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Re-sampling of Vegetation Survey Sites within Cape Sable seaside sparrow Habitat

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Executive Summary

Cape Sable seaside sparrow (CSSS), a federally endangered species, and vegetation within its habitat are highly sensitive to changes in hydrologic regimes. In the Everglades, the CSSS has remained at the center of the water management strategies primarily because a decline in sparrow population in the early 1990s was attributed in part to management-induced alterations in hydrologic regimes. Guided by the 1999 CSSS Biological Opinion, a number of changes in water management activities have been implemented since early 2000s. The question is whether the water management activities aimed at mitigating damage to Everglades ecosystems caused by past management would affect the CSSS habitat, and how the impact on vegetation structure and composition would varry spatially and temporally in relation to the preferred CSSS habitat conditions. The results of hydrologic modelling associated with Everglades Restoration Transition Plan (ERTP) and Central Everglades Planning Project (CEPP) have suggested an improvement in habitat condition to the east of sub-population A, while areas in the western portion of sub-population B and E may become wetter and thus less suitable for the sparrows. The objectives of our study were to establish baseline vegetation data, at both fine and broad scales, in areas identified by modeling as potential suitable habitat or to be adversely impacted by the water management activities, and to assess suitability of these areas as CSSS habitat.

In 2016, we sampled 103 sites: 72 in the northeastern portion of sub-population A (NE-A) and 41 sites along the western edge of sub-population E (West-E). Vegetation sampling procedure was the same as was done to study vegetation at the network of 906 sites in the previous years (2003-2010). At each sampling location, we recorded species cover in ten 0.25 m^2 sub-plots in a 60 x 1 m^2 plot, and community structure in 30 sub-plots. In the rainy season when there was standing water at the sites, we measured water depths that were later used to calculate ground elevation, using the water surface elevations provided by Everglades Depth Estimation Network (EDEN) for the specific date. EDEN daily water surface elevation data were also used to calculate hydroperiod, and dry season, wet season and annual mean daily water depth for each site. Vegetation composition and structure data were summarized using several multivariate techniques: hierarchical agglomerative cluster analysis to define vegetation types, non-metric multidimensional scaling (NMDS) ordination to examine the relationship between vegetation composition and hydrologic parameters, and weighted averaging partial least square (WA-PLS) regression model to calculate vegetation-inferred hydroperiod.

The CSSS habitat condition was evaluated using observed pattern of sparrow occurrence along the hydrologic gradient and range of vegetation composition throughout its habitat. Our analysis included two different approaches. In the first approach, the 2003-2005 census sites were classified into two groups: 1) CSSS-P sites, the sites where CSSS was recorded at least once in the three years prior to vegetation sampling, and 2) CSSS-0 sites, the sites where sparrow census was carried out, but sparrows were not observed. The Bray-Curtis similarity between each site surveyed in 2016 and 2003-2005 sites was averaged separately for CSSS-P and CSSS-0 sites. Assuming that a site will be likely to support sparrows if its vegetation composition is more similar to sparrow-occupied sites than non-occupied sites, we calculated the difference in similarity of a site with CSSS-P and CSSS-0. The values were then standardized by the range of the differences and multiplied by 100, so that the final values, Vegetation-based Habitat Suitability Index (VHSI), ranged between 0 and 100. In the 2nd approach, we used vegetation-inferred hydroperiod, an indicator of vegetation composition adapted to particular hydrologic condition. In 2003-2005 study, vegetation-inferred hydroperiod, predicted for 608 census sites using weighted averaging partial least square (WA-PLS) model developed from vegetation composition and hydrology data collected at 290 transect sites, was a strong predictor of CSSS occurrence. In this study, we fitted a skewed normal distribution (SND) curve to the frequency of CSSS occurrence in relation to vegetation-inferred hydroperiods in 2003-2005 study. The three parameters *location*, *scale* and *shape* from the SND model were then used to predict the SND frequency for CSSS occurrence at the 2016-sampled sites, and the *max* was used to standardize the SND Index, an indicator of relative occurrence of sparrow, to vary between 0 and1.

The northeastern part of the sub-population A (NE-A) was relatively dry, as two thirds of the sites in the area had the hydroperiod <= 210 days. In contrast, the sites in western portion of sub-population E (West-E) were much wetter than the sites in NE-A. In these areas, both marl wet prairie (WP) and marsh (M) vegetation types were identified. Wet prairie vegetation primarily included *Cladium* WP and *Schizachyrium* WP, whereas the Marsh vegetation types were *Cladium* marsh, *Cladium-Rhunchospora* marsh, and *Rhynchospora* marsh. In NE-A, 50% of sites had prairie vegetation, whereas the study sites in West-E had mostly marsh vegetation. The presence of wet prairie vegetation at many sites in NE-A seems to be the result of the restriction on water deliveries through S12s, as most of the sites are within the 6 km radius from the NP-205. The mandated regulation is to maintain water levels at NP-205 below ground (≤ 6 ft NGVD) for a minimum of 60 consecutive days between March 1 and July 15. The farthest sites to the south and east of NP-205 still had relatively long hydroperiod marsh vegetation. Short hydroperiod marl prairie burns frequently. However, the study area in both NE-A and West-E have not burned for more than twenty-five years. Within NE-A, there was a small fire (12.7 ha) in July 2015, but it did not have widespread impact on the vegetation pattern in the study area. However, in past two years (2014-2015), three fires separately burned 94, 1,121 and 105 ha in sub-population A. In fact, these fires burned 10, 7 and 2 sites, respectively in the existing CSSS vegetation-monitoring network. Since, these sites have pre-burn vegetation data, resampling of these sites in coming years will help to explain vegetation responses to fire in the western marl prairie.

Only a comprehensive modeling effort that includes all aspects of sparrow habitat characteristics including hydrology, herbaceous vegetation structure and composition, woody plants, time since last fire and other habitat factors can fully evaluate the suitability of an area for the Cape Sable seaside sparrow. However, the preliminary evaluation based on vegetation composition and vegetation-inferred hydroperiod suggests that a large portion of study area in NE-A appears to be suitable habitat for CSSS. Thus, the question arises whether those areas are currently occupied or even will be occupied in the near future by sparrows for breeding. Since 1992, the number of sparrows in sub-population A has remained very low, and the sparrows are mostly confined in the eastern portion of the habitat. Since 2010, a small number of sparrows have also been observed at some sites in the study area. Considering the relative sedentary nature of the sub-species, the spatial shift in habitat range is likely to occur only in adjoining areas. Since the initial comprehensive survey of sparrow population in 1981, together with a sharp decline in population or even complete disappearance of sparrow from some areas, there has also been a shift in sparrow range over time. Thus, it is likely that if the area to the northeast of sub-population A sampled in this study continue to improve in habitat quality, as is predicted by recent modeling, that area may support a breeding sparrow population.

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General Background

The Cape Sable seaside sparrow (CSSS) as well as the vegetation within its habitat are highly sensitive to natural and management-caused changes in both hydrologic and fire regimes. With a broad goal of assessing the response of marl prairie ecosystems to the Everglades restoration efforts, a study intended to characterize marl prairie vegetation and monitor its responses to hydrologic alterations and fire within CSSS habitat was conducted between 2003 and 2010 with funding from U.S. Army Corps of Engineers (USACE). In the first three years of the project (2003-2005), a detailed account of vegetation composition and structure was documented. Subsequently, during 2006-2010, sub-sets of sites in six sparrow sub-populations (A-F) were re-visited annually to assess vegetation dynamics over space and time. The sub-set sampled each year included both unburned and burned sites. After three years, the vegetation study was resumed in FY 2014 with funding from Everglades National Park. In FY 2014, the focus of the study was to assess the impact of the fire-hydrology interaction on vegetation along wide range of hydrologic conditions.

In recent years, the hydrologic modelling carried out using Regional Simulation Model (RSM) tool to evaluate the potential impact of Everglades Restoration Transition Project (ERTP) has shown that habitat in the eastern portion of CSSS sub-population A will be relatively dry (USCACE 2011, 2014; USFWS 2016) in comparison to 1990s and existing hdyrologic conditions. Likewise, under CEPP-ALT 4R2, the recommended restoration alternative for Central Everglades Planning Project (CEPP), the CSSS habitat suitability index (HIS), calculated using habitat suitability modeling approach, suggests that some additional areas northeast of currently occupied habitat in sub-population A will exhibit improved hydrologic condition that is more suitable than without restoration. In contrast, habitat along the western edge of sub-populations B and E, the two largest and most persistent sub-populations, will be wetter than the sparrow prefers (Pearlstine et al. 2014). Thus, a vegetation study focusing on these most sensitive areas within the marl prairie landscape was conducted in FY2016 with the funding from Everglades National Park (Task Agreement # P13AC01271, Cooperative Agreement # H5000-06-0104). This document summarizes the vegetation pattern observed at 103 sites, established and sampled in FY 2016. The major activities included site establishment and vegetation survey in spring 2016, followed by water depth measurement in the wet season of the same year.

The report describes vegetation structure and composition in relation to hydrologic conditions in northeastern portion of sub-population A and western portion of sub-population E, and the suitability of the survey sites for sparrow occurrence. In addition, the report also includes the preliminary results from comparison of LiDAR data obtained in sub-population E during Everglades National Park Pilot Project in 2016 and field-based ground elevation and vegetation height data.

1.1 Introduction

In the Everglades, the Cape Sable seaside sparrow (CSSS), a federally endangered species, is a pivot point for water management operations primarily because a decline in sparrow population in the early 1990s was attributed in part to management-induced alterations in hydrologic regimes. In general, the sparrow populations respond to changes in both hydrology and fire regime, either directly through their nesting success or failure (Pimm et al. 2002; Baiser et al. 2008), or indirectly, mediated through vegetation change in their habitat (Nott et al. 1998). Human influence on both these factors is pervasive, through the management of the extensive south Florida canal system, and through the fire management policies or plans of Everglades National Park (ENP) and Big Cypress National Preserve (BCNP). The question is whether the water management activities aimed at mitigating damage to Everglades ecosystems caused by past management would affect the CSSS habitat, and how the impact on vegetation structure and composition will vary spatially and temporally in relation to the preferred CSSS habitat conditions.

The Cape Sable seaside sparrow (CSSS), originally described from brackish coastal marsh habitat, currently inhabits freshwater short hydroperiod marl prairies present on both flanks of the Shark River and Taylor Sloughs. The marl prairie habitat has gone through many transitions in hydrologic and fire regime due to management-induced changes in water flow pattern in the southern Everglades. Such changes in habitat conditions during the 1980s and 1990s resulted in an unexpected decline in sparrow numbers in four of six sub-populations. Guided by the 1999 CSSS Biological Opinion, recent water management activities have impacted occupied and adjacent potential CSSS habitat which had deteriorated due to extreme water conditions before the late 1990s. For instance, regulatory schedules for the S-12 structures along Tamiami Trail - followed under the operational objectives of Interim Structural and Operation Plan (ISOP)/Interim Operational Plan (IOP) (USACE 1999; USFWS 2002) - have caused consistently low water levels at NP-205 and nearby areas, resulting in drier vegetation in the northeastern part of sub-population A (Sah et al. 2011, 2015). In contrast, in the eastern marl prairies, operated under Interim Operation Plan (IOP) to provide protection for the adjacent CSSS habitat (USFWS 2002), the S332B and S332C pump structures deliver water from the L31N canal into a series of inter-connected detention ponds. In these areas, both the overflow above a fixed-crest weir and subsurface seepage from the pond to adjacent marl prairies in ENP have helped to control seepage back to the canal and to protect the sparrow habitat from further deterioration (USACE 2007). Accordingly, vegetation in areas adjacent to the canal has shifted towards a more mesic type (Sah et al. 2011, 2015), possibly improving the CSSS habitat, as these areas were considered over drained followed frequent fires that adversely impacted the habitat resulting in reduced sparrow numbers (Pimm et al. 2002). These vegetation shifts are subject to change due to future restoration activities associated with Comprehensive Everglades Restoration Plan (CERP) and its recently outlined components, such as Everglades Restoration Transition Plan (ERTP) and Central Everglades Planning Project (CEPP) (USACE 2011; USACE 2014; USFWS 2016).

During CEPP planning, the Refined Recommended Plan (i.e. Alternative 4R2) has been considered the best alternative in comparison to the existing condition baseline (ALT EC) (USACE 2014). Modeled under these two scenarios, CEPP-ALT EC and CEPP-ALT 4R2, the CSSS habitat suitability index suggests that under the latter, some areas of sparrow habitat within both western (sub-population A) and eastern (B, E and F) sub-populations will become wetter, and thus possibly less suitable than at present (Pearlstine et al. 2014). Specifically, habitat along the western edge of sub-population E, one of the two largest and most persistent sub-populations, will be wetter than the sparrow prefers (Pearlstine et al. 2016), in association with increased water flow through the Blue Shanty area as well as Northeast Shark Slough (USACE 2014). In contrast, the model also predicts that some additional suitable habitat may become available outside the recent range of CSSS occurrence. In particular, adjoining areas to the northeast of currently occupied habitat boundary of sub-population A are expected to exhibit improved condition (Pearlstine et al. 2014, 2016). The results of hydrologic modelling associated with Everglades Restoration Transition Plan (ERTP) and Central Everglades Planning Project (CEPP) have also suggested an improvement in habitat condition to the east of sub-population A (USACE 2011, 2014).

Habitat conditions in some of the sensitive areas likely to be impacted by future water management were regularly monitored between 2003 and 2010 (Ross et al. 2006; Sah et al. 2011). The areas as such contain an established network of monitoring sites at both fine (sites at 100 m along the transects) and broader landscape scales (sites 1 km apart in a gridded layout). However, the existing monitoring network did not include sites in the area to the northeast of occupied habitat in sub-population A. Likewise, in the western portion of sub-population E, some of existing sparrow census sites and 17 new sites added in 2014 to the sparrow census network also were not included in the vegetation-monitoring network. Thus, the objectives of our study were to establish baseline vegetation data, at both fine and broad scales, in areas identified by modeling as potential suitable habitat or to be adversely impacted by the water management activities, and to assess suitability of these areas as CSSS habitat.

1.2.1 Data Collection

1.2.1.1 Study Area:

The study area included the portion of existing and future potential CSSS habitat within the marl prairie landscape. Between 2003 and 2006, we established a network of 906 vegetation-monitoring sites in the marl prairies, most of which were congruent with sparrow census sites. While the vegetation-sampling network was widespread and covered almost all the recent range of CSSS habitat (**Figure 1**), it did not include all the sparrow census sites that were established in 1981/1992 or added later over the years. Specifically, the sparrow census sites not included in the vegetation survey were mostly in the northeast portion of sub-population A (NE-A), where sparrows have not been sighted since 1992, and the 55 sites in other populations, including 17 sites in the western portion of sub-population E (West-E), that have been added to the sparrow census network since 2009. Thus, we established new vegetation survey sites both NE-A and West-E. Specifically, we extended the current Transect A eastward for 3 km to capture potential CSSS habitat, and Transect E westward for 4 km up to the transition to the ridge-and-slough landscape that may be responsive to the expected changes in hydrologic regime. On the extended portions of the transect, vegetation survey sites were established every 100-200 m, following the methods outlined in Ross et al. (2003).

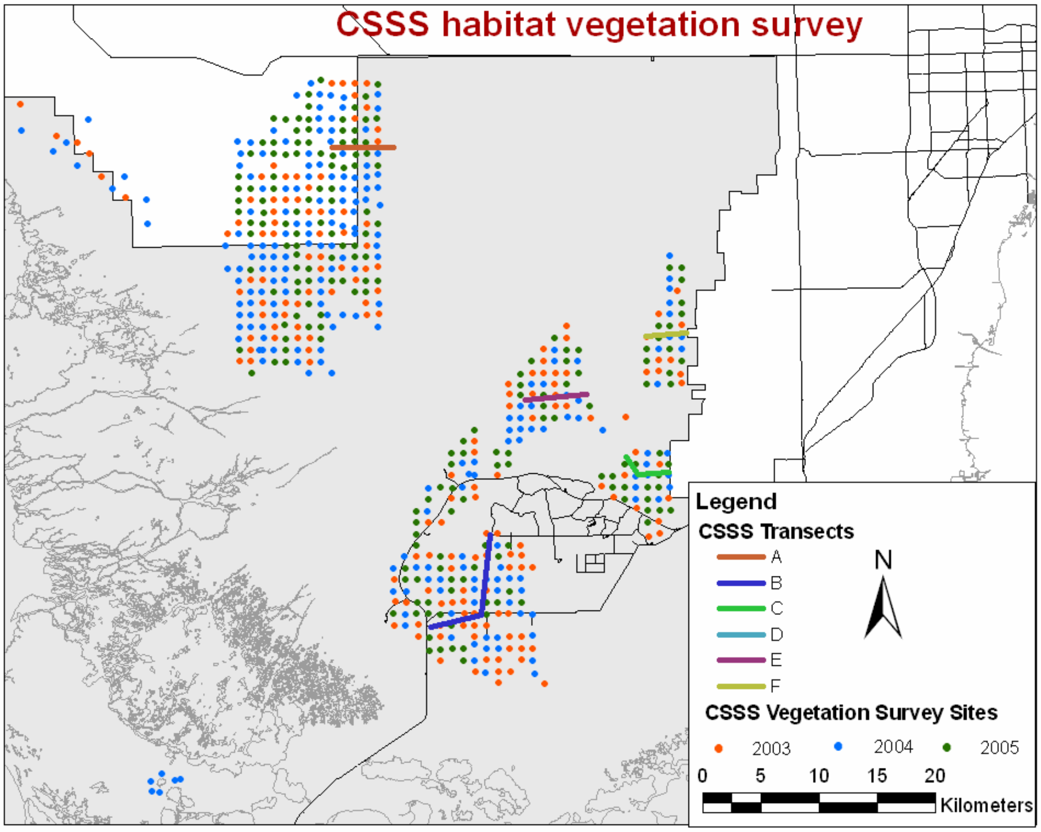

Figure 1: A network of vegetation monitoring sites. A total of 906 sites (293 transect and 613 census sites) were established over three years (2003-2005), and were sampled at least twice in 8-year period (2003-2009).

In 2016, we sampled 58 census sites, 45 in northeastern portion of sub-population A (NE-A) and 13 sites along the western edge of sub-population E (West-E) (**Figure 2**). In addition, on the extended portion of the Transect A, we sampled 27 sites, established every 100 m on the whole transect except a 300 m section covered by tree island and woody vegetation. On the extended portion of Transect E, we sampled 18 sites. The sampling in sub-population E was impacted by unusually high water level during the dry season of 2016. Normally, when sites on a CSSS vegetation survey transect are sampled, the field crew are dropped off in the morning and picked up in the afternoon. During the day, the field crew walk and sample the sites every 100 m. However, during the current sampling, the high water condition in sub-population E was not favorable for walking long distance. Thus, on the extended portion of Transect E, we accessed the sites by helicopter, and sampled the sites every 200 m instead of 100 m that was originally proposed. In West-E, however, there were four sites, two transect and two census sites, where water was too high even for landing the helicopter, and thus those sites were not sampled.

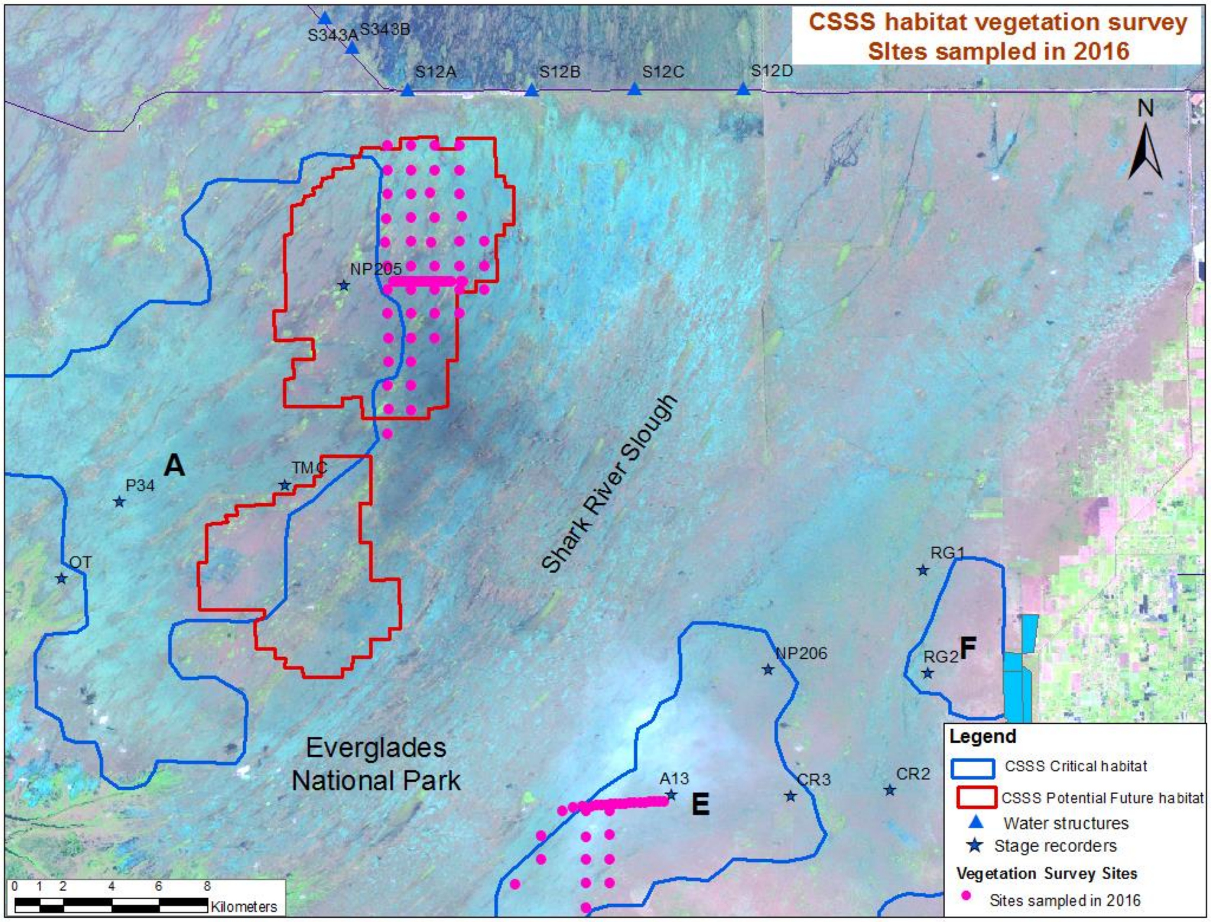

Figure 2: Vegetation Survey sites established and sampled in 2016. (45 transect and 58 census sites) were established and first time sampled in 2016.

1.2.1.2 Vegetation sampling

At each sampling site, vegetation was sampled in a N-S oriented, 1 x 60 m rectangular plot beginning 3 m south of a rebar established to permanently mark the sampling site. Nested within the plots were ten 0.25 m^2 (0.5 x 0.5 m) subplots (compositional sub-plots), arrayed at 6-meter intervals along the baseline (east side) beginning at Meter 5. In each subplot, we recorded our ocular estimate of cover (live + dead) of each species. We also noted any additional species present in the 1 x 60 m plot, and assigned these species a mean cover of 0.01% for the plot as a whole. In addition, a suite of structural parameters was recorded in 30 0.25 m^2 (0.5 x 0.5 m) subplots (structural sub-plots) arrayed every two meters beginning at Meter 1. Structural sampling included three attributes: 1) Canopy height, i.e., the tallest vegetation present within a cylinder of ~5 cm width, measured at 4 points in each quadrat; 2) Total vegetative cover, in percent; and 3) live vegetation, expressed as a percent of total cover. In the compositional sub-plots, we also measure soil depth at 4 points in each quadrant by probing to bedrock with a 1-cm diameter aluminum probe rod.

1.2.1.3 Hydrology

Hydrological variables used in this study were based on elevations determined from either topographic survey (for transect sites) or water depths measured in the field (for census sites). At each site, first we measured water depth in sub-plots within each 1x 60 m plots at the time of sampling and then in wet season when sites in the region were inundated with standing water. Later, using the water surface elevations provided by Everglades Depth Estimation Network (EDEN) for the specific date, we calculated ground elevation for each plot. EDEN daily water surface elevation data (http://sofia.usgs.gov/eden/models/watersurfacemod_download.php) were then used to calculate annual mean daily water depth and hydroperiod for each site. Hydroperiod of each year was defined as the discontinuous number of days in a year when water level was above the ground surface. In addition, we also computed mean wet and dry season water depths, as these variables are also considered to have a significant relationship with vegetation structure and composition in the wetland marshes, especially in the ridge and slough landscape (Hotaling et al. 2009; Zweig and Kitchens 2008). In the marl prairies, recent observations indicate that dry down of the areas within sub-population A in dry season has resulted in change in vegetation composition from *Cladium*- and *Rhynchospora*- dominated marsh to *Cladium* and *Schizachyrium*-dominated wet prairies (Sah et al. 2011). In some areas, *Muhlenbergia capillaris* ssp. *filipes,* which was absent during 2003-2005 sampling, was found at a few sites in 2010.

1.2.1.4 LiDAR data

The Everglades National Park LiDAR Pilot project tasked by the U. S. Geological Survey (USGS) and implemented in April 2016 collected high-resolution elevation data (Dewberry 2016). The project area covered approximately 85.5 Km^2 (33 square miles), including a significant portion of CSSS sub-population E habitat. The LiDAR data collected using Green and Infrared channels (wavelengths) of two different sensors, Riegl VQ880G and Titan, were processed by Dewberry, Inc and were available from the Park. The data were separately labelled as Riegl Green, Riegl NIR, Titan Green and Titan IR representing the wavelength and sensor used in data acquisition. The LiDAR data that we obtained from the Park included both raw and modeled high-resolution elevation data. The modeled data were in form of DEM (Digital Elevation Model) and DSM (Digital Surface Model), gridded at 1 m resolution.

1.2.2 Data Analysis

1.2.2.1 Vegetation Classification

In this study, the sites were sampled for the first time in 2016. To examine the spatial distribution of vegetation types, we used cluster analysis to classify the sites. We first summarized the data by computing mean cover of each species for each site and created site x species matrix. We used an hierarchical agglomerative cluster analysis to define vegetation types at the transect and census sites surveyed in 2016. We used 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).

1.2.2.2 Vegetation-environment relationships

To examine the relationship between vegetation composition and existing hydrological conditions, vegetation data was first summarized by a non-metric multidimensional scaling (NMDS) ordination. For NMDS ordination, cover data were relativized by site total. The hydrology vector was derived by calculating plot level hydroperiod, using mean plot elevation, obtained using field measurements of water depths and EDEN daily water surface elevation data. In ordination space, the vectors for the hydrologic gradient were defined by the vector fitting technique in DECODA (Minchin 1998). In this method, a gradient is defined in the direction through the ordination that produces maximum correlation between the measured environmental attribute and the scores of the sampling units along the vector. The statistical significance of such correlations is tested using a Monte-Carlo permutation test with 10,000 random permutations, as samples in the given ordination space are not independent (Minchin 1998). The orientation of the ordination is then rotated so that hydroperiod has a perfect correlation ($r = 1.0$) with axis-1, the ordination's principal axis.

1.2.2.3 Species richness, evenness and biomass

Vegetation structural measurements were summarized for each plot, and mean canopy height and total vegetative cover were used to estimate above ground plant biomass, using the allometric equation developed by Sah et al. (2007) for marl prairie vegetation within CSSS habitat. The equation for calculating biomass was as follows:

$$\sqrt{Biomass} = 6.708 + 15.607*\text{arcsine } \sqrt{Cover/100} + 0.095*\text{Ht}$$

where Biomass = Total plant biomass (g/m^2), Cover = Total crown cover (%), and Ht = Mean crown height (cm).

1.2.2.4 Vegetation composition-based habitat suitability for CSSS occurrence

To assess how closely vegetation composition at the study sites resembles vegetation in areas where CSSS are frequently observed, we used two different approaches. First, Non-metric multidimensional scaling (NMDS) ordination was used to illustrate the similarity in vegetation composition between the 2016-sampled sites and the census sites that had sparrows recorded over three years prior to vegetation sampling in 2003-2005. The 2003-2005 census sites were classified into two groups: 1) CSSS-P sites, the sites where CSSS was recorded at least once in the three years prior to vegetation sampling, and 2) CSSS-0 sites, the sites where sparrow census was carried out, but sparrows were not observed. The sites where sparrow census was not done over three years prior to vegetation sampling were not considered. Centroids for both, CSSS-P and CSSS-0, groups were calculated from the ordination Axis scores, and plotted with 2016-sampled sites. The sites that were likely to be suitable for CSSS would be closer to CSSS-P centroid in the ordination space. To examine the degree of resemblance of individual sites with CSSS-P, the Bray-Curtis (BC) similarity matrix was calculated. The BC similarity between each site surveyed in 2016 and 2003-2005 sites was then averaged separately for CSSS-P and CSSS-0 sites. Assuming that a site will be likely to support sparrows if its vegetation composition is more similar to sparrow-occupied sites than non-occupied sites, we calculated the difference in similarity of a site with CSSS-P and

CSSS-0 as: BC Similarity with CSSS-P – BC Similarity with CSSS-0. The values were then standardized by the range of the differences and multiplied by 100, so that the final values, Vegetation-based Habitat Suitability Index (VHSI), ranged between 0 and 100: the higher the value, the more suitable the site for the sparrow.

The Vegetation-based Habitat Suitability Index (VHSI) was primarily based on vegetation composition, which varies along the hydrologic gradient (Armentano et al. 2006; Ross et al. 2006). Vegetation-inferred hydroperiod, an indicator of vegetation composition adapted to particular hydrologic condition, has been used to elucidate the spatio-temporal variation in vegetation responses to hydrologic changes (Armentano et al. 2006; Sah et al. 2011). In 2003-2005 study, vegetation-inferred hydroperiod, predicted for 608 census sites using weighted averaging partial least square (WA-PLS) model developed from vegetation composition and hydrology data collected at 290 transect sites, was a strong predictor of CSSS occurrence. In this study, we fitted a skewed normal distribution (SND) curve to the frequency of CSSS occurrence in relation to vegetation-inferred hydroperiods that were grouped in 30 days interval in 2003-2005 study. To fit the SND curve, we used ELVeSkew program (Ecological Modeling Team, South Florida Natural Resource Center, Everglades National Park, 2011) and obtained its parameters, *location*, *scale*, *shape* and *max*. The three parameters *location*, *scale* and *shape* were used to predict the skewed normal distribution of CSSS occurrence at the 2016-sampled sites, and the *max*, the maximum value of skewed normal distribution was used to standardize the SND Index (hereafter termed as 'Scaled SND Index" – an indicator of relative occurrence of sparrow) to vary between 0 and1.

1.2.2.4 Validating DEM and DSM derived from LiDAR data

From our CSSS vegetation study in 2003-2016, ground elevation and vegetation height data were available for several sites within the ENP LiDAR Pilot project area. In a portion of the CSSS sub-population E habitat, we used these data to evaluate the LiDAR data. We had estimates of ground elevation and vegetation height for 737 and 2610 locations, respectively. Ground elevation data had been obtained in two different ways. For 561 locations (510 0.5 x 0.5 m sub-plots and 51 site locations), data had been obtained by surveying from a known benchmark. The survey was done in two steps. In the first step, elevations were established along the 5 km transect (CSSS Vegetation Transect E) by surveying by autolevel from a nearby USGS vertical-control benchmarks (JBA-327 & JBA-151). Temporary and semi-permanent (rebar) benchmarks were established along the way, and elevation differences between adjacent benchmarks were determined from at least two positions, such that the two estimates did not differ by more than 1 mm. The semi-permanent benchmarks were the tops of rebar driven to bedrock, established at 100-meter intervals along the 5km transect. The rebar benchmarks denote the north ends of the 60m x 1m vegetation plots. In the second step, the elevations of 10 0.25 m^2 (0.5 x 0.5 m) sub-plots within the vegetation plots were determined, again by autolevel, with reference to the previously determined rebar elevations. Ground elevation at each rebar was also determined and included in the analysis. For the rest of the 176 locations, ground elevation was based on the field measurement of water depth and EDEN water surface elevation, following the method described in sub-section 1.2.1.3.

Vegetation height, also termed as the ‘canopy height’, is the average of four measurements taken in 0.25 m^2 (0.5 x 0.5 m) sub-plots. There are thirty subplots, arrayed at 2-meter intervals and nested within each 60 x 1 m N-S oriented rectangular plot that begins 3 m south of the rebar established to mark both census and transect sites. Vegetation height was measured in all thirty sub-plots. It is the height of the tallest vegetation present within a cylinder of ~5 cm width, measured at 4 points, usually at the center of each quadrant, within the sub-plot.

From the LiDAR DEM dataset (Riegl Green), 36 raster files from that contained the locations of vegetation sites were selected. Using the ‘Create Raster Dataset Tool’ and ‘Mosaic Tool’, a mosaic of raster files was created. We then extracted the z values for each location from both the DEM and DSM raster mosaics. Modeled vegetation height for each location was calculated by subtracting ground elevation from canopy surface elevation. Field data was then plotted against the modeled values.

1.3 Results

1.3.1 Hydrologic conditions

The hydrologic conditions in the area to the northeast of sub-population A (NE-A) varied with space and time. However, in general, the area was relatively dry in recent years. In NE-A, the four-year average hydroperiod ranged between 65 and 334 days, with a mean (±SD) value of 186 (±64) days. Two thirds of the sites in the area had the hydroperiod <= 210 days (**Figure 3**), which is considered suitable for marl wet prairie vegetation, a preferred habitat for CSSS. In contrast, the sites in western portion of sub-population E (West-E) were significantly ($F_{1,99} = 94.9$; $p < 0.001$) wetter than the sites in NE-A. In West-E, the mean ((±SD) annual hydroperiod over four years (WY2012-2016) was 304 (±19) days, and almost all sites sampled in 2016, the four-year average hydroperiod was => 270 days (**Figure 4**).

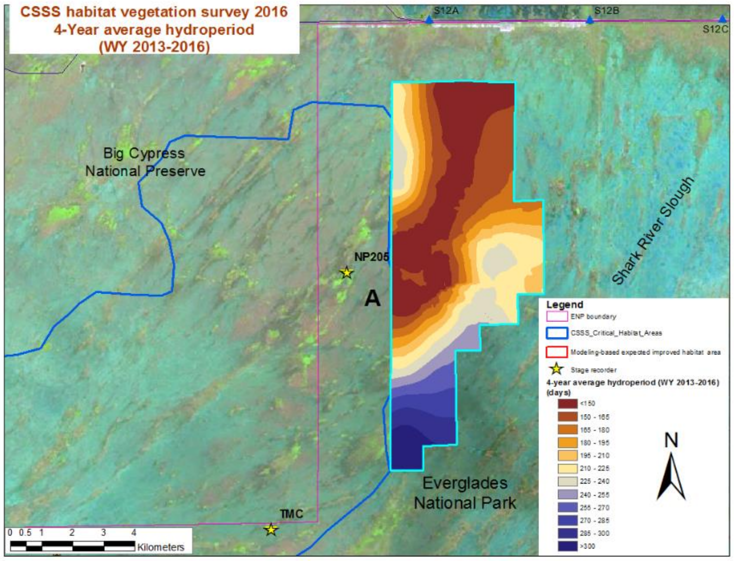

Figure 3: Hydroperiod averaged over four years prior to vegetation sampling at the sites sampled in 2016 in the northeastern part of sub-population A (NE-A)

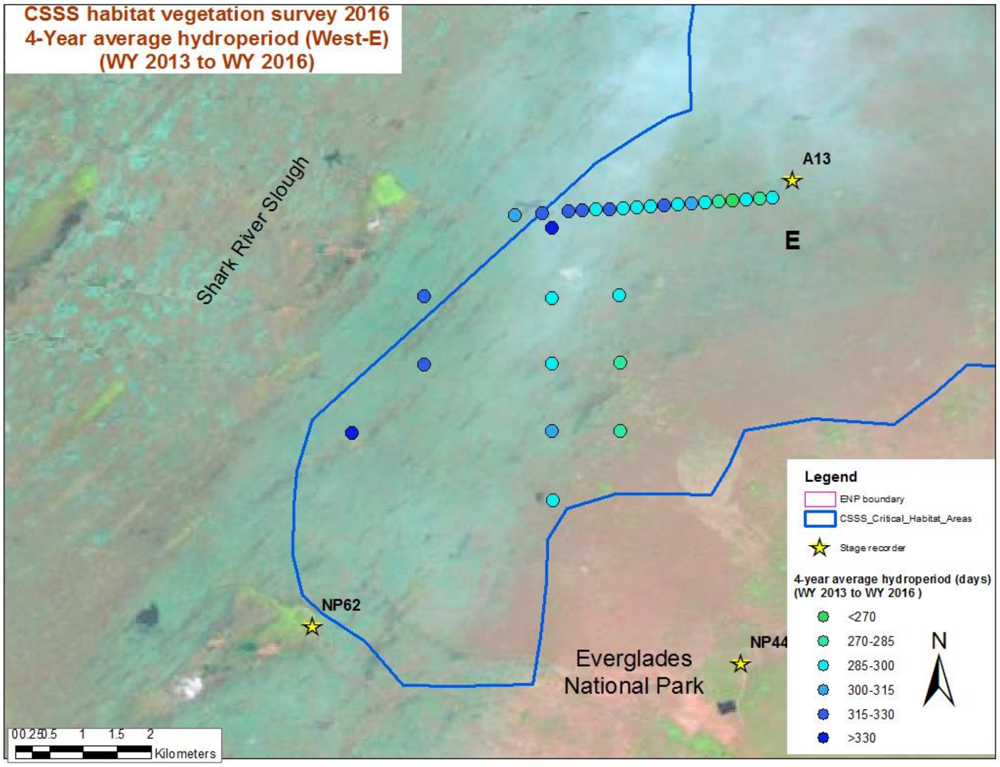

Figure 4: Hydroperiod averaged over four years prior to vegetation sampling at the sites sampled in 2016 in the western part of sub-population E (West-E)

In the last two and half decades, the relatively dry conditions in NE-A are a recent phenomenon. Between 1991 (the starting year of the EDEN data) and 2002, the year when restricted water delivery schedules for S12s were implemented, most years had mean hydroperiod >210 days (**Figure 5**). In contrast, after 2002, mean hydroperiod was <= 210 in 10 of 14 years. Similarly, during the pre-2002 period, only 7% of the sites had four-year average hydroperiod <= 210 days for at least 50% of time, whereas in the last one decade (2006-2015), 78% of sites had <=210 days hydroperiod for more than half of the time. Mean annual water depth also significantly differed (Paired t-test: df = 71, $p < 0.001$) between pre- and post- 2002 periods. The mean annual water depth was 11.6 cm lower in post-2002 than pre-2002 period (**Figure 6**). The difference in water depth was more dramatic in the dry season than in the wet season. Water depth differed between periods by only 5.8 cm in the wet season, but in the dry season, mean water depth was 36.2 cm lower in post-2002 period than pre-2002 (**Table 1**). In the pre-2002 period, dry season mean water level was above ground most of the year, whereas post-2002 period the mean water level dropped below ground every single year except 2016 (**Figure 7**). In the dry season of 2015-2016, an unusual high water condition was observed throughout the Everglades, including the marl prairies.

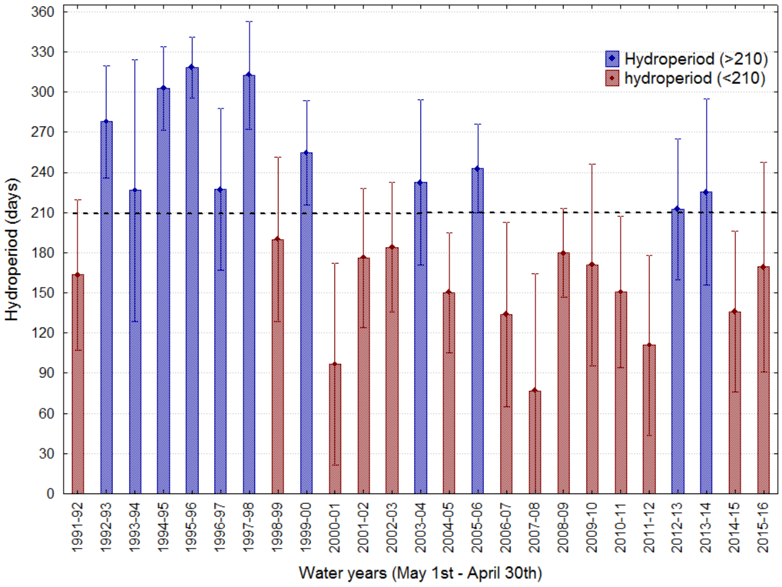

Figure 5: Mean hydroperiod averaged over all vegetation monitoring sites sampled in 2016 in the northeastern part of sub-population A (NE-A). Water year is from May 1st to April 30th of the next year.

Figure 6: Box-plot of mean annual water depth averaged vegetation monitoring sites sampled in 2016 in the northeastern part of the sub-population A (NE-A). Pre-2002 and Post-2002 represent the water management periods. In 2002, restricted deliveries through S12s were implemented.

Table 1: Mean (±SD) annual and seasonal (dry season = Nov 1st t - May 31st: wet season = June 1st - Oct 31st) water depth averaged over all sites sampled in NE-A. p-value is based on paired 't'-test (df = 71).

Mean water depth (cm)	Water management period		p-value
	WY 1992-2002	WY 2003-2016	
Annual	8.4 (± 8.7)	-3.2 (± 9.0)	<0.001
Wet Season	15.8 (± 8.6)	9.9 (± 8.6)	<0.001
Dry Season	2.8 (± 8.8)	-33.4 (± 8.9)	<0.001

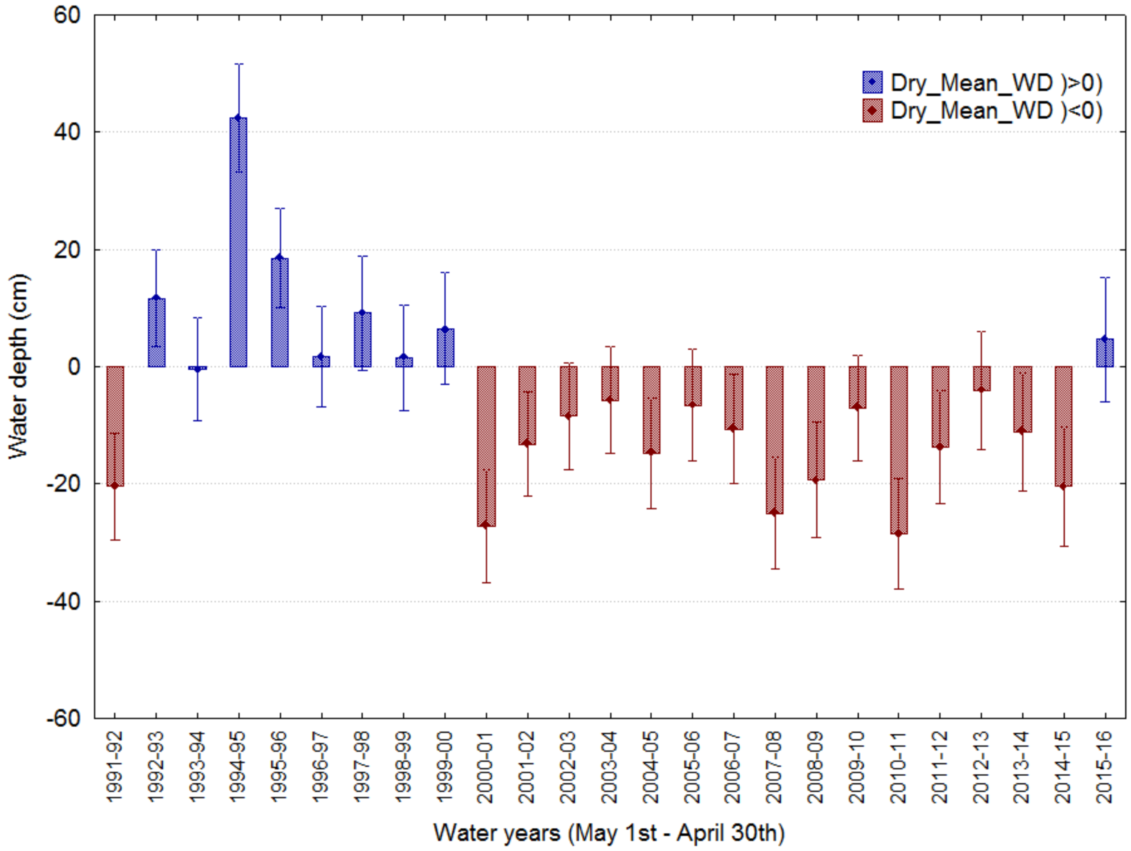

Figure 7: Dry season (Nov 1st – may 31st) mean water depth averaged over all vegetation monitoring sites sampled in 2016 in the northeastern part of sub-population A (NE-A). Water year is from May 1st to April 30th of the next year.

1.3.2 Vegetation composition and structure

Both marl wet prairie (WP) and marsh (M) vegetation types were identified at the sites surveyed to the northeast of sub-population A (NE-A) and west of sub-population E (West-E). Wet prairie vegetation primarily included *Cladium* WP and *Schizachyrium* WP., whereas the Marsh vegetation types were *Cladium* marsh, *Cladium-Rhunchospora* marsh, and *Rhynchospora* marsh. The five community types identified in cluster analysis are well separated along the hydrology vector fitted in the NMDS ordination (**Figure 8**). The *Schizachyrium* WP shares the hydrological niche with *Cladium* WP. However, unlike *Schizachyrium* WP, the niche of *Cladium* WP is extensive and is spread over a wide range of hydrologic condition. Likewise, *Cladium-Rhynchospora* is more heterogeneous than the other two marsh-communities. In the area of NE-A, 50% of sites had prairie vegetation, including both *Cladium* WP and *Schizachyrium* WP. The wet prairie vegetation was dominant mostly in the western and southern part of NE-A, whereas in the eastern portion, close to the Tram Road and the Shark River Slough, marsh vegetation was dominant (**Figure 9a**). In contrast, the study sites in West-E had mostly marsh vegetation, and only 22% of sites had wet prairie vegetation (**Figure 9b**). *Schizachyrium* WP was observed only in NE-A, whereas *Rhynchospora-Cladium* marsh vegetation was observed only in West-E.

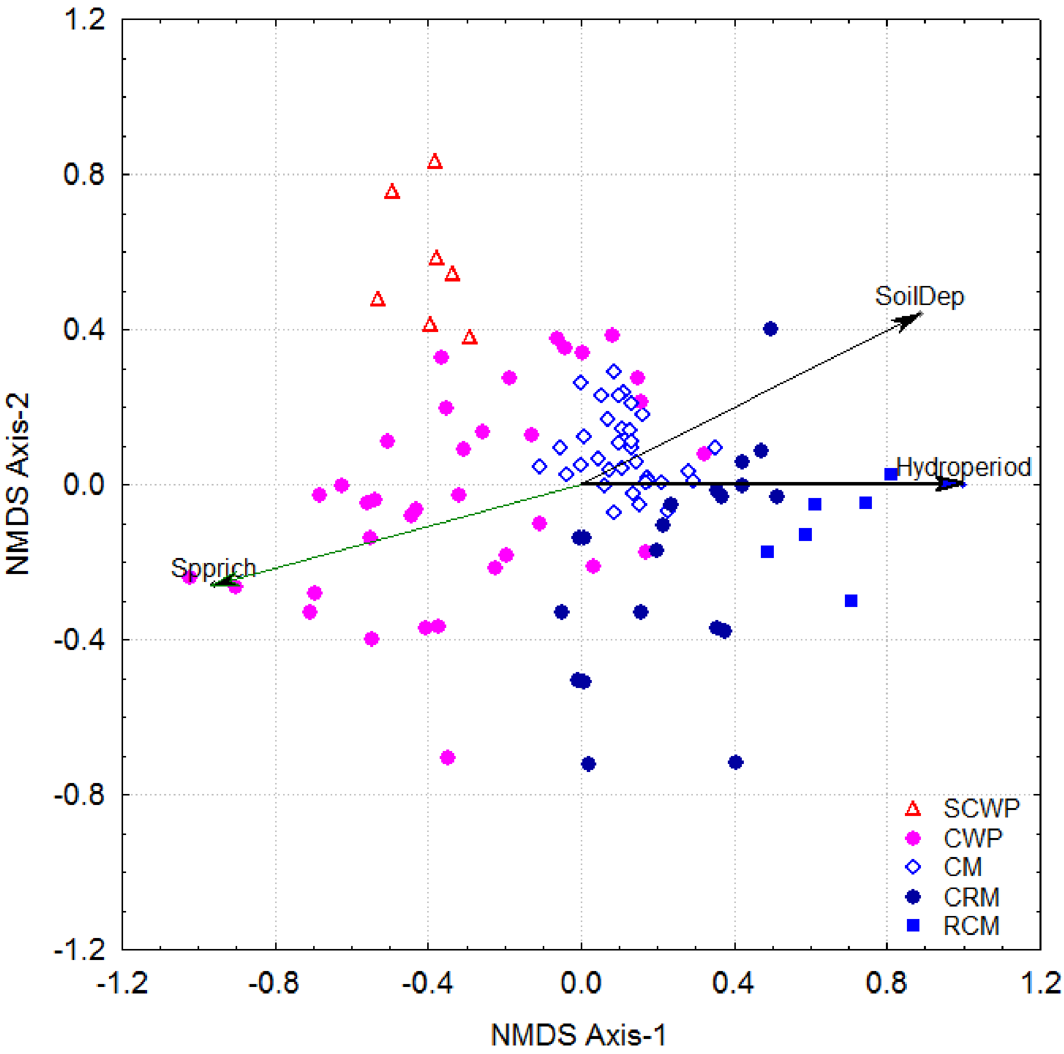

Figure 8: Scatterplot of site scores from 3-axis non-metric multidimensional (NMDS) ordination based on relative cover at 103 census plots sampled in 2016. Vegetation types were identified through hierarchical agglomerative cluster analysis with Bray-Curtis dissimilarity and flexible beta method.

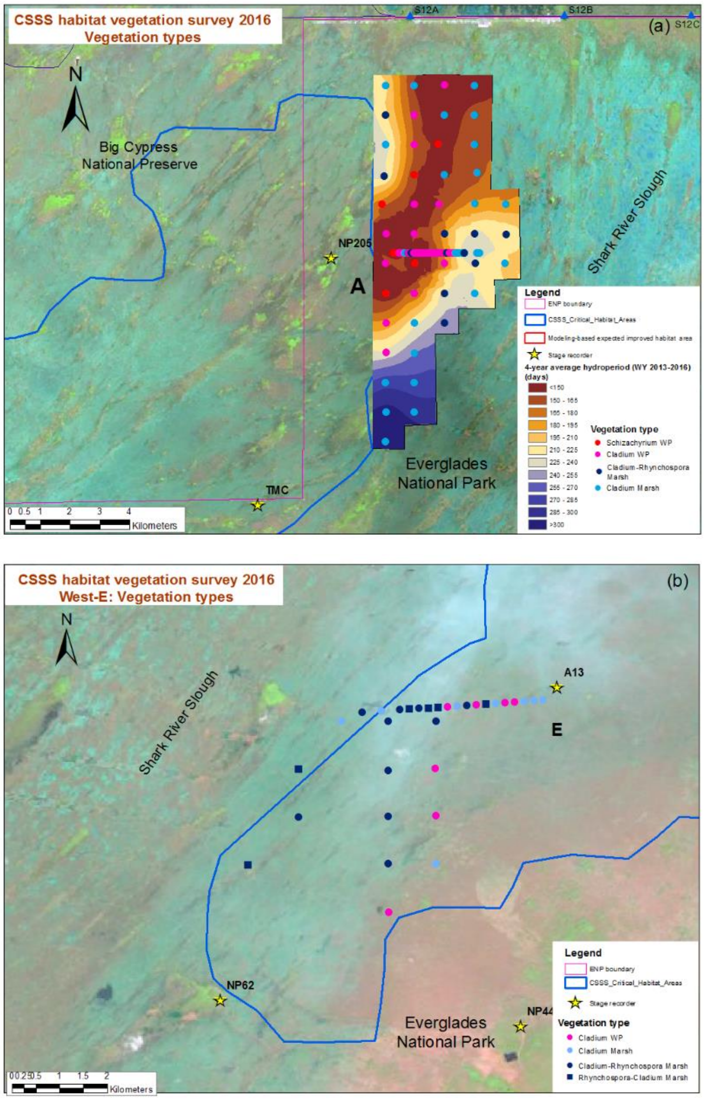

Figure 9: Spatial distribution of vegetation types at the 2016 sampling sites in (a) northeast of the sub-population A (NE-A), and (b) western portion of sub-population E (West-E).

In NE-A, species richness differed among vegetation types (**Table 2**). Mean (±SD) species richness was significantly higher (One-way ANOVA; $F_{1,\,70} = 13.2$, $p < 0.001$) in the wet prairie communities (21.7 ± 5.3 species/plot) than marsh communities (17.3 ± 5.1 species/plot) (**Figure 10**). In West-E, however, the difference in species richness between two communities was not significant. Moreover, both vegetation height and crown cover differed significantly between wet prairie and marsh sites (**Table 3**), while biomass and percent green cover did not differ between the two ecosystem types. The wet prairie sites were less open and had shorter vegetation than the marsh sites (**Figure 11**). Among the prairie sites, *Schizachyrium*-dominated prairies were shorter and less open than *Cladium*-dominated prairies, while among the marsh sites, *Cladium* marsh was taller than *Cladium-Rhynchospora* marsh, but they did not differ in cover. In West-E, vegetation was relatively uniform in structure, as the wet prairies and marshes were not different in any of the four vegetation structural variables (**Figure 11**).

Table 2: Mean (±SD) species richness, evenness, and diversity in five vegetation types identified at the sites sampled in 2016. S = number of species per plot (60x1m). H' = Shannon's diversity (Shannon and Weaver 1949), and E = H'/logn(S).

Vegetation types	Species richness (S)		Shannon's diversity (H')		Evenness (E)	
	NE-A	West-E	NE-A	West-E	NE-A	West-E
Schizachyrium WP	22.7^{a} (±6.6)		1.327^{a} (±0.234)		0.432^{a} (±0.061)	
Cladium WP	21.5^{a} (±5.1)	17.8 (±4.3)	1.638^{a} (±0.312)	1.155^{a} (±0.212)	0.537^{a} (±0.091)	0.406^{a} (±0.080)
Cladium Marsh	16.9^{b} (±5.2)	15.1 (±4.7)	0.863^{b} (±0.306)	0.806^{ab} (±0.319)	0.310^{b} (±0.103)	0.306^{a} (±0.131)
Cladium Rhynchospora Marsh	19.2^{ab} (±5.1)	15.8 (±8.6)	1.542^{a} (±0.286)	1.389^{ac} (±0.390)	0.542^{a} (±0.103)	0.549^{b} (±0.112)
Rhynchospora-Cladium Marsh		12.3 (±7.3)		1.377^{ac} (±0.370)		0.578^{b} (±0.033)
p-value	**0.006**	ns	**<0.001**	**<0.001**	**0.005**	**<0.001**

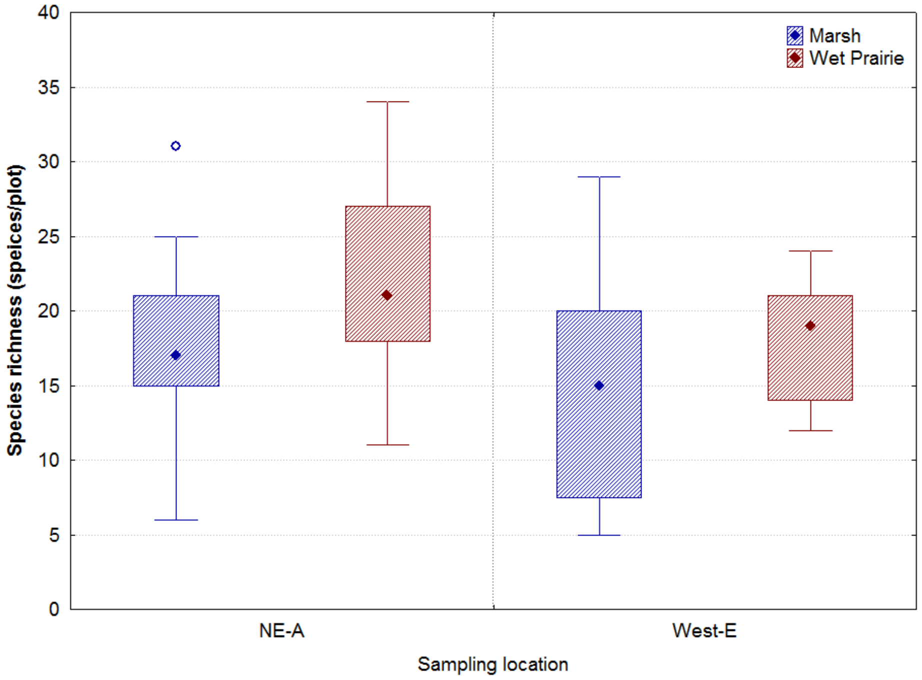

Figure 10: Box plots (Median, 25-75 quartiles, non-outlier range) showing plant species richness in wet prairie and marsh communities in northeastern portion of sub-population A (NE-A) and western part of the sub-population E (West-E).

Table 3: Mean (±SD) for four important structural variables in Marsh (M) and Wet prairie (WP) vegetation sites in the northeastern portion of sub-population A (NE-A) and western portion of sub-population E (West-E). P-value is based on one-way ANOVA test (α = 0.05).

Structural variables	NE-A			West-E		
	M	WP	p-value	M	WP	p-value
Crown height (cm)	60.5±17.0	52.9±8.9	<0.05	74.8±10.5	72.7±12.1	NS
Total cover (%)	29.2±11.8	37.0±12.3	<0.01	26.2±7.9	28.3±4.9	NS
Green cover (%)	10.0±4.0	10.4±3.4	NS	11.1±3.2	11.2±2.2	NS
Aboveground Biomass (g m^{-2})	462.8±147.6	483.9±106.9	NS	492.4±64.0	501.9±78.1	NS

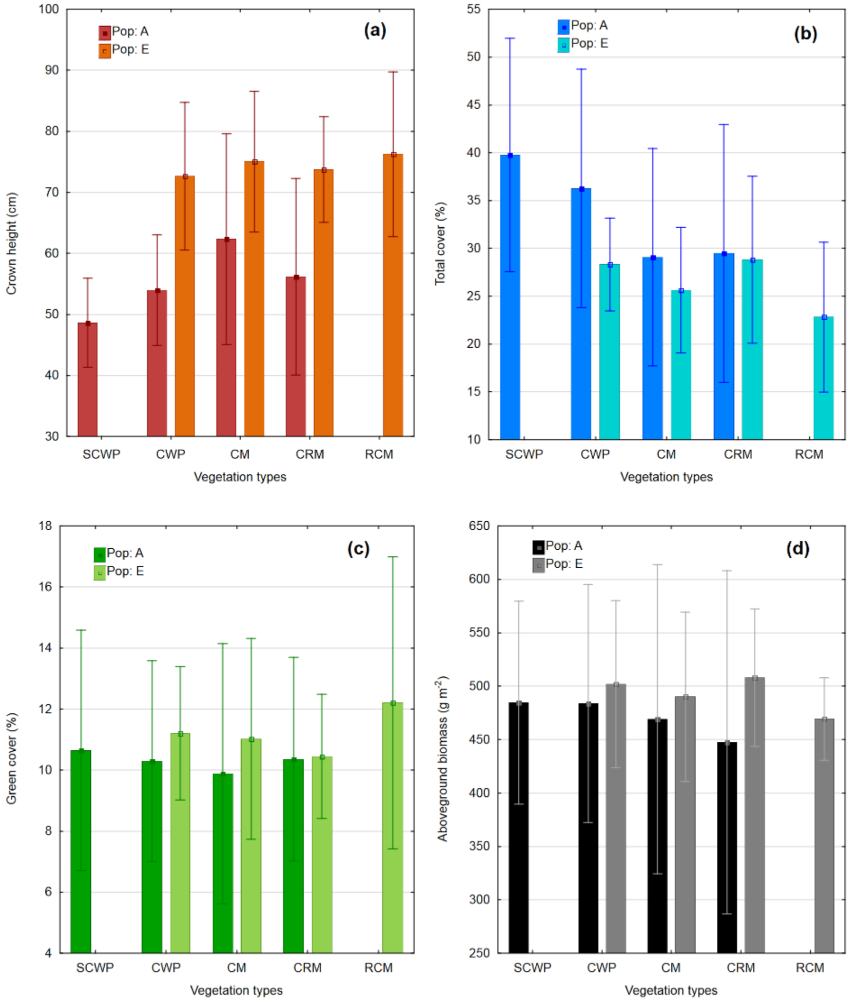

Figure 11: Mean (±SD) for 4 structural variables in herb stratum of five vegetation types based on census and transect plots sampled in 2016 in the northeast portion of the sub-population A and southern portion of sub-population E. SCWP: *Schizachyrium* wet prairie, CWP: *Cladium* wet prairie, CM: *Cladium* marsh, CRM: *Cladium-Rhynchospora* marsh, RCM: *Rhynchospora-Cladium* marsh.

Vegetation: environment relationships

In NE-A, as we expected, wet prairie sites were present in relatively dry areas. Mean four-year average hydroperiod was significantly shorter (Kruskal-Wallis test: $p < 0.001$) at wet prairie sites than the marsh sites. However, there was no significant difference in hydroperiod between two wet prairie or two marsh vegetation types (**Figure 12**). All but one wet prairie site had a 4-year average hydroperiod <=210 days. In contrast, 65% of marsh sites had hydroperiod >210 days, but the remaining 35% of sites had <=210 days. The 4-year mean annual water depth at the wet prairie sites was 13.3 cm lower than marsh sites (**Figure 13**). Difference in water depth between these two types of site was similar in both wet and dry seasons. However, the water depth at all those sites in the one and half decades was much lower than in 1990s, and the difference between wet and dry seasons was much greater in recent years than before 2002 (**Figure 14a, b**).

The presence of marsh vegetation at some of the relatively dry sites suggest the communities are in transition. Evidence includes the presence of several prairie species in marsh communities, but in low abundance. The hydrologic conditions in NE-A are suitable for two other dominant wet prairie vegetation types, *Muhlenbergia* WP and *Schoenus* WP. However, the two species dominants, *Muhlenbergia capillaris* ssp. f*ilipes* (muhly grass) and *Schoenus nigricans* (black-top sedge), common to wet prairie vegetation types in other sub-populations, were rarely present in NE-A. Muhly grass was present at only two sites; one site had 11% cover, whereas blacktop sedge was present at four sites, but only in trace (0.1% cover).

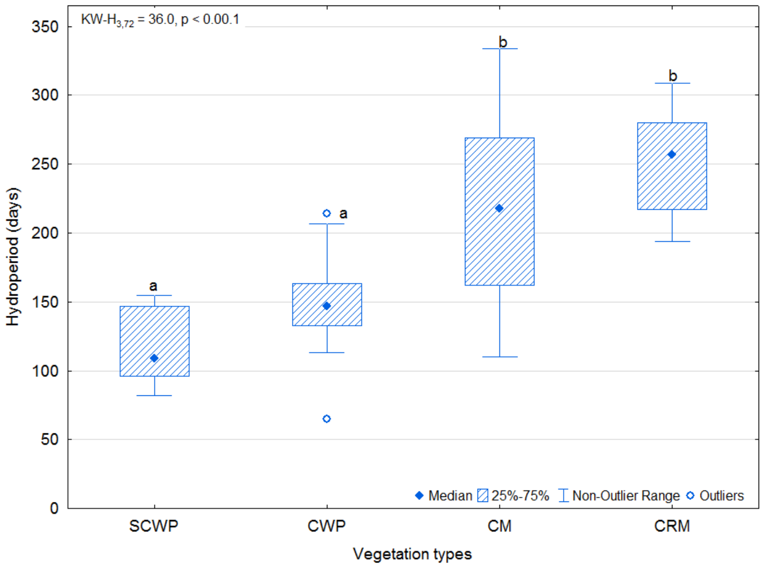

Figure 12: Box-plot showing the 4-year average hydroperiod at the sites with different vegetation types.

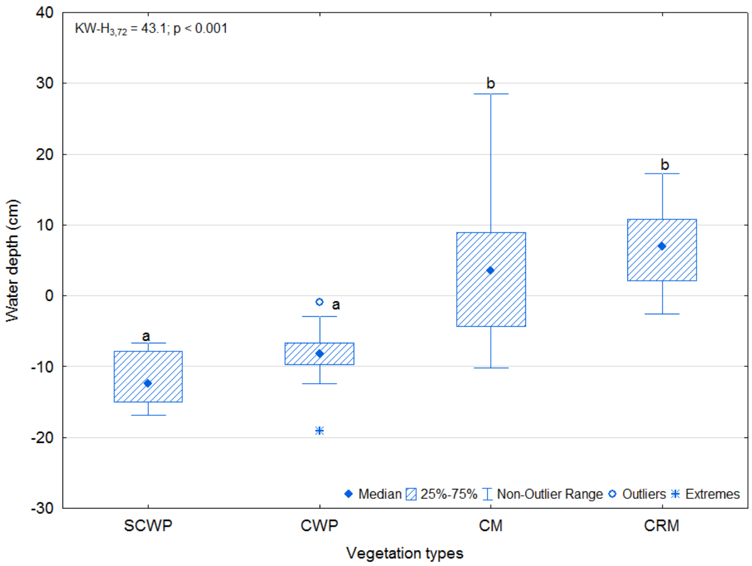

Figure 13: Box-plot showing the 4-year average water depth at the sites with different vegetation types.

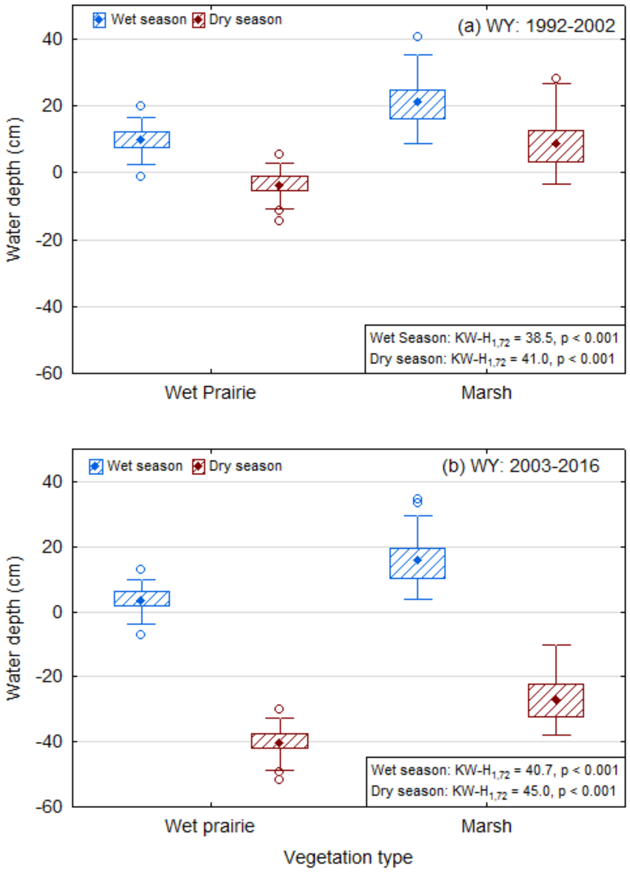

Figure 14: Box-plot showing the distribution of mean water depth averaged over two management periods (a) WY 1992-2002, and (b) WY 2002-2016 at the wet prairie and marsh sites in the northeast of sub-population A (NE-A).

Vegetation in burned areas

In both NE-A and West-E, most of the area sampled in 2016 has not burned for more than twenty-five years. Everglades National Park fire records showed that within the study area in NE-A, there was a fire (West Camp WF Fire # 62) in July 2015 (**Figure 15**). However, the fire was relatively small (12.7 ha), and the new transect that we established in 2016 as an eastward extension of existing Transect-A was 2 km to the south of the fire boundary. Likewise, none of our 2016 census sites that were established at 1 km grid was placed in the area burned by the 2015 West Camp WF fire. Nevertheless, three of the 2016 sampling sites were within the area burned in a 2008 fire (West Camp Fire; # 08040). This fire burned 997 ha of the CSSS habitat in sub-population A, including seven vegetation-monitoring sites. The pre- and post-burn vegetation dynamics at those sites have already been reported in Sah et.al (2016). Three sites burned in that fire were first time sampled in 2016, and thus did not have pre-fire data. Moreover, the vegetation structure and composition, 8 years after the fire, did not differ notably from the vegetation at unburned sites sampled in 2016.

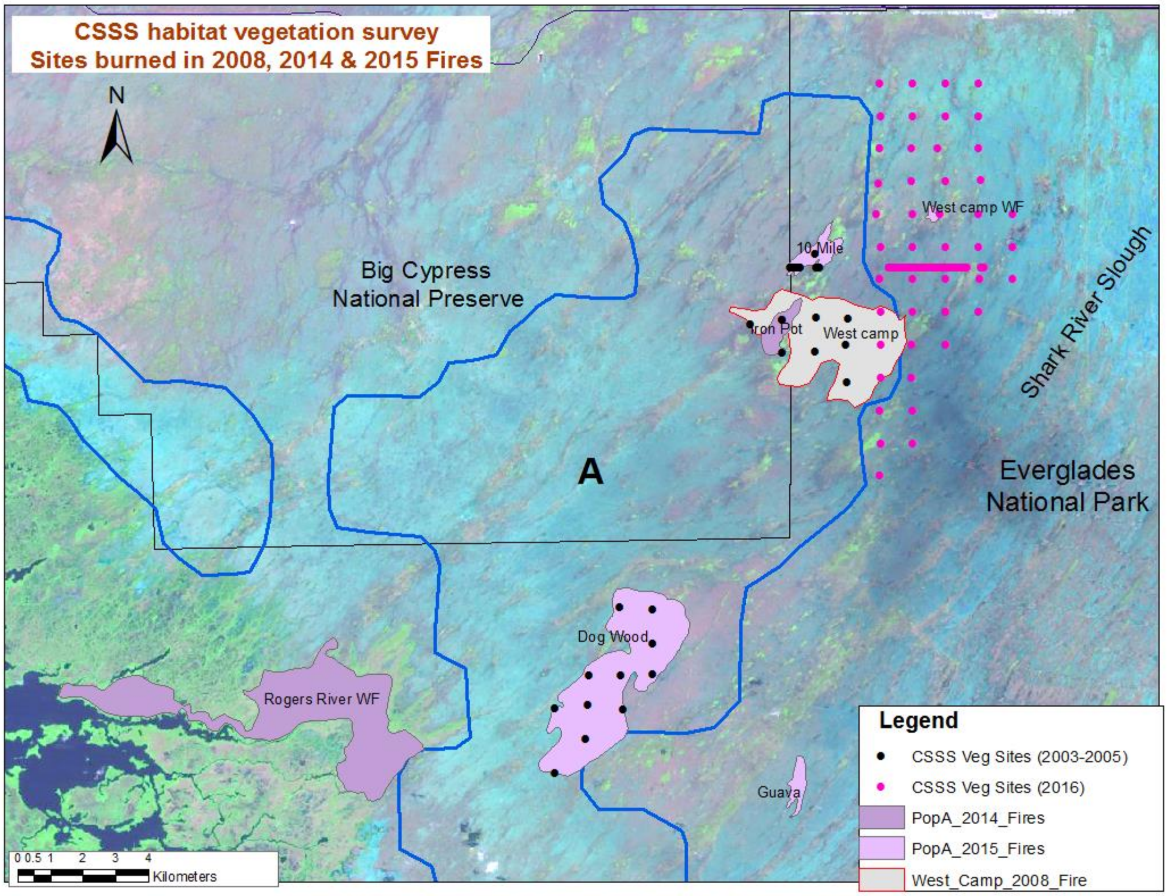

Figure 15: Vegetation survey sites sampled in 2016 in northeastern portion of sub-population A (NE-A) and 2003-2005 vegetation sites burned in recent (2008, 2014 & 2015) fires.

1.3.3 Vegetation and CSSS occurrence

In both NE-A and West-E, vegetation composition at many sites, especially at marl wet prairies, was similar to sparrow-occupied sites within the marl prairie landscape. The NMDS ordination plot of 2016-sampled sites with centroids for CSSS-P and CSSS-0, two groups of sites where the sparrow was or was not recorded in past, respectively, revealed that the wet prairie sites were closer to the centroid of CSSS-P than the marsh sites (**Figure 16**). A comparison of mean BC similarity between 2016 and 2003-2005 sites showed that in NE-A, 60% of wet prairie census sites had significantly higher mean BC similarity with CSSS-P than CSSS-0 sites. In contrast, only 7% of marsh census sites were more similar to CSSS-P than CSSS-0 sites. In West-E, 20% of marsh sites and almost all prairie sites retained vegetation composition similar to the vegetation at the sites (CSSS-P) where sparrow was recorded in early 2000s. Vegetation composition-based habitat suitability index (VHSI) also was significantly higher (Mann-Whitney test: $p < 0.001$) in wet prairie sites than marsh sites in both areas (**Figure 17**).

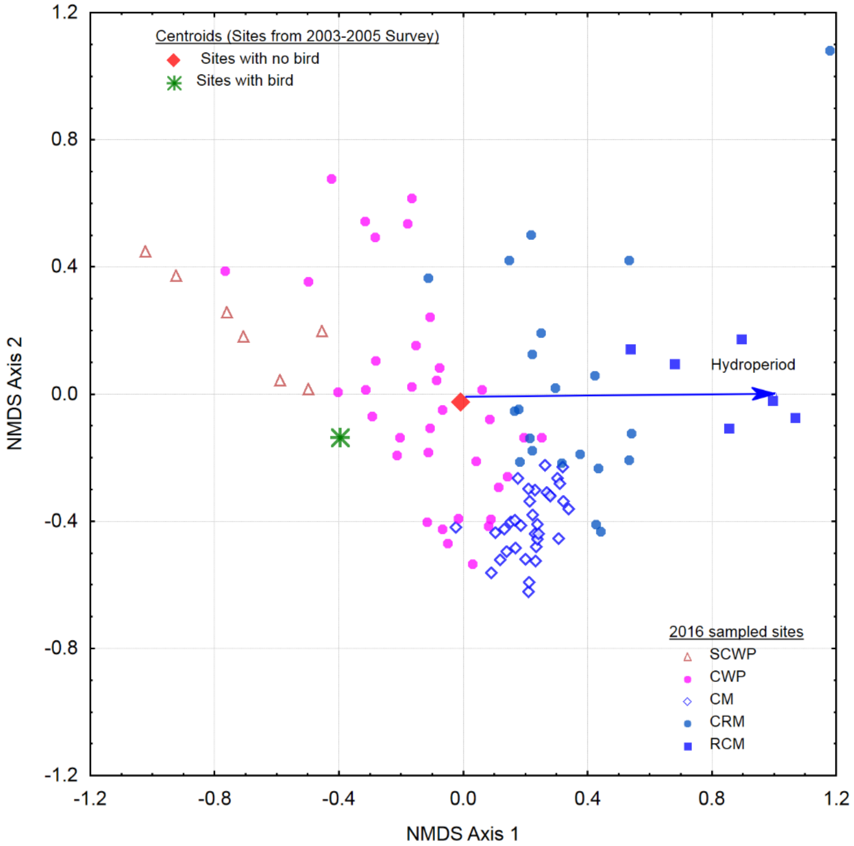

Figure 16: Scatterplot of site scores from 3-axis non-metric multidimensional (NMDS) ordination based on relative cover at 103 2016-sampled sites and 608 census sites sampled over three years between 2003 and 2005. The 2003-2005 sites where sparrow census was done over three years prior to vegetation sampling were grouped into two group, CSSS-P and CSSS-0, and their centroids are plotted here. Vegetation types for 2016-sampled sites were identified through hierarchical agglomerative cluster analysis with Bray-Curtis dissimilarity and flexible beta method.

In both NE-A and West-E, scaled SND Index, an indicator of relative occurrence of CSSS, was calculated from vegetation-inferred hydroperiod of the study sites using skewed normal distribution model parameters derived from the frequency of sparrow occurrence in relation to vegetation-inferred hydroperiod observed in 2003-2005 study (**Figure 18**). As expected, sparrow occurrence index was higher in wet-prairie sites than in marsh sites. But, surprisingly the inferred-hydroperiod based index for both wet prairie and marsh sites in NE-A was higher than West-E. Both the vegetation composition-based and inferred hydroperiod-based suitability index were fairly well correlated (**Figure 19**), especially separately within NE-A or West-E. In NE-A, the inferred hydroperiod-based index was higher in western and central area where the wet prairie vegetation is notably present, whereas in the area further east near Tram road and in the northern portion, close to Tamiami Trail, had low scaled SND index (**Figure 20**). Spatial pattern of suitability index in this area matches with the recent observation of sparrow occupancy. Since 2010, sparrows have been sighted at one or more of the seven sites in the area of high suitability index (**Figure 21a**). In contrast, even though the sites in West-E had relatively low scaled SND index, sparrows had also been regularly observed at one or more of these sites (**Figure 21b**).

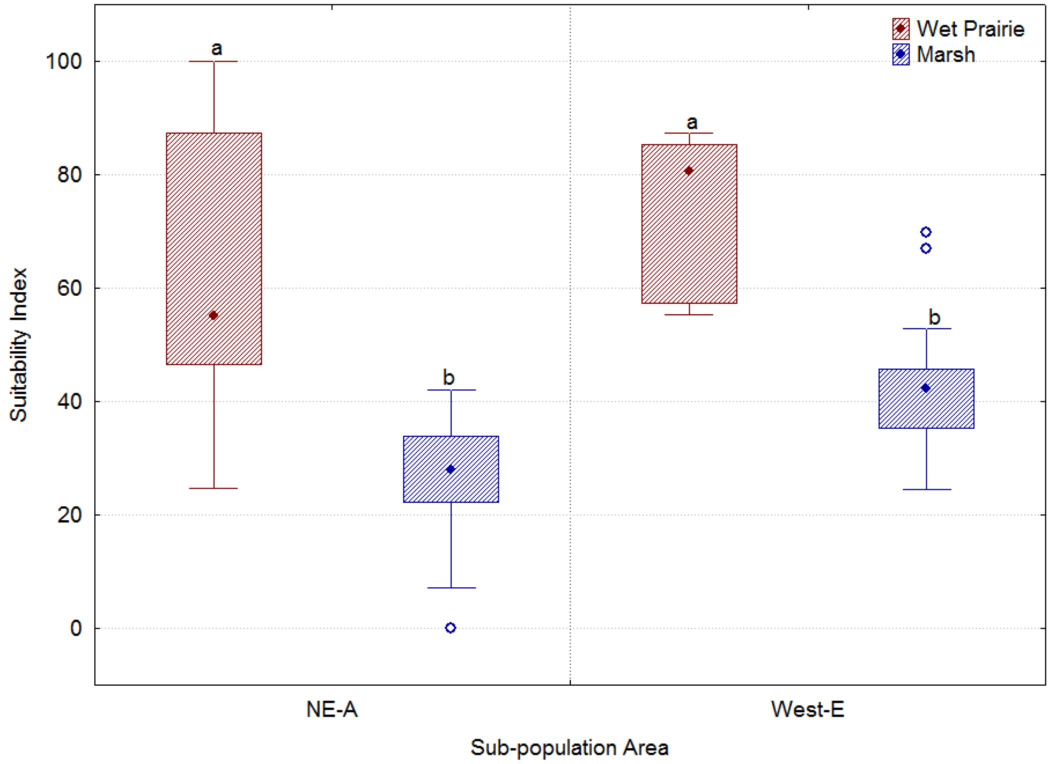

Figure 17: Box-plot showing the vegetation composition-based habitat suitability index in marl wet prairie and marsh sites in both NE-A and West-E.

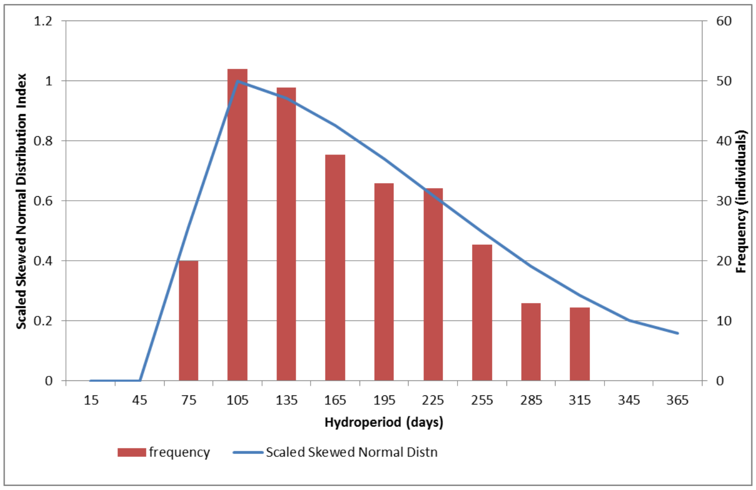

Figure 18: Skewed normal distribution curve fitted to the frequency of CSSS occurrence along vegetation-inferred hydroperiod (bin = 30 days) predicted for the census sites sampled over three years (2003-2005).

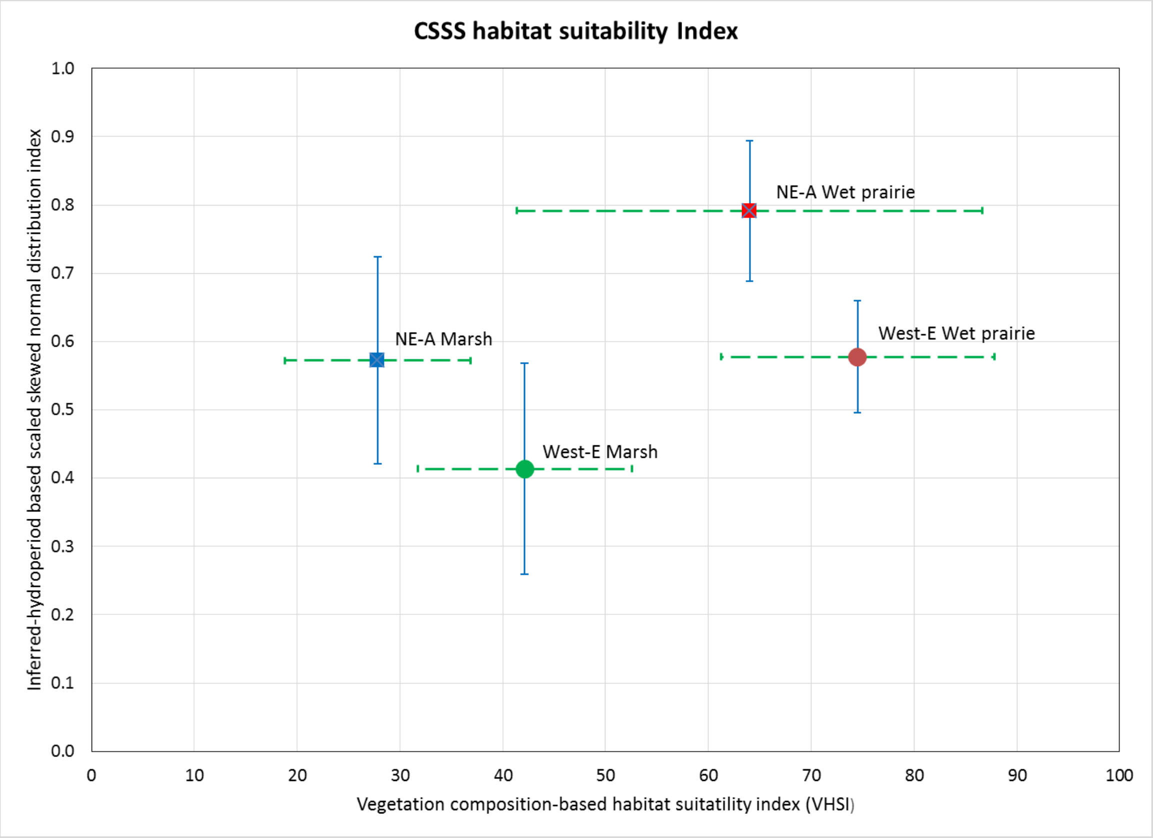

Figure 19: Mean (± SD) vegetation composition-based habitat suitability index (VHSI) and vegetation-inferred hydroperiod-based scaled skewed normal distribution (SND) index of CSSS occurrence at wet prairie and marsh vegetation sites sampled in 2006 in NE-A and West-E.

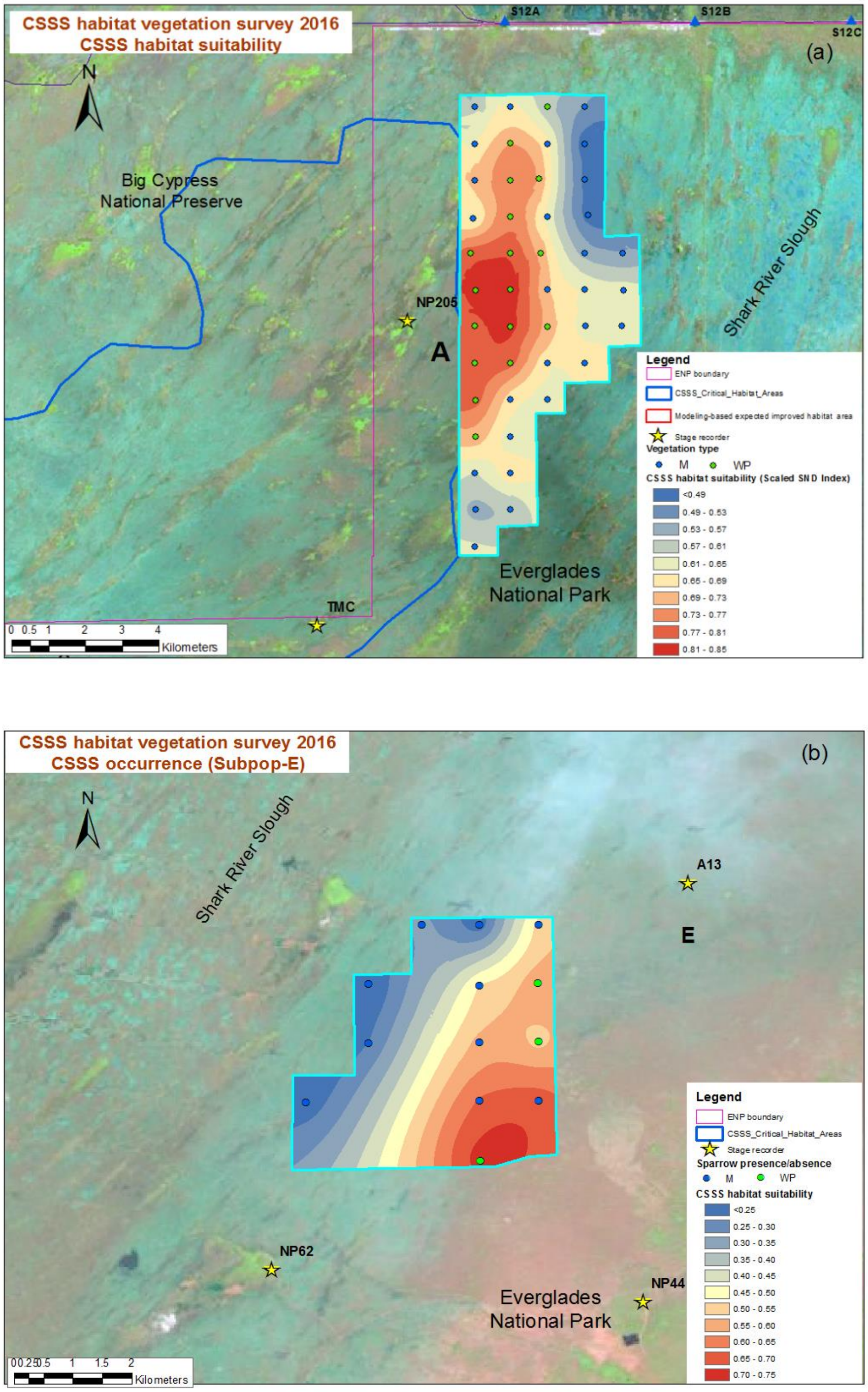

Figure 20: CSSS habitat suitability map based on scaled skewed normal distribution (SND) index predicted from vegetation-inferred hydroperiod at 2016-sampled sites in (a) NE-A, and (b) West-E, using skewed normal distribution model. The model was developed from sparrow survey results for three years prior to vegetation sampling and vegetation inferred hydroperiod at the sites in the vegetation survey network sampled over three years (2003-2005).

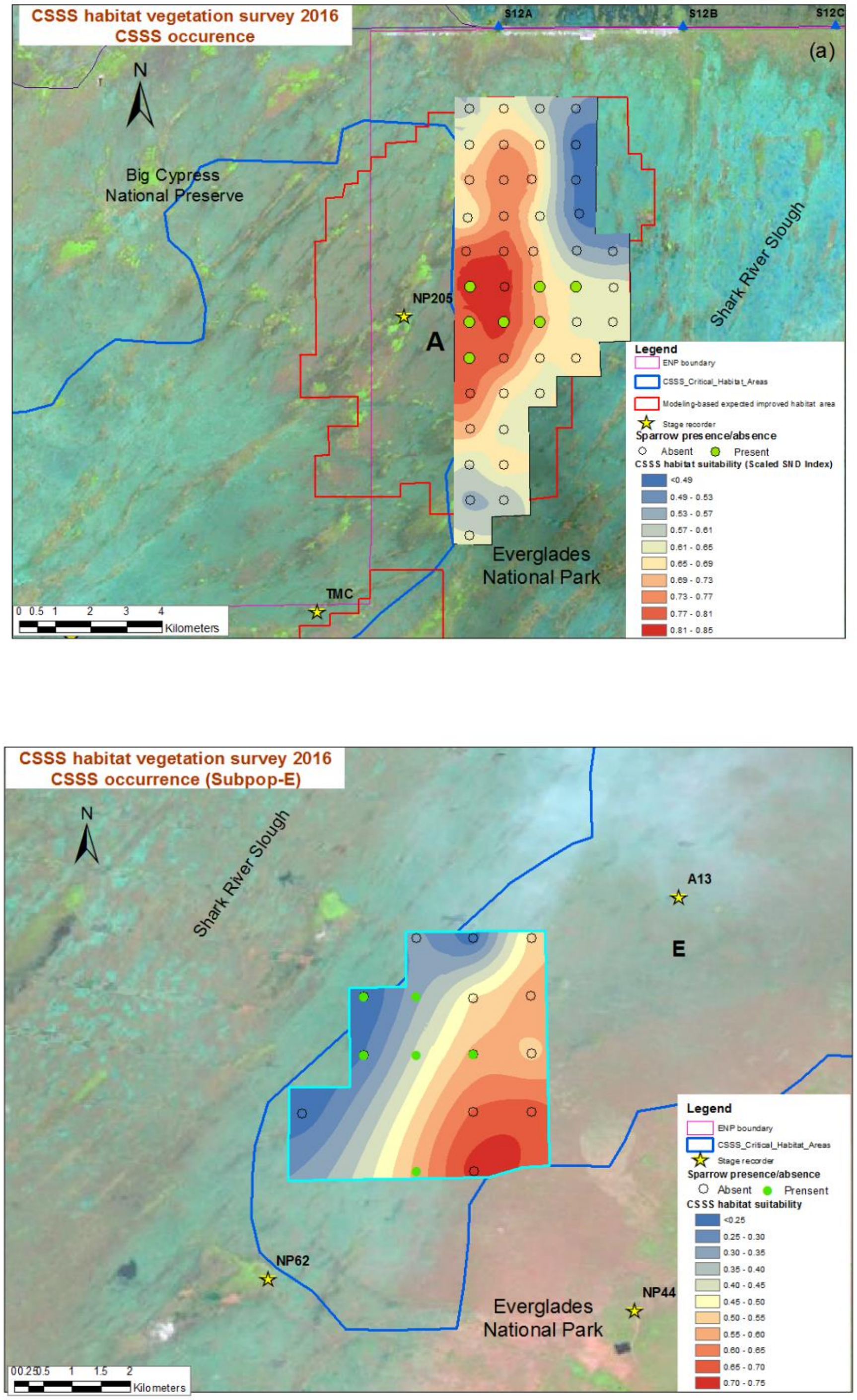

Figure 21: Map showing the sites where sparrows were observed since 2010 overlaid on scaled skewed normal distribution (SND) index surface predicted from vegetation-inferred hydroperiod at 2016-sampled sites in (a) NE-A and (b) West-E.

1.3.4 Use of LiDAR data

The airborne laser altimetry technology, LiDAR (Light Detection And Ranging) is capable of providing high resolution topographic data. In addition, it also has potential to differentiate morphological features on the land surface, such as structures in urban area, canopy heights in the forest, etc. Florida Everglades National Park LiDAR Pilot project, implemented in spring 2016, covered a significant portion of CSSS sub-population E habitat, where we had ground elevation and vegetation height data from 737 and 2,610 locations, respectively. A comparison between LiDAR-derived topographical data (Riegl-Green) and field survey or EDEN-based ground elevation data revealed that mean elevation from LiDAR DEM was 11.88 cm higher than the value obtained in the field (**Figure 22**). The differences in ground elevation from these two sources ranged between -27.7 cm and 57.6 cm. However, both LiDAR DEM-derived and field ground elevation data were moderately (R^2 = 0.46, RMSE = 16.3) correlated. When 5% of extreme differences were removed, the relationship slightly improved (R^2 = 59, RMSE = 13.9).

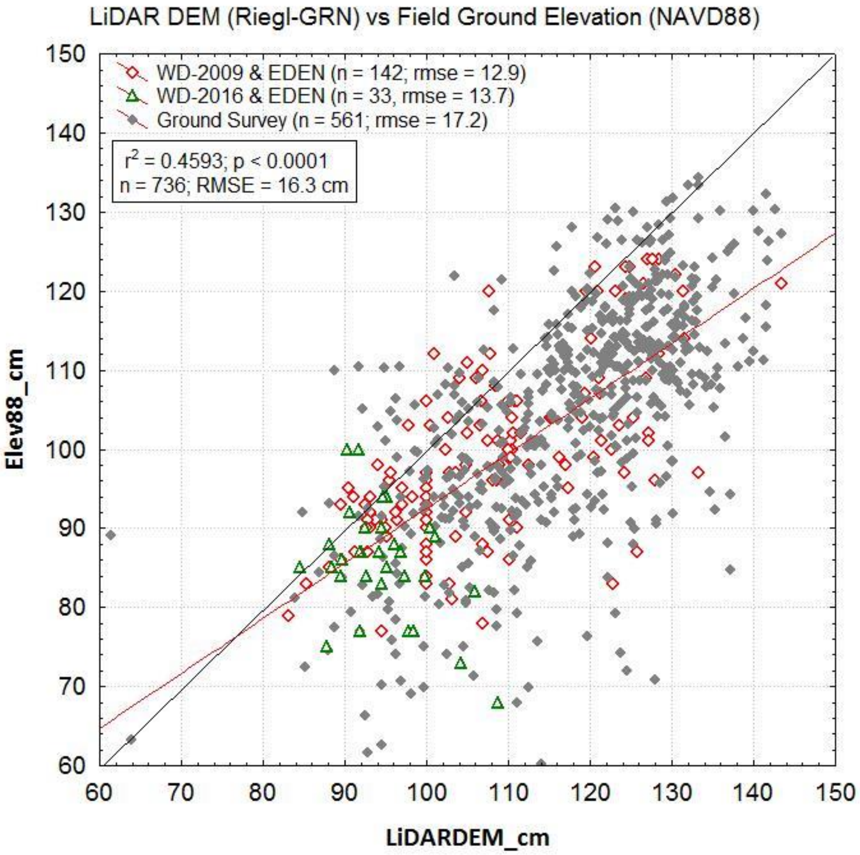

Figure 22: LiDAR DEM (digital elevation model)-derived topographic data vs. ground elevation obtained in the field by surveying or a combination of field measurements of water depths and EDEN (Everglades Depth Estimation Network) water surface elevation.

Ground elevation in the field was obtained by two different methods; a) topographic survey, and (b) a combination of field measurements of water depths and EDEN water surface elevation. For 175 points, where ground elevation was based on water depths (WD), the mean difference in elevation between LiDAR-DEM and field water depth-based elevation was 8.8 cm, and it ranged from -12.4 to 48.8 cm. However, the mean difference in elevation between LiDAR DEM and field survey data was relatively high, 12.8 cm. The differences at those sites ranged between -27.7 and 57.6 cm. The survey sites are on a 5 km transect of which most of the sites are in the eastern part of the sub-population where topographic variation is probably high due to presence of sinkholes in the rocky glades.

Unlike the ground elevation, measured vegetation height did not show any relation with the LiDAR canopy height. LiDAR-derived vegetation height (DSM minus DEM) was consistently low (mean value 7.4 cm), as most of the values (~88%) were <15 cm, ranging between -0.8 to 310 cm (**Figure 23**). In contrast, mean (±SD) vegetation height measured in the field was 63.6 cm (± 20.5).

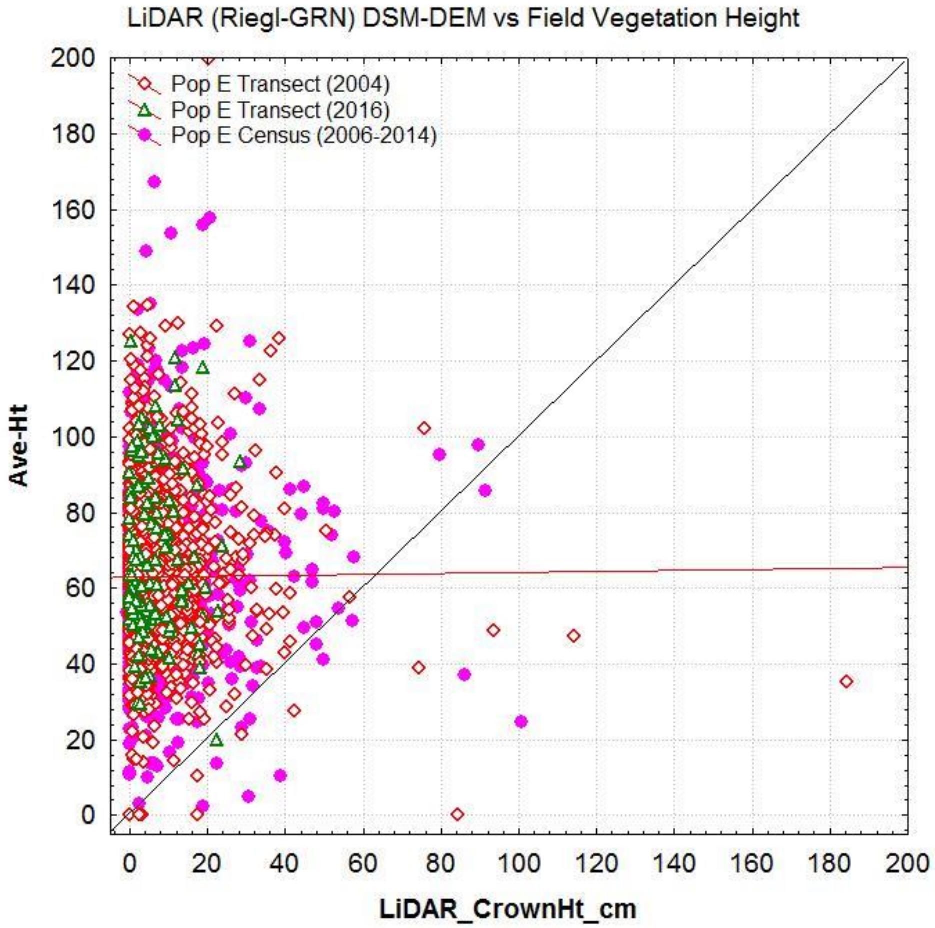

Figure 23: Scattered plot of LiDAR derived crown height (DSM-DEM) vs. vegetation height measured in the field. LiDAR data were obtained in spring 2016. Vegetation height data were gathered in the field between 2004 and 2009 (2,548 sub-plots) or in 2016 (90 sub-plots).

1.4 Discussion

In the Everglades, spatio-temporal variation in vegetation composition and structure tracks the changes in environmental drivers, primarily the hydrologic characteristics. Hydrology is considered as the main driver of the Everglades ecosystem and the ecological entities within it. Thus, an alteration in hydrologic conditions is directly reflected also in plant community characteristics. This study reveals that existing vegetation composition in marl prairie landscape reflects the recent changes in hydrologic conditions, partly resulted from the water management activities implemented for improving CSSS habitat conditions in the western marl prairies.

In some wetlands, even small hydrological variations can result in major changes in plant community composition and animal habitat, occasionally leading to habitat degradation. Hydrological alterations have been considered as a major cause of habitat degradation in wetlands, including floodplains and other wetland types (Toth et al. 1998; Dudgeon 2000; Acreman et al. 2007). Thus, restoration activities that would result in modification of hydrologic characteristics are considered a crucial step in habitat restoration (Acreman et al. 2007). In the Everglades, where preferred habitat of threatened or endangered species were lost or degraded by extreme or multi-decadal practice of hydrologic alterations (Nott et al. 1998; Jenkins et al. 2003; Bennetts et al. 2002), a number of restoration activities were initiated in 2000 (USACE 1999). These restoration efforts, which involve adaptive water management activities, would also result in modification of hydrological conditions. Guided by the 1999 CSSS Biological Opinion (USACE 1999, USFWS 2002), several water management activities under Interim Operation Plan (IOP) were directed towards improvement of areas of sparrow habitat that had deteriorated due to extreme water conditions before the late 1990s. In this regard, since 2002 regulatory schedules have been imposed for water deliveries through the S-12s structures. Those regulations on water deliveries caused consistently low water levels at NP-205 and nearby areas for several years, resulting in a less hydric vegetation type in the northeastern part of sub-population A (Sah et al. 2011, 2015). Such changes in the vegetation composition was probably the primary reason for sparrow occupancy, though still in low numbers, concentrated in that part of sub-population A in recent years. The presence of wet prairie vegetation at many sites in the present study also seems to be the result of the same restriction on water deliveries in that region, as most of the sites are within the 6 km radius from the NP-205. The farthest sites to the east of NP-205 still had relatively long hydroperiod and the marsh vegetation.

Since 2000, several restoration activities associated with Comprehensive Everglades Restoration Plan (CERP) and its recently outlined components, such as Everglades Restoration Transition Plan (ERTP) and Central Everglades Planning Project (CEPP) are underway (USACE 2011; USACE 2014). These restoration projects will continue to impact marl prairie on both sides of the Shark River Slough. As observed in this study, presence of suitable habitat in some portion of NE-A, the area northeast of the existing habitat of sub-population, supports the notion that the area must have dried in recent years. Recent modeling carried out using Regional Simulation Model (RSM) tool to evaluate the potential impact of ERTP also has shown that marl prairies in the eastern portion of CSSS sub-population A will be relatively dry (USCACE 2011, 2014; USFWS 2016). The reason for such a change in marl prairie habitat conditions can be related to the planned management activities described in CEPP. During CEPP planning, the Refined Recommended Plan (i.e. Alternative 4R2) has been considered the best alternative in comparison to the existing condition baseline (ALT EC) (USACE 2014). In this recommended scenario, flow connectivity between Water Conservation Areas 3A and 3B will be restored and water will be allowed to flow eastward and southward to the Park (USACE 2014), potentially resulting in less water in the prairies west of Shark River Slough. Under that management scenario, the recently observed trend of vegetation change towards a drier type may be expected to continue within that area.

In contrast to NE-A, the area in the western portion of sub-population E (West-E) was much wetter, and marsh vegetation is dominant in this area. This is evidenced also from our finding that scaled SND index for CSSS occurrence based on vegetation-inferred hydroperiod was relatively low in this area (**Figure 18**). The sub-population E habitat is within the eastern marl prairies where the S332B and S332C pump structures deliver water from the L31N canal into a series of inter-connected detention ponds. In these areas, both the overflow above a fixed-crest weir and subsurface seepage from the pond to adjacent marl prairies in ENP have helped to control seepage back to the canal and to protect nearby sparrow habitat from further deterioration (USACE 2007). In recent years, vegetation in areas adjacent to the canal has shown sign of shifting towards a more mesic type (Sah et al. 2011, 2015), possibly improving habitat conditions for the CSSS, an outcome also expressed by USFWS in their 2016 biological opinion for ERTP (USFWS 2016). However, West-E sampled in 2016 are > 5 km far from the boundary. Thus, the observed wet conditions and associated vegetation in that area do not seem to have been impacted by the seepage from retention ponds. Instead, the area is close to the Shark River Slough, and thus is probably impacted by the increased flow in the Slough. During more than 50% of years between 1992 and 2016, hydroperiod at all but three sites in this area were >240 days. Despite the sites being relatively wet and having low scaled-SND index for CSSS occurrence, sparrows had been frequently observed during the helicopter survey in this area (**Figure 21b**). The reason could be the vegetation at some sites is still in transition, and has patches of prairie vegetation. In fact, 60% of the sites had muhly grass (*Muhlenbergia capillaris* subsp. *filipes*), bluestem (*Schizachyrium rhizomatum*), though they had low cover. In addition, the vegetation composition of relatively wet type observed in sub-population E in this study may also be the result of unusually high water condition in the spring of 2016. The other reason for sparrow occupancy in this area could be also the nature of sparrow itself. The sub-population E is the 2nd largest and stable sub-population of sparrows in ENP. The CSSS is a territorial species, and in large population, they may tend to occupy also the marginal habitat. In contrast, in a small population, they remain confined to the most favorable part of the habitat range. Before 1993, when sub-population A was the largest sub-population, sparrows there also were occupying relatively wide range of vegetation types than they occupy in recent years. In sub-population D also, sparrow study at the finer scale than helicopter survey has shown that a small number of sparrows is confined on only high ground that has *Cladium* mix-prairie or *Schoenus* wet prairie (Virzi & Davis, 2014, 2015; Sah et al. 2016).

In the marl prairie landscape, where vegetation is adapted to 3-8 months of hydroperiod (Ross et al. 2006), a normal dry season is essential for forbs as well as major perennial graminoids such as muhly grass (*Muhlenbergia capillaris* subsp. *filipes*), bluestem (*Schizachyrium rhizomatum*) and black-top sedge (*Schoenus nigricans*). In sub-population A, high water conditions in 1993 and 1995 during the traditional dry season caused vegetation to shift from muhly and bluestem-dominated to sawgrass-dominated, resulting in destruction of the sparrow habitat (Nott et al. 1998; Jenkins et al. 2003). The occurrence of such events contributed to implementation of restricted delivery schedules on S12s resulting in an improvement in habitat conditions in recent years. However, during the winter and spring of 2016, unusually high water conditions were also observed in marl prairies throughout the Everglades, with water levels much higher (up to 50 cm above ground) in sub-populations E and F than in A. While such an unusual high water level during the breeding season had a direct impact on sparrow nesting success, it might have also affected vegetation composition. Species richness in those areas was much lower than in an average year. The intensity and duration of effects that this extreme event will have on vegetation structure and composition in the coming years is uncertain, but has the management implications. Any level of flooding in the spring of 2017 may accentuate the adverse impact of 2016 event on both the sparrows and their habitat.

Short hydroperiod marl prairie burns frequently. However, the study area in both NE-A and West-E have not burned for more than twenty-five years. Within NE-A, there was a fire (West Camp WF Fire) in July 2015, but it burned only 12.7 ha. Thus, it did not have widespread impact on the vegetation pattern that we observed in our study. However, in the same month of 2015, two other fires, named as 10 Mile (Fire # 150049) and Dog Wood (Fire # 150050), burned 1,121 and 105 ha areas in sub-population A, west and southwest of 2016 study area. Similarly, in 2014, one fire (Iron Pot; Fire # 140030) burned 94 ha of the sub-population A. These fires might have also affected the vegetation in that area. In fact, these fires burned 10, 7 and 2 sites, respectively in the existing CSSS vegetation-monitoring network. The Dog Wood fire, though relatively small, burned seven sites; one census and six transect sites. Before these fires, the transect sites had been sampled three times and the census sites sampled twice. Thus, we have data with a potential for illustrating the pre-burn vegetation dynamics in that area. These sites are among those proposed to be sampled in the spring 2017, almost two years after fire, under the ENP-funded project. Regular monitoring of these burned sites at least up to 5-6 years after fire will help to explain vegetation responses to fire in western marl prairie.

Only a comprehensive modeling effort that includes all aspects of sparrow habitat characteristics including hydrology, herbaceous vegetation structure and composition, woody plants, time since last fire and other habitat factors can fully evaluate the suitability of an area for the Cape Sable sparrow. However, the preliminary evaluation based on vegetation composition and hydrology, especially vegetation-inferred hydroperiod, suggests that a large portion of study area in NE-A appears to be suitable habitat for CSSS. Thus, the question arises whether those areas are currently occupied or even will be occupied in the near future by sparrows for breeding. After 1992, while they occupy the eastern part of the sub-population A, not far from the area studied in 2016, since 2010, a small number of sparrows have also been observed at some sites in the study area (**Figure 21a**). Considering the relative sedentary nature of the sub-species (Walters et al. 2000; Lockwood et al. 2001), the spatial shift in habitat range is likely to occur only in adjoining areas. In the past, there were instances of sparrows utilizing different areas, even outside the current range of its occurrence (Stimson 1956; Walters et al. 2000). For instance, between late 1920s and mid-1950s, it was frequently sighted in a diverse range of habitat, including brackish marshes, *Spartina*-dominated prairies, and open savannah with fresh water species, mostly located southwest of Pinecrest and to the west and south of Ochopee (Stimson 1956). In those areas, however, sparrows are currently absent. Since the initial comprehensive survey of sparrow population in 1981, together with a sharp decline in population or even complete disappearance of sparrow from some areas, there has also been a shift in sparrow range over time (Post and Greenlaw

2000). Such a shift was observed in sub-population A in 1992, when there were more sparrows in the northeastern portion of the area than a decade earlier (Pimm et al. 2000). Thus, it is likely that if the area to the northeast of sub-population A sampled in this study continue to improve in habitat quality, as is predicted by recent modeling (USACE 1914; USFWS 2016), that area may support a breeding sparrow population.

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Appendix

Appendix 1: List of CSSS vegetation monitoring sites sampled in 2016. Vegetation types are based on Vegetation type at each site was identified through cluster analysis of species cover values at 710 sites, including 607 census sites sampled in three years (2003-05).

Pop	Site type	X_NAD83	Y_NAD83	Site ID	VegtypeID	Vegetation type
A	Census	517114	2847018	A-31-01	CM	*Cladium* Marsh
A	Census	518085	2847018	A-31-02	CM	*Cladium* Marsh
A	Census	519091	2847019	A-31-03	CWP	*Cladium* Wet Prairie
A	Census	520109	2847017	A-31-04	CM	*Cladium* Marsh
A	Census	517120	2846011	A-31-05	CRM	*Cladium Rhynchospora* Marsh
A	Census	518085	2846014	A-31-06	CWP	*Cladium* Wet Prairie
A	Census	519091	2846013	A-31-07	CM	*Cladium* Marsh
A	Census	520109	2846013	A-31-08	CM	*Cladium* Marsh
A	Census	517113	2845023	A-31-09	CM	*Cladium* Marsh
A	Census	518084	2845023	A-31-10	CWP	*Cladium* Wet Prairie
A	Census	518868	2845050	A-32-01	SCWP	*Schizachyrium* Wet Prairie
A	Census	520111	2845029	A-32-02	CM	*Cladium* Marsh
A	Census	517068	2843969	A-32-03	CRM	*Cladium Rhynchospora* Marsh
A	Census	518084	2844020	A-32-04	SCWP	*Schizachyrium* Wet Prairie
A	Census	519092	2844020	A-32-05	CM	*Cladium* Marsh
A	Census	520189	2844077	A-32-06	CM	*Cladium* Marsh
A	Census	517011	2843030	A-32-07	SCWP	*Schizachyrium* Wet Prairie
A	Census	518085	2843035	A-32-08	CWP	*Cladium* Wet Prairie
A	Census	518917	2843027	A-32-09	CWP	*Cladium* Wet Prairie
A	Census	520117	2843038	A-32-10	CM	*Cladium* Marsh
A	Census	521131	2843034	A-33-01	CM	*Cladium* Marsh
A	Census	517130	2842031	A-33-02	CWP	*Cladium* Wet Prairie
A	Census	518093	2842034	A-33-03	CWP	*Cladium* Wet Prairie
A	Census	519092	2842034	A-33-04	CRM	*Cladium Rhynchospora* Marsh
A	Census	520109	2842034	A-33-05	CRM	*Cladium Rhynchospora* Marsh
A	Census	521164	2842011	A-33-06	CRM	*Cladium Rhynchospora* Marsh
A	Census	517113	2841044	A-33-07	CWP	*Cladium* Wet Prairie
A	Census	518085	2841043	A-33-08	SCWP	*Schizachyrium* Wet Prairie
A	Census	519092	2841043	A-33-09	CWP	*Cladium* Wet Prairie
A	Census	520130	2841045	A-33-10	CRM	*Cladium Rhynchospora* Marsh
A	Census	521130	2841044	A-34-01	CM	*Cladium* Marsh
A	Census	517117	2840041	A-34-02	SCWP	*Schizachyrium* Wet Prairie
A	Census	518085	2840041	A-34-03	CWP	*Cladium* Wet Prairie
A	Census	519091	2840041	A-34-04	CRM	*Cladium Rhynchospora* Marsh
A	Census	520108	2840040	A-34-05	CM	*Cladium* Marsh
A	Census	517144	2839040	A-34-06	CWP	*Cladium* Wet Prairie

Pop	**Site type**	**X_NAD83**	**Y_NAD83**	**Site ID**	**VegtypeID**	**Vegetation type**
A	Census	518084	2839043	A-34-07	CM	*Cladium* Marsh
A	Census	519091	2839042	A-34-08	CRM	*Cladium Rhynchospora* Marsh
A	Census	517137	2838050	A-34-09	CWP	*Cladium* Wet Prairie
A	Census	518084	2838044	A-34-10	CM	*Cladium* Marsh
A	Census	517143	2836055	A-35-01	CM	*Cladium* Marsh
A	Census	517113	2837044	A-35-02	CM	*Cladium* Marsh
A	Census	517114	2835057	A-35-03	CM	*Cladium* Marsh
A	Census	518085	2837046	A-35-04	CM	*Cladium* Marsh
A	Census	518085	2836051	A-35-05	CM	*Cladium* Marsh
E	Census	526360	2819343	E-07-01	CRM	*Cladium Rhynchospora* Marsh
E	Census	525365	2819344	E-07-02	CRM	*Cladium Rhynchospora* Marsh
E	Census	524388	2819343	E-07-03	CM	*Cladium* Marsh
E	Census	526347	2818355	E-07-04	CWP	*Cladium* Wet Prairie
E	Census	525363	2818304	E-07-05	CRM	*Cladium-Rhynchospora Marsh*
E	Census	523483	2818338	E-07-07	RCM	*Rhunchospora Cladium* Marsh
E	Census	526360	2817359	E-07-08	CWP	*Cladium* Wet Prairie
E	Census	525365	2817357	E-07-09	CRM	*Cladium-Rhynchospora Marsh*
E	Census	523483	2817339	E-07-10	CRM	*Cladium Rhynchospora* Marsh
E	Census	526362	2816361	E-08-01	CM	*Cladium* Marsh
E	Census	525366	2816359	E-08-02	CRM	*Cladium-Rhynchospora Marsh*
E	Census	525368	2815347	E-08-03	CWP	*Cladium* Wet Prairie
E	Census	522418	2816328	E-08-04	RCM	*Rhunchospora Cladium* Marsh
A	Transect	517365	2841401	TA-90100	SCWP	*Schizachyrium* Wet Prairie
A	Transect	517465	2841401	TA-90200	SCWP	*Schizachyrium* Wet Prairie
A	Transect	517565	2841401	TA-90300	CWP	*Cladium* Wet Prairie
A	Transect	517665	2841401	TA-90400	CWP	*Cladium* Wet Prairie
A	Transect	517765	2841401	TA-90500	CM	*Cladium* Marsh
A	Transect	517865	2841401	TA-90600	CWP	*Cladium* Wet Prairie
A	Transect	517965	2841401	TA-90700	CRM	*Cladium Rhynchospora* Marsh
A	Transect	518065	2841401	TA-90800	CWP	*Cladium* Wet Prairie
A	Transect	518165	2841401	TA-90900	CWP	*Cladium* Wet Prairie
A	Transect	518265	2841401	TA-91000	CWP	*Cladium* Wet Prairie
A	Transect	518365	2841401	TA-91100	CWP	*Cladium* Wet Prairie
A	Transect	518465	2841401	TA-91200	CWP	*Cladium* Wet Prairie
A	Transect	518565	2841401	TA-91300	CWP	*Cladium* Wet Prairie
A	Transect	518665	2841401	TA-91400	CWP	*Cladium* Wet Prairie
A	Transect	518765	2841401	TA-91500	CWP	*Cladium* Wet Prairie
A	Transect	518865	2841401	TA-91600	CWP	*Cladium* Wet Prairie
A	Transect	518965	2841401	TA-91700	CWP	*Cladium* Wet Prairie
A	Transect	519065	2841401	TA-91800	CWP	*Cladium* Wet Prairie
A	Transect	519165	2841401	TA-91900	CRM	*Cladium Rhynchospora* Marsh
A	Transect	519265	2841401	TA-92000	CWP	*Cladium* Wet Prairie

Pop	**Site type**	**X_NAD83**	**Y_NAD83**	**Site ID**	**VegtypeID**	**Vegetation type**
A	Transect	519365	2841401	TA-92100	CWP	*Cladium* Wet Prairie
A	Transect	519465	2841401	TA-92200	CM	*Cladium* Marsh
A	Transect	519565	2841401	TA-92300	CM	*Cladium* Marsh
A	Transect	519665	2841401	TA-92400	CM	*Cladium* Marsh
A	Transect	519765	2841401	TA-92500	CRM	*Cladium Rhynchospora* Marsh
A	Transect	520165	2841401	TA-92900	CM	*Cladium* Marsh
A	Transect	520265	2841401	TA-93000	CM	*Cladium* Marsh
E	Transect	528602	2819780	TE-5200	CM	*Cladium* Marsh
E	Transect	528403	2819766	TE-5400	CM	*Cladium* Marsh
E	Transect	528203	2819753	TE-5600	CM	*Cladium* Marsh
E	Transect	528004	2819740	TE-5800	CWP	*Cladium* Wet Prairie
E	Transect	527804	2819726	TE-6000	CWP	*Cladium* Wet Prairie
E	Transect	527605	2819713	TE-6200	CM	*Cladium* Marsh
E	Transect	527405	2819699	TE-6400	RCM	*Rhunchospora Cladium* Marsh
E	Transect	527206	2819686	TE-6600	CWP	*Cladium* Wet Prairie
E	Transect	527006	2819673	TE-6800	CRM	*Cladium Rhynchospora* Marsh
E	Transect	526806	2819659	TE-7000	CM	*Cladium* Marsh
E	Transect	526607	2819646	TE-7200	CWP	*Cladium* Wet Prairie
E	Transect	526407	2819633	TE-7400	RCM	*Rhunchospora Cladium* Marsh
E	Transect	526208	2819619	TE-7600	RCM	*Rhunchospora Cladium* Marsh
E	Transect	526008	2819606	TE-7800	CRM	*Cladium Rhynchospora* Marsh
E	Transect	525809	2819593	TE-8000	RCM	*Rhunchospora Cladium* Marsh
E	Transect	525609	2819579	TE-8200	CRM	*Cladium Rhynchospora* Marsh
E	Transect	525210	2819553	TE-8600	CM	*Cladium* Marsh
E	Transect	524811	2819526	TE-8800	CRM	*Cladium-Rhynchospora Marsh*