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Effect of Hydrologic Restoration on the Habitat of The Cape Sable Seaside Sparrow

2008 – Final Report

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Table of Contents

Summary

This document summarizes the activities that were accomplished in 2008, the sixth year of the research project "Effect of hydrologic restoration on the habitat of the Cape Sable seaside sparrow", a collaborative effort among the US Army Corps of Engineers, Everglades National Park, Florida International University, and the US Geological Survey (Florida Integrated Science Center). The major activities in 2008 included field work, data analysis, and presentations. Jay Sah presented the results of 6th year field work at the Cape Sable seaside sparrow (CSSS) Fire Meeting 2008, held on December 2-3 at the Krome Center, Homestead, Florida. In the same meeting, Mike Ross presented results from a related USFWS-funded project on encroachment pattern of woody plants in Cape Sable seaside sparrow habitat.

We commenced vegetation sampling on March 31 and continued through June 6, 2008. During this period, we re-sampled 165 census and 10 transect sites, including 37 sites that were burned either in 2005, 2006 or 2007. In general, 2008 sampling sites other than the 37 burned sites were initially sampled in either 2004 or 2005; burned sites were re-visited at a shorter interval in order to learn more about vegetation recovery after fire and to assess the effects of the fire-hydrology interaction on vegetation. Structural and compositional vegetation parameters recorded at both unburned and burned transect and census sites in 2008 were as the same as utilized in the first five years of the study. In 2008, we also tagged all the woody plants (>1m height) present in the 5x60 m plot. In addition to the vegetation sampling, we also re-visited 62 of 72 vegetation survey sites that were burned in four different fires during the 2008 fire season, where we recorded the status of the site expressed as % burn. These observations will help us to schedule for monitoring of the vegetation recovery at those sites. During the rest of the year, data were entered, thoroughly checked and analyzed.

We used a non-metric multidimensional scaling (NMS) ordination to visualize temporal change in vegetation composition, and Analysis of Similarity (ANOSIM), a nonparametric multivariate analytical procedure, to quantify differences in vegetation composition between two sampling years at unburned sites, and among different groups of sites at burned sites. Sites that hadn't burned during the four year period before the 2008 survey were considered to be unburned. Vegetation data for unburned sites were also analyzed separately for each sub-population within CSSS habitat. We considered the sites that had burned in 2005, 2006 and/or 2007 (no sites were burned in 2004) to be burned sites. Vegetation change at the burned sites was analyzed in relation to time since last fire and interaction between fire and hydrology. Additionally, we performed spatial analysis on soil data to explore their relationships with hydrology and vegetation.

Vegetation composition (i.e., the relative cover of species) within CSSS habitat did not change significantly across all sub-populations, though changes in some species were apparent, and there was marginally significant change in all or portions of several populations (see below). Mean total cover and cover of major species like *Eleocharis cellulosa*, *Rhynchospora tracyi* and *Schizachyrium rihizomatum* was significantly higher in 2008 than in 2004-2005. Mean vegetation-inferred hydroperiod, i.e., the hydroperiod for a site predicted from vegetation composition using a Weighted Averaging Partial Least Square

(WAPLS) regression model developed in 2005, did not differ significantly between 2004-05 and 2008 sampling events. Nevertheless, vegetation in sub-population E had higher inferred hydroperiods in 2008 than three or four years earlier. In Sub-population A, where soil characteristics and hydrologic conditions showed strong anisotropy in spatial continuity, differences in mean vegetation-inferred hydroperiod between two surveys at the same sites also showed distinctive spatial pattern. The vegetation in the middle of the sub-population indicated a drying trend during the 3-4 year period, while vegetation in the western and southeastern corner of Area A indicated slightly wetter conditions in 2008 than 2004-2005, continuing a wetting trend observed in 2006 and 2007. This spatial pattern was consistent with mean annual water levels observed at the P34 and NP205 stage recorders in the southern and north central portions of the region; management of the S12 structures were successful in maintaining low water depths in that region, but water levels were nevertheless elevated at P34 . Across all sites, changes in wetness affected species richness, which decreased with increases in vegetation-inferred hydroperiod.

Changes in vegetation structure were also observed between 2004-2005 and 2008, including increases in total plant cover, vegetation height and above ground biomass at unburned sites. At burned sites, however, plant cover increased or decreased depending on the time since last burn and hydrologic conditions in the immediate post-burn period. The rate of annual change in vegetation cover after fire varied with vegetation type, fire history before burn, and post fire hydrology. A rise in water level associated with the passage of Hurricane Katrina immediately after an August 2005 fire killed most plants, including sawgrass culms, resulting in very low mean total plant cover (9%) even 3 years after fire. Three years after this fire, vegetation recovery remained much slower than at sites burned in the same year but not flooded during the first post-fire month. Post-fire vegetation cover also depends on the fire behavior, which is the function of weather, fuel load, fire history, hydrologic conditions at the sites. For instance, at the sites burned in 2008, the proportion of unburned patches was higher in sites with high vegetation-inferred hydroperiod.

In summary, re-survey of a sub-set of sites sampled in 2004 or 2005 revealed that vegetation composition and structure changed at some sites depending on their locations within the CSSS habitat. For instance, many sites in sub-population E, and sites in western part of sub-population A showed wetter vegetation whereas sites around NP205 showed drier vegetation in 2008 than in 2004-2005 survey. The persistence of wetter vegetation in the western part of sub-population might have limited the recovery of CSSS population in that part of its habitat. In addition, very low plant cover and a change in species composition at sites flooded after fire in 2005 and surveyed approximately 3 years after fire suggests that post-fire flooding delayed the vegetation recovery process, and also caused it to follow a different trajectory in terms of species composition. In turn, the altered course of vegetation recovery could ultimately impede the return of CSSS to those sites. Thus, re-sampling in 2008 of a sub-set of sites surveyed in 2004 or 2005, along with burned sites surveyed in 2004 and 2005, has answered some questions regarding vegetation change in response to hydrology and fire and its implications on the CSSS population. During 2009, a well-designed long-term vegetation monitoring in Mustang Corner fire in eastern Everglades and two fires in sub-population A are expected to answer related questions regarding the use of fire as a tool to restore the marl prairie habitat.

1. Introduction

Since the early 1990s, the Cape Sable seaside sparrow, a federally endangered species, has remained central to the operations of several water management structures that deliver water from Water Conservation Area 3A (WCA-3A) to the Everglades National Park, especially to the west of Shark River slough. The reason behind the chosen operational strategy was the dramatic decline of CSSS sub-population A after unprecedented high water level, caused primarily by water deliveries from WCA-3A through the S-12s during the 1993 sparrow breeding season. Later, researchers found that CSSS population respond to changes in hydrology not only directly through their nesting success or failure during the breeding season, but also indirectly mediated through vegetation change (**Nott et al. 1998**). After prolonged flooding for three years (1994-1996), most of the open marl prairies west of Shark Slough, which once supported nearly half of the Cape Sable seaside sparrow (CSSS) population, have changed to marsh vegetation. The question of immediate concern was whether the changes in water delivery schedules would reverse the habitat damage, and if so, how rapidly vegetation would respond to changes in water management operations. To address this question, the need for an appropriately scaled monitoring plan for vegetation was recognized by scientists, managers and policy makers. It was also essential that such an effort parallel and support the annual monitoring of sparrow populations that had been in place since 1992. In response, in 2002 FIU-USGS researchers initiated a vegetation study entitled "Effect of hydrologic restoration on the habitat of the Cape Sable seaside sparrow", with the goal of monitoring vegetation responses to hydrological restoration. In the initial phase of the study the objectives were to establish a vegetation monitoring network within the recent habitat of Cape Sable seaside sparrow, and to characterize the vegetation structure and composition in relation to hydrology. Since CSSS population as well as marl prairie vegetation, is also impacted by human- and lightning-ignited fires **(Curnutt et al. 1998**; **Jenkins et al. 2003**), particularly in the eastern Everglades, the study also addressed the characterization of vegetation in relation to time since last fire and burn frequency.

After producing a detailed account of spatial variation in vegetation structure and composition in relation to existing hydrologic regime, based on data from the first three years of the project (2003-2005) (**Ross et al. 2006**), our research focus shifted to address change in vegetation composition and structure in response to hydrologic alterations and fires in the marl prairie habitat. In this new phase of the study, vegetation re-sampling is directed at sites sampled for the first time in 2003-2005. However, in order to control costs while integrating the fire:hydrology:vegetation relationships more effectively, we altered the initial sampling schedule slightly. All 613 census sites, previously sampled within in a three-year period are now to be sampled within a four-year period, and 160 sites previously sampled along surveyed transects in Populations A, D, E, and F will be re-sampled in Year 5. The purpose of effectively reducing the sampling frequency for unburned plots to once in 5 years was to expand our sampling of the recovery process following fire, which we accomplish by re-sampling burned sites 1, 2 and 4 years after fire. In some situations in which we can learn much about hydrology-fire relationships, such as for a set of sites flooded immediately after fire in 2005, we sample annually during the first 4 post-fire years.

This document summarizes the activities that were accomplished in 2008, the sixth year of the research project. The major activities in 2008 included field work, data analysis, and presentations. Sampling was completed between March 31 and June 6, 2008. After processing the data in the remaining part of year, Jay Sah presented the results of 6th year field work at the Cape Sable seaside sparrow (CSSS) Fire Meeting 2008, held on December 2-3 at the Krome Center, Homestead, Florida. In the same meeting, Mike Ross presented results from a related USFWS-funded project on encroachment pattern of woody plants in Cape Sable seaside sparrow habitat. The document also includes the results from the reconnaissance of sites burned in 2008 fires.

2. Methods

2.1 Vegetation sampling

In 2008, the 6th year of field work, there was slight change in FIU sampling personnel. Lawrence Lopez joined our team, and was a member of the field crew for vegetation sampling. Erin Hanan, a graduate student at FIU who worked as a part-time research assistant in Dr. Ross' lab, frequently worked with the FIU team. Other FIU participants were the same in 2008 as in 2007. There was a change in USGS sampling team. Beyte Barrios who was part of the field crew in 2006 and 2007 was no longer with USGS in 2008. Instead, Jim Snyder recruited T. J. Hilton for vegetation sampling.

We commenced vegetation sampling on March 31 and continued through June 6, 2008. During this period, we re-surveyed 175 sites: 165 Census sites, 3 sites on Transect B, and 7 sites on Transect D. Census sites included 138 unburned and 27 burned sites, while Transect sites were all burned sites **(Figure 1)**. Sites which were not burned in the 4 years before 2008 sampling were considered to be unburned. In contrast, sites burned in 2005, 2006 and/or 2007 were considered to be burned sites. No CSSS vegetation sampling site was burned in 2004.

Unburned sites included sub-sets of sites initially sampled in either 2004 or 2005. For re-sampling purpose, 429 census sites initially sampled in those two years were grouped into 3 sub-sets scheduled to be sampled in three years instead of two to accommodate the increased sampling frequency on burned sites. In 2008 we sampled a total of 138 unburned sites, 79 first sampled in 2004 and 59 first sampled in 2005 (Table 1). Among the former group were six sites from the Cape Sable area of south-western ENP. We also sampled 37 sites burned in 2005, 2006, and 2007. For the first time, pre-burn vegetation data was available for all burned sites re-sampled in 2008, enabling us to assess vegetation recovery more precisely. Moreover, since some of these burned sites were flooded immediately after fire while others experienced delayed flooding, we could infer more about the effects of pre- and post-fire hydrology on vegetation recovery.

Vegetation re-sampling at all the census sites was done in the same months as in the 2004 and 2005 surveys, in order to assure that any change in vegetation composition between the two sampling periods would not be confounded by seasonal variation in species abundance. The only exceptions were 10 burned Transect sites that had been sampled initially in January-February. In 2008, they were re-sampled in April-May, when the census sites were sampled.

Structural and compositional vegetation parameters recorded at both unburned and burned transect and census sites in 2008 were the same as in the first five years of the study. However, 2008 was the first year in which all shrubs (woody plants > 1 m) present in the 5 x 60 m plots were tagged. Tagging will allow us to track the fate of these individuals when these plots are re-sampled next. Soon after sampling was completed, data were entered, thoroughly checked and analyzed during the remainder of the year.

Table 1: Number of sites sampled during Year 6 field season (March 31 – June 6, 2008)

Transect/ Census sites	Sub-pop	Unburned		Burned							# of sites sampled in 2008
		First-time sampled		First-time sampled				Burn year			
		2004	2005	2003	2004	2005	2006	2005	2006	2007	
Transect	B					3				3	3
	D				7			7			7
Census sites	A	48	29	1	1	1	1		2	2	81
	B	11	8	12	6	2		13		7	39
	C	1	10			2				2	13
	D	4	3	1				1			8
	E	6	4								10
	F	3	5								8
	G	6									6
Total		**138**						**37**			**175**

2.2 Analytical methods

2.2.1 Vegetation change

A non-metric multidimensional scaling (NMS) ordination was used to assess temporal change in vegetation composition between sampling years. Points in ordination space represent the sites sampled at a specific time, and the distance between points is an indicator of the underlying dissimilarity between those points. Hence, when a site is annually surveyed, the distances between successive sampling points (years) in the NMS ordination shows the magnitude of change in vegetation composition. As a distance measure for the ordination, we used Bray-Curtis dissimilarity on mean species cover averaged by site and year of sampling. However, for the ordinations of unburned sites, we relativized mean species cover by the total cover of all species present.

To examine the differences in vegetation composition between two groups, we used Analysis of Similarity (ANOSIM), a nonparametric permutation procedure (**Clarke 1993**).

This procedure is applied to a rank similarity matrix, and is recommended over the parametric test MANOVA (**Clarke and Warwick 2001**). We conducted 999 random permutations to assess the statistical significance of Global-R, a test statistic generated in ANOSIM. For the unburned sites, the groups were sampling events, i.e. initially sampled in 2004 or 2005 (hereafter termed as '2004-05') and re-surveyed in 2008. Differences in vegetation composition between successive samples were examined for all unburned sites pooled together and also separately for each sub-population within CSSS habitat. For burned sites, the groups were pre-burn, post burn and subsequent years after burn. Grouping of the burned sites on the basis of time since last fire yielded five groups: pre-burn, post-burn, and 1, 2, and 3 years after burn. Sites burned in 2004, thus representing 4 years after fire when sampled in 2008, were not present within our network. We used PRIMER Ver. 5 for NMS ordination and ANOSIM.

2.2.2 Vegetation change and hydrology

The basics of the method used to assess whether a change in vegetation composition between 2004-05 and 2008 sampling events was in response to parallel changes in hydrology during the period were similar to those used in 2006 and 2007. (**Sah et al. 2007, 2008**). The approach is similar to **Armentano et al. (2006)**, who described temporal changes in vegetation composition in response to hydrologic changes in Taylor Slough. We analyzed the differences in mean vegetation-inferred hydroperiod, i.e. the hydroperiod for a site predicted from vegetation composition using a Weighted Averaging Partial Least Square (WAPLS) regression model developed in 2005 (**Ross et al. 2006**). We estimated changes in hydroperiod from Everglades Depth Estimation Network (EDEN) hydrological data. From the EDEN website (http://sofia.usgs.gov/eden/models/water surfacemod.php), we downloaded water stage data which are available since Jan 1, 2000. We calculated hydroperiod for each hydro-year (May 1-April 30), and analyzed the differences in 3-year mean hydroperiods prior to the 2004-05 and 2008 samplings, using pair-wise t-tests. For statistical analysis, we used STATISTICA Version 7.0 (StatSoft Inc. Tulsa, OK, USA).

2.2.3 Fire, hydrology and vegetation

Our purpose in monitoring burned plots is to assess the trajectory of vegetation change after fire. In the analysis, we used non-metric multidimensional scaling (NMS) ordination to illustrate the trajectory of vegetation change over time, as we had for the unburned plots. However, in this case we calculated Bray-Curtis dissimilarities based on mean absolute cover of species averaged by site and sampling event, thereby incorporating post-fire recovery of total vegetation cover into the analysis.

Vegetation in marl prairies is believed to recover to its pre-burn conditions in 3-4 years after fire (**LaPuma et al. 2007**), but recovery is likely to follow different trajectories where post-fire hydrologic conditions differ (**Sah et al. 2008**). To examine these effects, we compared two sets of sites that were burned in May and August 2005 (May_burn and Aug_burn, respectively). May_burn sites remained unflooded for >1 month after fire, and for two months thereafter experienced a gradual increase in water level, while Aug_burn sites were flooded by more than a foot of water by Hurricane Katrina within 7 days of fire. Among

May_burn sites, however, one site (D-2500), located immediately north of an impoundment at the southwest end of Transect D, was identified as an outlier based on Bray-Curtis dissimilarity. Its status as an outlier probably resulted from denudation of the site due to prolonged flooding following the 2005 hurricanes. The elevation at D-2500 is almost 10 cm less than that at the nearest vegetation sampling site (D-2400), resulting in deeper water.

To quantify vegetation change and direction at the May_burn and Aug_burn sites before and after fire, we used trajectory analysis. Our approach was similar to the method described in **Benscoter and Vitt (2008**) However, those authors used distance in ordination space as their measure of vegetation change, while we used the raw Bray-Curtis sample-to-sample dissimilarities in species composition. **Cushman and McGarigal (2006)** followed a similar approach, but used Euclidean distances. For each site we calculated B-C dissimilarity between adjacent sampling years, i..e. Pre-burn/Year-1, Year-1/Year-2, and Year-2/Year-3, and summed them up to compute total change. We also calculated absolute change (i.e. displacement from the pre-burn condition) during the period in consideration as the B-C dissimilarity between Pre-burn and each of the subsequent sampling years after fire. One way analysis of variance (One-way ANOVA) was used to test differences in mean absolute vegetation change between May_burn and Aug_burn for each sampling year after fire.

To test whether different post-fire hydrology at May_burn and Aug_burn sites resulted in a difference in the degree of deviation from the pre-burn condition, we assessed the directionality of change by calculating the absolute change as a proportion of total change, i.e. absolute:total change ratio (**Benscoter and Vitt 2008**). A higher value of this ratio at any point of time is indicative of greater deviation from the pre-burn condition. However, high values also signify a relatively slow rate of vegetation recovery after fire. As the Year-1 vegetation survey was the first sampling after fire, we quantified vegetation recovery rate (VRR) as the rate of vegetation change after Year-1, using the formula as follows:

$$VRR_i = \frac{1}{T_i} * \frac{D_{p1} - D_{pi}}{D_{p1}} * 100\%$$

where, D_{p1} = B-C dissimilarity between pre-burn and Year-1; D_{pi} = B-C dissimilarity between pre-burn and subsequent sampling year in consideration (i = 2, 3 or so on), Ti = number of years.

2.2.4 Soil, hydrology and vegetation: Spatial Analysis

Preliminary results of soil analysis are described in the 2006-Annual report (**Sah et al. 2007**). In 2008, we performed additional analyses on soils data to examine the spatial relationship of soil characteristics with hydrology and vegetation. The soil parameters included in the analyses were total nitrogen (TN), total phosphorus (TP), soil pH, soil depth, iron (Fe), Potassium (K), inorganic carbon (IC), and organic carbon (OC). We first used principal component analysis (PCA) to reduce the dimensionality of data and to extract only meaningful factor components. Factor 1 which represented the organic carbon gradient was used to explore the spatial pattern of organic carbon and its relationship with hydrology and vegetation. For hydrologic condition of the sites, we used vegetation-inferred hydroperiod, which encompasses the characteristics of both existing vegetation and hydrologic conditions of the sites. In general, we expected that sites with vegetation that is indicative of relatively long hydroperiod and/or high plant biomass would have higher organic carbon than the sites with vegetation adapted to shorter hydroperiod and low biomass.

We used statistical software GS+ (**Robertson, 2008**) to examine the spatial patterns of soil, hydrology, and biomass in sub-population A. In particular, we wished to make inferences regarding the association of organic carbon in surface soil and the hydrologic character of standing vegetation. Out of 359 census sites for which soil data were available, 156 were in sub-population A. This area has been of much interest for researchers and managers because of the dramatic decline of sparrow population in 1993 and vegetation change that occurred in response to consistent high water levels for several years in the mid-1990's. Soil characteristics and vegetation-inferred hydroperiod were rank-transformed (**Rossi et al. 1992**), and spatial patterns were investigated by calculating omnidirectional (isotropic) semi-variograms. The semivariogram models the semivariance (i.e. one-half of the average squared difference in data values) among data pairs separated from one another by different distances, and provides information on the autocorrelation present in spatial data. Semivariogram models that gave the best fit to the data were selected based on smallest residual sum of squares (RSS). For many spatially patterned data sets, the semivariance first increases with distance between data points, and then levels off to a maximum (the *sill*) at a distance termed the *range*. Data points closer together than the range value are autocorrelated whereas points further apart are spatially independent (**Isaaks and Srivastava 1989**). The spatial variability at a distance smaller than the minimum distance between points is represented by the intercept, termed as the *nugget*. Two indices, Q value ((sill-nugget)/sill) and the range value were used to describe the spatial structure. Q value indicates the degree of spatial structure and the range value indicates the limit of spatial dependence. In addition, anisotropic semi-variograms were calculated for 0^o, 45^o, 90^o, and 135^o with 22.5^o tolerance to examine directionality in the gradients (**Rossi et al. 1992**). A lag distance (the size of the bins into which data pairs are grouped) of 1000 m was chosen.

2.3 Reconnaissance of sites burned in 2008

In 2008, significant portions of CSSS habitat in sub-populations A, E and F were burned in 4 different fires. The Mustang Corner fire, which started on May 14 and was declared out after one month on June 14, burned 15,971 ha (39,465 acre) area in the eastern Everglades. In the third week of June, the West Camp and Lime Tree fires burned a total of 1,917 ha (4,741 aces) in sub-population A, west of Shark Slough. The Radius Rod fire was relatively small, burning 387 ha (957 acres) in sub-population E during the 3rd week of July. We used GIS layers of fire perimeters provided by National Park, Fire and Aviation Division for three fires (Mustang Corner, Key West and Radius Rod) and by Big Cypress National Preserve for the Lime Tree fire to determine the CSSS vegetation sites that were within the fire boundaries. To assess post fire conditions at the vegetation monitoring sites, we visited 60 sites within the Mustang Fire and West Camp fire boundaries, and recorded the percent of burn and water depth, if any, on July 16 and 17, 2008.

3. Results and Discussions

In 2008, vegetation within the Cape Sable seaside sparrow habitat showed mixed response to natural and management-induced hydrologic changes, depending on where sites were located in the landscape and whether the sites were burned or not in the four previous years. Plots re-surveyed in 2008 included both unburned and burned sites. The sites which were not burned in the four years prior to the 2008 sampling season were considered as unburned sites. Those sites were represented in all six sub-populations, and also in the Cape Sable area, which was the primary habitat of the Cape Sable seaside sparrow a century ago. In contrast, burned sites re-sampled in 2008 were only from sub-populations A, B, C and D.

3.1 Vegetation change at unburned sites

3.1.1 Change in vegetation composition

In general, vegetation composition, expressed in terms of relative cover of species in the marshes and wet prairies within CSSS habitat, did not differ significantly between 2004-05 and 2008 surveys (**Figure 2**: ANOSIM – Global R = 0.005, p-value = 0.116). However, this stability was not maintained in all sub-populations when they were considered individually. In Sub-population A, the difference in vegetation composition between the two surveys was significant **(Table 2;** ANOSIM – R =0.018, p-value = 0.040**).** In this sub-population, however, results of the NMS ordination also revealed a difference in the direction of change in vegetation composition (**Figure 3)**. Marsh sites seemed to have become wetter, whereas wet-prairie sites showed mixed results. Since these marsh and prairie are not randomly distributed within the area (see below), vegetation may be responding to spatially variable hydrologic changes in recent years.

Within the recent habitat of the seaside sparrow, an increase in total plant cover and mean cover of a few of the major species was observed **(Figure 4)**. Between the two surveys, total plant cover increased from 30.8% to 35.9% (Pairwise t-test; p < 0.001). Mean cover of *Eleocharis cellulosa* and *Rhynchospora tracyi* both species indicative of relatively wet condition in CSSS habitat, was significantly higher in the 2008 surveys than in 2004-05 (**Figure 4**). Cover of *Rhynchospora tracyi* increased more than two-fold (from 2.0% to 5.0%) between 2004-05 and 2008. Similarly, the mean cover of *Eleocharis cellulosa* almost doubled (from 1.7% to 2.9%) in the same period. In contrast, cover of other major species (mean cover > 0.5%), such as *Bacopa caroliniana*, *Cladium jamaicense*, *Muhlenbergia capillaris ssp. filipes, Schizachyrium rhizomatum,* and *Schoenus nigricans* did not change.

Change in total plant cover was not consistent in all sub-populations and across all vegetation types described for CSSS habitat (**Ross et al. 2006**). Consistent with the trend observed in 2007, total plant cover significantly increased in sub-populations A, E and F, but did not change in sub-populations B, C, D, and G (**Figure 5a**). In sub-population E, total plant cover nearly doubled (from 17.9% to 32.8%) in these unburned sites between 2004-05 and 2008. Overall marsh sites experienced a larger and more consistent increase in cover than wet prairie sites (**Figure 5b**).

Change in cover of major species varied with sub-population. Three major species that changed significantly in one or more sub-populations were *Eleocharis cellulosa, Rhynchospora tracyi* and *Schizachyrium rhizomatum* (**Figure 6)**. Mean cover of *S. rhizomatum* increased more than twice (2.7% to 6.0%) in sub-population F, suggesting drier conditions in 2008 than 3-4 years earlier. In contrast, mean cover of *S. rhizomatum* decreased significantly in sub-population C. In sub-population A, mean cover of *Eleocharis cellulosa* and *Rhynchospora tracyi* significantly increased, indicating vegetation at the some sites in sub-population A was wetter in 2008 than in 2004-05.

3.1.2 Vegetation change and hydrology

At the unburned CSSS census sites vegetation change between sampling events in 2004-05 and 2008 was marked by an increase or decrease in the wetness of the sites, depending on their locations, though mean vegetation-inferred hydroperiod did not differ significantly between 2004-05 and 2008 across all sites (Pair-wise t-test: n = 138, p-value = 0.232). Nevertheless, sites sampled in sub-population E did exhibit a net increase in mean vegetation-inferred hydroperiod between the two sampling events (Pair-wise t-test; n = 11, p = 0.049). Mean hydroperiods in sub-population E were 240 and 249 days in 2004-05 and 2008 surveys, respectively. Likewise, vegetation at many of the census sites in sub-populations C and D showed signs of increase in wetness in the four years (**Figure 7)**, though the difference in mean hydroperiod was not statistically significant. In Sub-population A, differences in mean vegetation-inferred hydroperiod between 2004-05 and 2008, averaged over all unburned sites, was not significant. However, vegetation at the sites present in the western and southeastern parts of the sub-population was indicative of wetter conditions in 2008 than in 2004-05, whereas the sites close to NP-205 and at high ground in the middle of the sub-population showed a decrease in wetness. This pattern appears to reflect the consistent high mean annual water levels reported for the area near water level recorder P-34 in the western part of sub-population in recent years (**Pimm et al. 2007**). Wet conditions in these areas occur despite efforts to regulate water deliveries from S12 structures. under the operational objective of ISOP/IOP, which have resulted in low water depth at NP-205.

For an analysis of concurrent on-ground hydrologic conditions within CSSS habitat, we calculated hydroperiod using ground elevation and water stage data obtained from Everglades Depth Estimation Network (EDEN). Three year average of hydroperiod calculated from EDEN data were higher for 2008 than for 2004-05 in sub-population A and F, whereas the sites showed the sites showed mixed results in other sub-populations (**Figure 8**). Nevertheless, the results obtained using EDEN stage data should be interpreted cautiously, as the hydroperiods estimated from EDEN water stage data are based on ground elevation surveyed by USGS at 400 x 400 m grid, which does not account for small scale topographic variation within the grid cell. Although the relationship between the 3 year average hydroperiod estimated using EDEN data and vegetation inferred hydroperiod was reasonably strong (R^2 = 0.60), EDEN-estimated hydroperiod values for prairie sites were lower than vegetation inferred hydroperiod (**Figure 9**). Similar results were obtained when we validated hydroperiod inferred from vegetation composition data against hydroperiods estimated in two ways: (1) using USGS elevations, and (2) using one-time measurement of real water depth at 100 sites, both in conjunction with stage data from recorders present within 1.5 km of the sites (See **Ross et al. 2006).**

3.1.3 Vegetation structure, biomass, and species richness

Like plant cover, mean vegetation height also increased significantly (Pair wise t-test: n = 138, p = 0.009) over the two sampling periods. However, breakdown of analysis by individual sub-populations revealed that the increase was significant only in sub-population D (**Figure 10A**). Mean vegetation height in sub-population D increased from 54.3 cm to 72.7 cm in 4 years.

Changes in mean above ground plant biomass at the unburned sites sampled in both 2004-05 and 2008 paralleled the increases in vegetation cover and height noted above. In those sites not burned for four years or more prior to the 2008 sampling, the mean (± SD) plant biomass increased from 457 ± 176 g/m^2 in 2004-05 to 545 ± 197 g/m^2 in 2008. However, biomass did not increase uniformly across all sub-populations, even decreasing slightly in sub-population D (**Figure 10B**). Nevertheless, the observed increase in biomass at the unburned sites over the period was significant in subpopulations A and E.

Species richness (total number of species recorded within 60x1 m plot at each site) did not differ significantly between the two surveys. This result differs from our finding in 2007, when species richness was significantly lower than in 2004. In 2008, the temporal trend in species richness among sites was highly variable. The only pattern in the data was that species richness decreased where vegetation-inferred hydroperiod increased, i.e. the sites that became wetter in 2008 than 3 to 4 years earlier had fewer species than before (**Figure 11**). This trend is to be expected given the negative spatial association between species richness and hydroperiod in the marl prairie landscape, previously reported by **Sah et al. (2008**).

3.2 Vegetation change at burned sites

Unlike the burned sites surveyed in 2006 and 2007, pre-burn data were available for those surveyed in 2008, enabling us to examine post-fire vegetation change on a site-specific basis. We found that vegetation composition and the trajectory of post fire vegetation recovery differed among the sites, depending on vegetation type, time since last fire, long-term fire history, and pre- and post-fire hydrology.

Results of non-metric multidimensional scaling (NMS) ordination revealed that the sites were roughly arranged along two gradients in ordination space, i.e. hydrology and time since last fire (**Figure 12**). However, groups were not well separated (stress 0.18), mainly because there was considerable overlap among wet prairie types, whereas marsh sites were clearly separated from them. Most of the marsh sites burned in May-2005, and were exposed to similar post-fire hydrologic conditions. In contrast, wet prairie sites differed greatly in burn year, the fire history before the latest burn, and post fire hydrology, and thus followed different paths of vegetation recovery after fire. For instance, a group of thirteen sites that were burned in August 2005 and flooded immediately thereafter showed relatively high dispersion away from the group's centroid in the ordination space. Sites burned in 2007 and sampled 1 year later were not dispersed far from their pre-burn locations in ordination space, probably because half of them were also burned in 2003, and may not have recovered fully by the time they burned next in 2007.

At sites burned in 2005, above ground vegetation cover remained much lower than pre-burn levels, even 3 years after fire (**Figure 13**). These sites were a heterogeneous group, including some that burned in May 2005, but did not flood immediately afterward (May_burn), and others that burned in August, then flooded deeply within one week (Aug_burn). To illustrate differences in post-fire trajectory of these groups, we plotted the centroids of post fire hydrology x time since last fire (**Figure 14**). Both groups differed significantly in vegetation composition from pre-burn condition 3 years after fire (**Table 3:** ANOSIM – p=0.003 and p=0.001, respectively). However, mean Bray-Curtis dissimilarity (absolute change) between 2005 (pre-burn) and 2008 composition differed between the two groups (One-way ANOVA: p=0.022). Three years after fire, vegetation composition at the May_burn sites was more similar to the pre-burn vegetation composition than at the Aug_burn sites (**Figure 15**), indicating that vegetation recovery was slowed substantially by rapid flooding after fire. Percent of vegetation recovery (VR) by post-fire Year 3 was much lower for the August burn (2.1% per year) than for the May_burn (13.9% per year).

Table 3: Global R and *p*-values from analysis of similarity (ANOSIM) testing for among-year differences in vegetation composition before and after fire for two burn groups, May_burn (7 sites) and Aug_burn (13 sites).

Burn group	Sampling event (Before & year after burn)	Year-1	Year-2	Year-3
2005 May_burn	Pre-burn	0.964 (0.002)	0.798 (0.001)	0.861 (0.003)
	Year-1		0.553 (0.002)	0.832 (0.001)
	Year-2			0.103 (0.149)
2005 Aug_burn	Pre-burn	0.718 (0.001)	0.691 (0.001)	0.640 (0.001)
	Year-1		0.175 (0.008)	0.208 (0.003)
	Year-2			-0.014 (0.556)

A second way of looking at post-disturbance vegetation trajectories is Benscoter and Vitt's (2008) absolute:total change ratio. This value was significantly higher in Aug_burn (0.47) than in May_burn (0.34), indicating that sites affected by the August 2005 fire were taking a more circuitous route back to their compositions prior to the fire.

May_burn and Aug_burn sites also differed in species richness and turnover. At the May_burn sites, species richness was significantly lower in Year-1 than in pre-burn, but by the following year (and continuing through Year 3) had recovered to pre-fire levels (**Figure 16A**). In contrast, the mean number of species at the Aug_burn sites decreased slightly from pre-burn levels in each of the first three years after fire. At Aug_burn sites, because the decline in species richness would have been much steeper had it not been for the appearance of several opportunistic species after the demise of most of the community as a result of fire followed by immediate flooding. At those sites, 20 species that were absent in the pre-burn survey were present during the 2006, 2007 or 2008 surveys (**Table 4**). At the Aug_burn sites, species which were present in one or more sites in first or second year after burn included *Asclepias lanceolata*, *Asclepias longifolia, Dichanthelium aciculare, Euphorbia capitellatum, Eustachys petraea, Flaveria linearis, Leersia hexandra, Linum virginianum, Ludwigia repens*, and *Panicum hemitomon*. Moreover, the mean number of species that were present only in the post-burn surveys, particularly in the first and second years after fire, was significantly higher in Aug_burn than in May_burn sites (**Figure 16B**). However, such difference between two subsets of sites was not found in 2008 survey, as some of the early invaders in Aug-burn, e.g., *Asclepias lanceolata, Asclepias longifolia, Dichanthelium aciculare, Euphorbia capitellatum, Eustachys petraea, Flaveria linearis, Linum viginianum* and *Ludwigia repens* disappeared from the recovering community.

Change in species composition at the burn sites is further confirmed by a shift in rank abundance curves (**Figure 17**). At the Aug_burn sites, where sites were immediately flooded after fire, the relative cover of dominant species, such as *Cladium jamaicense*, *Muhlenbergia capillaris* subsp. *filipes*, *Schizachyrium rhizomatum* and *Schoenus nigricans* decreased greatly after fire (**Sah et al. 2007**). Even after three years, the relative cover of those species was considerably lower than pre-fire levels. Other Everglades studies have also documented the synergistic effects of fire and flooding that submerges the remnant culms of plants. For instance, **Herndon et al. (1991**) and **Snyder and Schaffer (2004**) showed that this confluence of events can be locally detrimental to species like *Cladium jamaicense* and *Muhlenbergia capillaris* subsp. *filipes*. In 2008, the relative cover of several minor species, especially *Centella asiatica* and *Rhynchospora microcarpa* increased. In contrast, at May_burn sites, where water level increased gradually, providing ample opportunity for the re-growth of plants after fire, the dominant *Cladium jamaicense* was the primary species to display a large decrease in relative cover. Interestingly, at the May_burn sites, the relative cover of *Muhlenbergia capillaris, Schoenus nigricans* and *Rhynchospora microcarpa* all increased together with an increase in relative cover of *Rhynchospora tracyi*.

In addition to post-fire hydrology, May_burn and Aug_burn also differed in the vegetation types that were burned. Out of 7 sites in the May_burn, 6 were categorized as marsh vegetation, while all of the Aug_burn sites were wet prairies. For this reason, our results need to be interpreted cautiously. Post-fire vegetation recovery at one marsh and one wet prairie reference site burned (without subsequent flooding) in 2003 frames the responses to post-fire hydrology observed in 2005 well; vegetation composition 4 years after fire in the reference sites was more or less the same as before the fire (**Figure 14**).

Table 4: List of the species that were present only in either pre-burn or three post-burn vegetation survey at the two sets of sites, one burned in May 2005 and the other burned in August 2005.

Species	Sites burned in May, 2005				Sites burned in Aug, 2005			
	Pre-burn	2006	2007	2008	Pre-burn	2006	2007	2008
Agalinis linifolia	+		+	+	+	+	+	+
Agalinis purpurea					+			
Agalinis spp.					+			
Andropogon virginicus var. *virginicus*					+	+		
Annona glabra				+		+		
Aristida purpurascens	+		+	+	+			
Asclepias lanceolata							+	
Asclepias longifolia						+		
Aster dumosus	+	+			+	+	+	+
Aster spp.						+		
Calopogon tuberosus			+	+	+	+		
Cassytha filiformis	+			+	+		+	+
Cephalanthus occidentalis					+			
Chamaesyce adenoptera subsp. *pergamena*					+			
Chiococca parvifolia					+		+	
Chrysobalanus icaco	+			+				
Cirsium horridulum					+	+	+	
Dichanthelium aciculare						+	+	
Dichanthelium spp.						+	+	
Elytraria caroliniensis var. *angustifolia*					+	+		
Eragrostis elliottii	+				+	+	+	+
Erianthus giganteus					+			
Erigeron quercifolius					+			
Eupatorium capillifolium							+	
Eupatorium leptophyllum						+	+	+
Eustachys petraea							+	
Flaveria linearis							+	
Fuirena breviseta								+
Helenium pinnatifidum					+	+		
Hypoxis wrightii					+	+		
Juncus megacephalus					+	+		
Justicia angusta	+				+	+		

Species	**Sites burned in May, 2005**				**Sites burned in Aug, 2005**			
	Pre-burn	**2006**	**2007**	**2008**	**Pre-burn**	**2006**	**2007**	**2008**
Leersia hexandra						+		
Linum medium var. *texanum*			+		+	+	+	+
Linum virginianum							+	
Lobelia glandulosa	+		+		+		+	+
Ludwigia alata					+	+		+
Ludwigia microcarpa	+		+	+	+	+	+	+
Ludwigia repens							+	
Mitreola petiolata	+				+	+	+	+
Myrica cerifera			+	+	+			
Nymphoides aquatica					+			
Oxypolis filiformis	+			+	+	+	+	+
Panicum hemitomon						+		
Persea borbonia					+		+	+
Phyllanthus caroliniensis					+	+		
Phyllanthus pentaphyllus								+
Piriqueta caroliniana					+	+	+	
Pityopsis graminifolia					+			
Polygala grandiflora var. *leiodes*			+		+	+	+	+
Proserpinaca palustris	+			+	+	+	+	+
Rhynchospora divergens	+		+	+	+	+	+	+
Ruellia caroliniensis						+		+
Sabatia grandiflora			+		+	+	+	
Sabal palmetto					+			
Sabatia stellaris			+	+			+	+
Schoenolirion albiflorum						+	+	+
Solidago stricta				+	+	+	+	+
Spermacoce terminalis						+		+
Stenandrium dulce var. *floridanum*					+		+	
Taxodium distichum var. *imbricarium*	+							
Teucrium canadense					+	+	+	
Unkknown grass								+
Unknown species-2					+			
Utricularia cornuta				+				
Utricularia foliosa	+							
Utricularia purpurea	+	+						
Utricularia subulata	+	+	+					

3.3 Vegetation change and CSSS population

In 2008, the annual CSSS population survey, conducted jointly by Everglades National Park personnel and Dr. Pimm's team, was limited to subpopulations A, C, D, E and F. Since sub-population B has been the only large (~2000 birds), stable population since 1993, there was a shift in surveying strategy for this sub-population. The current plan is to survey sub-population B every three years, so that focus can be given to the other five sub-populations, which are demographically more vulnerable. This has also limited the scope of our analysis, particularly the relationship between CSSS population distribution and vegetation change. Among 138 unburned sites surveyed for vegetation in 2008, 16 were in sub-population B and 6 in sub-population G. Sparrow populations were sampled at 39 randomly selected sites of the remaining 116 in which vegetation was sampled in 2008, and our analysis of the sparrow-vegetation relationship is therefore based on those few locations.

CSSS were observed in 2004-05 or 2008 at only seven of the 39 sites described above - five sites in sub-population E, and one in both A and C (**Figure 18**). At the sub-population A site, sparrow number was higher in 2008 than in 2005. Likewise, at two sites in sub-population E, sparrows were absent in 2004 but present in 2008. At the other four sites, however, sparrows were either not sighted in 2008 or if sighted, density was lower in 2008 than in 2004 or 2005, when their vegetation composition and structure was first surveyed. At these sites, the differences in bird count between the two surveys could simply reflect stochastic variation, as there was not much change in vegetation and vegetation-inferred hydroperiod. Unlike previous results (e.g., Sah et al. 2008), change in bird number in relation to vegetation-inferred hydroperiod in 2008 show no pattern, probably because hydroperiod at these few sites during were within an acceptable range for CSSS during both surveys.

Within CSSS habitat in the Everglades, fire also plays an important role in modifying vegetation composition and structure, which ultimately influences CSSS population dynamics (**Pimm et al. 2002; LaPuma et al. 2007**). In 2008, vegetation was sampled at 27 census sites that were burned within four years of sampling. Fourteen sites were burned in 2005, 2 sites in 2006 and 11 sites in 2007. Only 23% of sites burned in 2006 or 2007 were occupied by CSSS during the three-year period before the fire. CSSS had not been surveyed since 2000 in three such sites in sub-population A. Only two sites burned in 2007 were surveyed for sparrows in 2008, and neither supported CSSS one year after fire. In contrast, 79% of the 14 sites burned in 2005 were occupied by CSSS prior to the fire. These sites were also surveyed for sparrows in 2006 and 2007, i.e. 1 and 2 years after fire. All but one of these sites were in sub-population B, and thus were not surveyed for birds in 2008, though birds were observed in five of them in 2007, two years after fire (**Sah et al. 2008**). These 13 sites are the same sites that were burned, then flooded by hurricane immediately after fire in 2005. Since vegetation recovery at these sites is not only very slow (See section 3.2), but will probably take on a different trajectory, regular monitoring of burned sites for sparrows during this recovery stage is highly desirable, particularly to gain an in-depth understanding of CSSS population dynamics in response to vegetation changes mediated by the interaction of fire and hydrology.

3.4 Soil, hydrology and vegetation: Spatial analysis

The first two axes of the principal component analysis explained 68.5% of the total variation in eight soil variables. Axis 1, which alone explained more than half (52.0%) of the total variation, represented the gradient between carbonate and organic soils present in the southern Everglades marl prairie landscape (**Figure 19**). Total nitrogen and phosphorus also had high weightings on Axis 1, as they were strongly correlated with soil organic carbon. Despite showing significant correlation with organic carbon, soil depth and pH had the highest weightings on Axis 2, which explained 16.5% of variation in the data (**Table 5**). The correlation matrix further highlights the importance of the organic-carbonate gradient, represented by Factor 1 of the PCA, in structuring the soils of the study area.

Table 5: Correlation matrix among soil variables. Red values are significant at p<0.5.

	SD	TN	IC	pH	TP	OC	Fe	K
Soil depth (SD)	-	-0.60	0.51	0.10	-0.71	-0.47	-0.54	-0.50
Total nitrogen (TN)		-	-0.85	-0.43	0.74	0.92	0.89	0.82
Inorganic carbon (IC)			-	0.47	-0.65	-0.93	-0.79	-0.67
Soil pH				-	-0.25	-0.39	-0.36	-0.35
Total phosphorus (TP)					-	0.64	0.70	0.74
Organic carbon (OC)						-	0.82	0.74
Iron (Fe)							-	0.81
Potassium (K)								-

Within the marl prairie landscape of CSSS sub-population A, the carbonate-organic soil gradient showed some degree of spatial continuity (Range = 12.5 km) (**Figure 20**), but with strong directionality. In the north-south direction (0^o), small semi-variance and the almost flat shape of the variogram indicate lack of spatial structure, and weak auto-correlation beyond the lag distance of 1 km (**Figure 20**). The continuous, steep slope of the variogram in the east-west direction (90^o) indicates a strong, simple gradient with strong spatial structure (positive autocorrelation over short distances, negative autocorrelation at long distances) within the maximum distance modeled (15 km) (**Rossi et al. 1992**). Soils rich in organic carbon were present mostly in the eastern part of sub-population A bordering the Shark River slough. In the western part of sub-population A, the soils were mostly marls with very little organic carbon, and relatively low nitrogen and phosphorus.

Current vegetation pattern in the sub-population A is the expression of hydrologic conditions that have prevailed in the area in last 5-10 years. Vegetation-inferred hydroperiod, which is the representation of current vegetation and hydrologic condition extending to a few years before sampling, revealed a spatial pattern that resembled that of the soils, but differed in several important ways. The isotropic variogram showed strong spatial structure (**Figure 21),** but its shorter range (7.8 km) indicated less extended vegetation structure than the one for soils portrayed in Figure 20. As it was for soils, strong directionality was observed also in vegetation pattern. Except a few sites in the north-east and south-east corners of the sub-population, most marsh sites of long inferred hydroperiod occur in the western part of the area (see **Ross et al. 2006**, Figure 5). The variograms of inferred-hdyroperiod are strongly anisotropic, i.e. its spatial continuity differs with directions. Low spatial autocorrelation exist between 0° to 45° direction that follows the orientation of high ground bordering the Shark River slough (**Figure 21**). Perpendicular to this direction, however, hydrologic condition changes quickly, a feature which corresponds to the steep slope of 135° variogram.

Aboveground plant biomass exhibited spatial structure that resembled but was somewhat weaker than we observed for inferred hydroperiod (**Figure 22**). At 6.2 km, the range for the best biomass model was nearly identical to that for inferred hydroperiod, with both indicating smaller-scale underlying processes than for the soils data. The variograms for biomass also display some anisotropy, but the difference in the structures of the 4 directions tested is not so strong as for soil characteristic and inferred hydroperiod (**Figure 22**). Nevertheless, the presence in the southeastern portion of the area of a zone of maximum biomass produces the relatively strong structure displayed by the 135° and 90° variograms (roughly perpendicular to the flow of Shark Slough), which reach a maximum at about 7 km.

Analysis of spatial relationship between soil characteristics and hydoperiod revealed that they exhibit some degree of spatial continuity, as indicated by the range values of their isotropic variograms (**Table 6**). However, they both have strong directionality in their spatial pattern, and their directions of spatial continuity differed somewhat. Carbonate-organic soil gradient which is primarily oriented in east-west direction showed maximum spatial continuity in the N-S direction, whereas hydrology followed the topographic orientation of the landscape, basically following the NE-SW direction that roughly parallels the flow of the Everglades. We explored their spatial relationship through the cross-correlogram. The cross-correlogram for soil Factor-1 and hydroperiod showed strong negative correlation at long distances, but positive correlations at shorter distances up to 2 km, particularly in E-W (90°) direction (**Figure 23**). This pattern suggests that processes that shape the landscape at small scales are not the same as those that shape it at larger scale.

Table 6: Semivariogram statistics for soil factor-1, vegetation-inferred hdyropeirod and above ground biomass in the marl prairie habitat within CSSS sub-population A. The model with the parameters in red was the chosen as the best-fit model.

	Model	**Nugget (C_0)**	**Sill (C_0+C)**	**Range**	**Residual SS**	**R^2**	**(Sill-nugget) /Sill**
Soil Factor-1	Spherical	0.0416	0.1002	13.45	0.00046	0.905	0.580
	Gaussian	0.0506	0.1032	12.52	0.00032	0.935	0.510
	Exponential	0.0414	0.1012	29.34	0.00060	0.879	0.660
Inf-Hydroperiod	Spherical	0.0403	0.0922	7.79	0.00021	0.936	0.563
	Gaussian	0.0463	0.0927	6.53	0.00023	0.931	0.501
	Exponential	0.0266	0.0932	7.74	0.00037	0.886	0.715
Biomass	Spherical	0.0129	0.0844	2.17	0.00041	0.628	0.847
	Gaussian	0.0128	0.0843	1.71	0.00042	0.617	0.848
	Exponential	0.0437	0.0877	6.21	0.00011	0.899	0.502

Within CSSS sub-population A, soils have less organic carbon in the western prairies, where marsh vegetation adapted to the longer hydroperiod is dominant. This result differs from what we had expected. In general, soil organic matter is expected to be high in areas with long hydroperiod, which usually create an environment conducive to the accumulation of peat soils over long periods of time (**Gleason and Stone 1994**). The presence of lower soil organic carbon at long hydroperiod sites in the western part of sub-population A suggests that the prevalence of marsh vegetation and long hydroperiods are a recent phenomenon, possibly management-induced. Researchers and managers are aware that vegetation changed over recent decades in this area, due to extended flooding by waters delivered through the S12 structures during several wet years in the mid-1990's (**Nott et al. 1998**; **Ross et al. 2004**). Our soils data suggest that the drier conditions that preceded these recent flooding events were not short-lived, but prevailed long enough to form at least 10 cm of marl soil. Though few studies of marl production in the Everglades have been completed, accretion rates generally range between 1-2 mm per year (e.g., **Meeder et al. 1996**). If that is the case in the western prairies, then the 10 cm soil samples we collected represent at least the last 50-100 years. Our results do not support, but may not necessarily be in conflict with results from pollen and sawgrass seeds that suggest that the area was wetter a century ago than in the recent years (**Brenhardt and Willard 2006**; **Saunders etl al. 2006; Willard et al. 2007**). It is possible, but by no means certain, that the surface soils with low organic carbon in the western part of Shark Slough were a result of prolonged dry conditions created by the reduction in flow of water towards the Everglades National Park due to construction of Tamiami Trail. Only an extensive study of multiple soil cores well distributed throughout the landscape would reveal the historical hydrologic pattern.

3.5 Reconnaissance of 2008 Burned sites

In 2008, 4 major fires burned a significant portion of CSSS habitat in sub-populations A, E and F (**Figure 24**). The fire perimeter produced immediately after the fire by Everglades National Park Fire and Aviation revealed that Mustang Corner fire was the largest fire after 1989 in Everglades National Park. It was the human-caused fire that originated near the eastern boundary of the park on May 14, 2008 and burned 15,971 ha (39,465 acre) area, including most of CSSS habitat in sub-population F, and part of sub-population E. In the area of sub-population E, a lightening-ignited fire, later named as 'Radius Rod fire', burned additional 387 ha (957 acres) of sparrow's habitat.

In the western Everglades, part of seaside sparrow's habitat was burned in two medium-sized fires, Lime Tree and West Camp that blazed the area in the 3rd week of June. Lime Tree wildfire began on June 21 and burned 921 ha (2,276 acres) habitat in Big Cypress National Preserve. The fire was in relatively wet area where marsh vegetation was dominated by *Cladium jamaisence* and *Rhynchospora tracyi* and no sparrow was sighted at the census sights within that fire in eight years prior to 2008 fire. In contrast, the West Camp fire which was the natural wildfire sparked by lightening on June 22, 2008 burned 997 ha (2,465 acres) of currently occupied sparrow's habitat west of Shark Slough. The vegetation in that part of habitat was primarily wet prairies dominated by mostly *Schizachyrium rhizomatum, Cladium jamicense* and *Paspalum monostachyum*. This fire encompassed seven vegetation survey sites, out of which at two sites ENP sparrow survey group sighted 4 birds (a population of 64) in 2008 pre-fire breeding season. Because of high vulnerability associated with sparrow's western sub-population, monitoring the impact of West Camp fire on this sparrow's population and their habitat is crucial. In and around the West Camp fire, the demographic change in sparrow population is regularly studied by Pimm's team, who had located 16 males and 11 females during the pre-2008 fire breeding season. Results of an on-foot mapping efforts in the burned area revealed that about half of those locations where the birds were re-sighted and banded by Pimm's team in 2008 were located within the West Camp fire boundary (**Boulton et al. 2008**).

A preliminary survey of 28 transect sites and 32 Census sites present within the fire boundary of Mustang Corner and West Camp fires showed that both fires were relatively intense, though, in general, the arson-lit dry season Mustang Corner fire was believed to be more intense than natural wet-season fires (i.e. Tree Lime and West Camp fires). Out of 53 sites present within Mustang Fire boundary, vegetation at 9 (17%) sites did not burn, whereas at 40 (75%) sites, ≥80 vegetation was burned. In contrast, ≥ 95% of vegetation at all 7 vegetation monitoring plots were burned in the West Camp fire. However, **Boulton et al.** (2008) had found some unburned patches in this fire too. The unburned vegetation patches were primarily in wetter areas and hammocks, which are not the preferable habitat for Cape Sable seaside sparrow. An analysis of burn conditions at vegetation monitoring sites in both fires together also divulged that percent of burned area was negatively related to vegetation inferred hydroperiod (**Figure 25**).

3.6 2008 Fires and Vegetation monitoring

While a long-term well-designed monitoring and research only may reveal the actual impact of Mustang Corner fire on Cape Sable seaside sparrow population and its habitat, its occurrence in the eastern edge of the Everglades, which is close to both human settlements and the sparrow's habitat, has already exemplified the complications in managing the critical habitat of an endangered species. A fire of that scales is believed to be as an outcome of several contributing factors, but mainly due to altered hydrology. Researchers have shown that recent management practices of diverting water to reduce flooding risk near the growing population close to eastern Everglades, have resulted in the marl prairies in that region to be drier far longer than in natural conditions (**Van Lent and Johnson, 1993; Light and Dineen 1994**). Although Comprehensive Everglades Restoration Plan (CERP) has envisioned to rehydrate the northeast and eastern Everglades, a delay at several fronts of proposed activities under the federal Everglades restoration plan has also delayed the opportunity to rehydrate eastern Everglades, which if accomplished would help to reduce the increased frequency of fires in that part of Everglades. Both altered hydrology and fire regimes are more likely to create unfavorable habitat for Cape Sable seaside sparrow. For instance, while the decline in CSSS sub-populations A and D has been attributed to the hydration of sites that created the long-hydroperiod marsh vegetation, the frequent fires caused by over drying of the rocky glades are considered as the major reason for a decline in sparrows in sub-population F (**Pimm et al. 2002**).

Long-term vegetation monitoring in relation to pre- and post-fire hydrology is critical for understanding the vegetation dynamics in relation to fire-hydrology interaction and their implications for sparrow habitat management in the Everglades. We have presented a schematic diagram showing the components that might be important to quantify the change in vegetation composition and structure after fire in the marl prairies (**Figure 26**). Pre-fire vegetation structure and composition data collected before 2008 fire will serve the basis for quantifying directionality in vegetation change. In marshes and prairies of the Everglades, trajectory of vegetation change after fire depends on both fire intensity and post-fire hydrology, while the fire intensity itself is the product of interactions among fuel load present at the sites, fuel moisture, water level, and prevailing weather conditions. Pre-fire fuel load data for the burned sites could be easily derived from vegetation structure data and the relationship developed to calculate biomass from vegetation cover and height (**Sah et al. 2007**). Since, the quantity of fuels present locally is primarily influenced by strong historical contingency, i.e. intensity and time since last fire, the fire records since 1948 compiled in a geo-database by Everglades National Park would help to characterize the fuel characteristics, including its connectivity in relation to fire frequency and time since last fire. Rate of spread of fire in the area with continuous fuels is also influenced by weather conditions. For instance, extensive area burned by Mustang Corner fire might be the result of low humidity, and strong wind coupled with continuous fuels. Finally, pre- and post-fire hydrologic conditions, could be available from the Everglades Depth Estimation Network (EDEN), would help to relate post-fire vegetation dynamics to hydrology-fire interaction. Monitoring of vegetation recovery at the 2008 burned sites for sparrow habitat management is highly desirable, particularly to gain in-depth understanding if fire, in combination with water management, can be used as tool to restore the altered sparrow's habitat.

4. Conclusions

In the marl prairie landscape within the recent habitat of Cape Sable seaside sparrow, the direction and magnitude of short-term vegetation change depends on position within the landscape. For instance, many CSSS vegetation survey sites in sub-population E, and sites in the western part of sub-population A showed wetter vegetation whereas sites around NP205 and at high ground in the middle of the sub-population showed drier vegetation in 2008 than in 2004-2005 survey. In the area of sub-population A, where the prevalence of marsh vegetation and long hdyroperiods have been management-induced recent phenomenon, efforts to regulate water deliveries from the S12 structures under the operational objective of ISOP/IOP have resulted in low water depth at NP-205. However, the persistence of wetter vegetation due to high water level in the vicinity of P-34 suggests an unanticipated water flow from the northwest, which might have limited the recovery of CSSS population in that part of its habitat. Another potential aggravating factor at these locations not far from the coast is sea level rise, which in south Florida has been ~2.5 mm per year over the last century. In addition, very low plant cover and a change in species composition at sites flooded after fire in 2005 and surveyed approximately 3 years later suggests that post-fire flooding delayed the vegetation recovery process, and also caused it to follow a different trajectory in terms of species composition. In turn, the altered course of vegetation recovery could ultimately impede the return of CSSS to those sites. Thus, re-sampling in 2008 of a sub-set of sites surveyed in 2004 or 2005, along with burned sites surveyed in 2004 and 2005, has answered some questions regarding vegetation change in response to hydrology and fire and its implications on the CSSS population. The year 2008 also witnessed fires of a magnitude and extent that occur only in the interval of decades. The 2008 fires blazed through vast areas in Everglades National Park, including large chunks of marl prairie habitat on both sides of Shark River slough. Well-designed long-term vegetation monitoring within those fire boundaries are expected to answer important questions regarding the use of fire as a tool to restore the marl prairie habitat.

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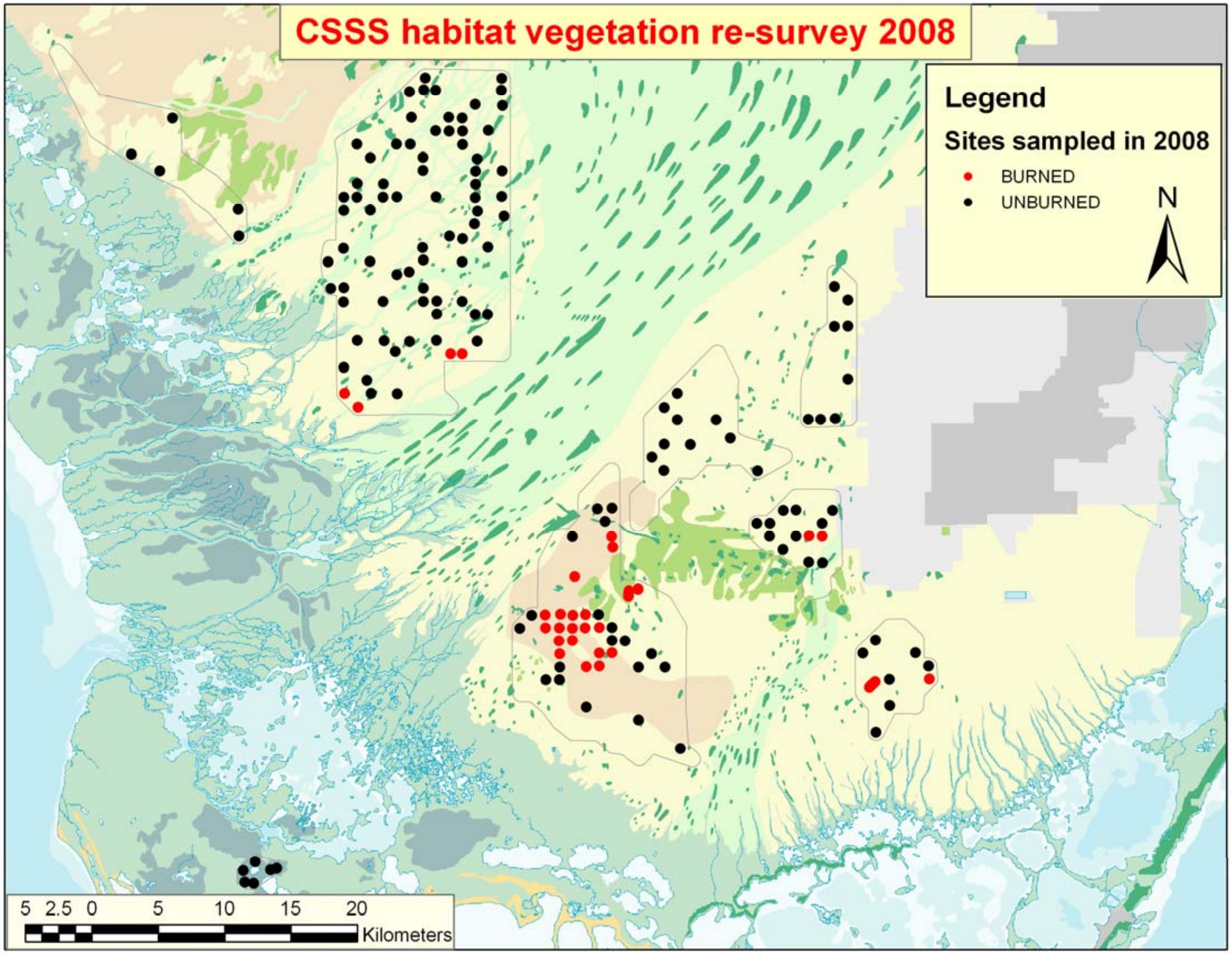

Figure 1: Location of sites within the Cape Sable seaside sparrow habitat sampled for vegetation in 2008.

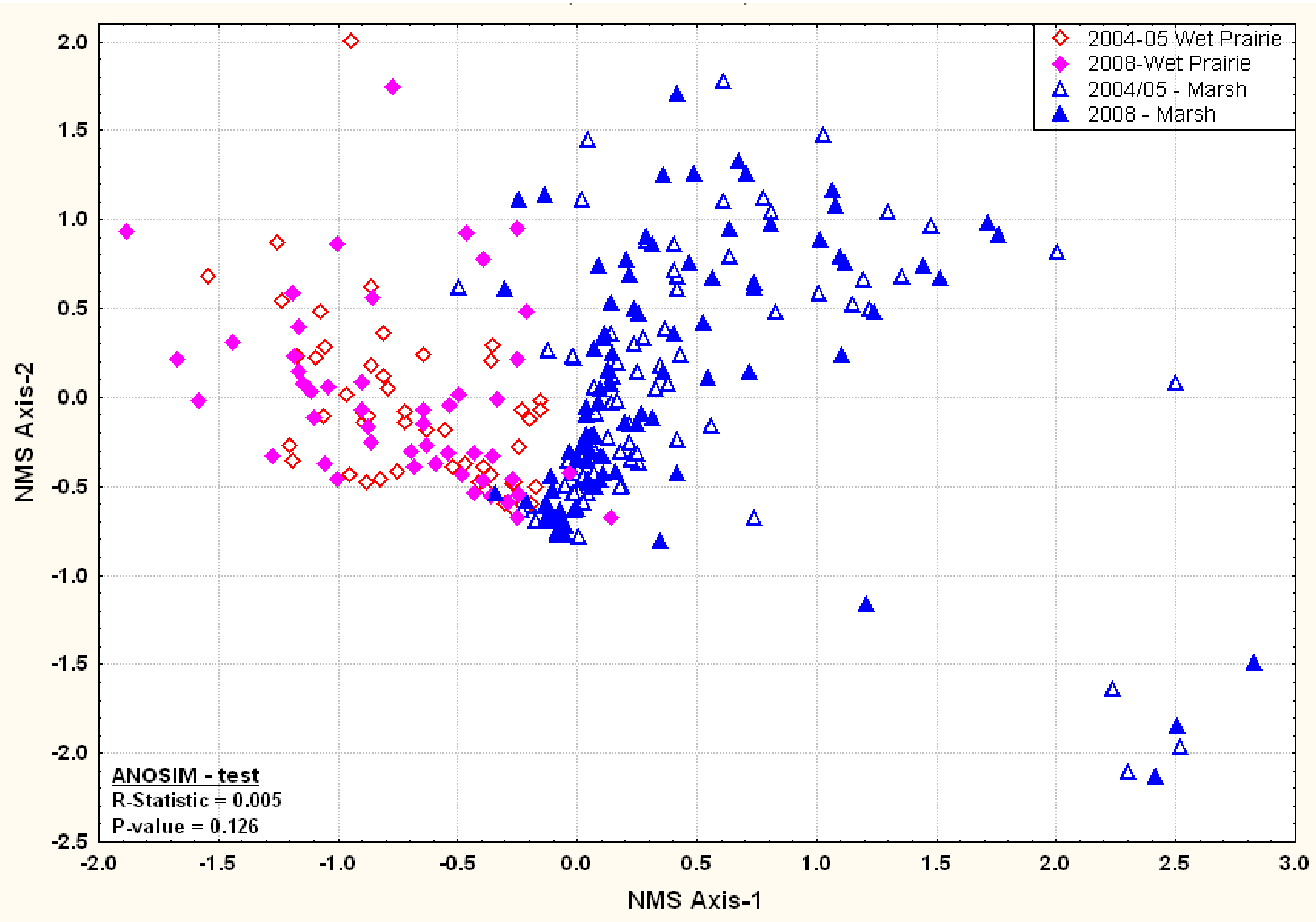

Figure 2: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on relative cover of species at 138 unburned CSSS census sites sampled in both 2004 and 2007. The figure illustrates distinct grouping between marsh (blue) and wet prairie (red) are easily distinguishable regardless of years sampled, but samples from 2004 (open) and 2007 (closed) are randomly dispersed within the cloud of marsh and prairie points.

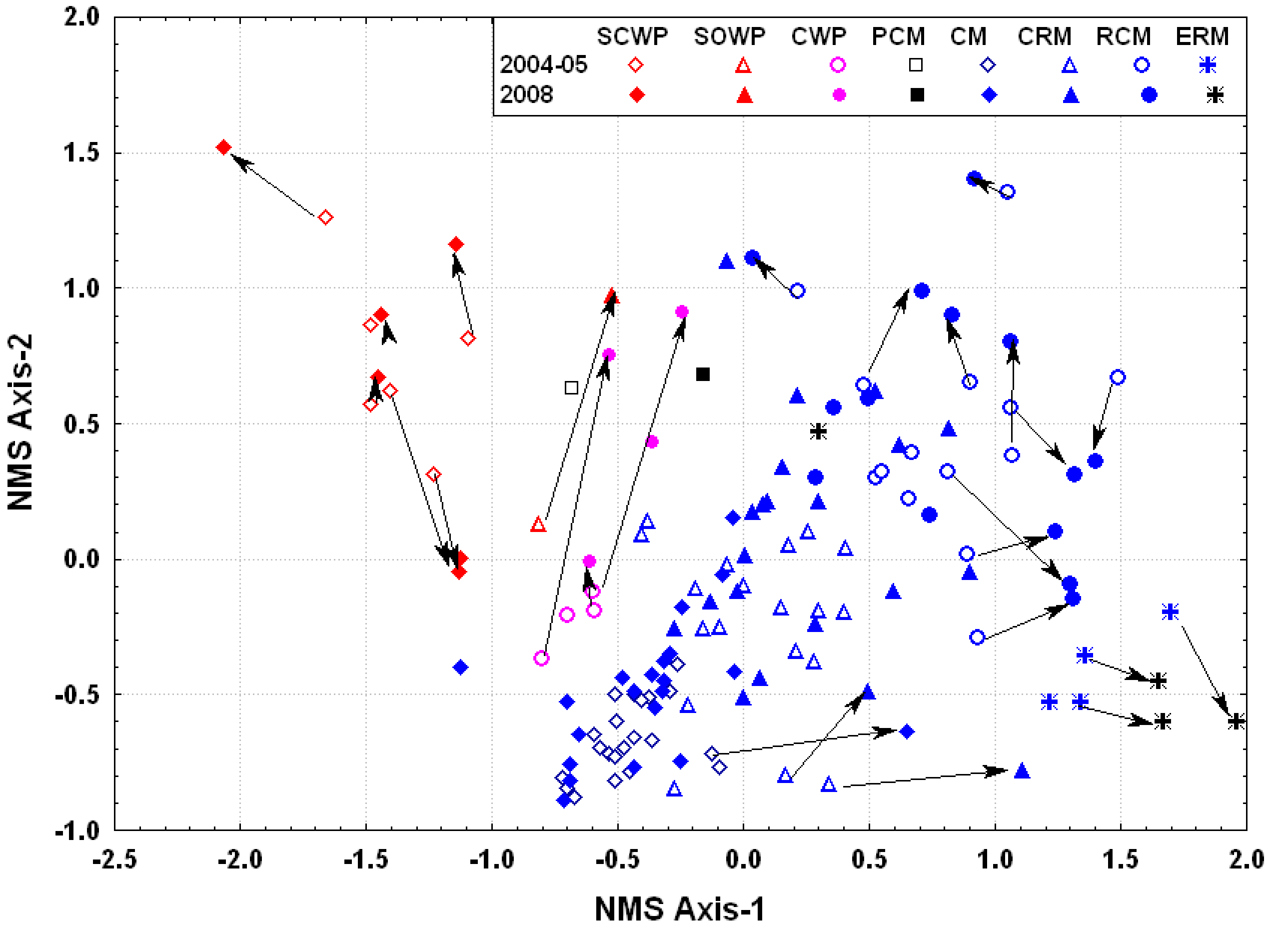

Figure 3: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on relative cover at 72 plots on Sup-population A. Arrows show the shift in site position in ordination space due to dissimilarity in vegetation structure and composition between 2004 and 2007. SCWP = *Schizachyrium* wet prairie; CWP = *Cladium* wet prairie; PCM = *Paspalum-Cladium* marsh; CM = *Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; RCM = *Rhynchospora-Cladium* marsh; ERM = *Eleocharis-Rhynchospora* marsh.

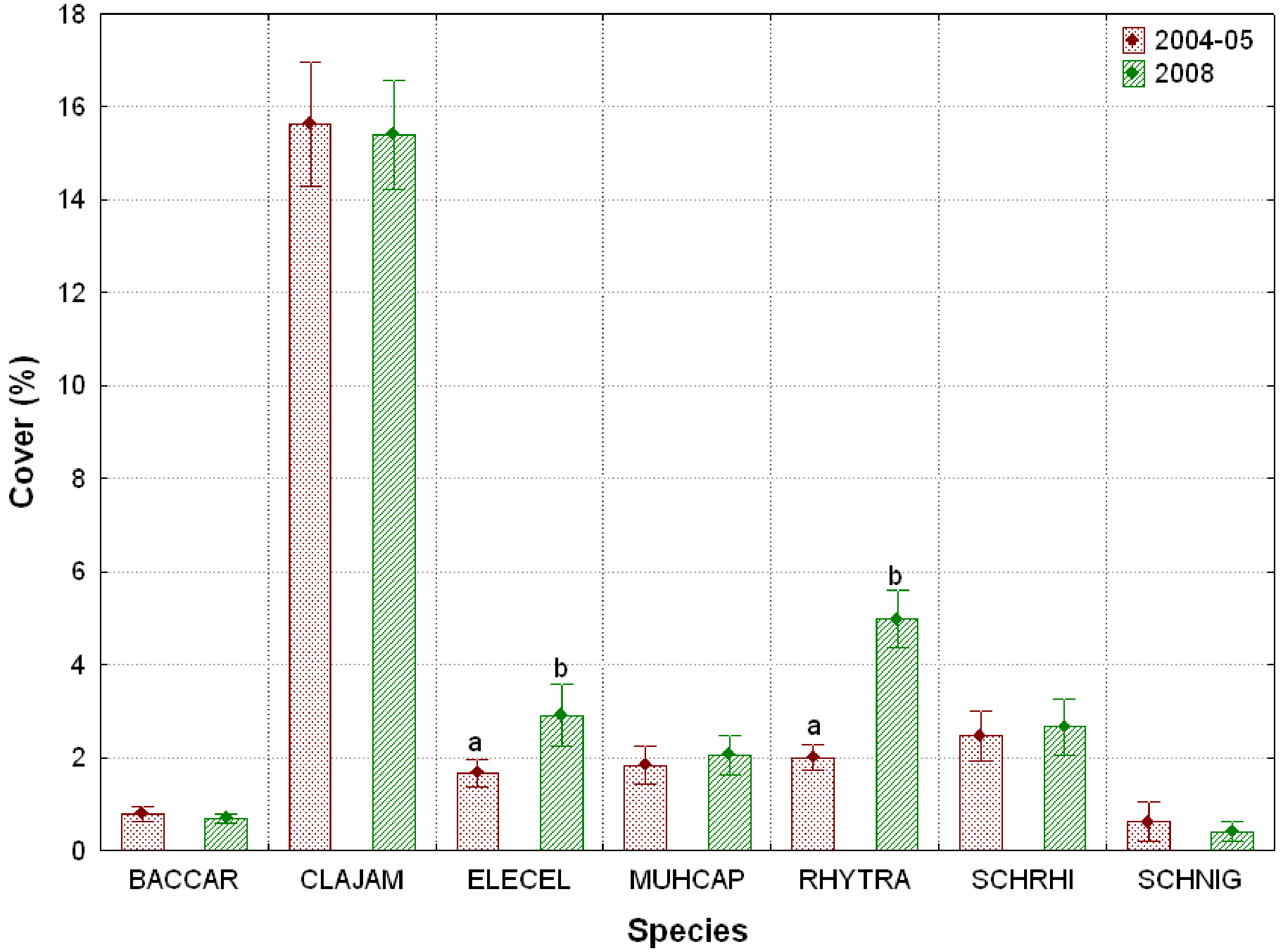

Figure 4: Mean (± 1 S.E.) cover of major species (mean cover >0.5%) in 138 CSSS census sites which were not burned for 4 years prior to vegetation sampling. Different roman letters indicate significant difference (pair wise t-test; $p < 0.05$) in cover of the particular species between two sampling events, 2004-05 and 2008. BACCAR = *Bacopa caroliniana*, CLAJAM = *Cladium jamaicense*, ELECEL = *Eleocharis cellulosa*, MUHCAP = *Muhlenbergia capillaris* var. *filipes*, RHYTRA = *Rhynchospora trayci*, SCHNIG = *Schoenus nigricans*, and SCHRHI = *Schizachyrium rhizomatum*.

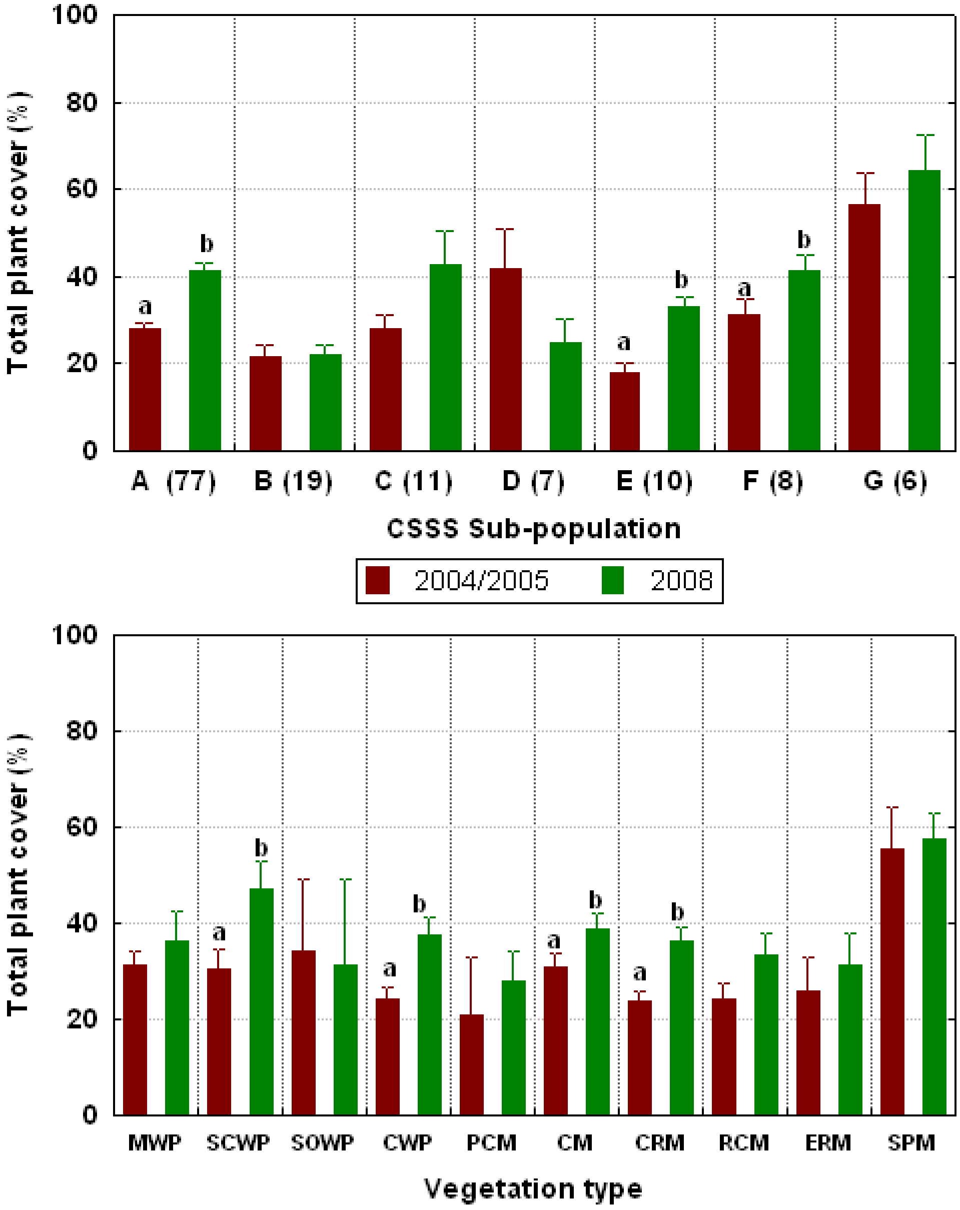

Figure 5: Mean (± 1 S.E.) above ground vegetation cover at the unburned CSSS census sites sampled in 2004/2005 and 2008. Total plant cover is averaged over (A) CSSS subpopulations, and (B) Vegetation types. Different roman letters indicate significant difference (pair wise t-test; $p < 0.05$) in total cover within particular sub-population or vegetation type between two sampling years, 2004/2005 and 2008. MWP = *Muhlenbergia* wet prairie; SCWP = *Schizachyrium* wet prairie; SOWP = *Schoenus* wet prairie; CWP = *Cladium* wet prairie; PCM = *Paspalum-Cladium* marsh; CM = *Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; RCM = *Rhynchospora-Cladium* marsh; ERM = *Eleocharis-Rhynchospora* marsh; and SPM = *Spartina* marsh.

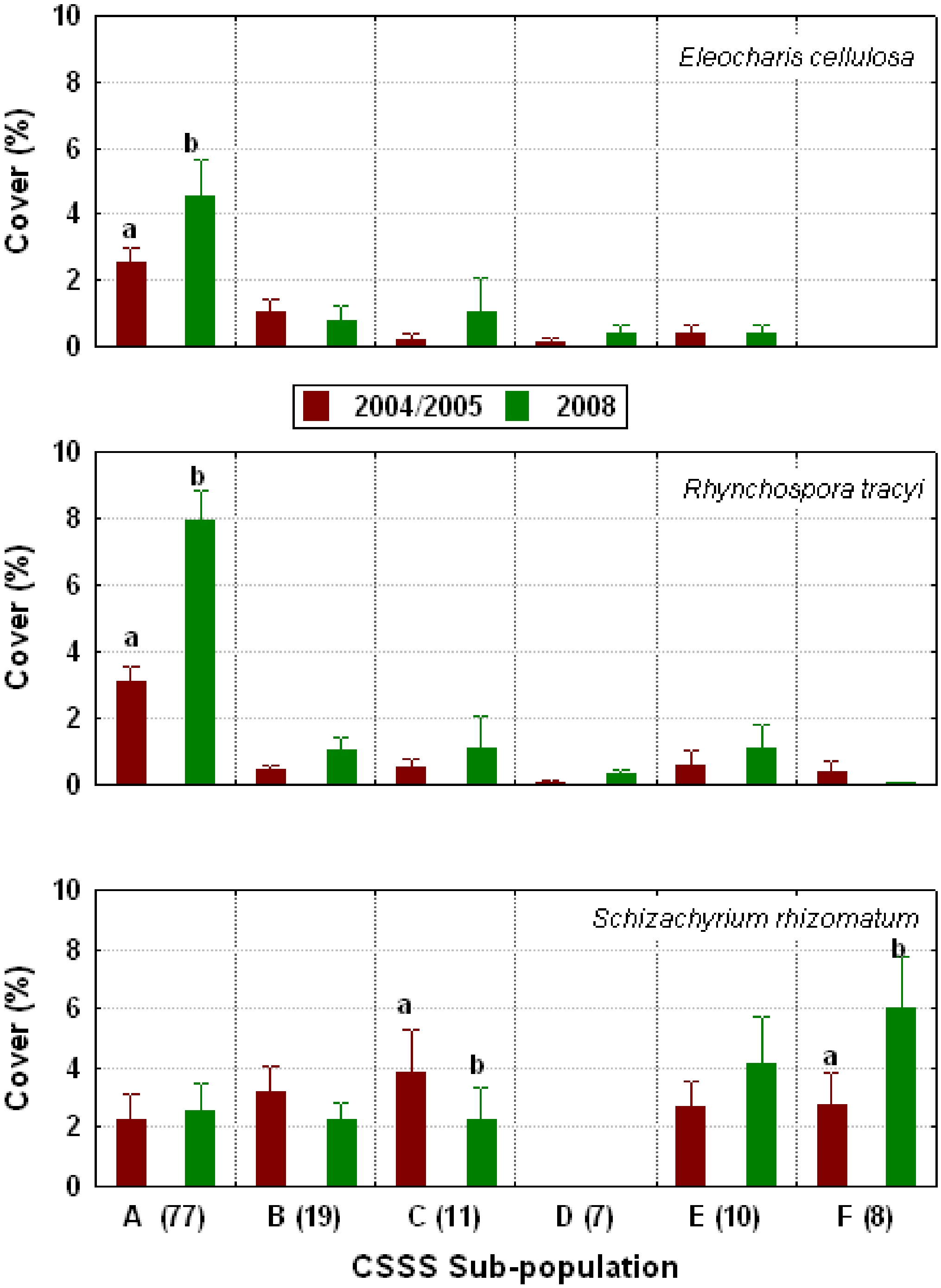

Figure 6: Mean (± 1 S.E.) cover of three major species that differed significantly in one or more populations at the unburned CSSS census sites sampled in both 2004/2005 and 2008.

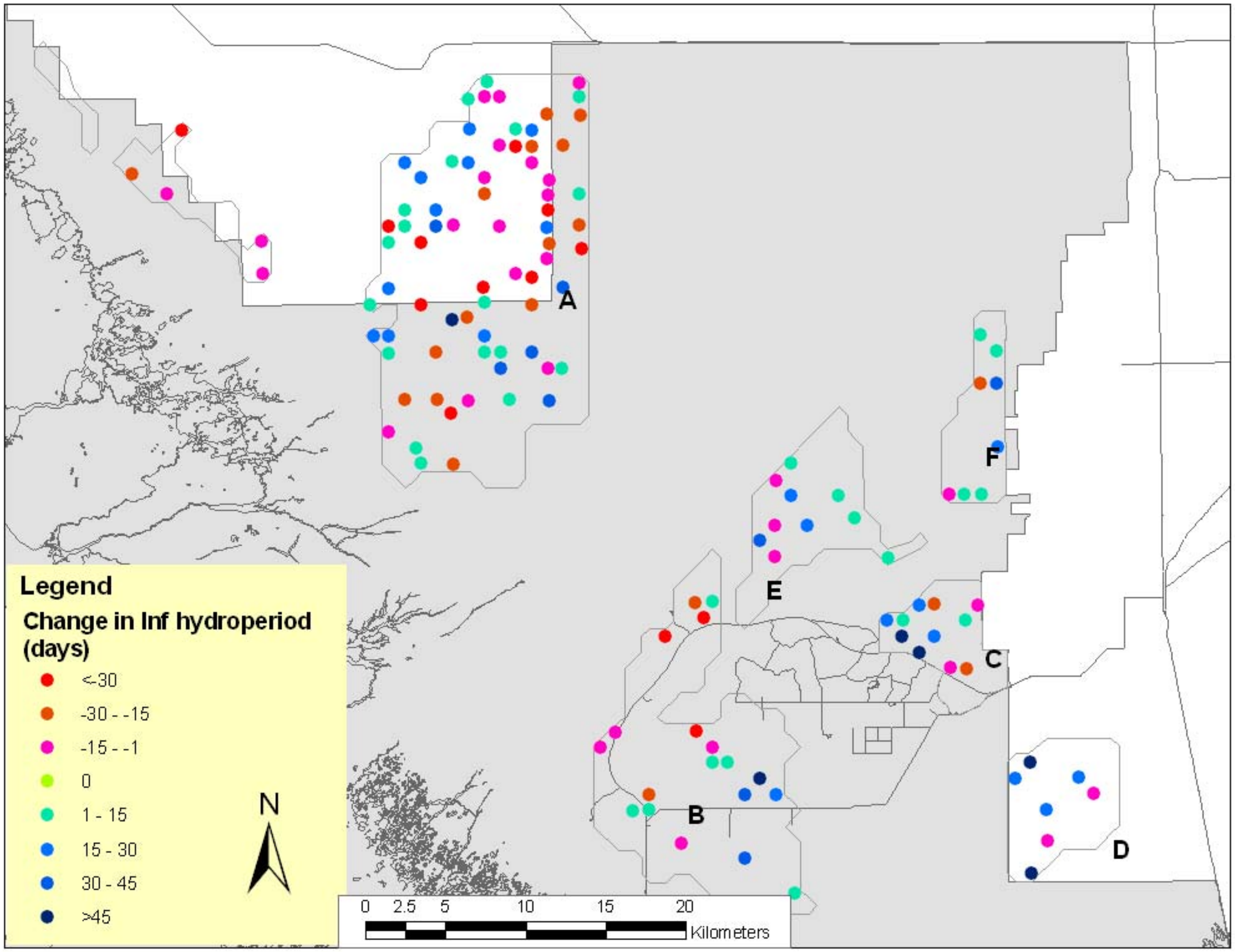

Figure 7: Change in vegetation inferred hydroperiod between 2004/2005 and 2008 sampling at 138 unburned sites within CSSS habitat.

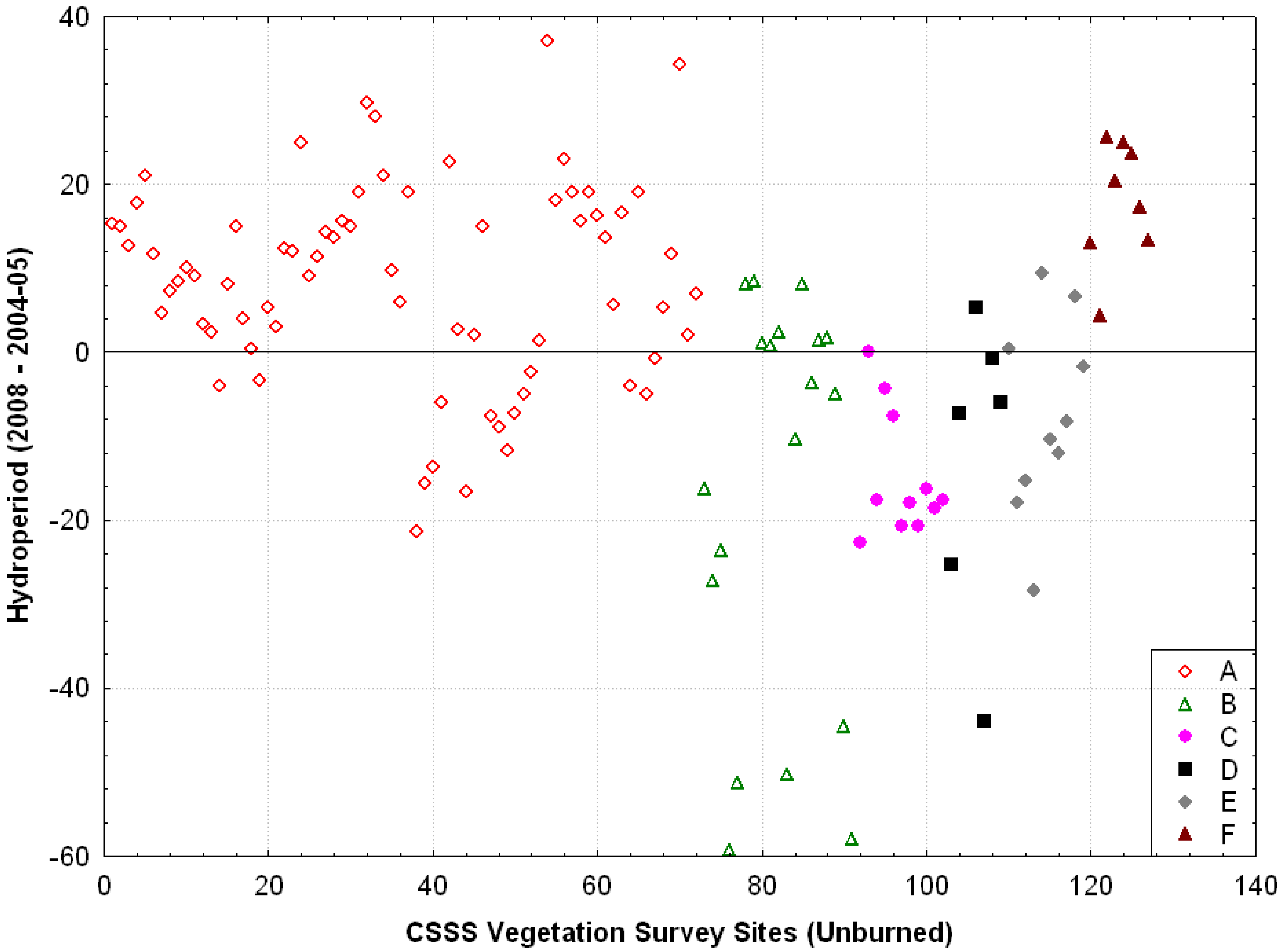

Figure 8: Difference in mean hydroperiod (days) averaged over three years prior to vegetation sampling in 2004-05 and 2008. Hydroperiod for the vegetation survey sites were calculated using USGS ground elevation and water stage data obtained from Everglades Depth Estimation Network (EDEN). .

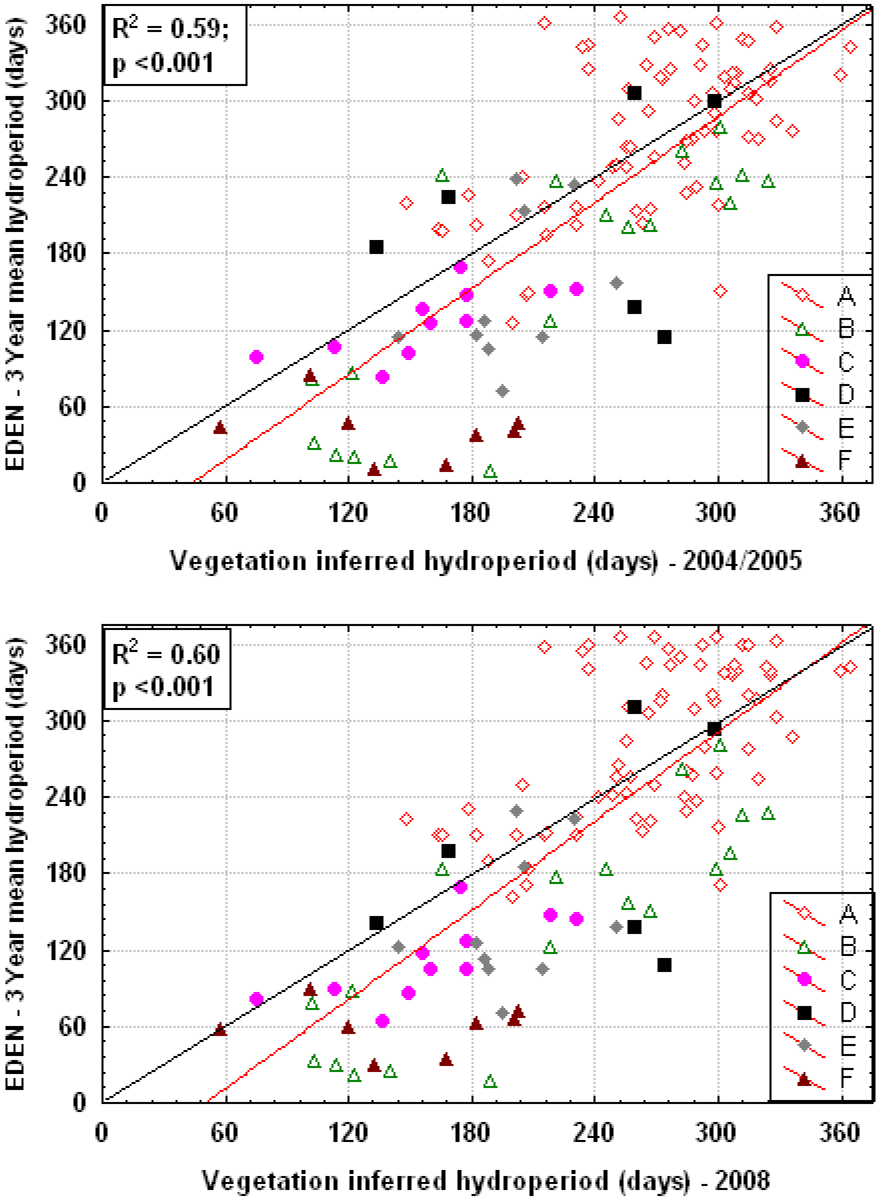

Figure 9: Relationships between 3-year mean hydroperiod inferred from vegetation data gathered at the unburned census sites sampled in both 2004-5 and 2008 and the hydroperiod estimated using from USGS ground elevation and water stage data obtained from the Everglades Depth Estimation Network (EDEN).

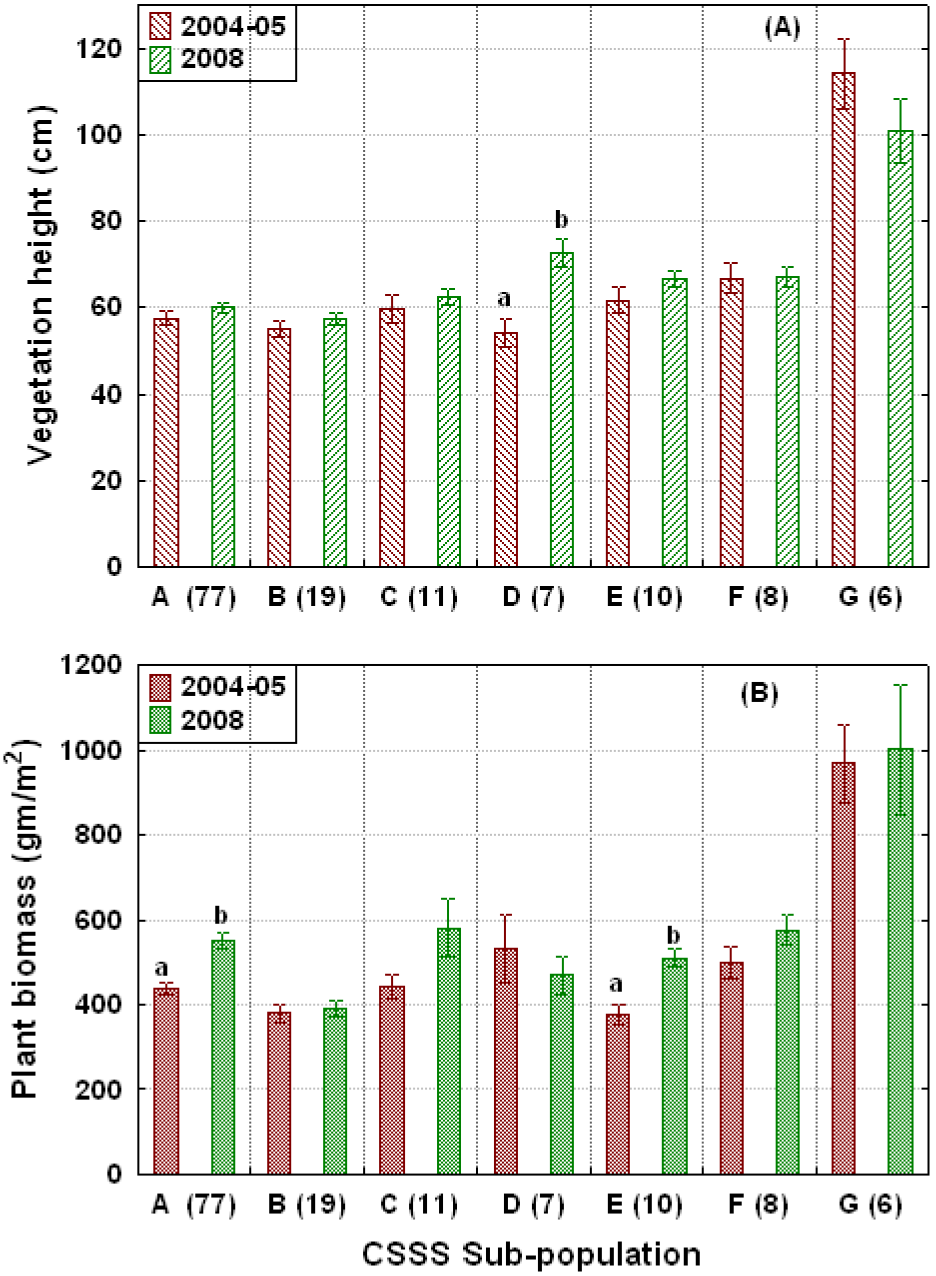

Figure 10: Mean (± 1 S.E.) (A) Vegetation height and (B) above ground plant biomass at the unburned CSSS census sites sampled in 2004-05 and 2008. Both vegetation height and plant biomass are averaged over CSSS subpopulations. Different roman letters indicate significant difference (pair wise t-test; $p < 0.05$) between two sampling events (2004-05 and 2008) within particular sub-population. Number of sites sampled in each sub-population is given in parenthesis.

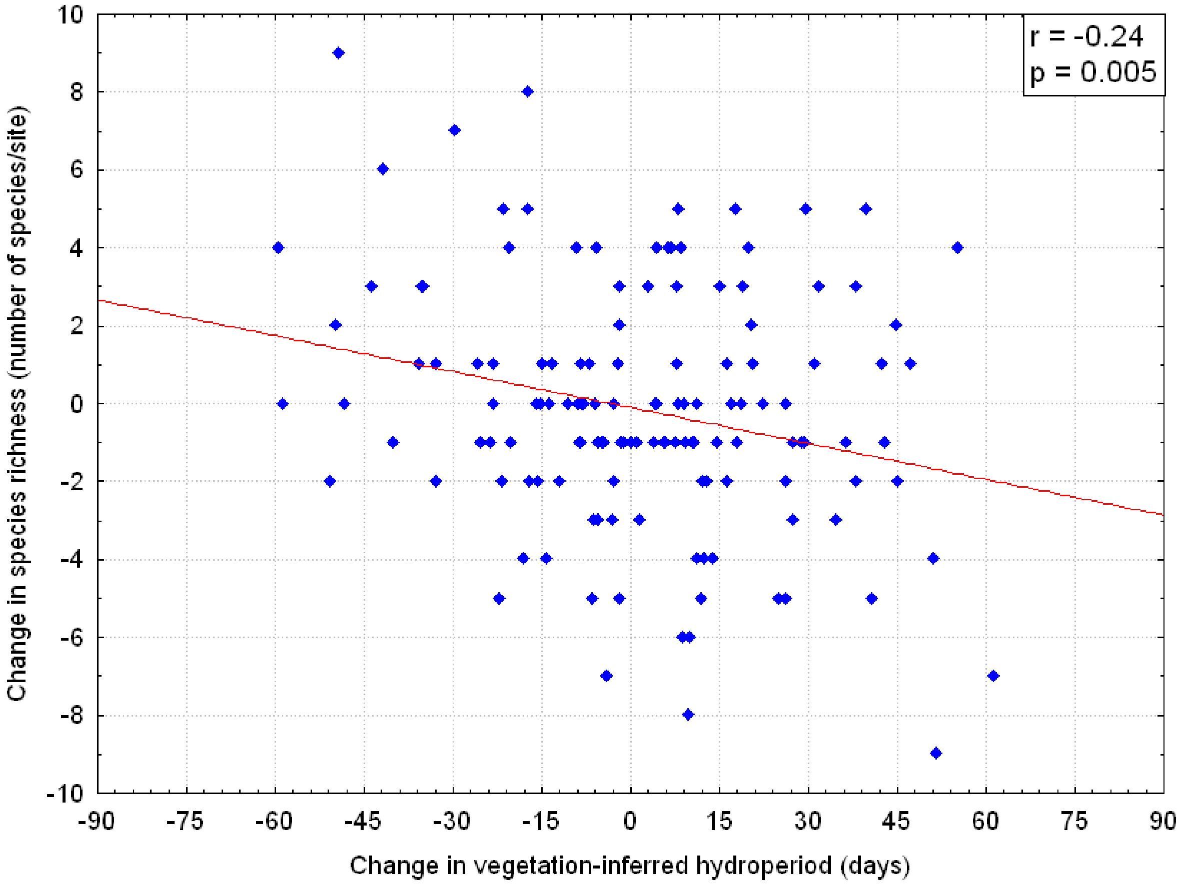

Figure 11: Relationship between change in vegetation-inferred hydroperiod and species richness at the unburned CSSS census sites sampled in 2004-05 and 2008.

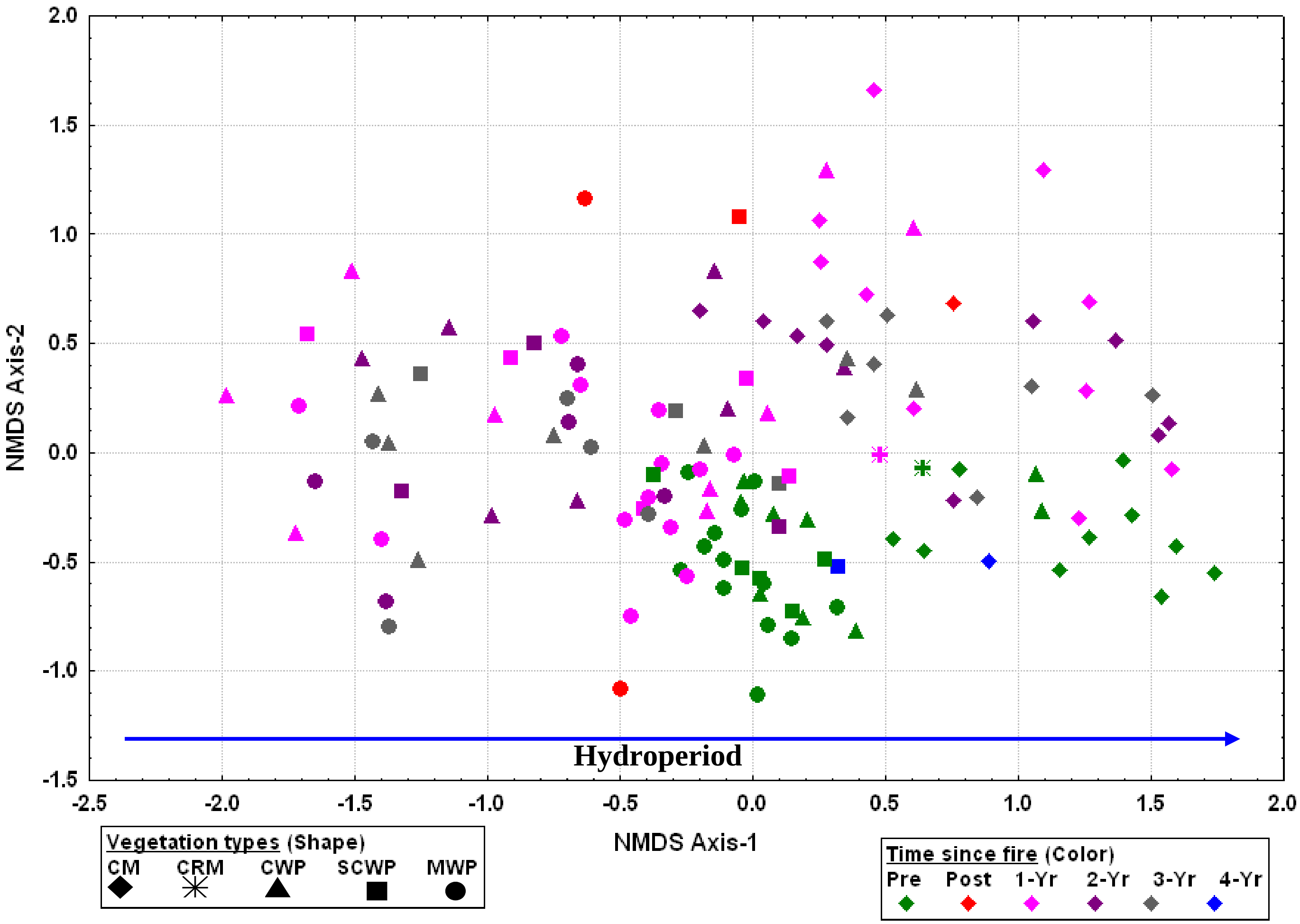

Figure 12: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on total cover at 27 sites burned in 2005, 2006 and/or 2007 and sampled in 2004 or 2005 and again in 2006. Two sites burned in 2003 and sampled every year for 4 years after fire are also included in the ordination. Hydrologic gradient is based on the vegetation inferred hdyroperiod calculated from pre-burn vegetation present at those sites. CM = *Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; CWP = *Cladium* wet prairie; SCWP = *Schizachyrium* wet prairie; MWP = *Muhlenbergia* wet prairie.

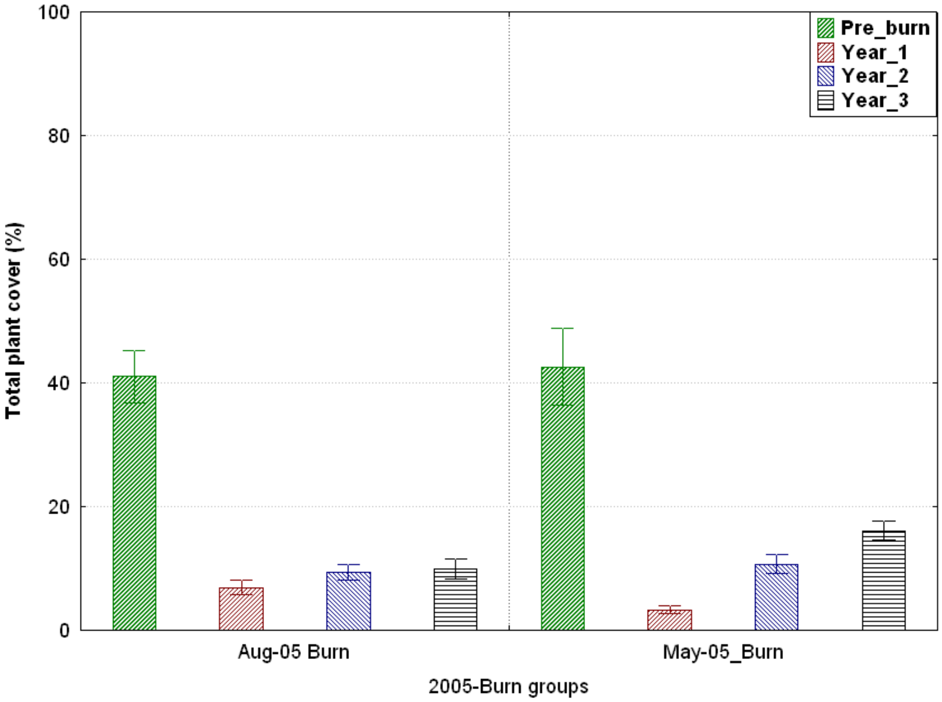

Figure 13: Mean total plant cover in pre-burn and subsequent year samples after fire for two groups of sites, one burned in May 2005 and the other in August 2005.

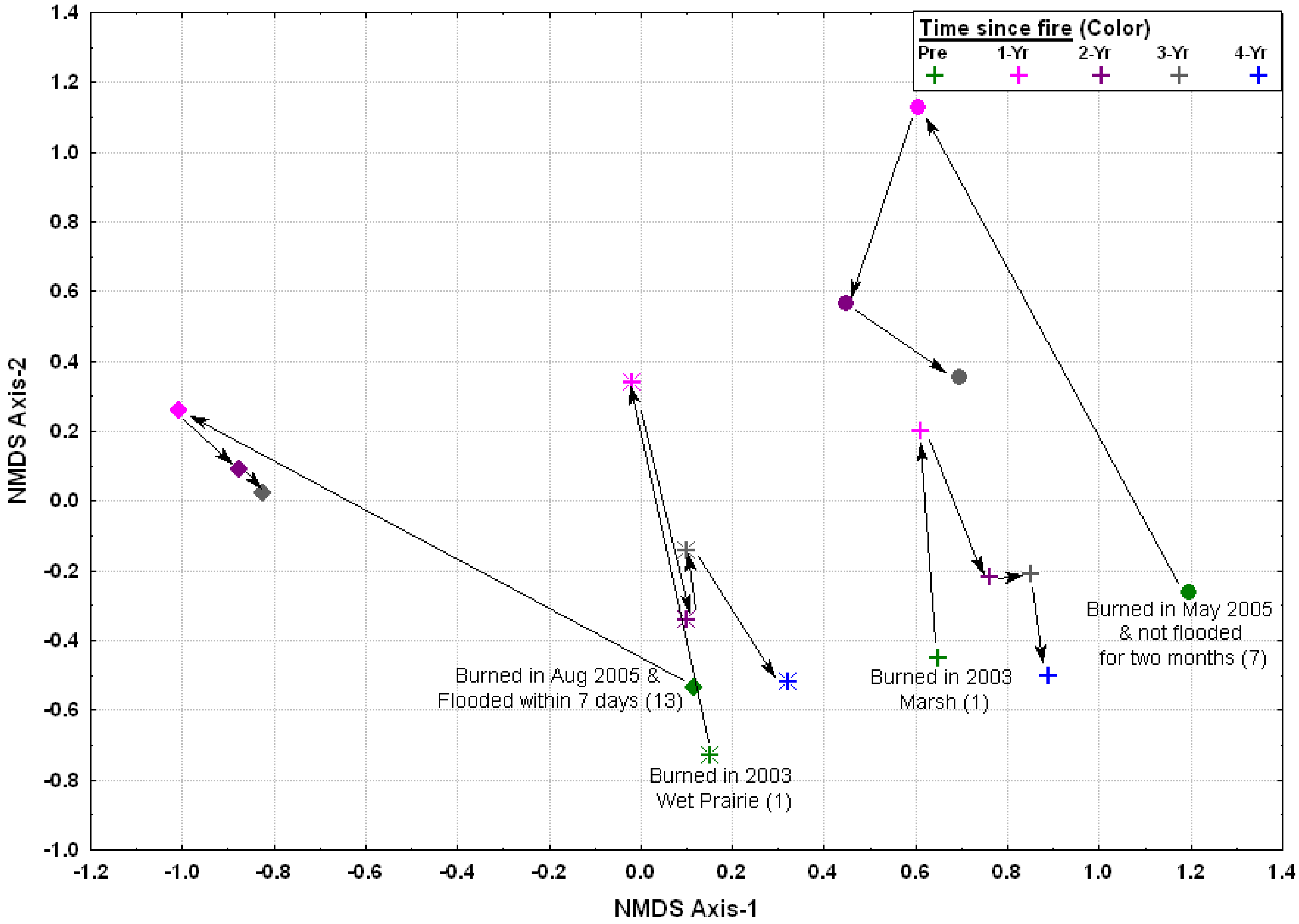

Figure 14: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on total cover at 2 sites burned in 2003 and 20 sites burned in 2005. Two sites burned in 2003 are used as reference sites. For the sites burned in 2005, points in ordination space represent centroids of sites grouped by month of burning and post-fire hydrology condition. Number of sites in each group is in parenthesis.

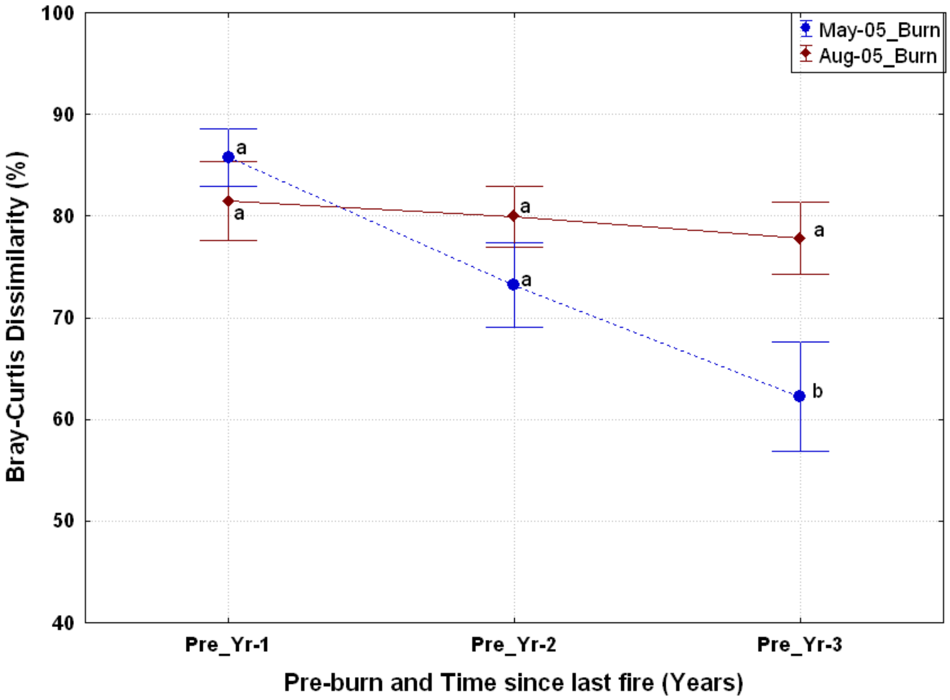

Figure 15: Mean dissimilarity between pre-burn and subsequent year samples after fire for two groups of sites, one burned in May 2005 and the other in August 2005.

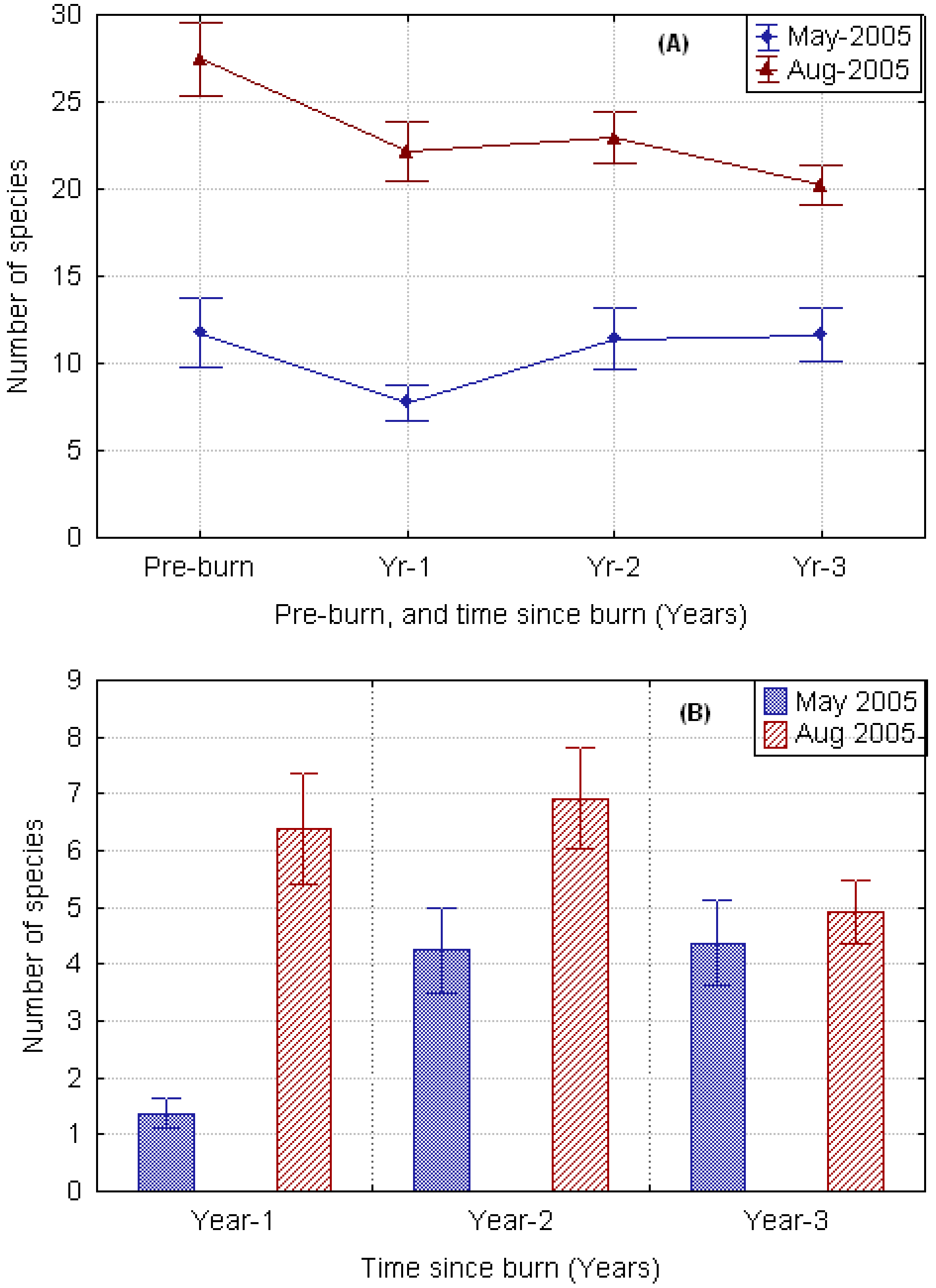

Figure 16: Change in number of species at the two sets of census sites, burned in May 2005 (May_burn) and August 2005 (Aug_burn), and sampled annually after burn. (A) Mean (± 1 S. E.) species richness (number of species per site) (B) Mean number of species that were not present before fire, but appeared during one or more of the next three years.

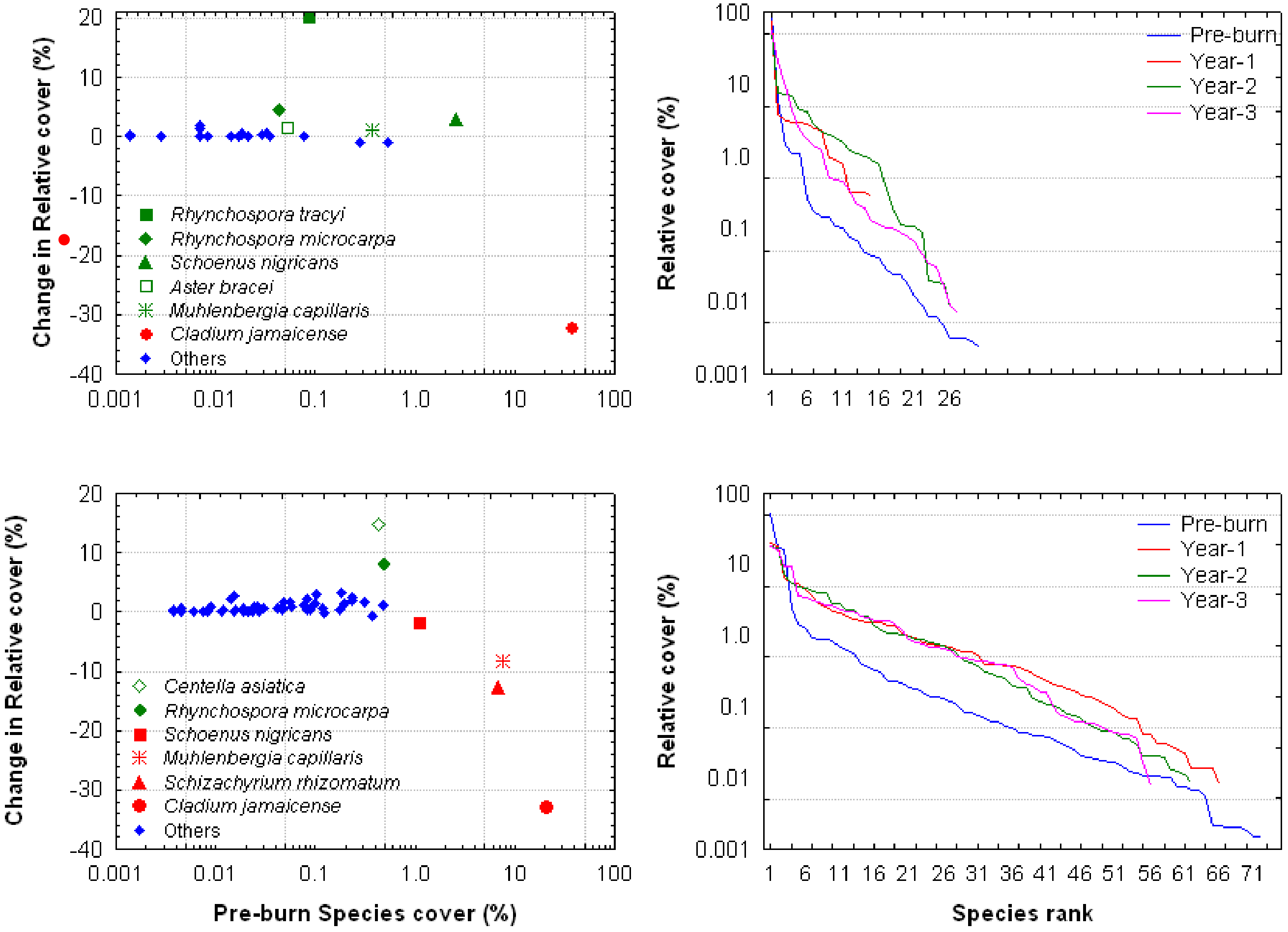

Figure 17: Change in the relative cover of species (A) and species rank abundance (B) at the sites burned in May 2005 (May_burn) and August 2005 (Aug_burn), and re-sampled 1, 2 and 3 year after burn

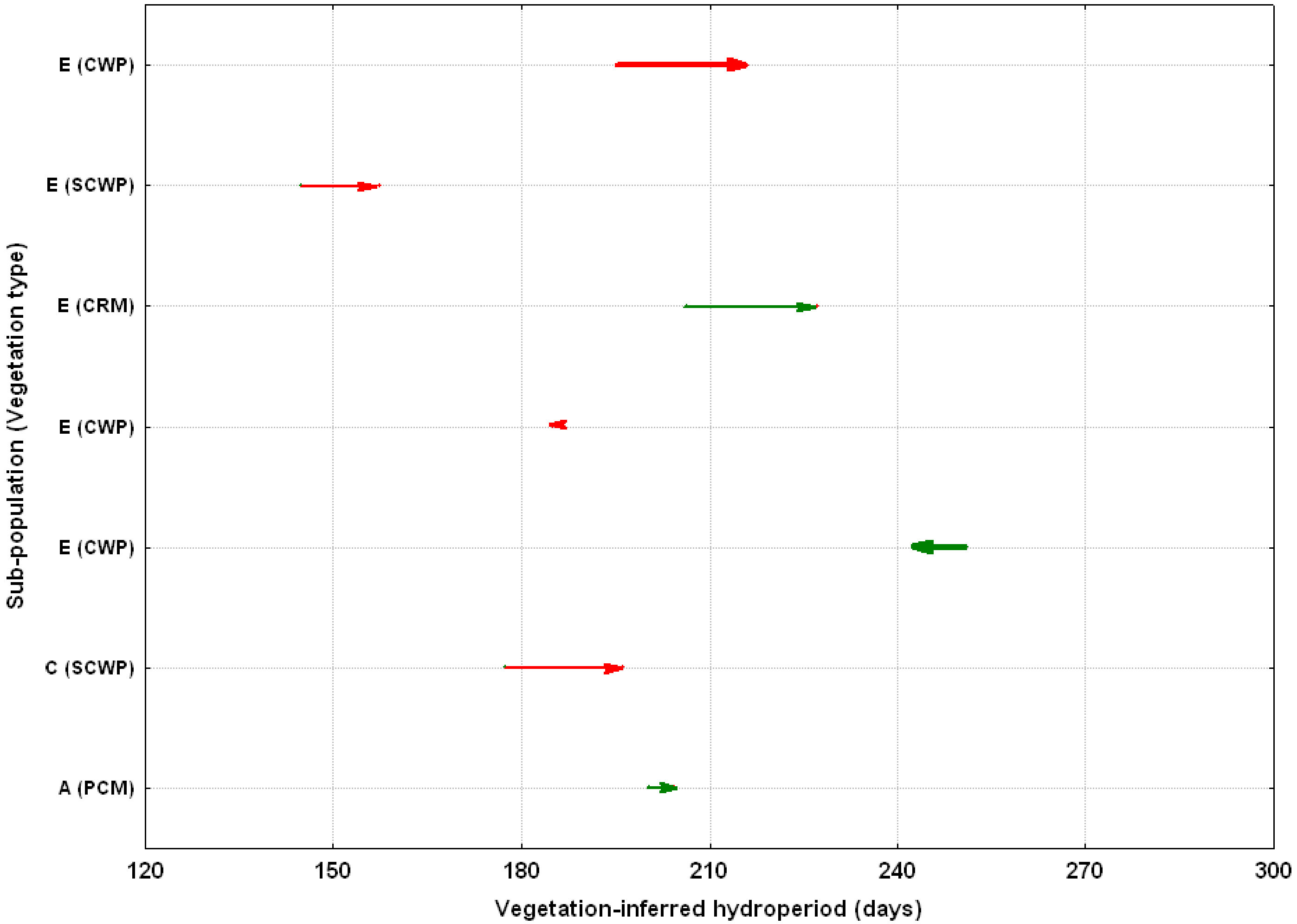

Figure 18: Change in CSSS counts with a change in vegetation inferred hydroperiod (days) at the sites which were sampled in both events, 2004 or 2005 & 2008, and were not burned at least for 4 years prior to 2008 sampling. Only those sites, at which CSSS population was surveyed in both years, and the count was ≥1 in either 2004-05 or 2008 survey are included. Green and red lines show gain and loss in CSSS numbers, respectively. The thickness of line indicates the CSSS count as 1 or 2 that were gained or lost in increasing order.

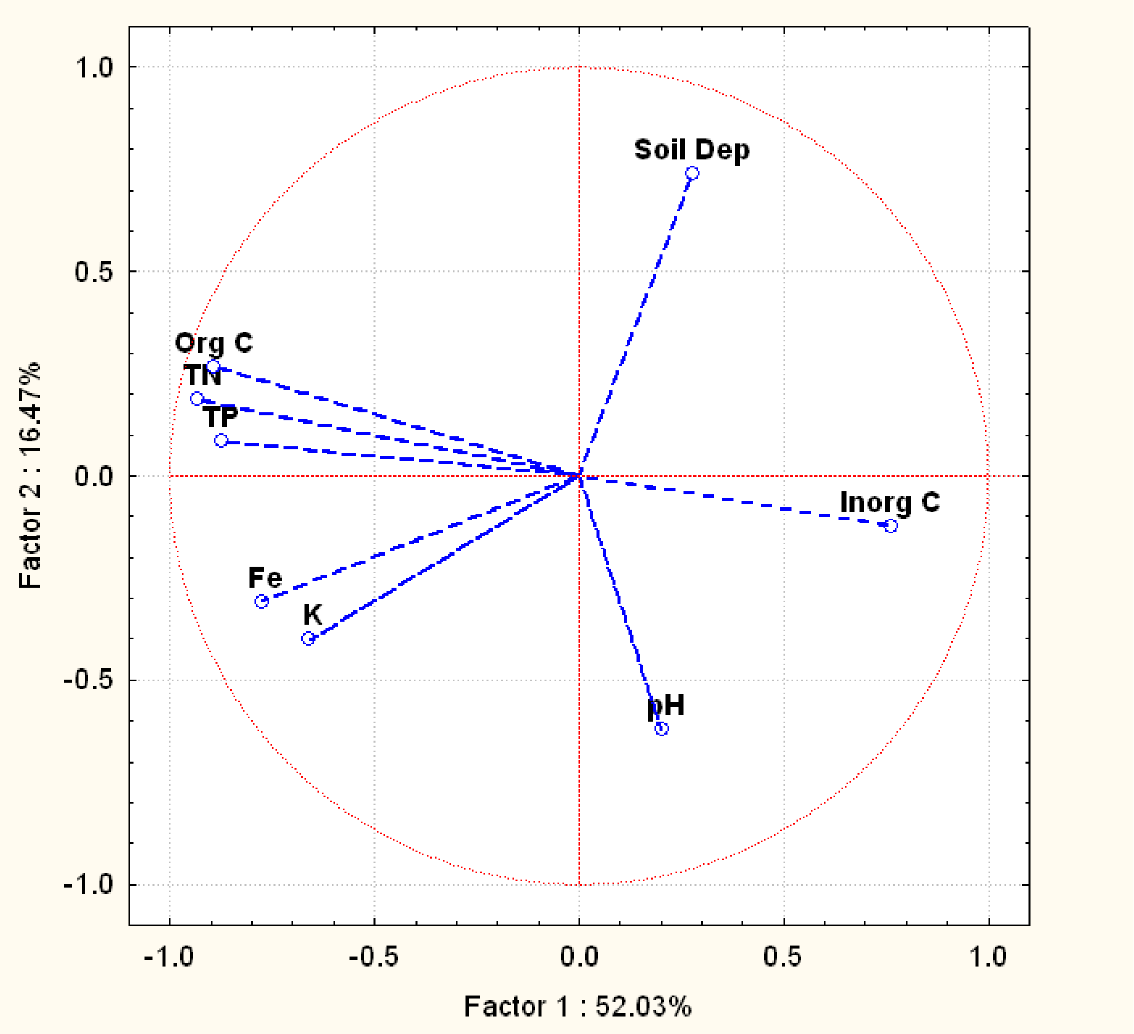

Figure 19: Principal component analysis of 8 soil variables from samples throughout the marl prairie landscape within recent habitat of Cape Sable seaside sparrow.

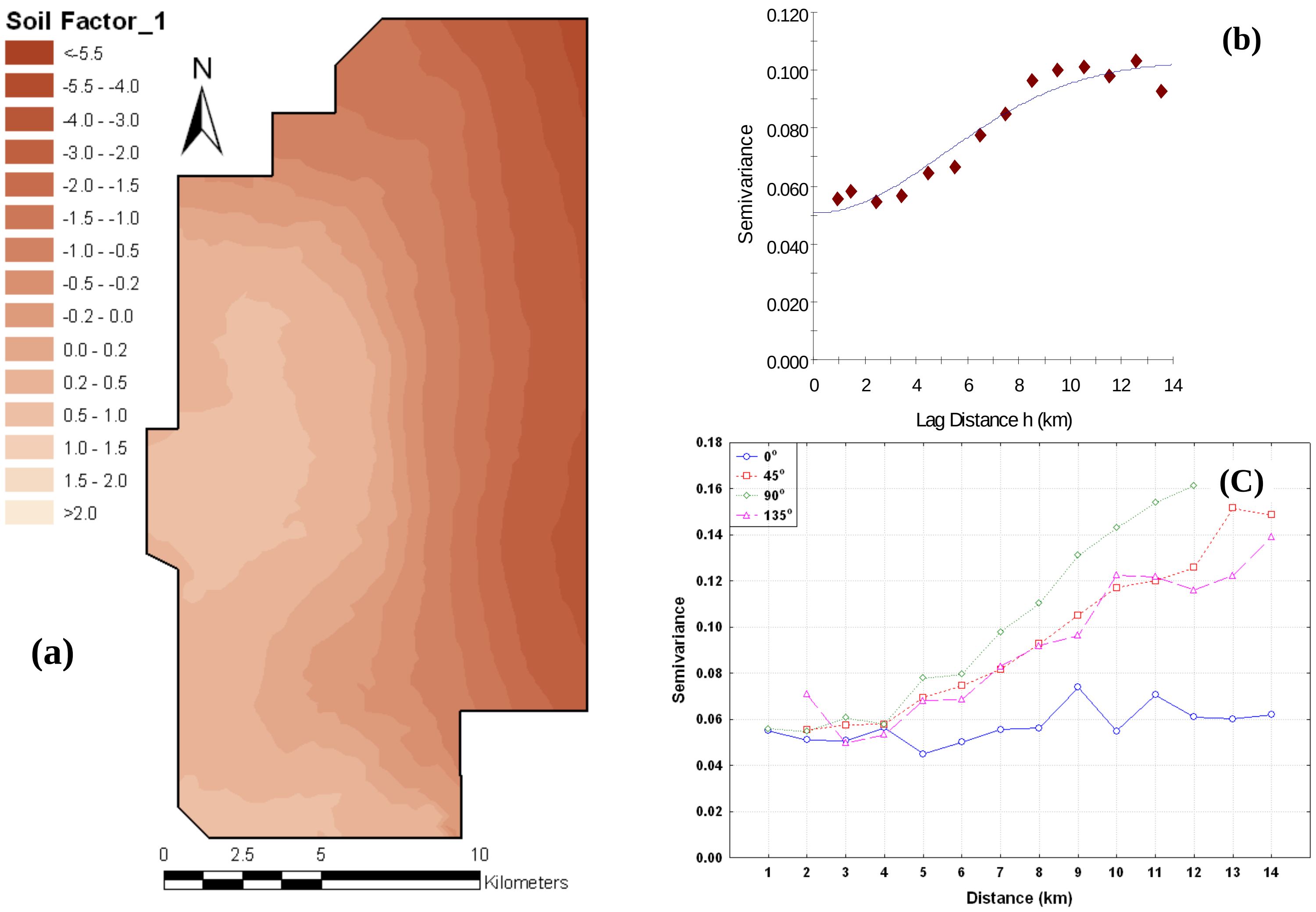

Figure 20: Spatial pattern in Soil Factor-1 representing carbonate-organic soil gradient within the marl prairie landscape of CSSS sub-population A. (a) Surface map using kriging interpolation (b) Isotropic variogram, fitted with Gaussian model, and (c) Directional variograms, beginning at 0^o (N-S) and continuing at 45^o increments and 22.5^o tolerances

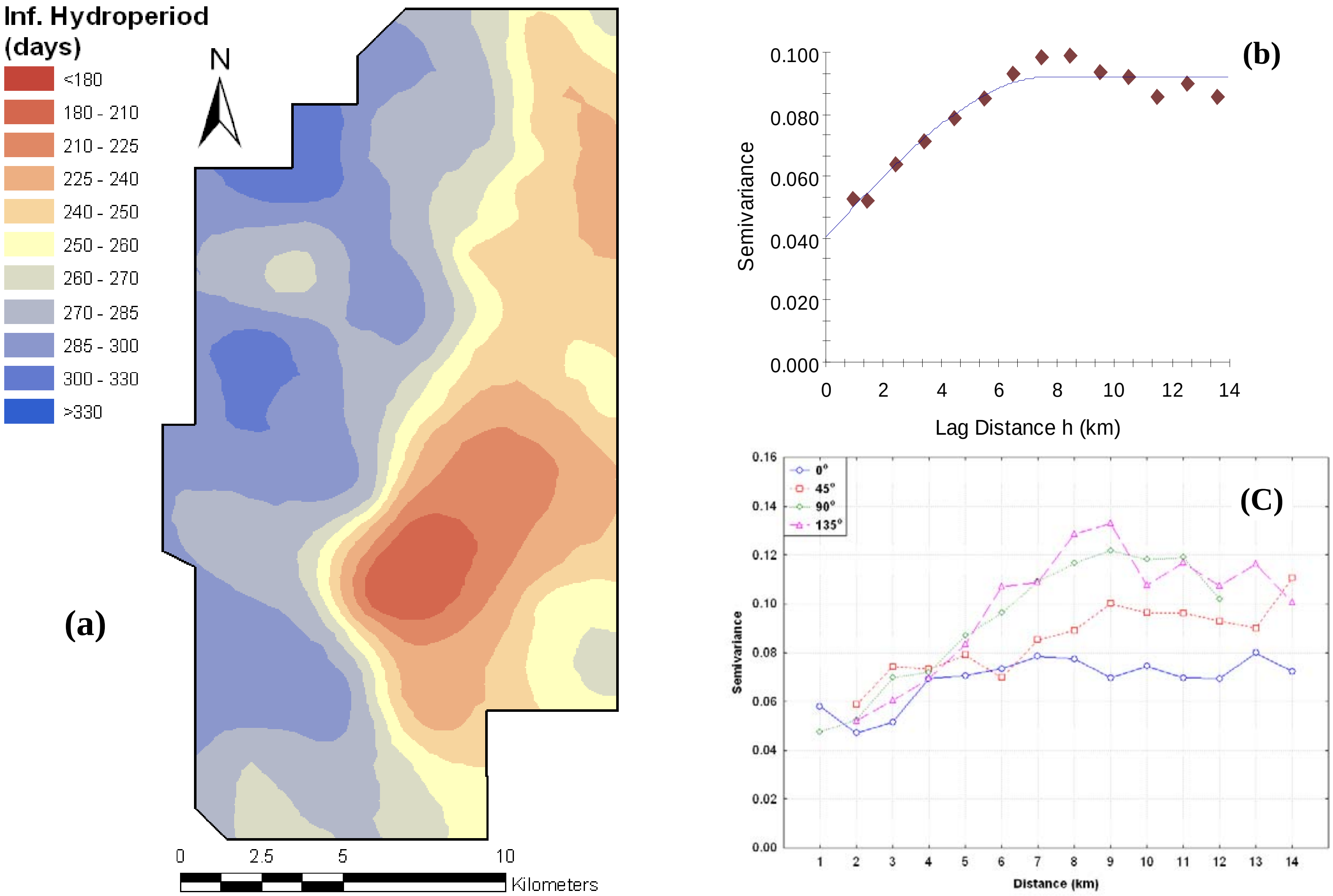

Figure 21: Spatial pattern in vegetation-inferred hydroperiod within the marl prairie landscape of CSSS sub-population A. (a) Surface map using kriging interpolation (b) Isotropic variogram, fitted with spherical model, and (c) Directional variograms, beginning at 0^{o} (N-S) and continuing at 45^{o} increments and 22.5^{o} tolerances.

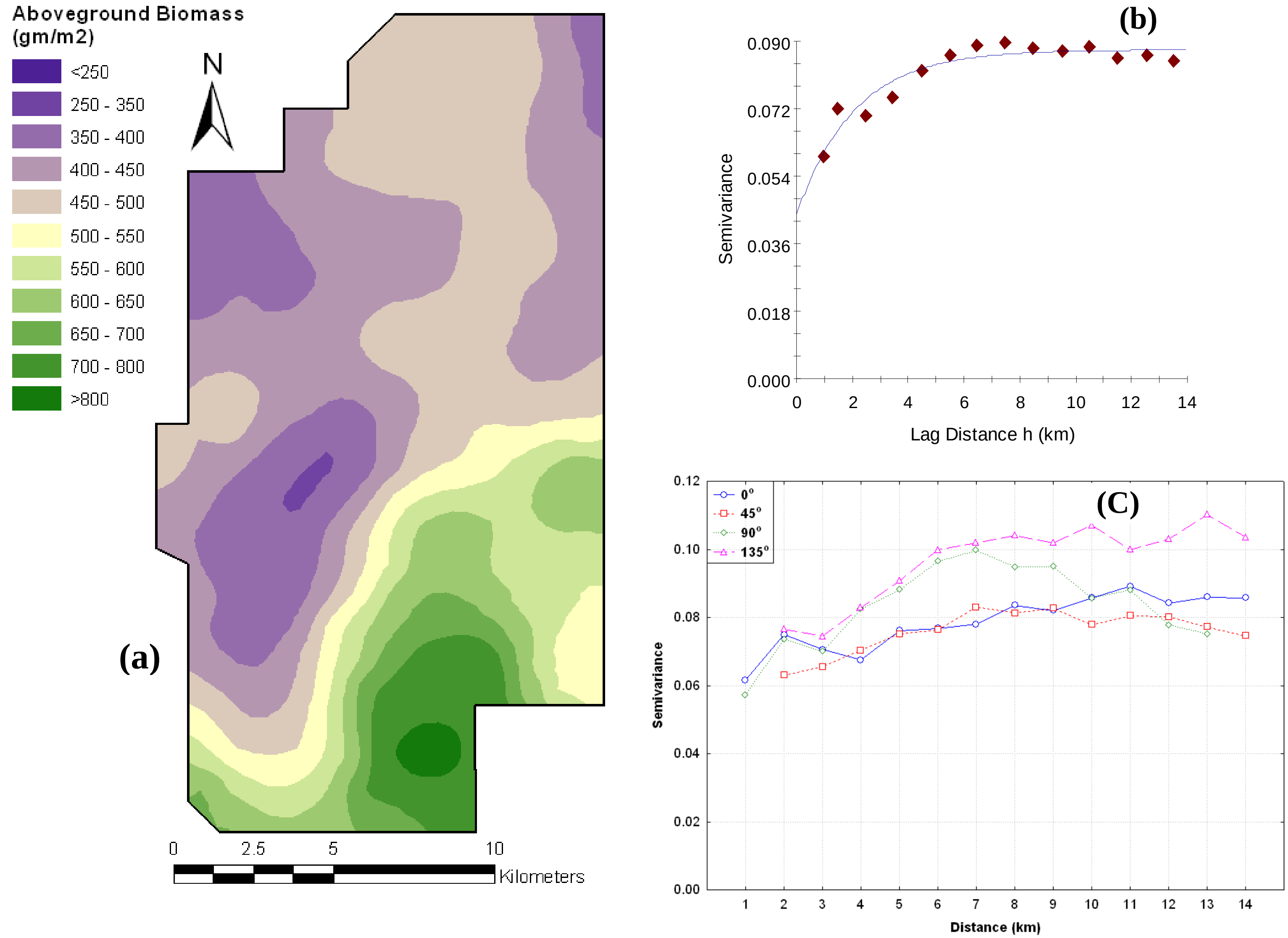

Figure 22: Spatial pattern in above ground plant biomass within the marl prairie landscape of CSSS sub-population A. (a) Surface map using kriging interpolation (b) Isotropic variogram, fitted with exponential model, and (c) Directional variograms, beginning at 0^{o} (N-S) and continuing at 45^{o} increments and 22.5^{o} tolerances.

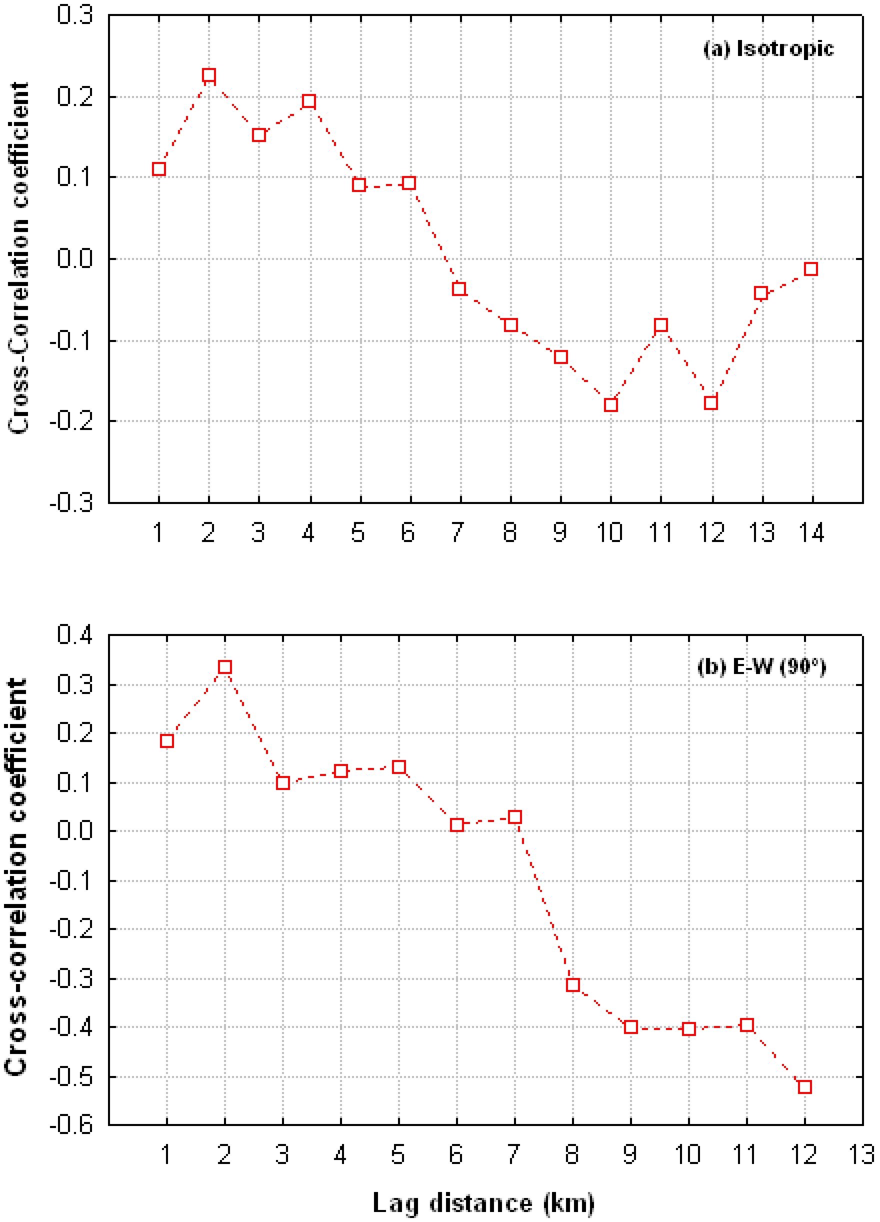

Figure 23: Cross-correlogram between Soil Factor-1 and vegetation-inferred hydroperiod.

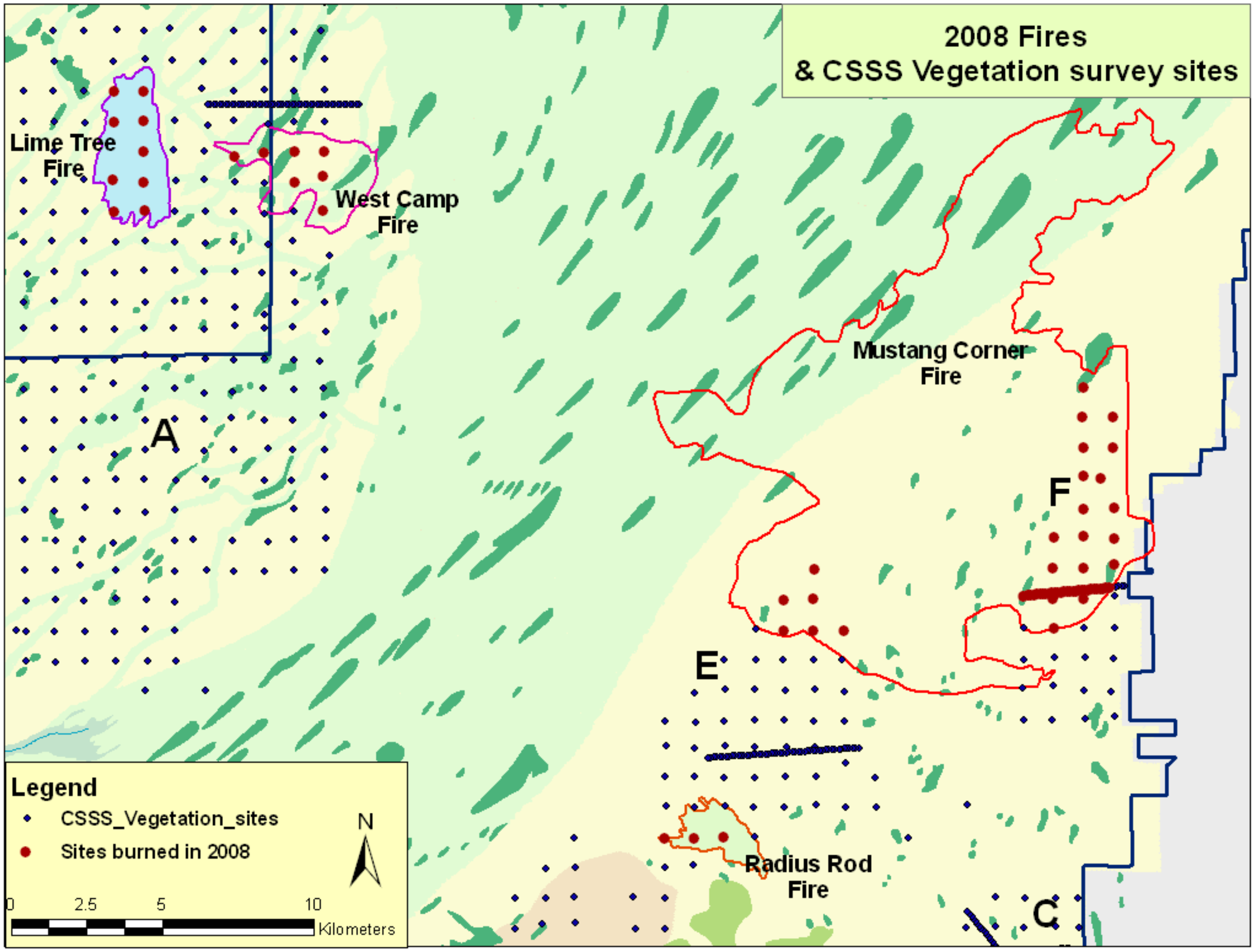

Figure 24: CSSS vegetation sites burned in 2008.

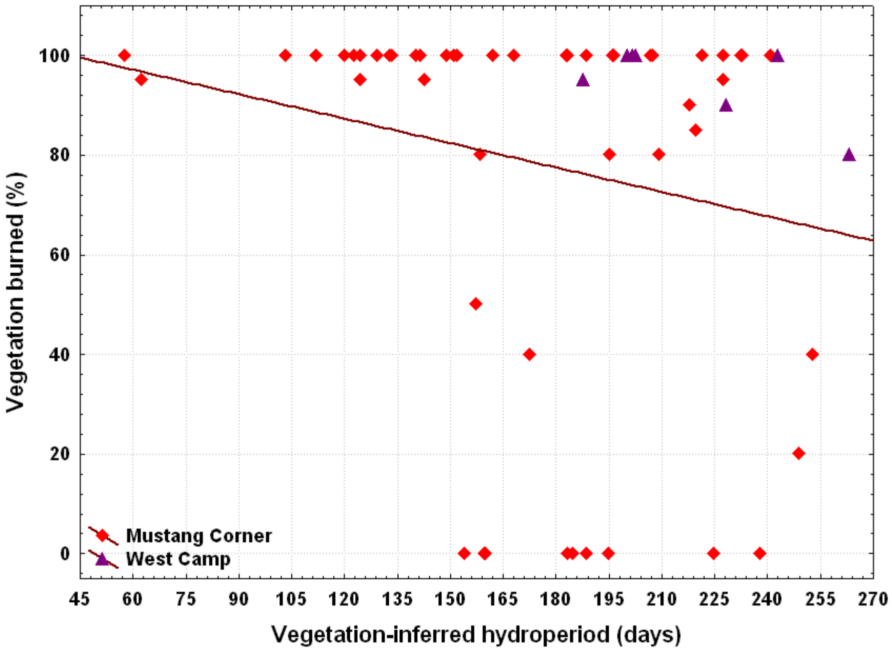

Figure 25: Relationships between vegetation-inferred hydroperiod and vegetation (%) burned at CSSS vegetation monitoring sites embedded within the boundaries of Mustang Corner and West Camp fires.

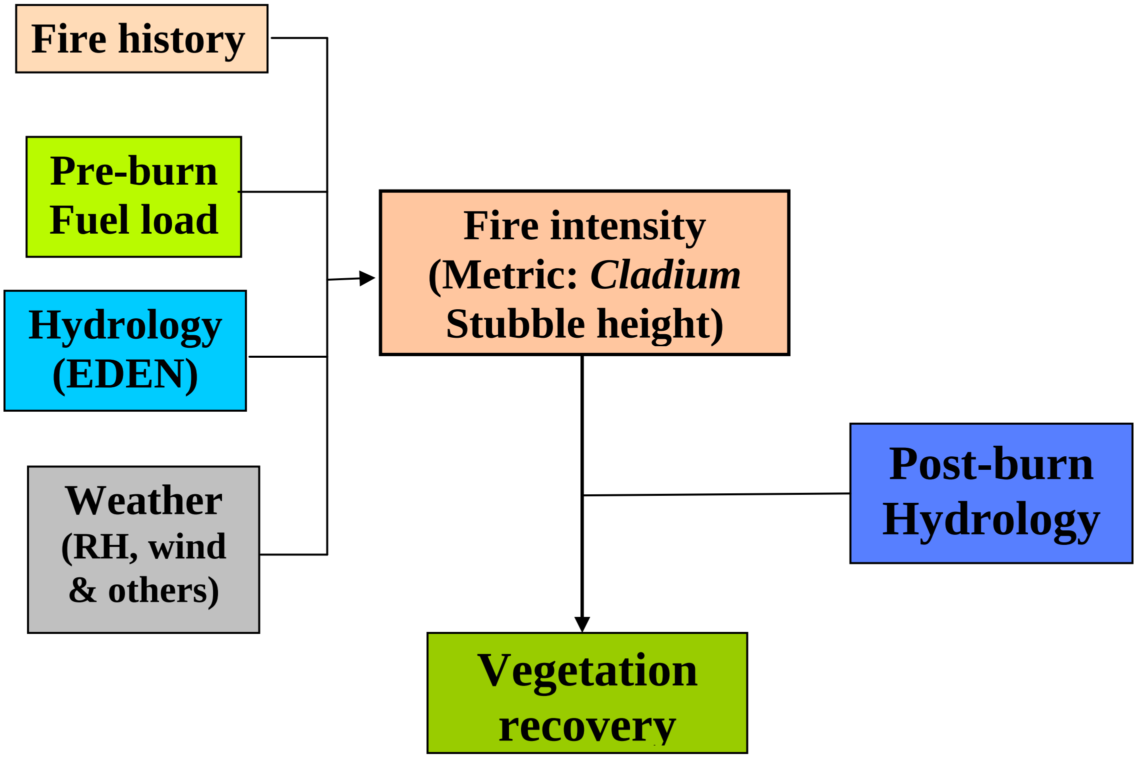

Figure 26: Schematic diagram showing how fire intensity, together with post-fire hydrology, affects post-burn vegetation recovery.