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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, 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. With funding support from SFWMD (PO # 450001267) for FY 2016, the present study examined any vegetation shift that might have occurred since the 2011 and 2014 surveys.

The sampling design was the same used in 2011, and 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), and Weighted Averaging Regression, a method used to calculate vegetation-inferred hydroperiod, i.e., the hydroperiod for a site predicted from vegetation composition. Changes in vegetation-inferred hydroperiod between successive samplings are indicative of changes in response to hydrology of the period. Repeated Measures-ANOVA was used to test for differences in vegetation structural variables, biomass, species richness and vegetation-inferred hydroperiod among three sampling events.

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 in first 3-years after the baseline survey. 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. 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. In 2016 dry season, however, the water level was unusually high, more than 15 cm above the 25-year average. The long-term effect of unusual high water condition on vegetation is uncertain at the moment, and will also depend on the hydrologic regime in subsequent years. In general, unusual dry season flooding followed by higher water level than normal in subsequent years causes degradation of sparrow habitat. Thus, it is important to minimize the chances of high water condition for next couple of years, so that this year dry season flooding will not have 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 project activities. Only a continued monitoring of vegetation and sparrow population dynamics can provide a conclusive assessment of synergistic effects of 2016 dry season flooding and the project activities on the future fate of the existing CSSS population and its habitat.

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Background

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. 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 Cape Sable seaside sparrow (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 United States Fish and Wildlife Service (USFWS's) Incidental Take Statement (ITS), the SFWMD is required to conduct CSSS habitat monitoring, and to document and track vegetation conditions in subpopulation D. As per the requirements stated in Term and Condition #6 of ITS, baseline conditions of the Cape Sable seaside sparrow (CSSS) sub-population D and its habitat were studied with funding support from South Florida Water Management District (SFWMD) in 2011, before project implementation. The project was implemented in 2012, and a follow up study was conducted in 2014, 2 years after the implementation of the project. 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 recently (2007-2010) begun to show signs of improvement that corresponded with an improvement 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, primarily 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 previous three years (Sah et al. 2014). Likewise, 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). 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 # 4500091267) for FY 2015/2016, we studied the current status of sparrow subpopulation D habitat. The specific objective of this study was to document the present status of vegetation structure and composition within the habitat of CSSS sub-population D, and to analyze any vegetation change that might have occurred since the baseline survey was performed.

Methods

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 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 44 SS and 36 CS sites for a total of 80 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 an additional 27 sites that were established in 2011 either at the corners of additional grid cells included in the critical habitat boundary of Unit-3 (subpopulation 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.

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, 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 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 %; and 4) live vegetation, expressed as a % 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 at three locations in each plot. **Figure 3** shows photo of research team members taking vegetation structural and compositional measurements in the field. Field sites were accessed from the Aerojet road or by helicopter (**Figure 4**).

Analytical method

During the 2016 field survey, majority of sites had standing water. However, 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 31st and Sept 9th, 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 C111canal, 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 5**). 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 year when water level was above the ground surface.

The vegetation data was summarized using a non-metric multidimensional scaling (NMDS) ordination. Analysis of Similarity (ANOSIM), a nonparametric multivariate analytical procedure, was used to examine the overall change in vegetation composition among the sampling years (McCune and Grace 2002). Vegetation change analysis also 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.

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).

Repeated measures analysis of variance (Repeated Measures-ANOVA) followed by Bonferroni post-hoc test was used to test for differences in vegetation structural variables, biomass, species richness and vegetation-inferred hydroperiod among three sampling events. Friedman-ANOVA (Non-parametric test for multiple dependent variables) was used to test differences in cover of major species among three sampling events. Spatio-temporal variation in hydrological and vegetation structural parameters was illustrated on the map using ArcGIS 10.2.

Results and Discussion

In 2016, marl prairie vegetation within the habitat of sub-population D were broadly categorized into two groups, 'wet prairies' and 'marsh' that are similar in species composition in other regions of marl prairies (Ross et al. 2006a). Wet prairie (WP) vegetation, grasslands with mixed dominance of muhly grass (*Muhlenbergia capillaris* ssp. *filipes*), sawgrass (*Cladium mariscus* ssp. *jamaicense*) and/or black-top sedge (*Schoenus nigricans*), were prevalent at the CS sites, in the vicinity of recently occupied portion of sparrow habitat (**Figure 6**). Marsh (M) sites had hydroperiods generally greater than 210 days, and the vegetation assemblages at the sites were mainly sawgrass (*C. mariscus* ssp. *jamaicense*) and sawgrass-beakrush sedge (*Cladium-Rhynchospora*) marsh. Two other marsh vegetation types were Beakrush sedge-sawgrass (*Rhynchospora-Cladium*) and spikerush-beakrush sedge (*Eleocharis-Rhynchospora*) Marsh. Vegetation change over five 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.

In this study, analysis of hydrologic conditions of the vegetation survey sites revealed that in project period (since 2012), three out of four years had mean water level higher than 25-year average. In contrast, before the baseline survey in 2011, the mean annual water level was below average for several years, except Water Year (WY: May 1^{st} - April 30^{th})) 2009/10 (**Figure 7**). When averaged over four year-period prior to 2011 and 2016 vegetation sampling, the mean hydroperiod was 47 days longer, and mean annual water depth was 5.7 cm higher during the project period (2012-2016) than the pre-project period, i.e. before baseline survey (2007-2011). In response, the species composition in 2016 was significantly different (ANOSIM: $R = 0.208$; p-value < 0.001) from that in 2011 (**Table 1**). Two post-project surveys, 2014 and 2016, also significantly differed (ANOSIM: $R = 0.143$; p-value <0.001) in species composition.

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 and 2016) the operation of the C111 spreader canal project began in 2012.

Sampling event	2011 (base line survey)	2014
2014	0.082 (0.001)	
2016	0.208 (0.001)	0.143 (0.001)

Observed- and vegetation-inferred hydroperiods were well correlated even when data were pooled for all three sampling years. In concurrence with the higher hydroperiod during both project-period samplings than pre-project period, the mean (± SD) vegetation-inferred hydroperiod was significantly (Repeated Measures ANOVA: Bonferroni test, $p < 0.01$) higher in 2014 (217 ± 46 days) and 2016 (221 ± 40 days) 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.

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 (Repeated measures ANOVA: Bonferroni test, $p < 0.01$) in both 2014 (32.6 ± 12.7%) and 2016 (34.1 ± 13.7%) than in 2011 (39.3 ± 17.2%). (**Figure 9a**) The cover value of major species (*Muhlebergia capillaris* ssp. *filipes*, *Schoenus nigricans*, *Rhyncohospora microcarpa*) that are characteristics of marl wet prairie sites, i.e. dry end of the marl prairie 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 mariscus* ssp. *jamaicense*) decreased by one third in first three years, but then remained same in next two years, whereas the cover of beakrush sedge (*Rhynchospora tracyii*) did not change much in first three years, but then significantly declined.

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**	
Cladium mariscus ssp. *jamaicense*	33.3±18.9^{a}	21.9±14.0^{b}	22.5±14.6^{b}	<0.001
Schoenus nigricans	11.1±17.8^{a}	6.0±10.5^{b}	5.2±9.5^{b}	<0.001
Muhlenbergia capillaris ssp. *filipes*	3.2±6.9^{a}	1.7±2.7^{b}	1.0±1.8^{c}	<0.001
Rhynchospora microcarpa	3.3±5.0^{a}	1.5±1.9^{b}	0.6±1.5^{c}	<0.001
Rhynchospora trayci	4.5±6.5^{a}	3.5±3.7^{a}	1.7±3.3^{b}	<0.001
Eleocharis cellulosa	3.2±10.0	2.3±7.0	1.2±4.7	0.362

In comparison to reduced cover, vegetation height increased over five years. The mean vegetation height was significantly higher (Repeated measures ANOVA: Bonferroni test, $p < 0.01$) in 2014 (57.1 ± 11.0 cm) than in 2011 (52.9 ± 14.1 cm), whereas vegetation height in 2016 (56.4 ± 12.5 cm) was intermediate, and the difference from 2011 or 2014 was not statistically significant (**Figure 9b**). The increase in vegetation height in project period was primarily at only marl wet prairie sites, whereas at the marsh sites, the mean vegetation height was primarily the same in all sampling years (**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 project period an increase in mean vegetation height with an increase in wetness at the relatively dry sites was normal.

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 and 2016 within the CSSS sub-population D habitat region. Grouping of sites as WP and M is based on the 2011 site classification.

Vegetation structural variables	**Vegetation type**	**Sampling years**		
		2011	**2014**	**2016**
Vegetation cover (%)	WP	38.9 ± 16.0^{a}	32.4 ± 12.1^{b}	34.3 ± 12.6^{b}
	M	40.0 ± 19.4^{a}	33.0 ± 14.0^{b}	33.7 ± 15.6^{b}
Vegetation height (cm)	WP	51.5 ± 13.1^{a}	58.0 ± 11.0^{b}	56.8 ± 12.3^{ab}
	M	55.6 ± 15.8^{a}	55.6 ± 11.2^{a}	55.6 ± 13.2^{a}
Species richness (species/plot)	WP	11.4 ± 3.0^{a}	9.8 ± 2.4^{b}	12.0 ± 4.3^{ab}
	M	6.1 ± 3.1^{a}	5.9 ± 3.3^{a}	6.2 ± 3.4^{a}
Aboveground plant biomass (g m^{-1})	WP	509±150	483±133	493±142
	M	542±218	476±145	484±164

Mean plant species richness was significantly lower in 2014 (8.4 ± 3.3 species/plot) than in 2011 (9.6 ± 3.9), however the mean richness in 2016 (9.9 ± 4.8) was almost the same as it was in 2014 (**Figure 9c**). In the marl prairies, species richness is negatively correlated with hydroperiod (Ross et al. 2006a). Thus, a decrease in species richness in first three years after the baseline survey was not a surprise, especially when such a reduction in mean number of species was primarily at the marl wet prairie sites (**Table 3**). In contrast, an increase in mean species richness in next two years after 2014 survey was observed. The reason could be high annual variability in hydrologic condition and unusual high water in early spring of 2016. In the present study, there was high variation in occurrence of species at the wet prairie sites (**Table 3**). Many of these sites had characteristic species from both marl wet prairie and marsh vegetation types, suggesting that due to relatively wet conditions after 2011, some of the sites might be transitioning from wet prairie to marsh vegetation sites. Several 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, when the field condition during the dry season was unusually wet. Only follow up surveys in next few years will help to ascertain the impact of unusual high water condition of the 2016 dry season.

The aboveground biomass was relatively low in 2014 and 2016, but the difference between these two surveys and base line survey was not statistically significant (**Figure 9d**). Mean above ground biomass in 2011, 2014 and 2016 was 520±176, 480±137, and 490±149 g m^{-1}, respectively. The observed changes in vegetation structure (cove and height), species richness and aboveground biomass over five years (2011-2016) were not the same throughout the study area (Appendices 2, 3).

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 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 till 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, and trajectory that might have implications on sparrow occupancy within the area.

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 have 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 (2011-2015) from Rutgers University (Lockwood et al. 2006, 2010; Virzi et al. 2011; Virzi and Davis 2013, 2014; Virzi et al. 2015). The bird nests were generally found within an area of high ground in northwest-central region of subpopulation D (Virzi and Davis 2013, 2014; Virzi et al. 2015), where ground elevation is relative high and WP vegetation is dominant (**Figure 6a**).

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; Table 4**), suggesting that after 2014, the habitat condition did not decline any further. In fact, WY 2014-2015 was drier than average (**Figure 7**), and total rainfall during 2015 wet season was also 15.5% less than average. This prolonged dry conditions might have temporarily reversed the trend of change in vegetation toward a wetter type, 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 Kitches 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). But, in the dry season (Nov 1st – April 30th) 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 25-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 25-year average. Though, the water level was high enough that the area was not considered suitable for sparrow study in 2016 (*Dr. Thomas Virzi*, *personal communication*). The long-term effect of this year dry season flooding on vegetation is uncertain at the moment, and will also depend on the hydrologic regime in subsequent years.

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). Nonetheless, the habitat condition in both sub-populations has improved in recent years (Sah et al. 2011a, b). Moreover, even though the sparrow population in sub-population D is very low, a substantial increase in number of sparrows was observed in last two years (Virzi et al. 2014, 2015). Thus, it is important to minimize the chances of high water condition for next couple of years so that this year dry season flooding will not have long-lasting adverse impact on sparrow and its habitat. This is crucial especially within the sub-population D habitat, where the hydrologic conditions are likely to be impacted by project activities. Only a continued monitoring of the vegetation as well as sparrow population dynamics can provide a conclusive assessment of synergistic effects of 2016 dry season flooding and the project activities on the future fate of the existing CSSS population and its habitat.

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References

Allen, C. D. and Breshears, D. D. (1998) Drought-induced shift of a forest-woodland ecotone: rapid landscape response to climate variation. *Proceedings of the National Academy of Sciences, USA*, 95, 14839–14892.

Armentano, T. V., Sah, J. P., Ross, M. S., Jones, D. T., Cooley, H. C. and Smith, C, S. (2006) Rapid responses of vegetation to hydrological changes in Taylor Slough, Everglades National Park, Florida, USA. *Hydrobiologia* 569: 293-309.

Jenkins, C. N., Powell, R. D., Bass, O. L. and Pimm, S. L. (2003) Demonstrating the destruction of the habitat of the Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*). *Animal Conservation* 6: 29-38.

John, R., Chen, J., Ou-Yang, Z.-T., Xiao, J., Becker, R., Samanta, A., Ganguly, S., Yuan, W. and Batkhishig, O. (2013) Vegetation response to extreme climate events on the Mongolian Plateau from 2000 to 2010. *Environment Research Letters* 8 (2013) 035033 (12pp)

Lockwood, J. L., Baiser, B., Boulton, R. and Davis, M. (2006). Detailed study of Cape Sable seaside sparrow nest success and causes of nest failure: 2006 annual report, p. 77. Rutgers, The State University of New Jersey, New Brunswick, NJ.

Lockwood, J. L., Virzi, T., Boulton, R. L., Gilroy, J. J., Davis, M. J., Baiser, B. and Fenn, K. H. (2010). Recovering small Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*) subpopulations: breeding and dispersal of sparrows in the Everglades, Report to US Fish and Wildlife Service and National Park Service, Homestead, Florida, USA.

McCune, B and Grace, J. B. (2002). Analysis of ecological communities. MjM Software Design, Gleneden Beach, OR. 300 pp.

Miao, S., Zou, C. B. and Breshears, D. D. (2009) Vegetation responses to extreme hydrological events: sequence matters. *The American Naturalist* 173 (1): 113-118.

Nott, M. P., Bass, O. L. Jr., Fleming, D. M., Killeffer, S. E., Fraley, N., Manne, L., Curnutt, J. L., Brooks, T. M., Powell, R. and Pimm, S. L. (1998) Water levels, rapid vegetational changes, and the endangered Cape Sable seaside sparrow. *Animal Conservation* 1: 23-32

Pimm, S. L., Lockwood, J. L., Jenkins, C. N., Curnutt, J. L., Nott, M. P., Powell, R. D., Bass, O. L. Jr. (2002) Sparrow in the Grass: A report on the first ten years of research on the Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*). Report to Everglades National Park, Homestead, FL, USA

Ross, M. S., Sah, J. P., Snyder, J. R., Ruiz, P. L., Jones, D. T., Colley, H., et al. (2004). Effect of Hydrologic Restoration on the Habitat of the Cape Sable seaside sparrow. 2003-2004. Year-2. Final Report submitted to Everglades National Park, Homestead, FL and U. S. Army Corps of Engineers, Jacksonville, FL. November 2004. 36 pp.

Ross, M. S., Sah, J. P., Snyder, J. R. Ruiz, P. L., Jones, D. T., Colley, H., et al. (2006a) Effect of Hydrologic Restoration on the Habitat of the Cape Sable seaside sparrow. 2004-2005. Year-3. Final Report submitted to Everglades National Park, Homestead, FL and U. S. Army Corps of Engineers, Jacksonville, FL. March 2006. 46 pp.

Ross, M. S. Ruiz, P. L., Sah, J. P., Reed, D. L., Walters, J. and Meeder, J. F. (2006b). Early stand development in Fringe mangrove forests of contrasting productivity following hurricane. *Plant Ecology* 185: 283-297

Ross, M. S., Ruiz, P. L., Sah, J. P. and Hanan, E. J. (2009) Chilling damage in a changing climate in coastal landscapes of the sub-tropical zone: a case study from south Florida. *Global Change Biology* 15 (7):1817-1832.

Sah, J. P., Ross, M. S., Snyder, J. R., P. L. Ruiz, Jones, D. T., Travieso, R., et al. (2007) Effect of hydrological restoration on the habitat of the Cape Sable seaside sparrow. Annual Report of 2005-2006. A report submitted to Everglades National Park, Homestead, FL. March 8, 2007. 49 pp.

Sah, J. P., Ross, M. S. and Ruiz, P. L. (2011a). Vegetation structure and composition within sparrow sub-population D. habitat. In Virzi et al. 'C-111 Project & Cape Sable seaside sparrow subpopulation D: Baseline data on sparrows, vegetation and hydrology – Annual Report 2011. pp: 39-60. Submitted to the South Florida Water Management District, West Palm Beach, FL.

Sah, J. P., Ross, M. S., Ruiz, P. L., Snyder, J. R., Rodriguez, D. and Hilton, W. T. 2011. Cape Sable seaside sparrow habitat – Monitoring and Assessment - 2010. Final Report submitted to U. S. Army Corps of Engineers, Jacksonville, FL. (Cooperative Agreement # W912HZ-10-2-0025). April. 2011. 57 pp

Sah, J. P., Ross, M. S., Saha, S., Minchin, P. and Sadle, J. (2014) Trajectories of vegetation response to water management in Taylor Slough, Everglades National Park, Florida. *Wetlands* 34 (Suppl. 1): S65-S79.

Sah. J. P., Ross, M. S., Blanco, J., and Freixa, J. 2015. Evaluation of WDAT vs EDEN Water Surface Elevation data for studying vegetation: hydrology relationship in the southern Everglades. Report submitted to US Army Corps of Engineers. (CA # W912HZ-14-2-0022-P00001 & W912HZ-14-2-0023-P00001). August 2015. pp 31

USFWS (2009) Biological Opinion for the C-111 Spreader Canal (SC) Western Phase 1 Project, and its potential effects on the Cape Sable seaside sparrow (CSSS) and designated CSSS habitat. US Fish and Wildlife Service, Vero Beach, FL.

Virzi, T., Davis, M. J., Sah, J. P., Ross, M. S. and Ruiz, P. L. (2011) C-111 Project and Cape Sable seaside sparrow subpopulation D: Baseline data on sparrows, vegetation and hydrology.

Annual Report – 2011. Submitted to South Florida Water Management District, West Palm Beach, FL. 80 pp.

Virzi, T. and Davis, M. J. (2013) C-111 Project and Cape Sable seaside sparrow subpopulation D. Annual Report – 2013. Submitted to South Florida Water Management District, West Palm Beach, FL. 38 pp.

Virzi, T. and Davis, M. J. (2014) C-111 Project and Cape Sable seaside sparrow subpopulation D. Annual Report – 2014. Submitted to South Florida Water Management District, West Palm Beach, FL. 40 pp.

Virzi, T. and Davis, M. J. (2015) C-111 Project and Cape Sable seaside sparrow subpopulation D. Annual Report – 2015. Submitted to South Florida Water Management District, West Palm Beach, FL. 50 pp.

Zweig, C. L. and Kitchens, W. M. (2008) Effects of landscape gradients on wetland vegetation communities: information for large-scale restoration. Wetlands 28:1086–1096

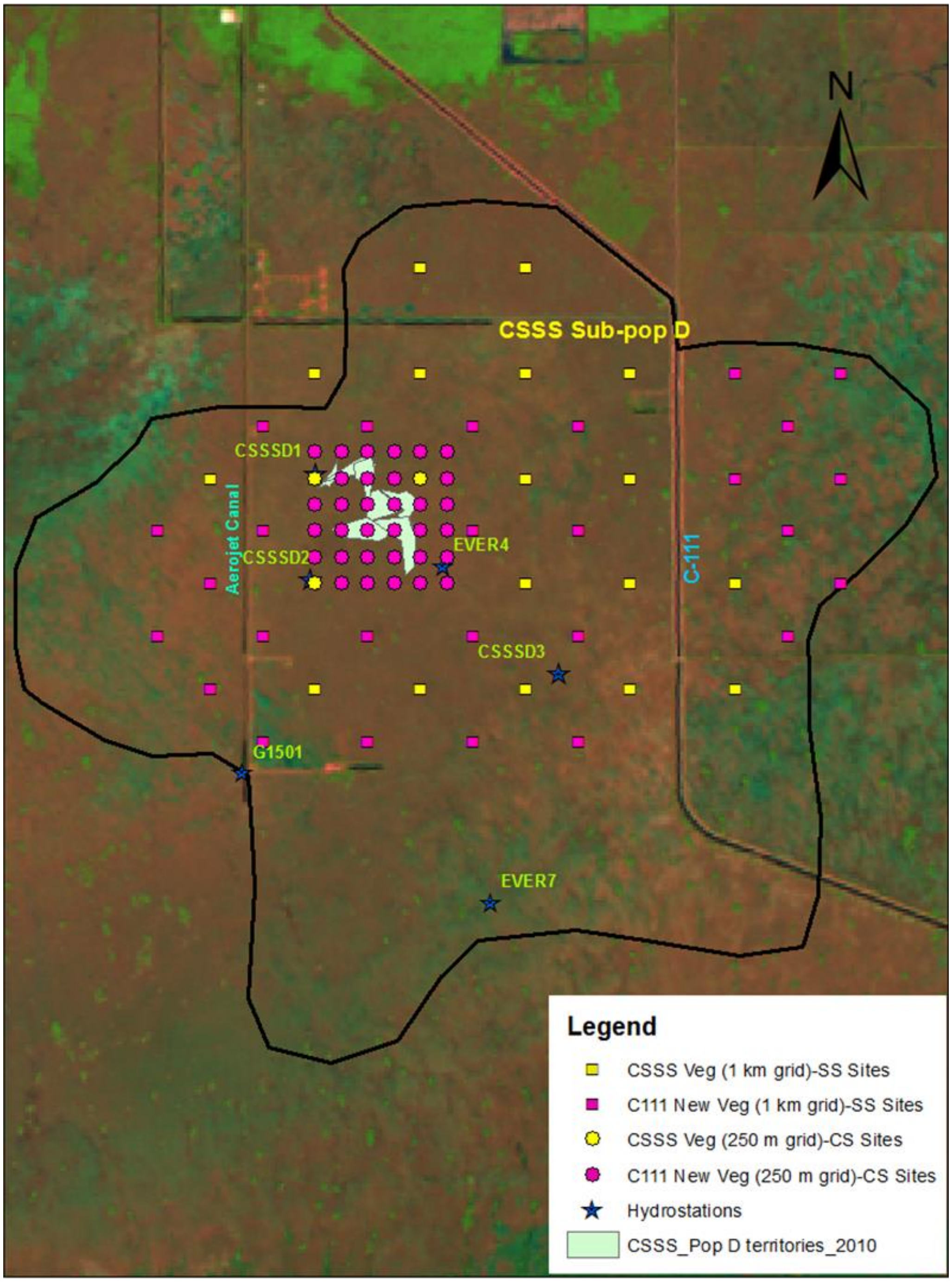


Figure 1: Vegetation survey sites within C111 Spreader Canal Western Project – CSSS Sub-population D area.

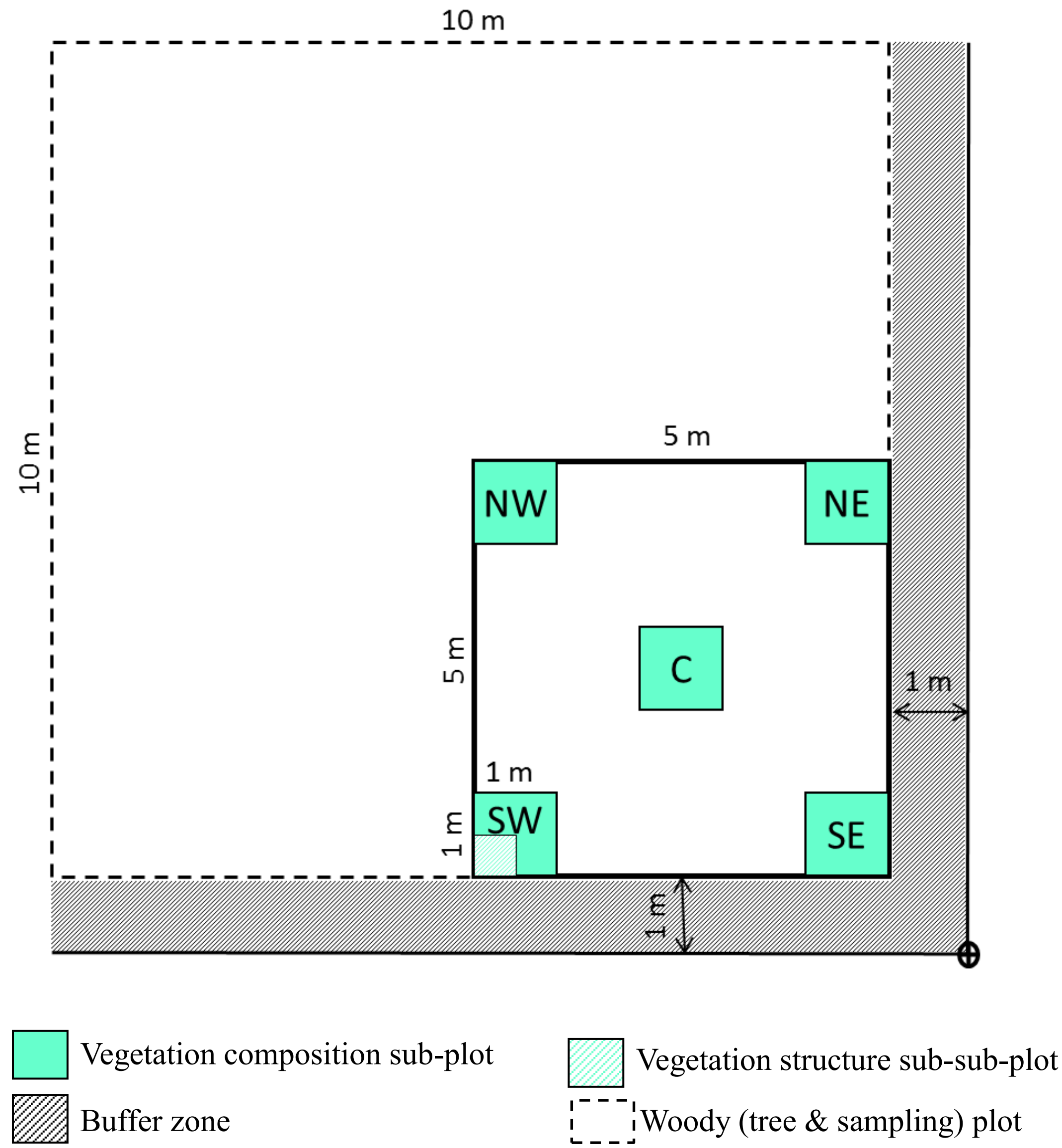


Figure 2: Vegetation sampling design at each of 80 sites sampled in 2014 to document status of vegetation structure and composition in the habitat of CSSS sub-population D within C111-Spreader Canal Project Area.

Figure 3: Vegetation sampling. (A) Standing water at a site sampled in 2016, (B) Field crews taking vegetation measurements in the field.

Figure 4: Means to access the vegetation survey sites in the spring of 2016

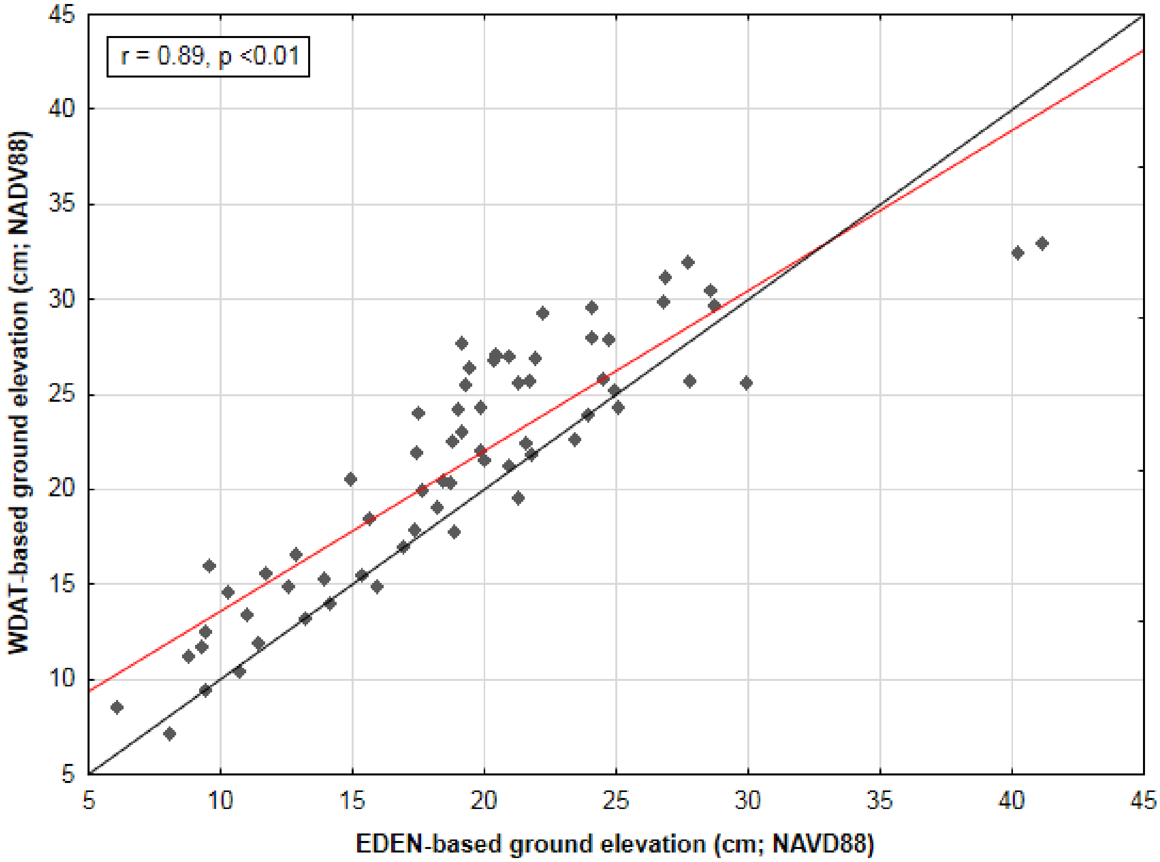


Figure 5: Scatterplot showing the relationship between EDEN (Everglades Depth Estimation Network)- and WDAT (Water Depth Assessment Tools)-based ground elevation of 69 vegetation survey sites within the habitat of CSSS sub-population D.

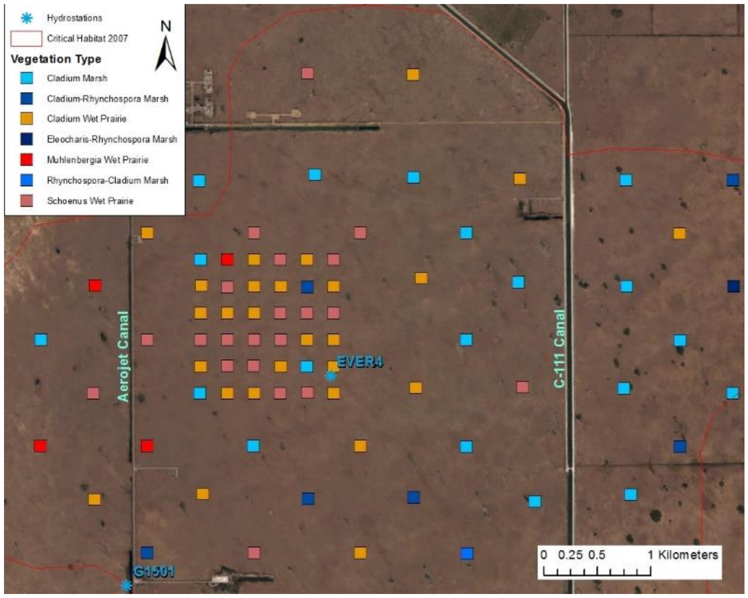


Figure 6a: Vegetation types at 80 sites in the habitat of CSSS sub-population D within C111-Spreader Canal Project Area. Vegetation type at each site was identified through cluster analysis of species cover values at 688 sites, including 608 census sites sampled in three years (2003-05). Vegetation types represent from the the dry (red) to wet (dark blue) community types.

Figure 6b: Black-top sedge (*Schoenus nigricans*)-dominated vegetation at the site D-04-06.

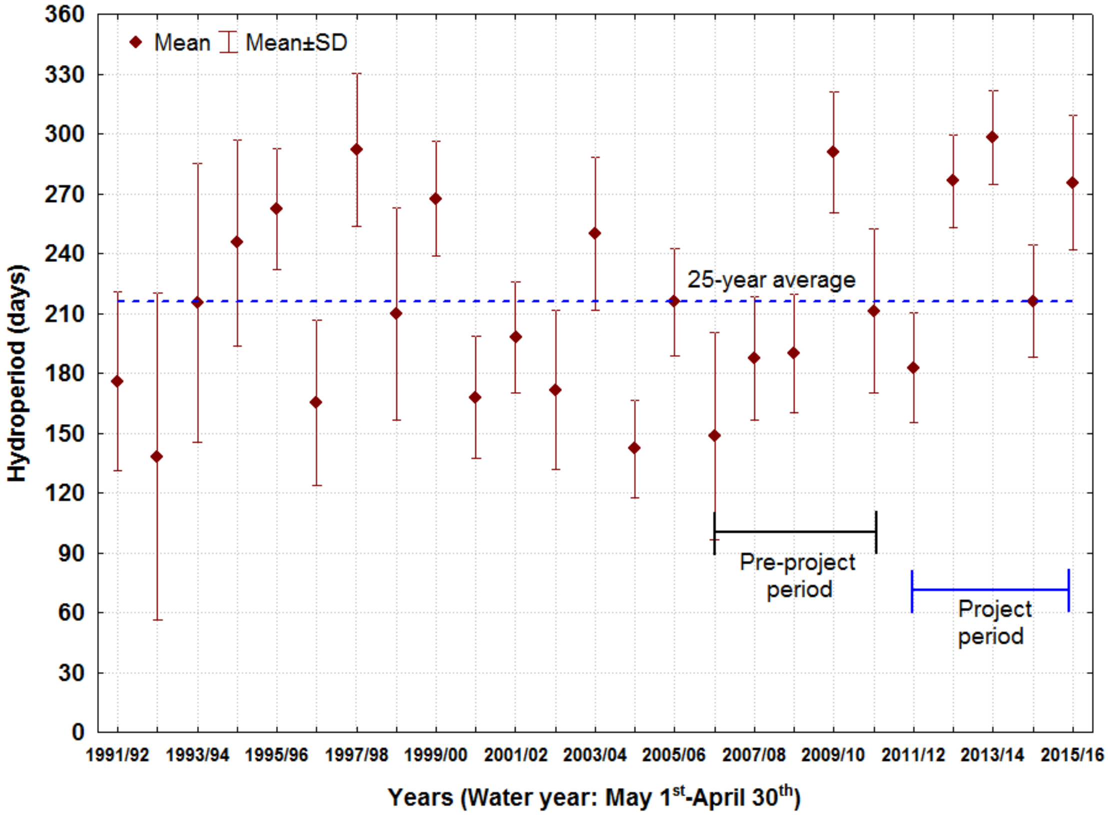


Figure 7: Annual mean hydroperiod at the vegetation survey sites (n = 69) for 25 years (1991/92-2015/16 water years: May 1st – April 30th). Dashed line is the 25-year (WY average value. Hydroperiod for each site was calculated using field water depth-based ground elevation and EDEN water surface time series data.

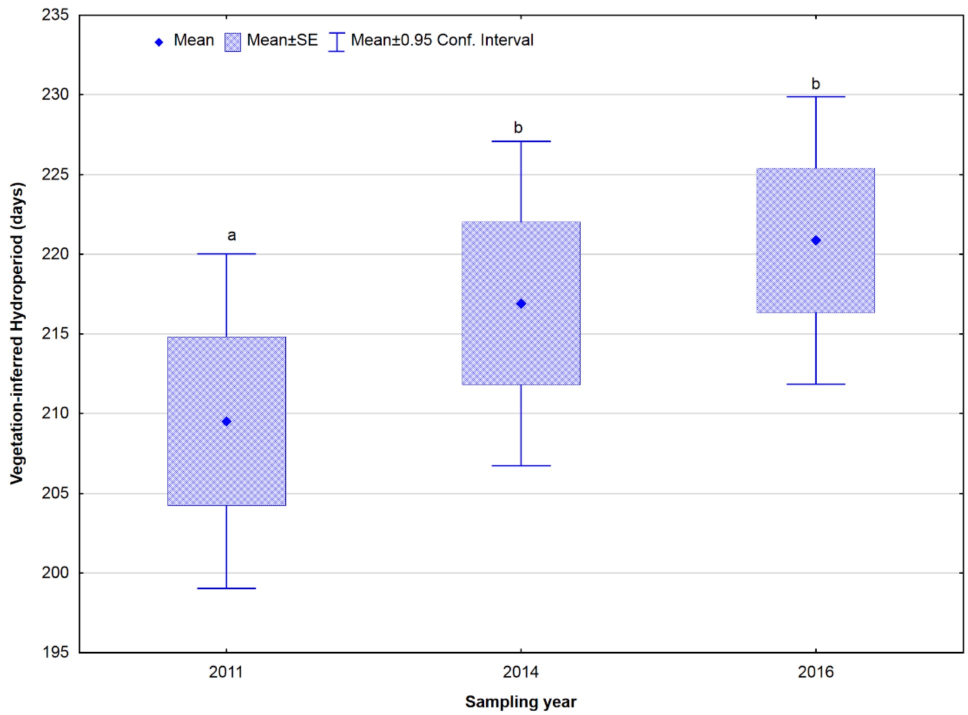


Figure 8: Box-plots (Mean, SE, and mean±1.96*SE) showing vegetation-inferred hydroperiod at the 80 sites within the habitat of CSSS sub-population D. Vegetation-inferred hydroperiod values were predicted from vegetation composition using Weighted Averaging regression model developed from the vegetation and hydrology data from CSSS vegetation transect D (Ross et al. 2006). Different letters above the whisker represent significant difference in Repeated measures ANOVA – Bonferroni test.

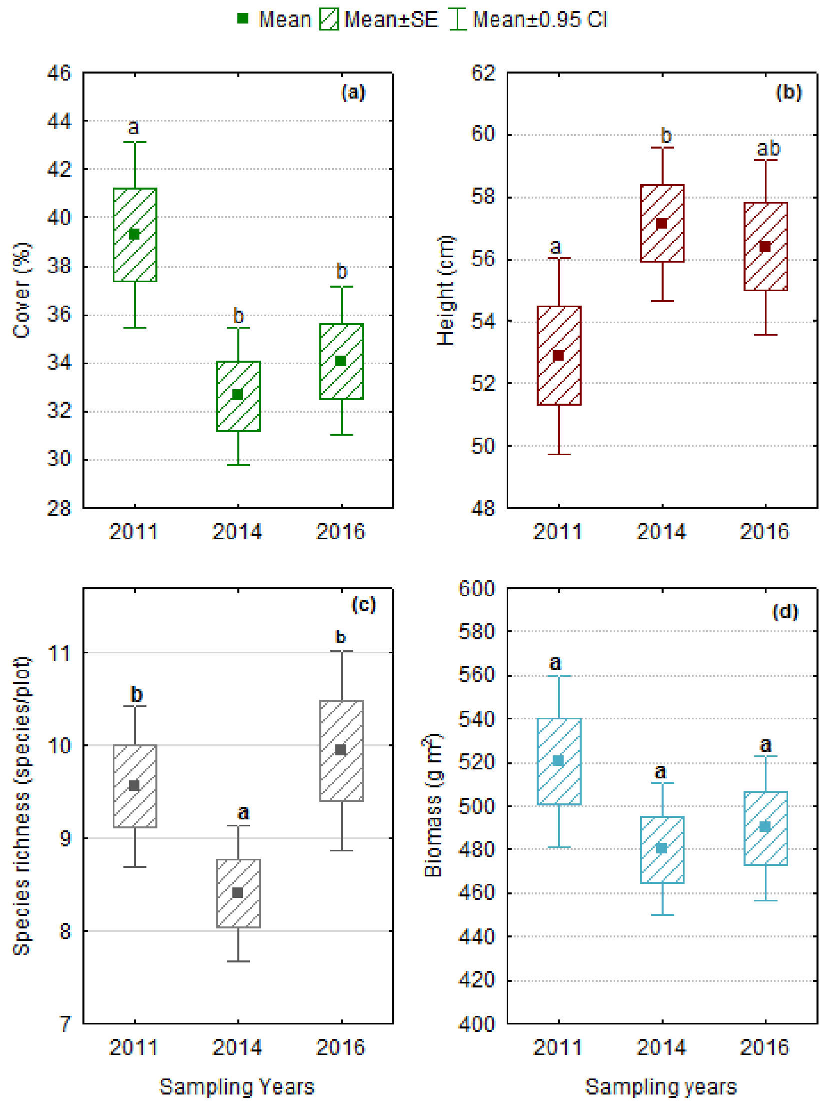
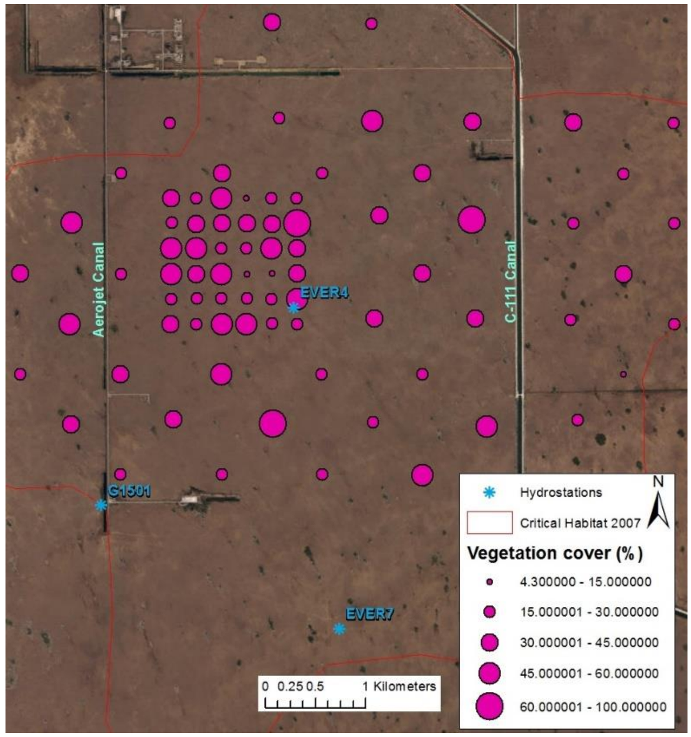


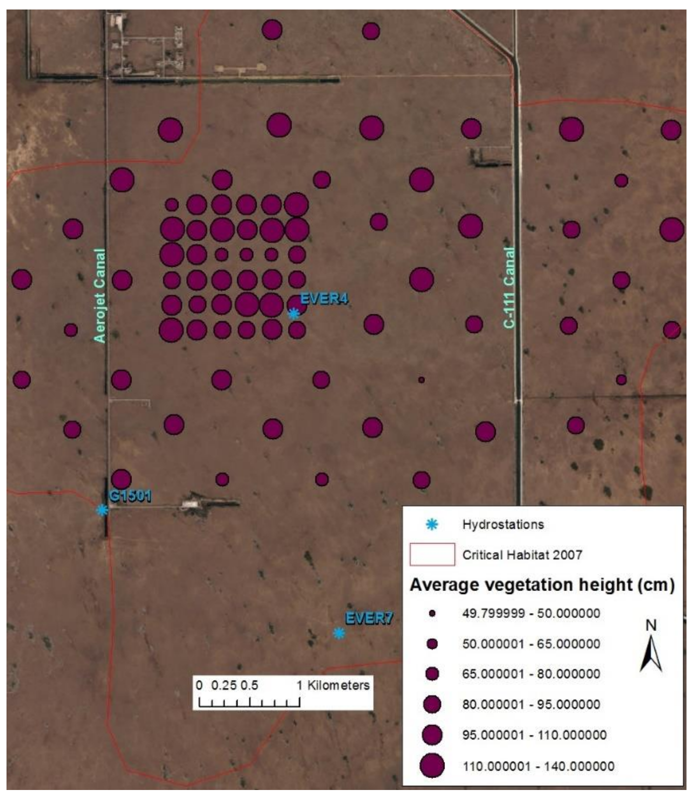
Figure 9: Box-plots (mean, SE, 95% CI) showing the vegetation structure, (a) vegetation cover, (b) vegetation height, (c) species richness, and (d) aboveground biomass in 2011 baseline survey, and 2014 and 2016 project period samplings (n = 80).

Appendix 1: List of CSSS sub-population D habitat vegetation monitoring sites sampled in 2014. Vegetation types are based on 2011 species composition data collected to document baseline vegetation condition. 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). 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.

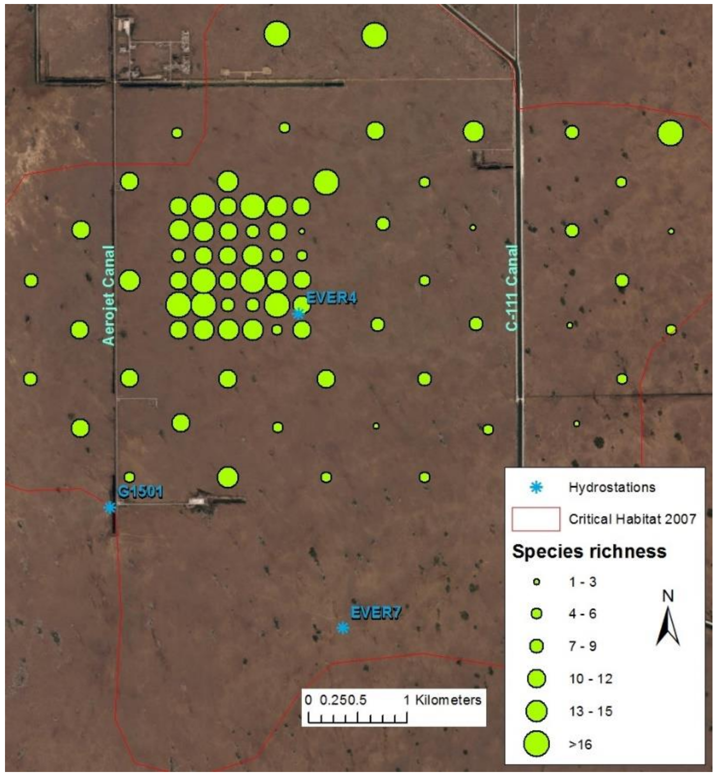
PLOT	X_UTM83	Y_UTM83	LAT_WGS84	LONG_WGS84	Vegetation type
D-01-02	544353	2801406	25.328592	-80.559292	CWP
D-01-03	545411	2804404	25.355633	-80.548679	CM
D-01-05	546405	2803430	25.346807	-80.538834	CWP
D-01-06	546354	2802406	25.337561	-80.539376	CWP
D-01-07	547357	2802410	25.337566	-80.529409	SOWP
D-01-08	547475	2801337	25.327872	-80.528274	CM
D-01-10	548377	2801401	25.328421	-80.519309	CM
D-02-01	545335	2805354	25.364214	-80.549403	SOWP
D-02-02	546327	2805342	25.364075	-80.539543	CWP
D-02-03	546334	2804375	25.355343	-80.539507	CM
D-02-04	543345	2803363	25.346294	-80.569245	MWP
D-02-06	547321	2803391	25.346426	-80.529732	CM
D-02-07	548307	2802395	25.337400	-80.519969	CM
D-03-01	547329	2804365	25.355221	-80.529619	CWP
D-03-02	544322	2804348	25.355160	-80.559504	CM
D-03-03	546337	2801375	25.328251	-80.539580	CRM
D-03-04	545343	2801363	25.328173	-80.549457	CRM
D-04-01	542834	2802855	25.341721	-80.574339	CM
D-04-02	542831	2801856	25.332700	-80.574401	MWP
D-04-03	543326	2802353	25.337173	-80.569466	SOWP
D-04-04	543338	2801354	25.328152	-80.569379	CWP
D-04-05	543835	2803855	25.350722	-80.564360	CWP
D-04-06	543835	2802853	25.341674	-80.564392	SOWP
D-04-07	543832	2801857	25.332680	-80.564454	MWP
D-04-08	543832	2800854	25.323622	-80.564486	CRM
D-04-09	544836	2803855	25.350693	-80.554412	SOWP
D-04-10	544832	2801855	25.332632	-80.554518	CM
D-05-01	544836	2800854	25.323592	-80.554511	SOWP
D-05-02	545835	2803854	25.350653	-80.544484	SOWP
D-05-03	545835	2802849	25.341578	-80.544518	CWP
D-05-04	545831	2801855	25.332602	-80.544591	CWP
D-05-05	545833	2800854	25.323562	-80.544605	CM
D-05-06	546832	2803854	25.350622	-80.534576	CM
D-05-07	546833	2802854	25.341592	-80.534600	CM
D-05-08	546830	2801851	25.332534	-80.534665	RCM
D-05-09	546834	2800850	25.323495	-80.534660	CM
D-06-01	548330	2804355	25.355099	-80.519671	CM
D-06-02	548333	2803356	25.346077	-80.519677	CWP

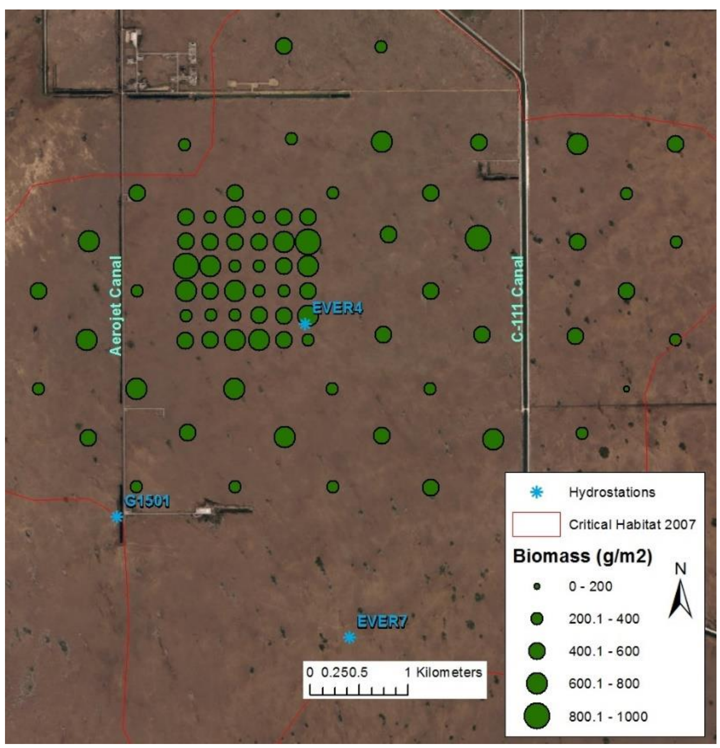
PLOT	X_UTM83	Y_UTM83	LAT_WGS84	LONG_WGS84	Vegetation type
D-06-03	548832	2803849	25.350513	-80.514700	CM
D-06-04	548834	2802850	25.341491	-80.514716	CRM
D-06-05	548834	2801851	25.332470	-80.514752	CRM
D-06-06	549331	2804349	25.355012	-80.509723	ERM
D-06-07	549336	2803354	25.346026	-80.509709	CM
D-06-08	549334	2802353	25.336987	-80.509766	CM
TD-01-01	544337	2803605	25.348450	-80.559379	MWP
TD-01-02	544583	2803606	25.348452	-80.556934	CWP
TD-01-03	544835	2803604	25.348426	-80.554430	SOWP
TD-01-04	545084	2803606	25.348436	-80.551955	CWP
TD-01-05	545333	2803606	25.348429	-80.549481	SOWP
TD-01-06	545582	2803607	25.348430	-80.547006	CWP
TD-02-01	544339	2803363	25.346264	-80.559367	SOWP
TD-02-02	544585	2803351	25.346149	-80.556923	CWP
TD-02-03	544837	2803353	25.346159	-80.554418	CWP
TD-02-04	545086	2803354	25.346161	-80.551944	CRM
TD-02-05	545337	2803351	25.346126	-80.549450	CWP
TD-02-06	545583	2803353	25.346137	-80.547005	CWP
TD-03-01	544337	2803104	25.343926	-80.559395	CWP
TD-03-02	544584	2803105	25.343927	-80.556941	CWP
TD-03-03	544834	2803107	25.343938	-80.554456	SOWP
TD-03-04	545084	2803104	25.343903	-80.551972	SOWP
TD-03-05	545332	2803104	25.343896	-80.549508	SOWP
TD-03-06	545584	2803105	25.343897	-80.547003	SOWP
TD-04-01	544335	2802852	25.341650	-80.559423	SOWP
TD-04-02	544585	2802853	25.341652	-80.556939	SOWP
TD-04-03	544835	2802853	25.341644	-80.554455	SOWP
TD-04-04	545085	2802853	25.341637	-80.551971	CWP
TD-04-05	545334	2802854	25.341638	-80.549496	CWP
TD-04-06	545584	2802856	25.341649	-80.547012	CWP
TD-05-01	544334	2802604	25.339411	-80.559442	SOWP
TD-05-02	544587	2802607	25.339430	-80.556927	SOWP
TD-05-03	544833	2802608	25.339432	-80.554483	CWP
TD-05-04	545085	2802605	25.339397	-80.551979	CM
TD-05-05	545332	2802603	25.339371	-80.549524	CWP
TD-05-06	545584	2802603	25.339364	-80.547020	CM
TD-06-01	544330	2802349	25.337108	-80.559490	CWP
TD-06-02	544585	2802352	25.337127	-80.556956	CWP
TD-06-03	544839	2802354	25.337138	-80.554432	SOWP
TD-06-04	545084	2802353	25.337121	-80.551997	SOWP
TD-06-05	545335	2802356	25.337141	-80.549503	CWP
TD-06-06	545585	2802355	25.337124	-80.547019	CM





Appendix 2: Mean total vegetation cover and height at 88 sites sampled in CSSS Sub-population D habitat within C111 SC Western Project area.





Appendix 3: Mean species richness and aboveground biomass at 88 sites sampled in CSSS Sub-population D habitat within C111 SC Western Project area.