487	0.127	-0.085	0.053
D-06-06	549331	2804349	ERM	CRM	-0.042	0.497	-0.064	0.308
D-06-07	549336	2803354	CM	CM	-0.217	0.214	-0.031	0.201
D-06-08	549334	2802353	CM	CM	-0.158	0.248	-0.023	0.220
TD-01-01	544337	2803605	MWP	CRM	0.653	0.117	0.081	0.137
TD-01-02	544583	2803606	CWP	CM	0.540	0.207	0.040	0.316
TD-01-03	544835	2803604	SOWP	CWP	0.584	0.154	0.086	0.138
TD-01-04	545084	2803606	CWP	CRM	0.201	0.298	0.005	0.415
TD-01-05	545333	2803606	SOWP	CRM	1.034	0.012	0.152	0.007
TD-01-06	545582	2803607	CWP	CM	0.305	0.199	0.045	0.181
TD-02-01	544339	2803363	SOWP	CRM	0.995	0.014	0.110	0.030
TD-02-02	544585	2803351	CWP	CM	0.434	0.070	0.055	0.085
TD-02-03	544837	2803353	CWP	CM	0.249	0.208	0.028	0.257
TD-02-04	545086	2803354	CRM	CM	0.384	0.171	0.070	0.097
TD-02-05	545337	2803351	CWP	CM	0.234	0.269	0.011	0.414
TD-02-06	545583	2803353	CWP	CM	1.101	0.003	0.176	0.002
TD-03-01	544337	2803104	CWP	CM	0.723	0.049	0.121	0.021
TD-03-02	544584	2803105	CWP	CM	0.617	0.066	0.102	0.035
TD-03-03	544834	2803107	SOWP	CRM	0.401	0.223	0.091	0.117
TD-03-04	545084	2803104	SOWP	RCM	0.720	0.097	0.101	0.085
TD-03-05	545332	2803104	SOWP	CRM	0.735	0.029	0.089	0.053
TD-03-06	545584	2803105	SOWP	SOWP	0.471	0.130	0.065	0.135
TD-04-01	544335	2802852	SOWP	SOWP	0.586	0.067	0.082	0.063
TD-04-02	544585	2802853	SOWP	SOWP	0.672	0.078	0.106	0.050
TD-04-03	544835	2802853	SOWP	CWP	0.621	0.008	0.092	0.000
TD-04-04	545085	2802853	CWP	CRM	0.263	0.273	0.051	0.192
TD-04-05	545334	2802854	CWP	SOWP	0.266	0.255	0.035	0.268
TD-04-06	545584	2802856	CWP	CM	0.614	0.053	0.092	0.033
TD-05-01	544334	2802604	SOWP	SOWP	0.686	0.049	0.077	0.088
TD-05-02	544587	2802607	SOWP	SOWP	0.324	0.184	0.061	0.096
TD-05-03	544833	2802608	CWP	CM	0.383	0.075	0.051	0.082
TD-05-04	545085	2802605	CM	CM	0.304	0.154	0.063	0.044
TD-05-05	545332	2802603	CWP	CM	1.148	0.007	0.169	0.007
TD-05-06	545584	2802603	CM	CM	0.485	0.081	0.081	0.043
TD-06-01	544330	2802349	CWP	CM	0.254	0.170	0.035	0.174
TD-06-02	544585	2802352	CWP	CRM	0.439	0.113	0.049	0.161
TD-06-03	544839	2802354	SOWP	RCM	0.446	0.234	0.082	0.140
TD-06-04	545084	2802353	SOWP	CRM	0.516	0.111	0.092	0.051
TD-06-05	545335	2802356	CWP	CM	0.199	0.245	0.023	0.327
TD-06-06	545585	2802355	CM	CRM	0.065	0.433	0.033	0.275

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).

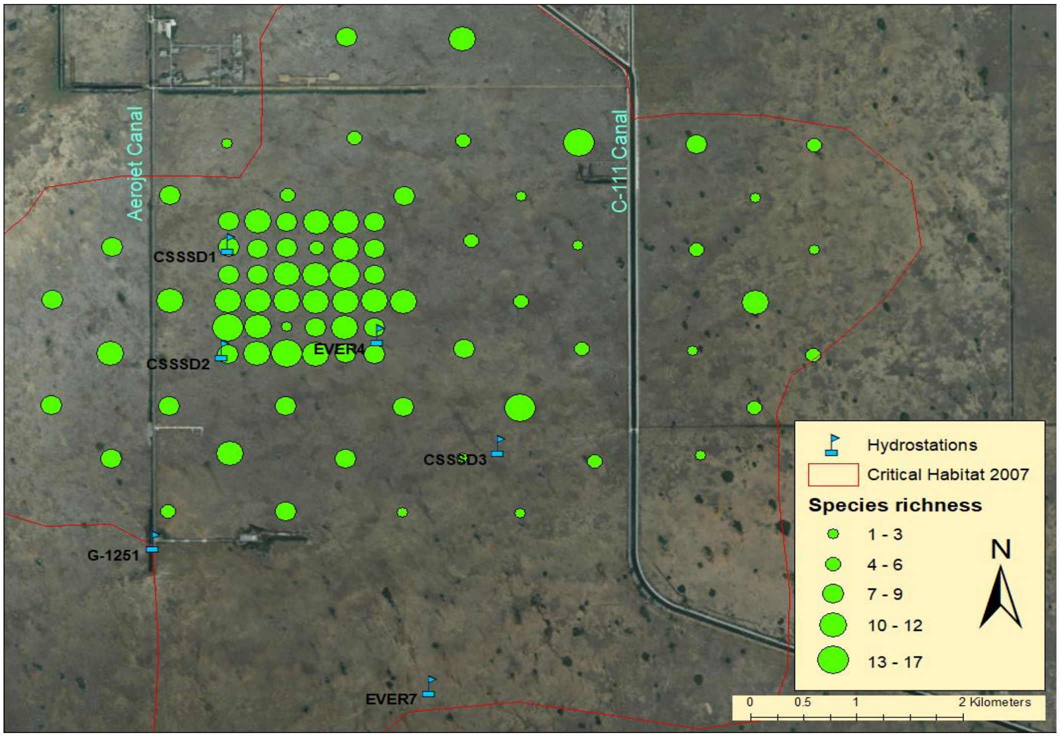
SPCODE	Species	Species_2011	Species_2014	Species_2016	Species_2018
AGALIN	*Agalinis linifolia*	*	*	*	*
ALEBRA	*Aletris bracteata*	*		*	
AMBART	*Ambrosia artemisiifolia*	*			
ANNGLA	*Annona glabra*			*	*
ARIPUR	*Aristida purpurascens*	*		*	*
ASCLAN	*Asclepias lanceolata*	*	*	*	*
ASTADN	*Aster adnatum (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*	*	*	*	*
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*			*	
ELYCAR	*Elytraria caroliniensis*				*
ERAELL	*Eragrostis elliottii*	*		*	*
FUIBRE	*Fuirena breviseta*			*	
HELPIN	*Helenium pinnatifidum*			*	
HYMPAL	*Hymenocallis palmeri*	*	*	*	*
HYPCIS	*Hypericum cistifolium*			*	
ILECAS	*Ilex cassine*	*	*	*	*
IPOSAG	*Ipomoea sagittata*	*	*	*	*
JUSANG	*Justicia angusta*		*	*	*

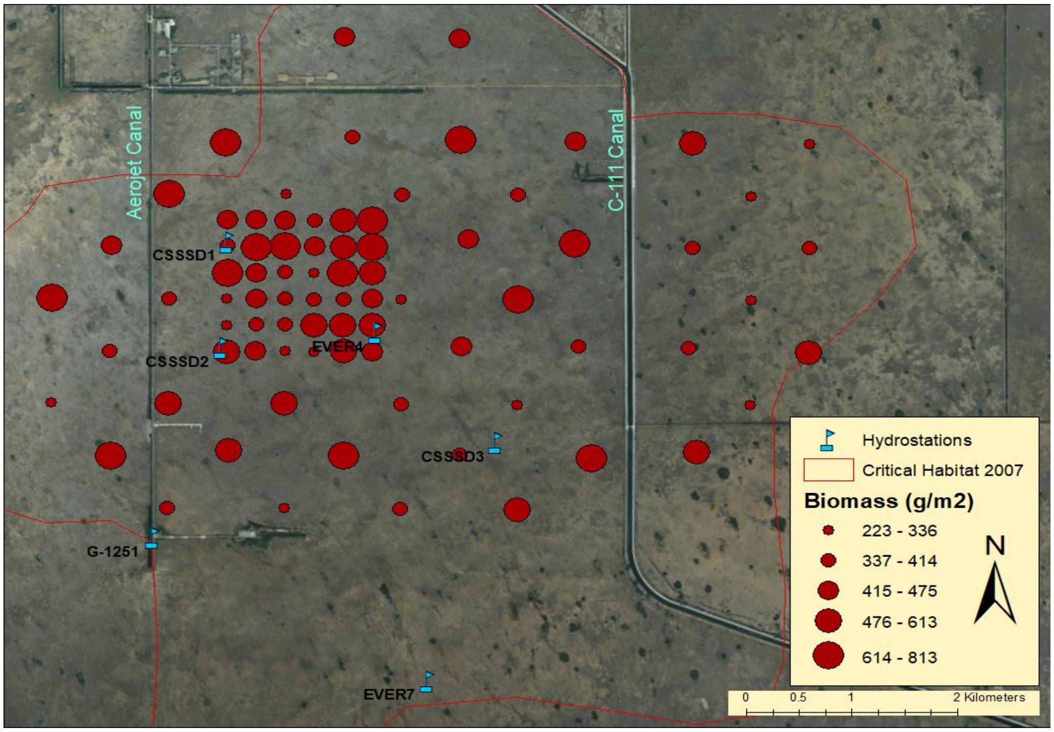
SPCODE	**Species**	**Species_2011**	**Species_2014**	**Species_2016**	**Species_2018**
LEEHEX	*Leersia hexandra*	*	*	*	
LINMED	*Linum medium* var. *texanum*	*	*	*	
LOBGLA	*Lobelia glandulosa*				*
LUDALA	*Ludwigia alata*			*	
LUDCUR	*Ludwigia curtissii*			*	
LUDMIC	*Ludwigia microcarpa*	*	*	*	*
LUDREP	*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*	*	*	*	*
SETPAR	*Setaria parviflora*	*			
SOLSTR	*Solidago stricta*	*	*	*	*
TAXDIS	*Taxodium distichum*		*	*	*

SPCODE	**Species**	**Species_2011**	**Species_2014**	**Species_2016**	**Species_2018**
TEUCAN	*Teucrium canadense*		*		
TYPDOM	*Typha domingensis*	*	*	*	*
UNKD2*	Unknown D02-0*			*	
UNKTD25	Unknown TD02-05	*			
UNKTD56	Unknown TD05-06		*		
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: Mean total vegetation cover and height at 80 sites sampled in CSSS Sub-population D habitat within C-111 Spreader Canal Western Project area.





Appendix 4: Mean species richness and aboveground biomass at 80 sites sampled in CSSS Sub-population D habitat within C-111 Spreader Canal Western Project area.