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

2006-2007

(Year 5 – Final Report)

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Summary

This document summarizes the activities that were accomplished during the fifth 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 Service (Biological Resources Division). The major activities in Year 5 included presentations, field work and data analysis, and presentations. In the fifth year of the project, we made five presentations. In April, Jay Sah gave a presentation at the Marl Prairie Workshop 2007 at the Everglades National Park. A second presentation, entitled 'Relationship between species richness and biomass along a hydrologic gradient in the marl prairie landscape in the southern Everglades, Florida, USA' was delivered at the Ecological Society of America's (ESA) 92nd Annual Meeting in the second week of August. Jay made another presentation on vegetation dynamics in Southern Everglades Marl Prairies and their implications for Cape Sable seaside sparrow at the Avian Ecology Workshop 2007 on August 13, 2007. In the same meeting, Mike Ross made a presentation on 'Vegetation dynamics in habitats of four endangered birds in the Florida Everglades', touching on Cape Sable seaside sparrow habitat as well as the habitat of other birds. In the first week of December 2007, Jay presented the results of 5th year field work at the Cape Sable seaside sparrow (CSSS) Fire Meeting 2007 at Everglades National Park (ENP). Mike and Jay also participated in several meetings with the Park and RECOVER staffs, and contributed in developing the Marl Prairie performance measures.

We commenced vegetation sampling on March 28 and continued through June 8, 2007. During the field work in 2007, we re-sampled 18 sites on Transect D and 148 of the 230 census points sampled in 2004. In addition, we also re-sampled 29 census sites that were sampled initially in 2003 or 2005, and were subsequently burned between 2003 and 2007. The burned sites were re-visited to learn more about vegetation recovery after fire and to assess the effects of the fire-hydrology interaction on vegetation. In general, structural and compositional vegetation parameters recorded at both unburned and burned transect and census sites in 2007 were as the same as utilized in the first four years of the study. In 2007, we tagged (for the first time) all the woody plants present in the compositional plots. To examine the contribution of C_3 and C_4 plants to the soil organic matter, we also collected vegetation and surface soil samples at 24 sites, and analyzed them for $\delta^{13}C$. Soon after vegetation sampling was completed, data were entered, thoroughly checked and analyzed during the remainder of the year.

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 quantitatively examine the differences in vegetation composition between two sampling years at unburned sites and among different groups at burned sites. Sites which were not burned during the four year period before the 2007 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 2003, 2005, 2006 and/or 2007 (no sites were burned in 2002 or 2004) to be burned sites. Vegetation change at the burned sites was analyzed by vegetation type and in relation to time since last fire.

Vegetation structure and composition within CSSS habitat did not change significantly in terms of relative cover of species. However, mean plant cover and absolute cover of three major species, *Schizachyrium rhizomatum*, *Muhlenbergia capillaris* and *Rhynchospora tracyi*, were significantly higher in 2007 than in 2004. 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 and 2007. Nevertheless, vegetation in the wet prairies in sub-population F, and along the south-western edge of sub-population E and sub-population B were indicative of slightly wetter conditions in 2007 than three years earlier. In Sub-population A west of Shark Slough, differences in vegetation-inferred hydroperiod between 2004 and 2007 was insignificant and did not reveal any definite spatial pattern. At unburned sites, plant cover, canopy height, and above ground biomass were significantly higher in 2007 than in 2004, whereas species richness showed the opposite trend. At burned sites, however, plant cover increased or decreased depending on the time since last burn and the hydrologic conditions in the immediate post-burn period. A rise in water level associated with the passage of Hurricane Katrina just after fire in August 2005 had killed most plants, including sawgrass culms, resulting in very low cover during 2006 survey, and the cover at those sites remained primarily unchanged even one year later.

In the marl prairie landscape, the abundance of C_4 species varied along the hydrologic gradient. This was reflected in significant differences in $\delta^{13}C$ values among vegetation types at 24 sampled sites. Mean $\delta^{13}C$ values of above ground vegetation were higher in *Muhlenbergia* and *Schizachyrium* wet prairies and in *Spartina* marsh than in other vegetation types. Moreover, $\delta^{13}C$ values of both above ground vegetation and surface soil organic matter had significant negative relationship with hydroperiod, suggesting that the carbon isotopic signature of soil organic matter can be used to approximate historical hydrologic regimes.

Re-survey of sites sampled in 2004 revealed that the vegetation structure and composition did not change much at sites that were not burned since 2003. However, many sites in sub-population E and F, and some sites in sub-population B showed slightly wetter vegetation in 2007 than in 2004. Hydroperiod over the three-year period before sampling, calculated from Everglades Depth Estimation Network (EDEN) data, was higher for these sites in 2007 than in 2004 in all sub-populations except B, in which mixed results were obtained. It is not clear at present whether such a difference in hydroperiod could have a significant effect on plant composition within this short time scale, as there is limited understanding yet regarding how rapidly vegetation changes in response to hydrologic alterations in CSSS habitat. In addition, very low plant cover and a change in species composition at sites flooded after fire in 2005 and surveyed approximately 2 years after fire suggests that post-fire flooding will not only delay the vegetation recovery process, but could also cause 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. In summary, our re-sampling in 2007 of sites surveyed in 2004, along with burned sites surveyed in 2004 and 2005, has answered some questions regarding vegetation change in response to hydrology and fire. Furthermore, the results of our study on C_3 and C_4 plants and the carbon isotopic signature of surface soil organic matter along the hydrologic gradient suggested that carbon isotopic signature in soil organic matter can be used to approximate historical hydrologic regimes and vegetation.

1. Introduction

This document summarizes the progress that was made during the fifth year of the research project “Effect of hydrologic restoration on the habitat of the Cape Sable Seaside Sparrow (*Ammodramus maritimus mirabilis*)”, a collaborative effort among the US Army Corps of Engineers, Everglades National Park, Florida International University, and the US Geological Service (Biological Resources Division).

Presentations

In the fifth year of the project, we made five presentations. In April, Jay Sah gave a presentation, entitled ‘Vegetation Dynamics in Southern Everglades Prairies in Recent Years: Causes and Implications’ at the Marl Prairie Workshop 2007 at the Everglades National Park. A second presentation, entitled ‘Relationship between species richness and biomass along a hydrologic gradient in the marl prairie landscape in the southern Everglades, Florida, USA’ was made at the Ecological Society of America’s (ESA) 92nd Annual Meeting, August 5-10, 2007, San Jose, CA. Jay Sah made a 3rd presentation, entitled ‘Vegetation Dynamics in Southern Everglades Marl Prairies and their implications for Cape Sable Seaside Sparrow’ at the Avian Ecology Workshop 2007 at Florida International University, Miami, FL on August 13, 2007. In the same meeting, Mike Ross gave a presentation on ‘Vegetation dynamics in habitats of four endangered birds in the Florida Everglades’ that included Cape Sable seaside sparrow habitat too. Both presentations included the materials on vegetation responses to hydrologic change and fire within the Cape Sable seaside sparrow habitat. Jay gave a 4th presentation at the Cape Sable seaside sparrow (CSSS) Symposium 2007 at Everglades National Park (ENP) on December 4-5. In this meeting, Jay presented primarily the results of 5th year field work. In addition, Mike and Jay participated in several meetings with the Park and RECOVER staff, and contributed in the ongoing development of Marl Prairie performance measures.

2. Methods

The major activities in Year 5 on ‘Effect of hydrologic restoration on the habitat of the Cape Sable seaside sparrow (CSSS)’ included field work, data analysis, and presentations.

2.1 Vegetation sampling

In the 5th year of field work, there was some change in FIU sampling personnel. David Jones and Rafael Travieso, who were involved in vegetation sampling since the beginning of the project, were no longer in our sampling team. Instead, Mike Kline and Brooke Shamblin joined our team and carried out most of field preparation, and also accompanied the field crew for vegetation sampling. Erin Hanan, Danielle Ogurcak and Daniel Gomez who are graduate students at FIU, and worked as part-time research assistants in Dr. Ross’ lab, frequently accompanied the FIU team. There was no change in USGS sampling personnel.

We commenced vegetation sampling on March 28 and continued through June 8, 2007. In the 5th year, we re-surveyed 195 sites, 177 Census sites and 18 sites on Transect D. Vegetation re-sampling at the census sites was done in the same months as 2004, in order to assure that any change in vegetation composition between two sampling periods would not be confounded by seasonal variation in species abundance. The only exceptions were the 18 sites on Transect D that were sampled initially in January 2004. In 2007, they were re-sampled in April-May, when the census sites were sampled.

During the field work in 2007, we re-sampled 148 of the 230 census sites that were sampled in 2004. Out of 148 census sites, 138 were unburned and 10 were burned sites **(Figure 1)**. Six census sites sampled in the Cape Sable area of south-western ENP in 2004 were not re-sampled in 2007. We also re-sampled an additional 18 sites on Transect D, and 29 census sites that were sampled for the first time in 2003 or 2005, and were burned in at least one year between 2003 and 2007. Burned sites were re-sampled to learn more about vegetation recovery after fire, and to assess the effects of the fire-hydrology interaction on vegetation. In general, structural and compositional vegetation parameters recorded at both unburned and burned transect and census sites in 2007 were the same as in the first four years of the study. Additionally, we tagged all the woody plants present in the compositional plots. 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 5 field season (March 28 – June 8, 2007)

Transect/ Census sites	Sub-population	Unburned	Burned							# of sites sampled in 2007
		First-time sampled	First-time sampled			Burn year				
		2004	2003	2004	2005	2003	2005	2006	2007	
Transect	D			18		11	7			18
Census sites	A	77	1		1			2		74
	B	27	16	8	1	12	13			52
	C	9			2				2	11
	D	4	7	2	1	9	1			14
	E	14								14
	F	7								7
Total		**138**				**57**				**195**

2.2 C_3 & C_4 analysis

As a pilot study to examine the contribution of C_3 and C_4 plants to the soil organic matter, we also collected vegetation and surface soil samples at 24 sites, and analyzed them for $\delta^{13}C$.We first searched the literature for information on the photosynthetic pathway of plant species found in the marl prairie landscape of the southern Everglades. We were able to find information on the photosynthetic pathway of 56 species that constituted 15% of all graminoids and forbs (50% of graminoids) reported from wet prairies and marshes by **Ross**

et al. (2006). However, the pathways of several dominant species, including *Schoenus nigricans* and *Rhynchospora tracyi* were unknown. In the present study, 14 major species, including 8 species for which information on photosynthetic pathway was not available, were collected and analyzed for $\delta^{13}C$ value. The photosynthetic pathway of the other 6 species was known from the literature, but we re-analyzed these dominant plants to ascertain their $\delta^{13}C$ values.

For determining the carbon isotopic signature of above ground vegetation and soil organic matter, we used stratified random sampling to ensure that a range of hydrologic conditions and fire regimes were represented. Sites were stratified first into ten vegetation types identified by **Ross et al. (2006)**, and then into two categories, burned and unburned, based on annual fire maps prepared for 1981 to 2005 by Everglades National Park. Altogether 24 sites were selected from among 8 vegetation types, having a mean hydroperiod ranging from 169 ± 49 to 298 ± 44 days (**Ross et al. 2006**). Among these 24 sites, sixteen (i.e., 2 sites per vegetation type) were unburned since 1990, and eight sites representing 4 vegetation types were burned in the same year, 2003 (**Table 2**). Sampling sites were selected from the Marl Prairie landscape on both sides of the Shark Slough **(Figure 2)**.

Table 2: Number of CSSS vegetation survey sites selected for analyzing $\delta^{13}C$ values of above ground vegetation and soil organic matter.

Vegetation type	Burned/ Unburned	Burn year
Muhlenbergia wet prairie	UB	
	BURNED	2003
Schizachyrium wet prairie	UB	
	BURNED	2003
Schoenus wet prairie	UB	
Cladium wet prairie	UB	
	BURNED	2003
Spartina wet prairie	UB	
Cladium marsh	UB	
	BURNED	2003
Rhynchospora-Cladium marsh	UB	
Eleocharis-Rhynchospora marsh	UB	

At each sampling site, the cover of each graminoid species and major forb present in a randomly selected 0.25 m^2 quadrat was recorded. In addition, structural measurements were taken following methods described in **Ross et al**. (2003). Crown height was measured in four quarters of the quadrat, and total crown cover was visually estimated. From each quadrat, all plant material above the ground surface was harvested, and soil cores of 5 cm depth were collected. Both plant and soil samples were packed and brought to laboratory.

Sample processing and $\delta^{13}C$ analysis

Since the purpose of the study was to assess the relationship between the most recent vegetation and its contribution to soil organic matter, material from the top 0-2 cm of the core were separated from the remainder. Visible litter and roots were separated by hand. Both plant and soil materials were then separately dried in oven at 65°C, ground, and further refined using a # 60 (250µ) mesh sieve. Materials that passed through the sieve were treated with 1N hydrochloric acid for one hour to remove carbonate, rinsed thoroughly with distilled water, air dried and sieved again. The stable carbon isotope ratio in plants and SOM was determined using a mass spectrometer, and the ratio was reported as $\delta^{13}C$ (%o) = $[(^{13}C/^{12}C)_{sample}/(^{13}C/^{12}C)_{PDB} - 1] \times 1000$, where PDB is the PeeDee Belemnite.

2.3 Analytical methods

Vegetation change

We used a non-metric multidimensional scaling (NMS) ordination (Kruskal, 1964) to visualize temporal change in vegetation composition between sampling years. In NMS ordination, sites are plotted as points in a space comprised of a fixed number of dimensions, typically two. The distance between points in the ordination diagram is indicative of the underlying dissimilarity between those points. Various types of dissimilarity measures can be used in NMS. For these analyses, we used the Bray-Curtis distance metric as a measure of dissimilarity. We used Analysis of Similarity (ANOSIM), a nonparametric permutation procedure (Clarke 1993), to quantitatively examine the differences in vegetation composition between two sampling years. In this analysis, an R-statistic is generated based on the difference of mean rank among groups. When R is near 0, differences between groups are no larger than differences between one replicate and another within a group. When R is near 1, there are likely to be real differences in samples in different groups. In our case, the groups may be vegetation types, fire history treatments, sampling years, etc.

To examine change in vegetation composition, analyses were done separately for transect and census sites, and for un-burned and burned sites. Sites which were not burned during the four year period before the 2007 survey were considered to be un-burned. Vegetation data for unburned sites were also analyzed separately for each sub-population within CSSS habitat. For sites that did burn during 2003-2007, we adopted a slightly different criterion. Grouping of these burned sites on the basis of time since last fire yielded five groups: pre-burn, post-burn, and 1, 2, and 4 years after burn; sites burned in 2004, thus representing 3 years after fire when sampled in 2007, were not present within our network. Two-way analysis of similarity (ANOSIM) was used to examine differences in vegetation composition among these different fire history groups within each vegetation type.

Vegetation-hydrology relationships

To assess whether a change in vegetation composition between 2004 and 2007 was in response to periodic differences in hydrology, 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**). Our approach is similar to **Armentano et al. (2006)**, who described temporal changes in vegetation composition in response to hydrologic changes in Taylor Slough. We considered that relative changes in vegetation-inferred hydroperiod between 2004 and 2007 would support the hypothesis that vegetation in sparrow habitat changed in response to hydrological changes. Additionally, we also analyzed the changes in hydroperiod estimated from Everglades Depth Estimation Network (EDEN) hydrological data. From 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 2004 and 2007 sampling events, using repeated-measures analysis of variance (repeated-ANOVA) in STATISTICA Version 7.0 (StatSoft Inc. Tulsa, OK, USA).

δ^{13}C values of vegetation and soil organic matter

Simple linear regression was used to assess the relationship of standing vegetation δ^{13}C values and those for surface soil organic matter at the same sites, and between recent hydroperiod and the δ^{13}C values of both vegetation and soil organic matter. A paired ‘t’-test was used to compare the δ^{13}C values of vegetation and soil organic matter at each site.

3. Results

3.1 Vegetation change

The CSSS vegetation sites sampled in 2007 included both unburned and burned sites. While unburned sites were represented in all six sub-populations, burned sites were present in only sub-populations A, B, C and D. The sites which were not burned in the three years prior to the 2007 sampling season were considered as unburned sites.

Vegetation change at unburned sites

Vegetation structure and composition in the marshes and wet prairies within CSSS habitat did not change significantly in three years between 2004 and 2007 (**Figure 3**: ANOSIM – Global R = 0.006, p-value = 0.097). However, vegetation change over the period was primarily specified by an increase in total plant cover and in mean cover of few major species throughout the CSSS habitat **(Figure 4)**. In three years, total plant cover increased from 27.6% to 32.4% (Pairwise t-test; $p < 0.001$). Mean cover of three major species, *Schizachyrium rhizomatum*, *Muhlenbergia capillaris* and *Rhynchospora tracyi*, was significantly higher in 2007 than in 2004 (**Figure 4**). Cover of *R. tracyi* almost doubled (from 2.5% to 4.6%) in three years. Mean cover of other major species (mean cover > 0.5%), such as *Bacopa caroliniana, Cladium jamaicense, Eleocharis cellulosa, Schoenus nigricans,* and *Paspalum monostachyum* did not change significantly.

Change in total plant cover was not uniform in all six sub-populations and across all vegetation types described for CSSS habitat (Ross et al. 2006). Total plant cover significantly increased in sub-populations A, E and F whereas it decreased in sub-population B, and did not change much in sub-population C and D (**Figure 5a**). In sub-population F, total plant cover almost doubled (from 23.9% to 43.3%) in three years. Overall marsh sites experienced a larger increase in cover than wet prairie sites (**Figure 5b**). Change in cover of major species showed mixed results. Four major species that changed significantly in one or more sub-populations were *Cladium jamaicense, Muhlenbergia capillaris, Rhynchospora tracyi* and *Schizachyrium rhizomatum* (**Figure 6**. *C. jamaicense* increased in cover by almost 50% in sub-population F, indicating wetter condition in 2007 than three year earlier. Nevertheless, such change seems to be limited to discrete portions of the area, as drier prairie species such as *M. capillaris* and *S. rhizomatum* in fact increased in other portions during the three year period. Mean cover of *M. capillaris* also increased in sub-populations B and D though the change was statistically significant only in the former. In sub-population A, mean cover of both *R. tracyi* and *S. rhizomatum* significantly increased. Increase in *R. tracyi* is indicative of wetter condition, whereas that of *S. rhizomatum* suggests the opposite trend. Results of NMS ordination based on relative cover of species in sub-population A also revealed a difference in the direction of change in vegetation composition (**Figure 7)**. This is possible when vegetation responds to spatially varying hydrologic changes in recent years.

Unlike plant cover, mean species richness (the number of species per site) decreased significantly (Pair wise t-test: $n = 138$, $p < 0.001$) over the three years, from 18.0 species per plot in 2004 to 15.9 in 2007. However, there were some sites where species richness either increased or did not change **(Figure 8)**. Decrease in species richness was prominent in *Muhlenbergia* wet prairie, *Cladium* wet prairie, and *Cladium-Rhynchospora* marsh whereas the change was statistically insignificant in other vegetation types. However, species richness decreased uniformly in all sub-populations but D and E (**Figure 9a & b**).

Vegetation change at burned sites

Among the 195 sites at which vegetation was re-sampled in 2007, 57 were burned during the previous three years. , Among these, one site (D-2500), located 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, once dominated by *Cladium*, due to impoundment-caused 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. We used non-metric multidimensional scaling (NMDS) ordination to illustrate the change in vegetation composition at the burned sites. For this ordination, however, we used absolute cover of species, as the purpose was to illustrate change in species cover after fire., The sites were arranged along two major gradients in ordination space, i.e., hydrology and time since last fire. The groups were not well separated (stress 0.19), probably because not all sites included all stages of recovery after fire, and there was substantial overlap among sites from different prairie vegetation types. However, when we plotted the centroids of vegetation types x time since last fire in the ordination space, the gradients became more evident. Sites sampled immediately after fire (Post-burn), were far apart from pre-burn sites (**Figure 10**), indicating strong differences in vegetation composition. Time since last fire also had a significant effect on vegetation composition (ANOSIM: R = 0.263; p = 0.001). Unburned sites, represented here as "Pre-burn", differed significantly from burned sites in vegetation composition, even 4 years after fire (**Table 3**).

Table 3: Global R and *p*-values from analysis of similarity (ANOSIM) testing for among-year differences in vegetation composition before and after fire

	Time since fire				
	Post-burn	1-Year	2-Year	3-Year	4-Year
Pre-burn	0809 (0.001)	0.407 (0.001)	0.881 (0.001)	0.476 (0.001)	0.252 (0.001)
Post-burn		(-0.047) 0.519	0.185 (0.17)	0.794 (0.001)	0.420 (0.006)
1-Year			0.005 (0.416)	0.037 (0.167)	0.058 (0.073)
2-Year				0.457 (0.001)	0.288 (0.004)
3-Year					(0.065) 0.052

Our results differed somewhat from those of **LaPuma et al.** (2007) who in sub-population E found overall differences among years after fire, but did not find a difference between unburned sites and sites sampled 3 years after burn. The reason could be that all unburned and burned plots monitored by **LaPuma et al.** (2007) were in one area and plots were burned in the same season in Lopez fire in 2001. In the present analysis, however, the sites representing various stages of post-fire recovery were not the same, and they included a range of vegetation types. Moreover, the sites were burned either in different years or in different seasons within a year, resulting in among site differences in vegetation composition to be confounded in the analysis. Repeated-sampling of burned sites that we initiated in 2006 will help us to understand the details of the effects of fire on marl prairies vegetation.

The nature of the relationship between time since fire and vegetation cover were different among vegetation types, and was also affected by hydrologic conditions during and after the burn. For instance, wet prairies showed higher compositional variability before and after fire than did *Cladium* marsh sites (**Figure 10**). Similar results were observed at one wet prairie and one marsh site which were monitored annually for four year after they burned in 2003. At those sites, mean plant cover after four years was similar to the pre-burn level, but site-related differences in compositional recovery between those sites were still maintained (**Figure 11 and 12**).

The interaction between hydrology and fire plays an important role in post-burn recovery of vegetation. In our analysis, burned sites did not differ in vegetation composition 1, 3 and 4 years after fire, whereas sites that burned in 2005 and were surveyed two years after fire were significantly different from those surveyed 3 and 4 years after fire (**Table 4**). The reason for such differences could be variation in post-burn hydrologic condition. Many of the sites burned in 2005 were flooded for several days immediately after fire by a rise in water level of more than a foot, associated with the passage of Hurricane Katrina. High water conditions at this sensitive time seem likely to have killed most plants (**Sah et al. 2007**). Other researchers have also observed that post fire flooding that submerges the remnant culms of plants could be detrimental to several species, such as *Cladium jamaicense* and *Muhlenbergia capillaris* subsp. *filipes*, which are dominant in southern Everglades marl prairies (**Herndon et al. 1991; Snyder and Schaffer 2004**). At marl prairie sites presented with these conditions, vegetation remained very sparse two years after fire (**Figure 13**), indicating that vegetation cover would not only take longer than expected to return to pre-burn condition, but recovery may also take on a different trajectory in terms of species composition.

We compared two sets of sites, all burned in 2005. One set consisted of sites burned in August (Aug_burn) that were flooded immediately thereafter. The other set included sites that were burned in May (May_burn), which experienced a gradual increase in water level, providing ample opportunity for the re-growth of plants after fire. In multidimensional ordination space, the distance between pair of points representing a site at different times reflects the magnitude of temporal change in the site characteristics **(Cushman and McGarigal 2007).** Moreover, the proximity of points in ordination space depends on the dissimilarity among sites. Thus, we analyzed mean dissimilarity among the groups of sites sampled in the same year to assess between-year differences in species composition. Mean dissimilarity (Bray-Curtis) in species composition between pre-burn and 2 years after burn was higher for Aug_burn sites (84%) than May_burn sites (73%), though the difference was not statistically significant. Analysis of species turnover revealed that the mean number of species that were absent in the pre-burn survey but present two years later was higher in Aug_burn (7 species/site) than in May_burn (4.2 species/site) sites. In total, 12 species that were present before the 2005 fire were not present during either 2006 or 2007 survey, whereas the same number of new species were found in 2007 (**Table 4**). At those sites, change in species composition is further confirmed by a shift in rank abundance curves (**Figure 14**). The relative cover of dominant species, such as *Cladium jamaicense*, *Muhlenbergia capillaris* subsp. *filipes*, *Schizachyrium rhizomatum* and *Schoenus nigricans* decreased greatly, whereas the relative cover of several minor species, especially *Centella asiatica*, *Panicum tenerum*, *Iva microcephala*, and *Heliotropium polyphyllum* increased. In contrast, at May_burn sites, where water level increased gradually, providing ample opportunity for the re-growth of plants after fire, the relative cover of only *Cladium jamaicense*, the dominant species of *Cladium* marsh, decreased considerably. However, the conclusion from this comparison should be interpreted cautiously, as the pre-burn vegetation were not a random subset, i.e., marsh vegetation predominated among May-burned sites, and wet prairies among August-burned sites. It is not yet clear whether the differences among the 2 sets of sites burned at different time of year resulted from differences in vegetation type or in post-burn hydrologic conditions. Repeated annual sampling at these sites and at burned sites with similar vegetation types but different post- and pre-fire hydrologic regimes will help to elucidate the effects of fire and hydrology more completely.

Table 4: List of the species that were present only in either pre-burn or two 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 August 2005**		
	Pre-burn	**2006**	**2007**	**Pre-burn**	**2006**	**2007**
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.					+	+
Dyschoriste oblongifolia						+

Species	Sites burned in May, 2005			Sites burned in August 2005		
	Pre-burn	2006	2007	Pre-burn	2006	2007
Elytraria caroliniensis var. *angustifolia*				+	+	
Eragrostis elliottii	+					
Erianthus giganteus				+		
Erigeron quercifolius				+		
Euphorbia capitellatum						+
Eupatorium leptophyllum					+	+
Eustachys petraea						+
Flaveria linearis						+
Helenium pinnatifidum				+	+	
Hypoxis wrightii				+	+	
Juncus megacephalus				+	+	
Justicia angusta	+			+	+	
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				+	+	
Pityopsis graminifolia				+		
Polygala grandiflora var. *leiodes*			+			
Proserpinaca palustris	+					
Rhynchospora divergens	+		+			
Ruellia caroliniensis					+	
Sabatia grandiflora			+			
Sabal palmetto				+		
Sabatia stellaris			+			+
Schoenolirion albiflorum					+	+
Spermacoce terminalis					+	
Stenandrium dulce var. *floridanum*				+		+
Taxodium distichum var. *imbricarium*	+					
Utricularia foliosa	+					
Utricularia purpurea	+	+				
Unidentified-01				+		

3.2 Biomass and species richness

In the Everglades marl prairies, our data indicates that species richness varies from 2 to 43 per plot while aboveground plant biomass varies from 113 to 1383 g/m^2. In analysis of plot level data from 2003-2006, species richness demonstrated a hump-shaped relationship with biomass across all the sites, and the relationship was maintained within vegetation types that included a relatively wide range of hydroperiods (**Sah et al. 2007**). After accounting for biomass at the plot level, species richness showed significant negative correlation with vegetation-inferred hydroperiod, confirming that wet prairies have higher species richness than marshes in the southern Everglades marl prairies (**Figure 15**). This year we further explored the relationship between biomass and species richness in different hydrologic conditions and at different spatial scales.

We found that the hump-shaped relationship between total plant biomass and species richness previously identified at the plot level was also present at the sub-plot scale (**Figure 16**). At this scale, we calculated hydroperiod for 2,390 0.25 m^2 sub-plots sampled at 293 sites on 6 transects. To examine the relationship between biomass and species richness across the hydrologic range present at the marl prairie vegetation sites, we subjectively grouped the sub-plots into four groups with equal range of hydroperiod (<90, 90-180, 180-270, and >270 days). Except at the lower end of the hydroperiod (<90 days), species richness maintained the hump-shaped relationship with total plant biomass within hydrologic groups (**Figure 17**). However, at this scale too, when the effects of biomass were partialled out, species richness showed significant negative correlation with hydroperiod, though the relationship was much weaker ($R^2 = 0.06$) than that at the plot level. Within the short hydroperiod (<90 days) prairie sites, at both plot and sub-plot scales, while the mean species richness is relatively high, the relationship between species richness and total biomass was not detected, suggesting the influence of other factors such as fire.

3.3 C_3 and C_4 plants and carbon isotopic signature in soil organic matter

Marl prairie vegetation in the southern Everglades consists of both C_3 and C_4 species. Forbs and sedges are mainly C_3 species, whereas 75% of grasses were C_4 species. Since information on species' photosynthetic pathways is more complete for graminoids **(Table 5)**, further analysis on the distribution and abundance of C_3 and C_4 species was limited to this group of plants.

Table 5: List of marl prairie plant species with known photosynthetic pathways (C_3 and C_4)

FAMILY	HABIT	SCIENTIFIC NAME	C3/C4
SCROPHULARIACEAE	forb	*Bacopa caroliniana*	C3
APIACEAE	forb	*Centella asiatica*	C3
CYPERACEAE	graminoid	*Cladium jamaicense*	C3
AMARYLLIDACEAE	forb	*Crinum americanum*	C3
CYPERACEAE	graminoid	*Cyperus haspan*	C3
POACEAE	graminoid	*Dichanthelium aciculare*	C3
POACEAE	graminoid	*Dichanthelium dichotomum*	C3
POACEAE	graminoid	*Dichanthelium spp.*	C3
CYPERACEAE	graminoid	*Eleocharis cellulosa*	C3
CYPERACEAE	graminoid	*Eleocharis geniculata*	C3
CYPERACEAE	graminoid	*Fuirena breviseta*	C3

FAMILY	HABIT	SCIENTIFIC NAME	C3/C4
CYPERACEAE	graminoid	*Fuirena scirpoidea*	C3
AMARYLLIDACEAE	forb	*Hymenocallis palmeri*	C3
JUNCACEAE	graminoid	*Juncus megacephalus*	C3
CYPERACEAE	graminoid	*Juncus roemerianus*	C3
POACEAE	graminoid	*Leersia hexandra*	C3
ONAGRACEAE	forb	*Ludwigia alata*	C3
ONAGRACEAE	forb	*Ludwigia microcarpa*	C3
ONAGRACEAE	forb	*Ludwigia repens*	C3
POACEAE	graminoid	*Panicum hemitomon*	C3
POACEAE	graminoid	*Phragmites australis*	C3
ASTERACEAE	forb	*Pluchea rosea*	C3
POLYGONACEAE	forb	*Polygonum hydropiperoides*	C3
CYPERACEAE	graminoid	*Rhynchospora inundata*	C3
CYPERACEAE	graminoid	*Rhynchospora tracyi*	C3
ALISMATACEAE	forb	*Sagittaria lancifolia* var. *lancifolia*	C3
CYPERACEAE	graminoid	*Schoenus nigricans*	C3
CYPERACEAE	graminoid	*Scleria verticillata*	C3
TYPHACEAE	forb	*Typha domingensis*	C3
LENTIBULARIACEAE	forb	*Utricularia cornuta*	C3
LENTIBULARIACEAE	forb	*Utricularia foliosa*	C3
LENTIBULARIACEAE	forb	*Utricularia gibba*	C3
LENTIBULARIACEAE	forb	*Utricularia purpurea*	C3
LENTIBULARIACEAE	forb	*Utricularia radiata*	C3
LENTIBULARIACEAE	forb	*Utricularia subulata*	C3
POACEAE	graminoid	*Andropogon glomeratus* var. *glomeratus*	C4
POACEAE	graminoid	*Andropogon virginicus* var. *virginicus*	C4
POACEAE	graminoid	*Aristida purpurascens*	C4
POACEAE	graminoid	*Coelorachis rugosa*	C4
CYPERACEAE	graminoid	*Cyperus polystachyos*	C4
POACEAE	graminoid	*Digitaria villosa*	C4
POACEAE	graminoid	*Echinochloa* spp.	C4
POACEAE	graminoid	*Eragrostis elliottii*	C4
POACEAE	graminoid	*Erianthus giganteus*	C4
POACEAE	graminoid	*Eustachys petraea*	C4
POACEAE	graminoid	*Muhlenbergia capillaris* var. *filipes*	C4
POACEAE	graminoid	*Panicum dichotomiflorum*	C4
POACEAE	graminoid	*Panicum rigidulum*	C4
POACEAE	graminoid	*Panicum tenerum*	C4
POACEAE	graminoid	*Panicum virgatum*	C4
POACEAE	graminoid	*Paspalidium geminatum* var. *geminatum*	C4
POACEAE	graminoid	*Paspalum blodgettii*	C4
POACEAE	graminoid	*Paspalum monostachyum*	C4
POACEAE	graminoid	*Schizachyrium rhizomatum*	C4
POACEAE	graminoid	*Setaria parviflora*	C4
POACEAE	graminoid	*Spartina bakeri*	C4

In the marl prairie landscape, the abundance of C_4 species varied along the hydrologic gradient. Analysis of species cover data at 906 sites revealed that the mean number and cover of C_4 graminoids were significantly (one-way ANOVA: $p < 0.001$) higher in short-hydroperiod wet prairies than in long-hydroperiod marshes (**Table 6**). Differences in the proportion of total vegetation cover represented by C_4 graminoids was also reflected in the carbon isotopic signature of above ground vegetation sampled at 24 randomly selected sites. At these sites, mean $\delta^{13}C$ values of above ground vegetation differed significantly among eight vegetation types (K-W test; p=0.008). Above ground vegetation in *Muhlenbergia* and *Schizachyrium* wet prairies and in *Spartina* marsh had significantly higher $\delta^{13}C$ values than the other wet prairies and marsh vegetation types (**Figure 18**).

Table 6: Mean number and cover of C_4 graminoids in wet prairie and marsh vegetation types.

C_4 graminoid species	Marsh (n= 418)	Wet prairie (n = 488)	p-value
Number	2.70	5.80	<0.001
Cover	2.58	15.16	<0.001

To examine relationship of $\delta^{13}C$ values of both standing vegetation and soil organic matter with hydrology, we used vegetation-inferred hydroperiod (**Ross et al. 2006**), derived from species cover at the 24 sample sites. The negative relationship between $\delta^{13}C$ values of above ground vegetation and hydroperiod was marginally significant ($p = 0.05$), suggesting that as sites get wetter the vegetation has more negative $\delta^{13}C$ values that are close to carbon isotopic signature of C_3-dominated vegetation (**Figure 19**). To our surprise, the positive relationship between $\delta^{13}C$ values for above ground vegetation and surface soil was not strong ($R^2 = 0.10$; **Figure 20**), possibly because of recent changes in vegetation composition and the time lag involved in transforming the isotopic signature of standing vegetation to soil organic matter. However, a strong negative relationship ($p = 0.009$) was observed between $\delta^{13}C$ value of surface soil organic matter and hydroperiod (**Figure 21**), providing a strong basis for the use of carbon isotopic signature in soil organic matter to approximate historical hydrologic regimes.

In general, fire in a grassland or savanna community is expected to favor the growth of C_4 grasses and decrease the abundance of C_3 species (Briggs and Knapp 1995; Bird et al. 2000; Roscoe et al. 2000; Biggs et al. 2002). In our study of C_3 and C_4 plants within CSSS habitat, 8 of the 24 sites we sampled were in areas burned in 2003. When summarized by vegetation types, mean $\delta^{13}C$ values of above ground vegetation showed a mixed relationship with recent fire history (**Figure 22**). In *Muhlenbergia* wet prairie and *Cladium* marsh mean $\delta^{13}C$ values were significantly higher in burned plots than in unburned plots, while in *Cladium* wet prairie the burned plots had higher $\delta^{13}C$ values than unburned plots, though the difference was not significant in the latter case. These results need to be interpreted cautiously, as the frequently burned plots had relatively short hydroperiod, and the higher $\delta^{13}C$ values representing the higher proportion of C_4 plants could be a byproduct of hydrology.

3.4 Vegetation change, hydrology and the Cape Sable seaside sparrow

Vegetation change at the CSSS census sites over the three-year period 2004-2007 was marked by an increase in the wetness of some sites, though 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 and 2007 across all sites (Pair-wise t-test: p-value = 0.161). Nevertheless, vegetation in the wet prairies in sub-population F, and along the south-western edges of sub-populations E and B were indicative of slightly wetter conditions in 2007, compared to three years earlier (**Figure 23**). In Sub-population A, differences in vegetation-inferred hydroperiod between 2004 and 2007 was not significant and did not reveal any definite spatial pattern. For an analysis of real time hydrologic data within CSSS habitat, we calculated hydroperiod using ground elevation and water elevation data obtained from Everglades Depth Estimation Network (EDEN). Three year average of hydroperiod at the sample sites, calculated from Everglades Depth Estimation Network (EDEN) data, was higher for 2007 than for 2004 in all the sub-populations but B, in which sites showed mixed results (**Figure 24**). However, the results need to be interpreted cautiously, as the hydroperiods estimated using EDEN water elevation data are based on ground elevation surveyed by USGS at 400 x 400 m grids, which do not account for topographic variation within the grid cell. For additional validation, we explored the relationship between hydroperiod estimated using EDEN data and vegetation inferred hydroperiod. Such relationship was modestly strong ($R^2 = 0.54$), as EDEN-estimated hydroperiod values for prairie sites were lower than values inferred from vegetation present at the sites. In contrast, values for marsh sites in sub-population A were higher (**Figure 25**). 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**).

At burned sites, plant cover increased or decreased during 2004-2007, depending on the time since last burn and the hydrologic conditions in the post-burn period. Results of the two-year post-fire vegetation survey at sites burned in 2005 revealed that some combinations of natural and/or anthropogenic disturbance, especially fire and hurricane-caused post-fire flooding, are capable of delaying vegetation recovery and altering vegetation composition. However, to fully understand the effect of such an interaction, these sites need to be studied closely in the next few years.

We examined sparrow occurrence at the census sites in relation to vegetation structure present in 2004 and 2007. Out of 138 un-burned sites, sparrow populations were surveyed in both 2004 and 2007 at only 57, and birds were sighted at only 26 (45%) in either 2004 or 2007. Two sites had the same number of birds in both years, whereas at 8 sites, sparrow counts in 2007 were different from those in 2004. Nine sites where birds were sighted in 2004 had no birds in 2007. In contrast, at 7 sites, birds were not recorded in 2004 but were sighted in 2007. The differences in bird count in 2004 and 2007 can simply be due to annual fluctuations in population. However, the analysis of change in bird number in relation to vegetation-inferred hydroperiod revealed that more sites in which CSSS density declined in 2007 were wetter than in 2004 (**Figure 26**), particularly when hydroperiod was close to or above 240 days. Moreover, these analyses suggest that sites can become "too dry", from the perspective of vegetation, with fewer birds in 2007 than 2004 (**Figure 27**). Perhaps CSSS may respond to changes in vegetation indicative of hydroperiods beyond its optimum range.

The relationship between CSSS population dynamics and vegetation is also affected by fire, as it modifies vegetation structure, a critical component of sparrow habitat. We examined the change CSSS population before and after fire at census sites that were burned in 2003, 2005, or 2006, and were surveyed for vegetation in both 2004 and 2007. Thirty seven percent of sites that were burned in 2003 had sparrows at least one of the three years prior to burn, while birds were present at only 16% of those sites 4 years after fire. Surprisingly, 38% of sites burned in 2005 were occupied by sparrows two years later **(Figure 28)**. It was unexpected as the immediate flooding of the sites after fire killed most of the vegetation (**Sah et al. 2007**, Figure 12), and vegetation at those sites is still sparse (See Figure 13). Close analysis of the sparrow survey notes reveal that at these sites, the bird song was observed to be distant, with an estimated distance of ~ 200 m. Given the patchiness of fire, it is most likely that birds occupied unburned patches within the boundary of burned area.

Conclusions

Re-survey of sites sampled in 2004 revealed that the vegetation structure and composition did not change much at sites that were unburned since 2003. However, many sites in sub-population E and F, and some sites in sub-population B showed slightly wetter vegetation in 2007 than in 2004. Three year average of hydroperiod at the sample sites, calculated from Everglades Depth Estimation Network (EDEN) data, was higher for 2007 than for 2004 in all the sub-populations except B, in which half of the sites had lower hydroperiod values. However, it is not clear at present whether such a difference in hydroperiod could have significant effect on plant composition within this short time frame, as there is limited understanding yet regarding how rapidly vegetation changes in response to hydrologic alterations in CSSS habitat (but see **Armentano et al. 2006**). Additionally, very low plant cover and a change in species composition at sites flooded after fire in 2005 and surveyed approximately 2 years later suggest that post-fire flooding will not only delay the vegetation recovery process, but could also cause 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. In summary, our re-sampling in 2007 of sites surveyed in 2004, along with burned sites surveyed in 2004 and 2005, has answered some questions regarding vegetation change in response to hydrology and fire. Furthermore, the results of our study on C_3 and C_4 plants and carbon isotopic signature of surface soil organic matter along the hydrologic gradient suggested that carbon isotopic signature in soil organic matter can be used to approximate historical hydrologic regimes and vegetation.

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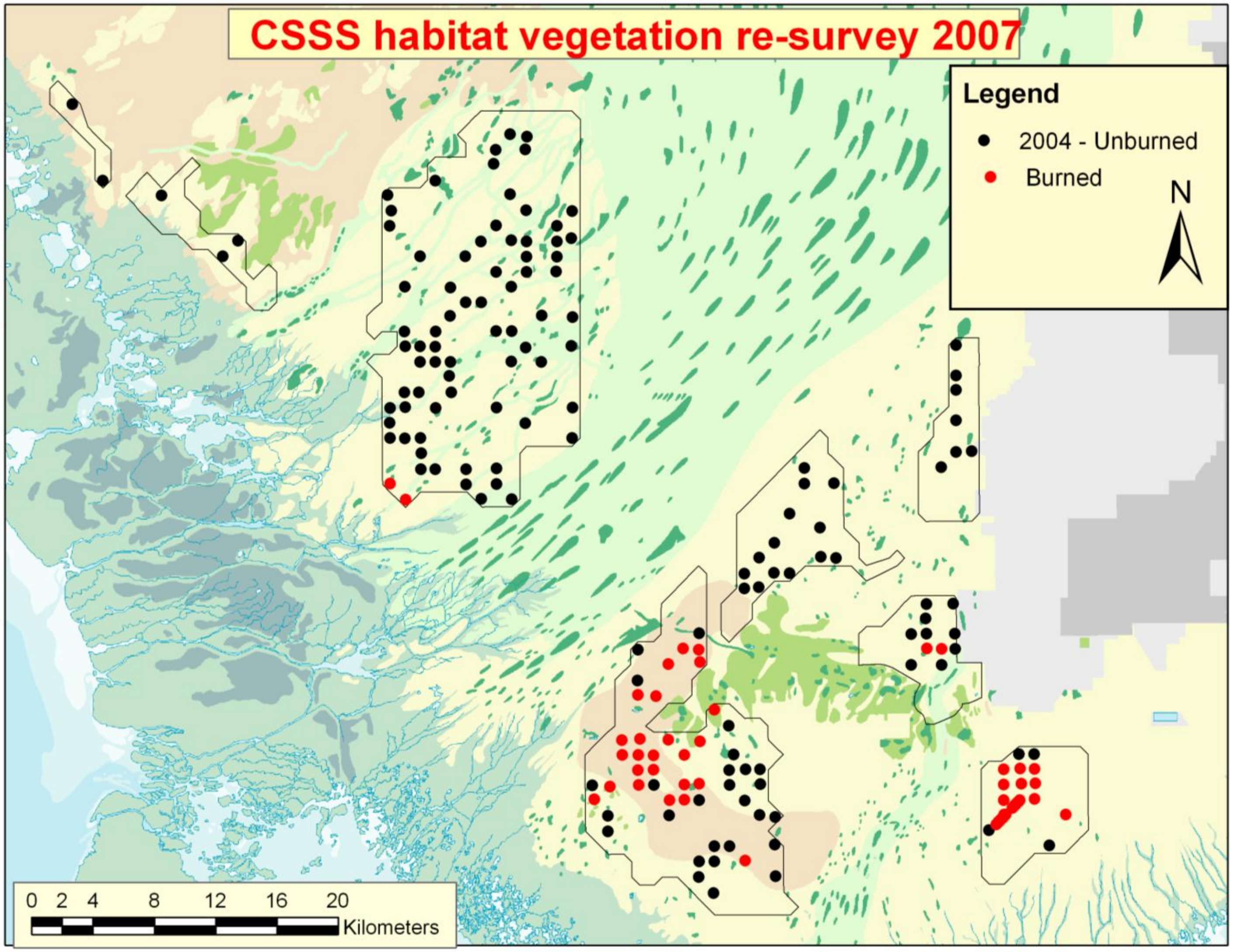

Figure 1: Location of sites within the Cape Sable seaside sparrow habitat sampled for vegetation in 2007.

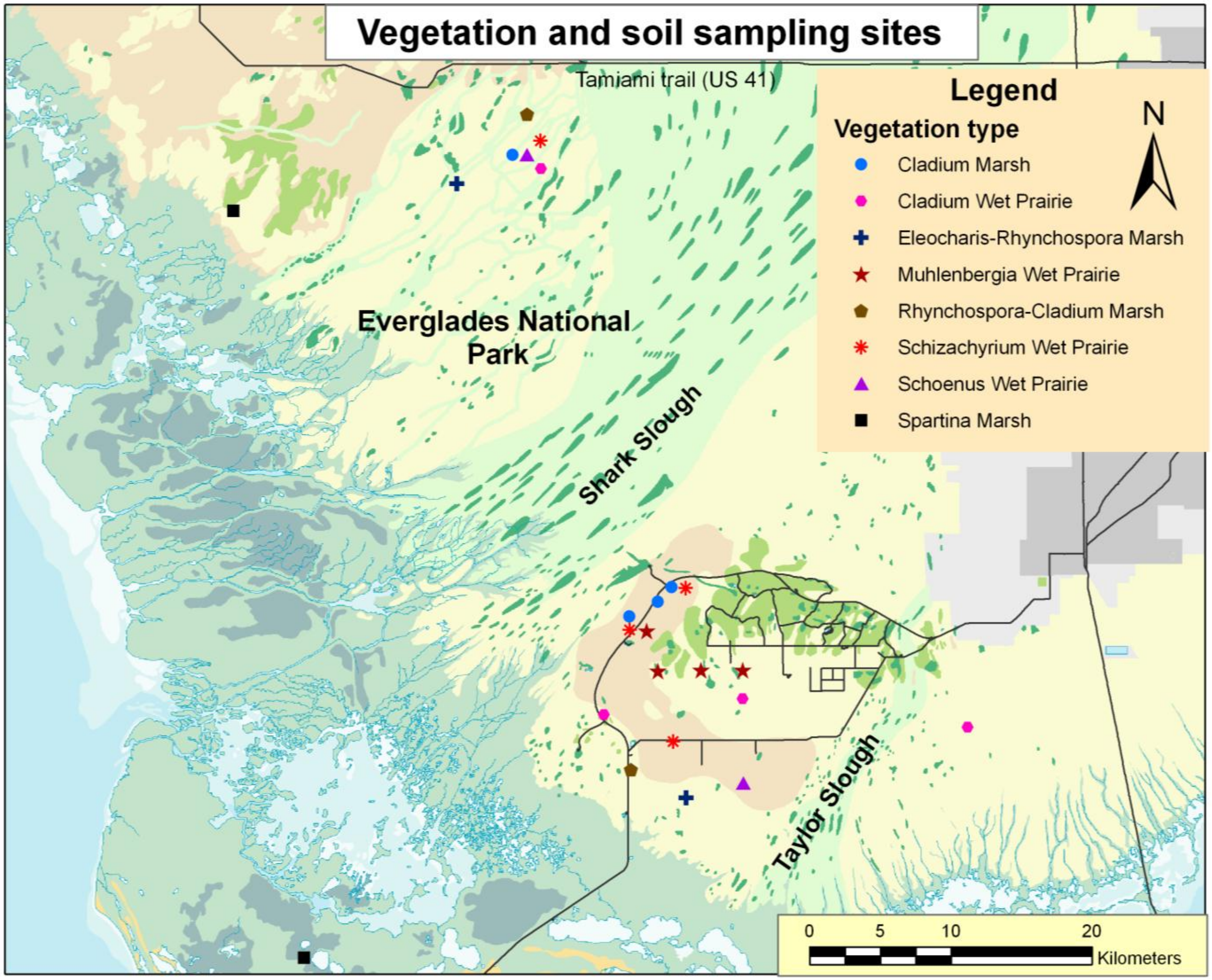

Figure 2: Location of sites within the Cape Sable seaside sparrow habitat sampled for analyzing $\delta^{13}C$ values of above ground vegetation and soil organic matter.

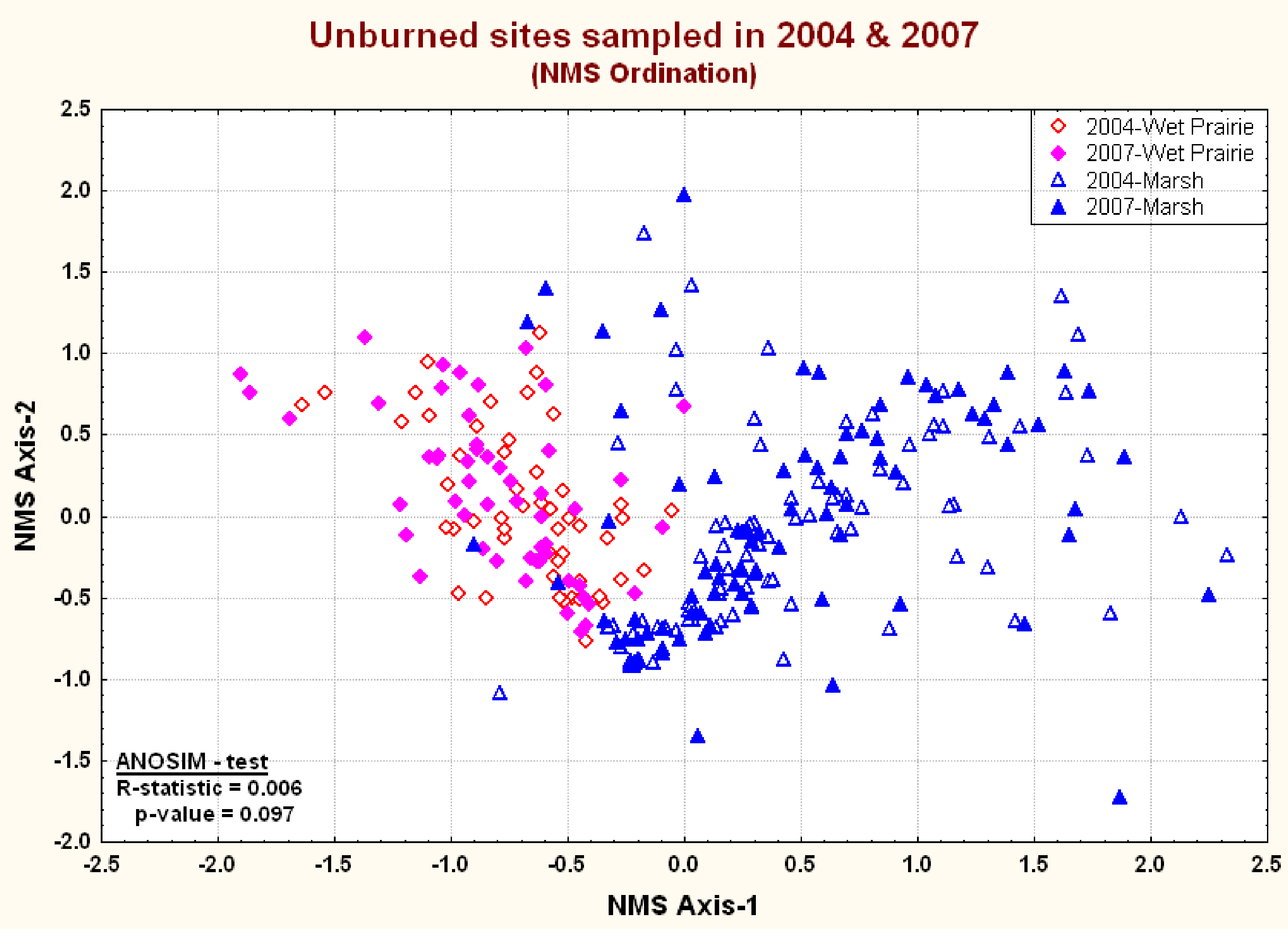

Figure 3: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on relative cover of species at 138 unburned CSSS census sites sampled in both 2004 and 2007. The figure illustrates distinct grouping between marsh (blue) and wet prairie (red) are easily distinguishable regardless of years sampled, but samples from 2004 (open) and 2007 (closed) are randomly dispersed within the cloud of marsh and prairie points.

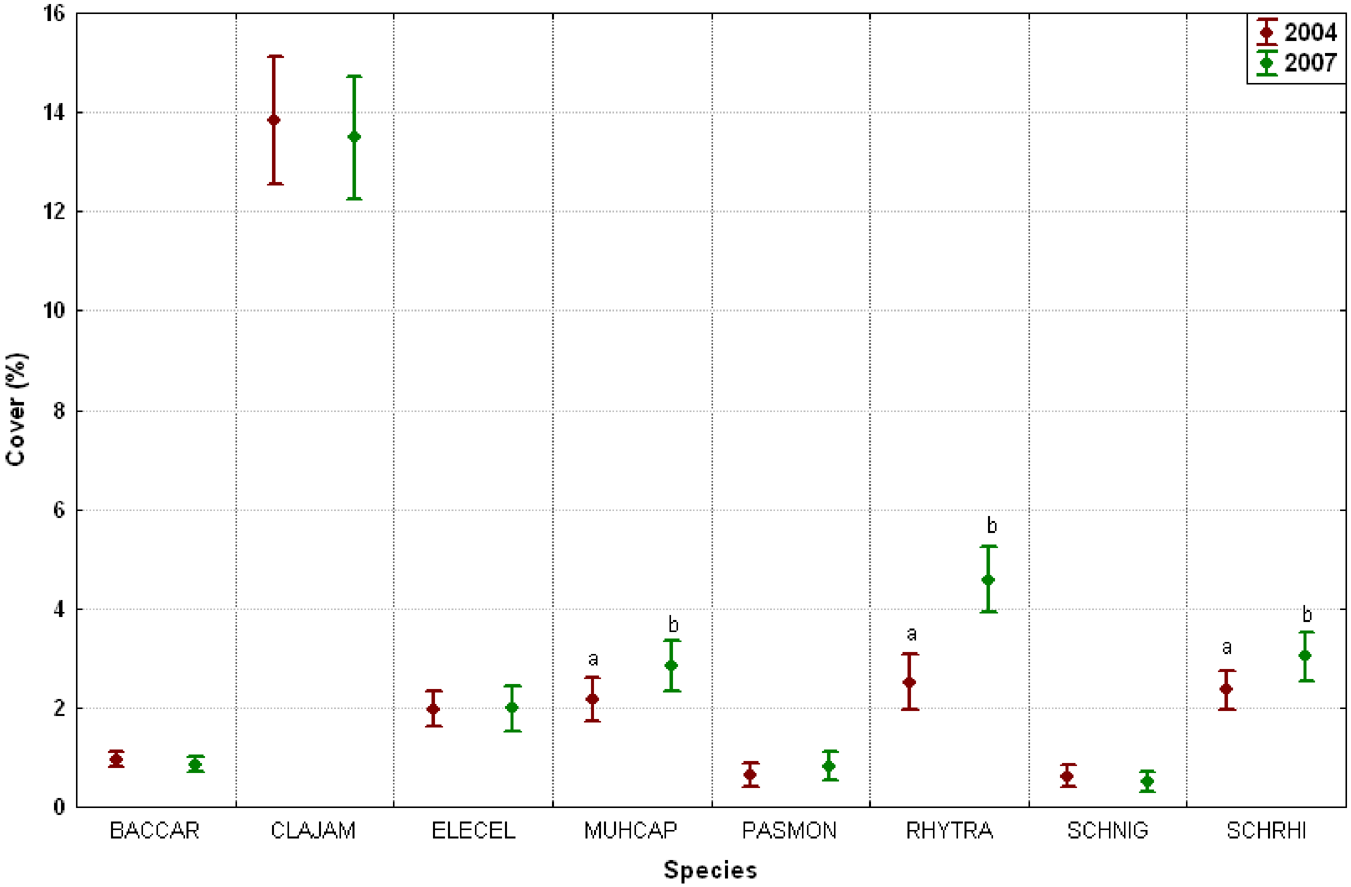

Figure 4: Mean (± 1 S.E.) cover of major species (mean cover >0.5%) in 138 CSSS census sites which were not burned for 3 years prior to vegetation sampling. Different roman letters indicate significant difference (pair wise t-test; $p < 0.05$) in cover of the particular species between two sampling years, 2004 and 2007. BACCAR = *Bacopa caroliniana*, CLAJAM = *Cladium jamaicense*, ELECEL = *Eleocharis cellulosa*, MUHCAP = *Muhlenbergia capillaris* var. *filipes*, PASGEM = *Paspalum monostachyum*, RHYTRA = *Rhynchospora trayci*, SCHNIG = *Schoenus nigricans*, and SCHRHI = *Schizachyrium rhizomatum*.

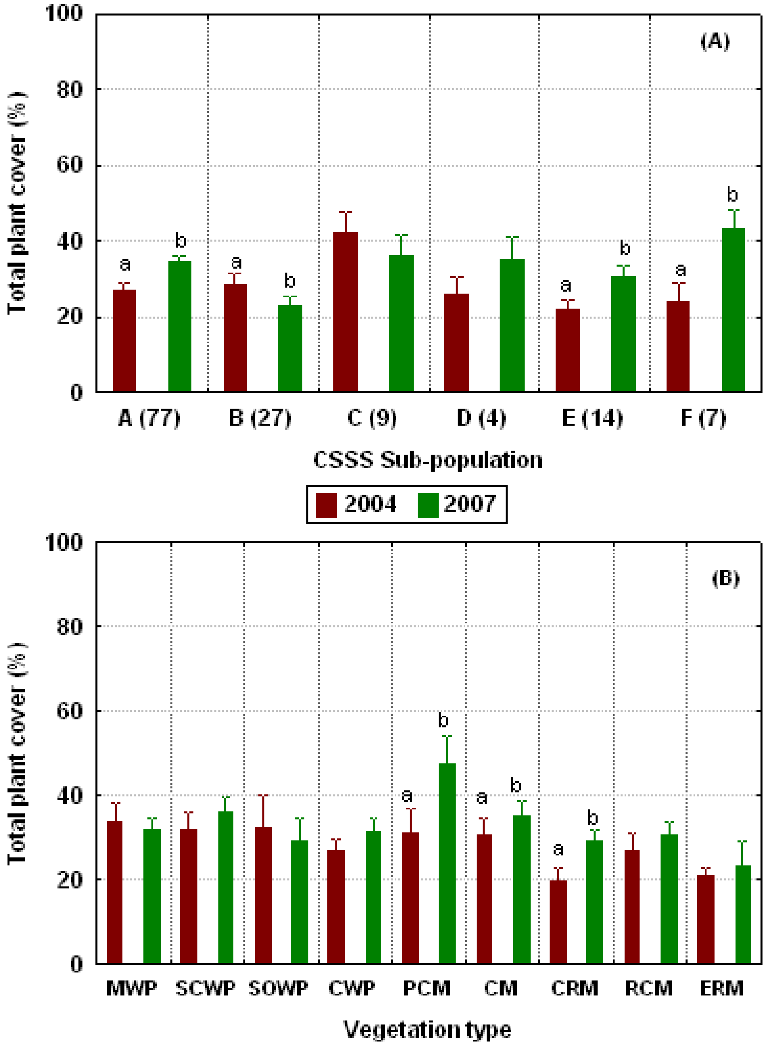

Figure 5: Mean (± 1 S.E.) crown cover at the unburned CSSS census sites sampled in both 2004 and 2007. Total crown cover is averaged over (A) CSSS subpopulations, and (B) Vegetation types. Different roman letters indicate significant difference (pair wise t-test; $p < 0.05$) in total cover within particular sub-population or vegetation type between two sampling years, 2004 and 2007. 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; and ERM = *Eleocharis-Rhynchospora* marsh.

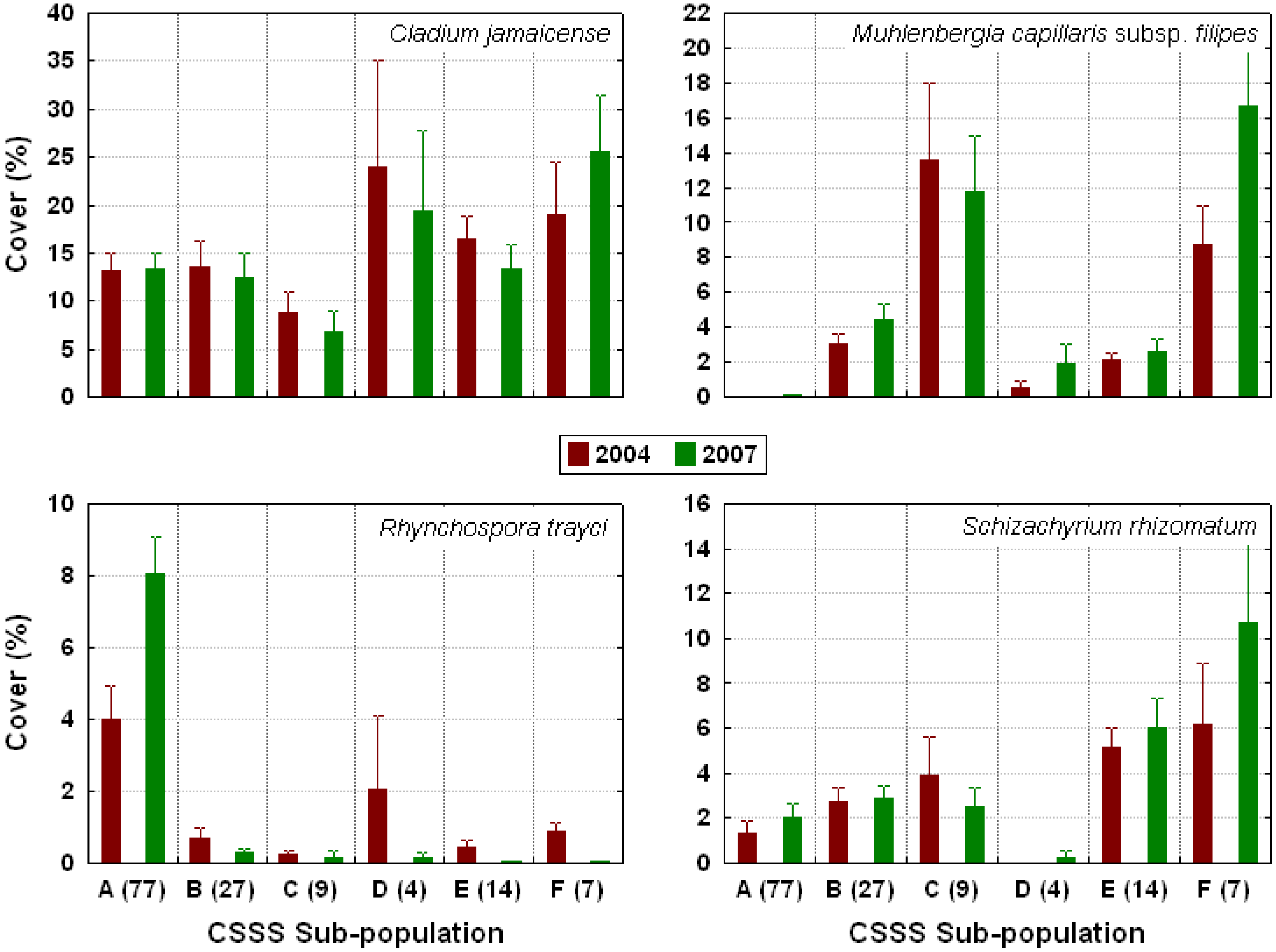

Figure 6: Mean (± 1 S.E.) cover of four major species at the unburned CSSS census sites sampled in both 2004 and 2007. Cover of a species is averaged over CSSS sub-populations in which the particular species was present either in 2004 or 2007.

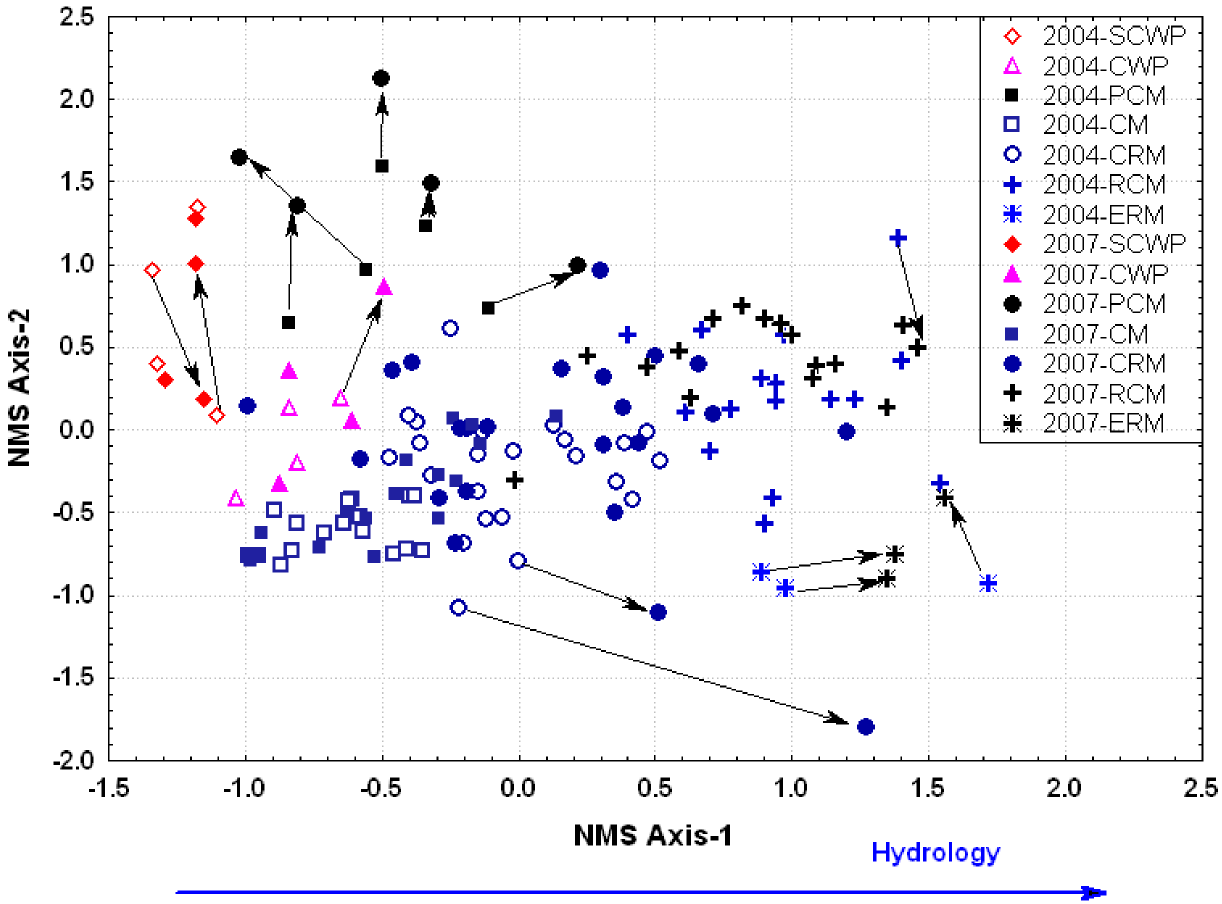

Figure 7: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on relative cover at 72 plots on Sup-population A. Arrows show the shift in site position in ordination space due to dissimilarity in vegetation structure and composition between 2004 and 2007. SCWP = *Schizachyrium* 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.

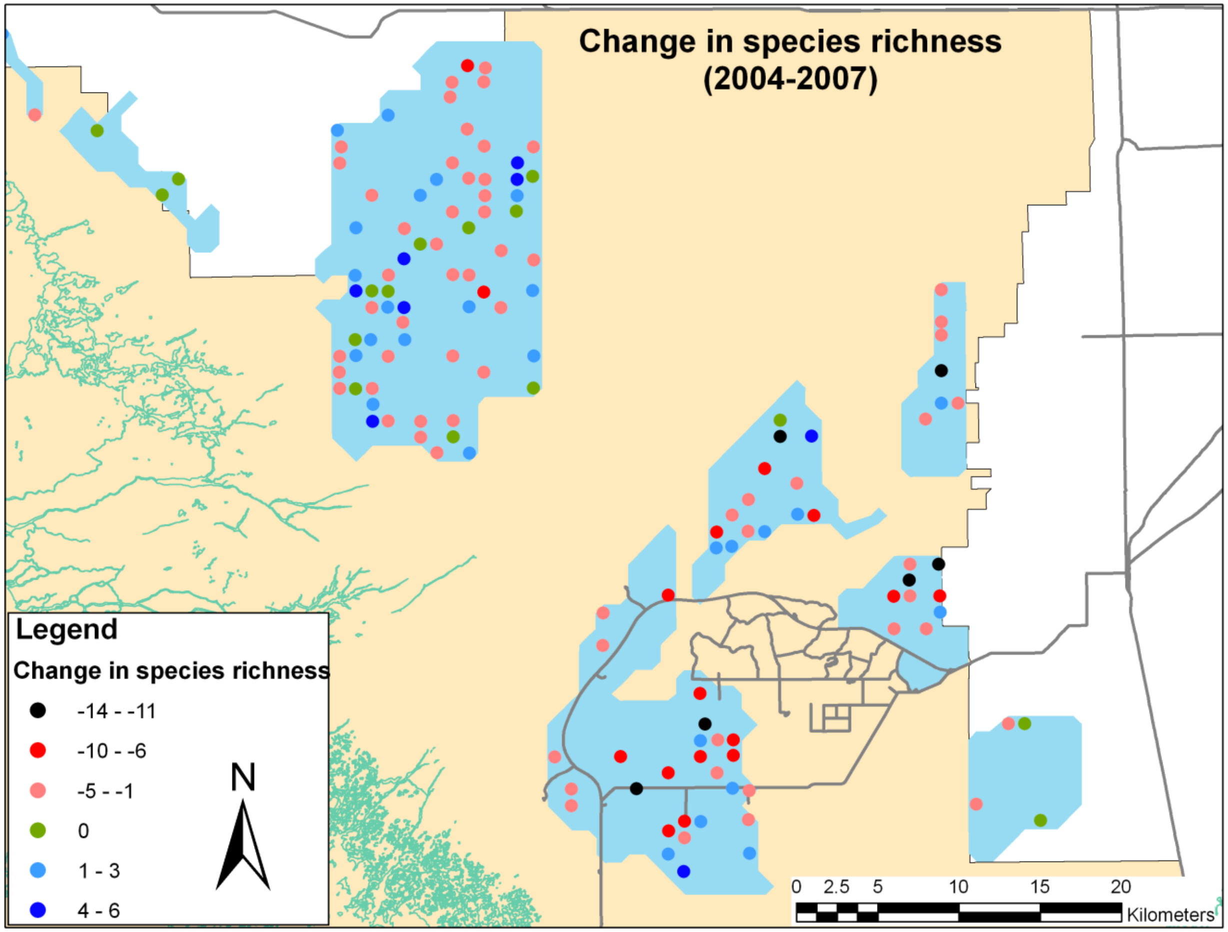

Figure 8: Change in species richness (number of species per site) between 2004 and 2007 sampling at 138 unburned sites within CSSS habitat.

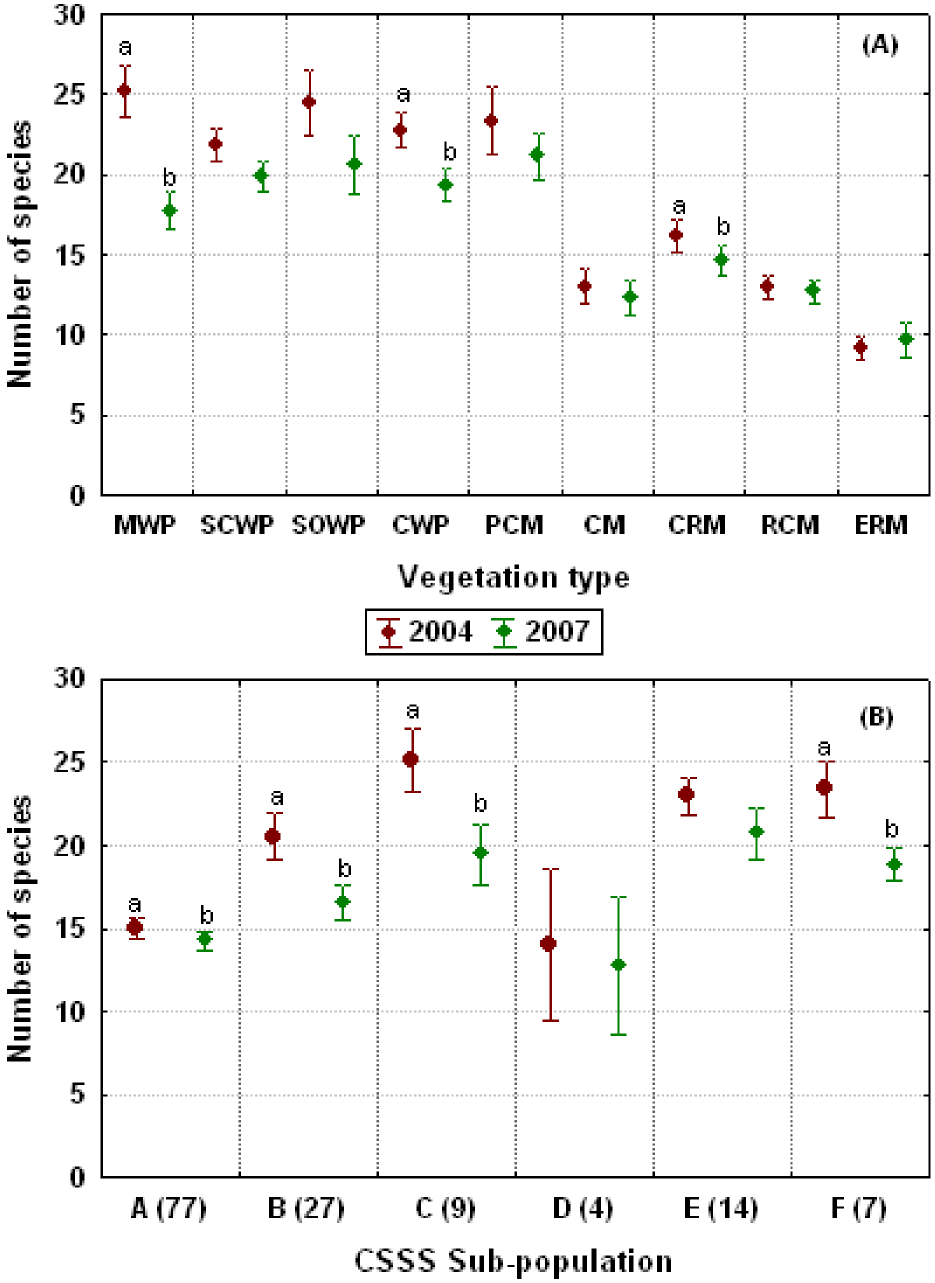

Figure 9: Mean (± 1 S.E.) species richness (number of species per site) in 2004 and 2007 samplings. Number of species is averaged over (A) vegetation types, and (B) CSSS subpopulations. Different roman letters indicate significant difference (pair wise t-test; $p < 0.05$) in species richness within particular vegetation type or sub-population between two sampling years, 2004 and 2007. 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; and ERM = *Eleocharis-Rhynchospora* marsh.

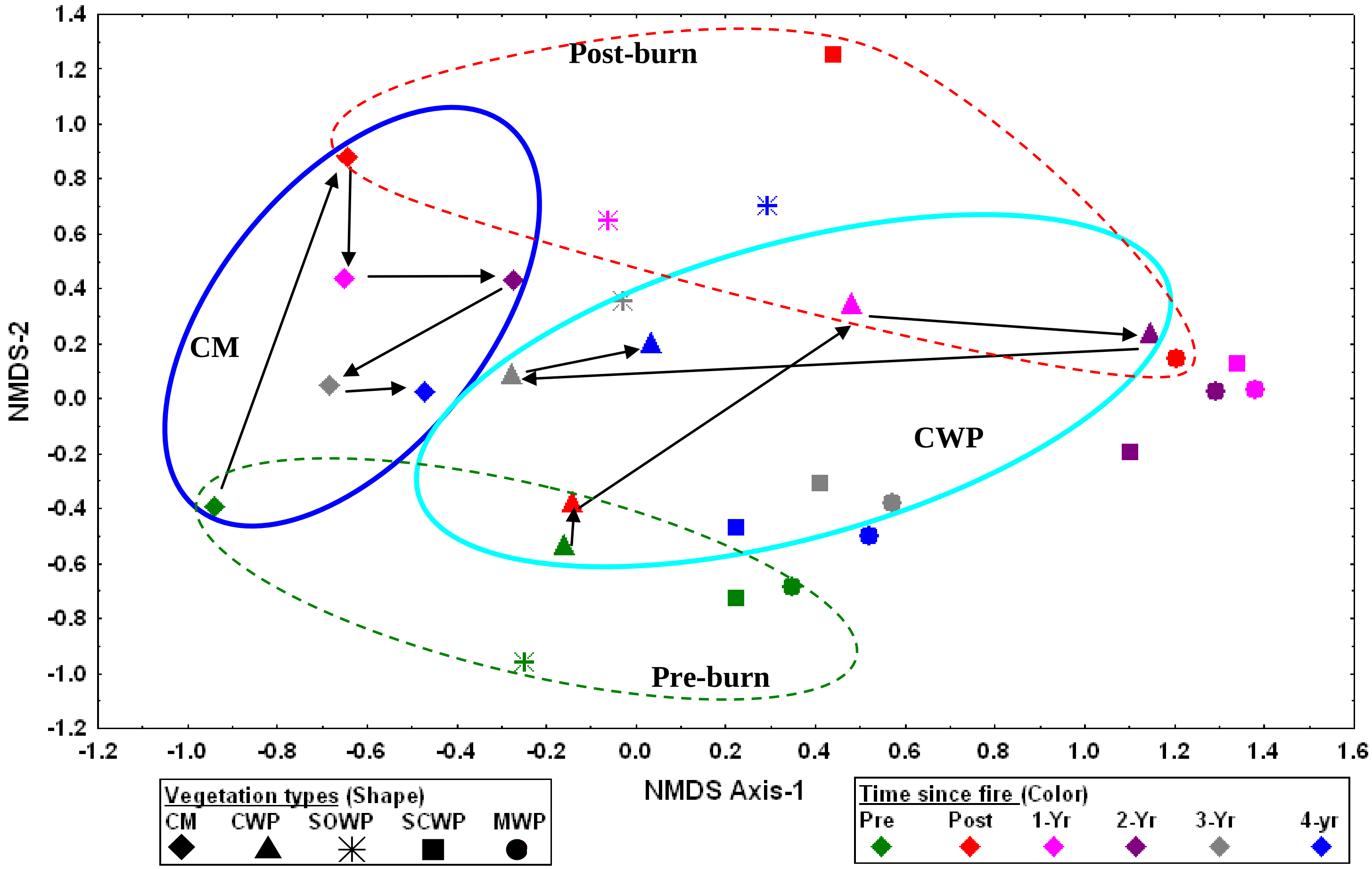

Figure 10: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on total cover at 57 sites burned in 2003, 2005, 2006 or 2007 and sampled in 2003, 2004 or 2005 and again in 2006 and 2007. Points in ordination space represent centroids of sites, grouped by vegetation type and time since last burn. CM = *Cladium* marsh; CWP = *Cladium* wet prairie; SCWP = *Schizachyrium* wet prairie; SOWP = *Schoenus* wet prairie; MWP = *Muhlenbergia* wet prairie.

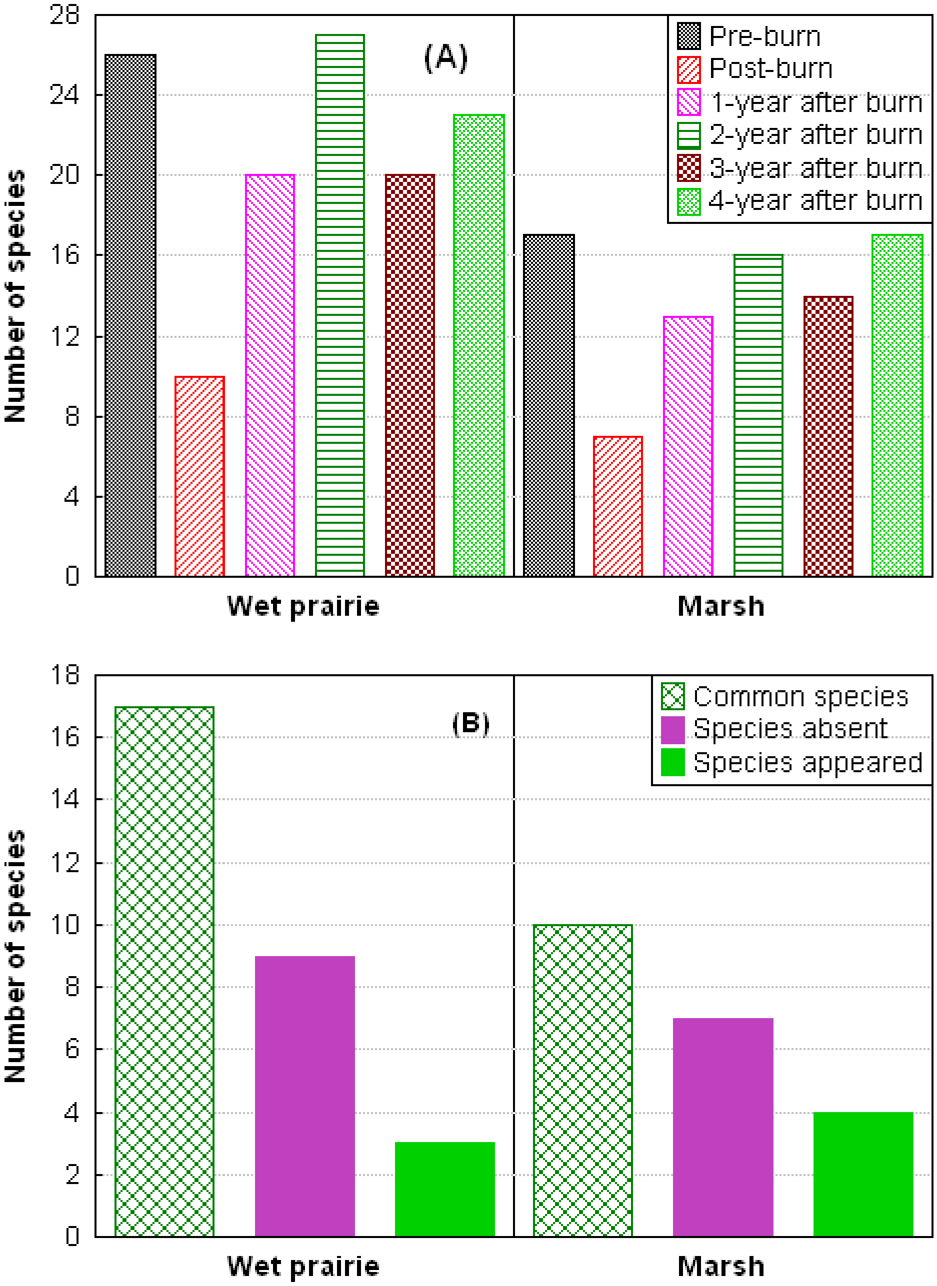

Figure 11: Change in number of species in one wet prairie and one marsh site burned in 2003 and sampled within one month after fire, and annually thereafter. (A) Total number of species (B) Species turnover.

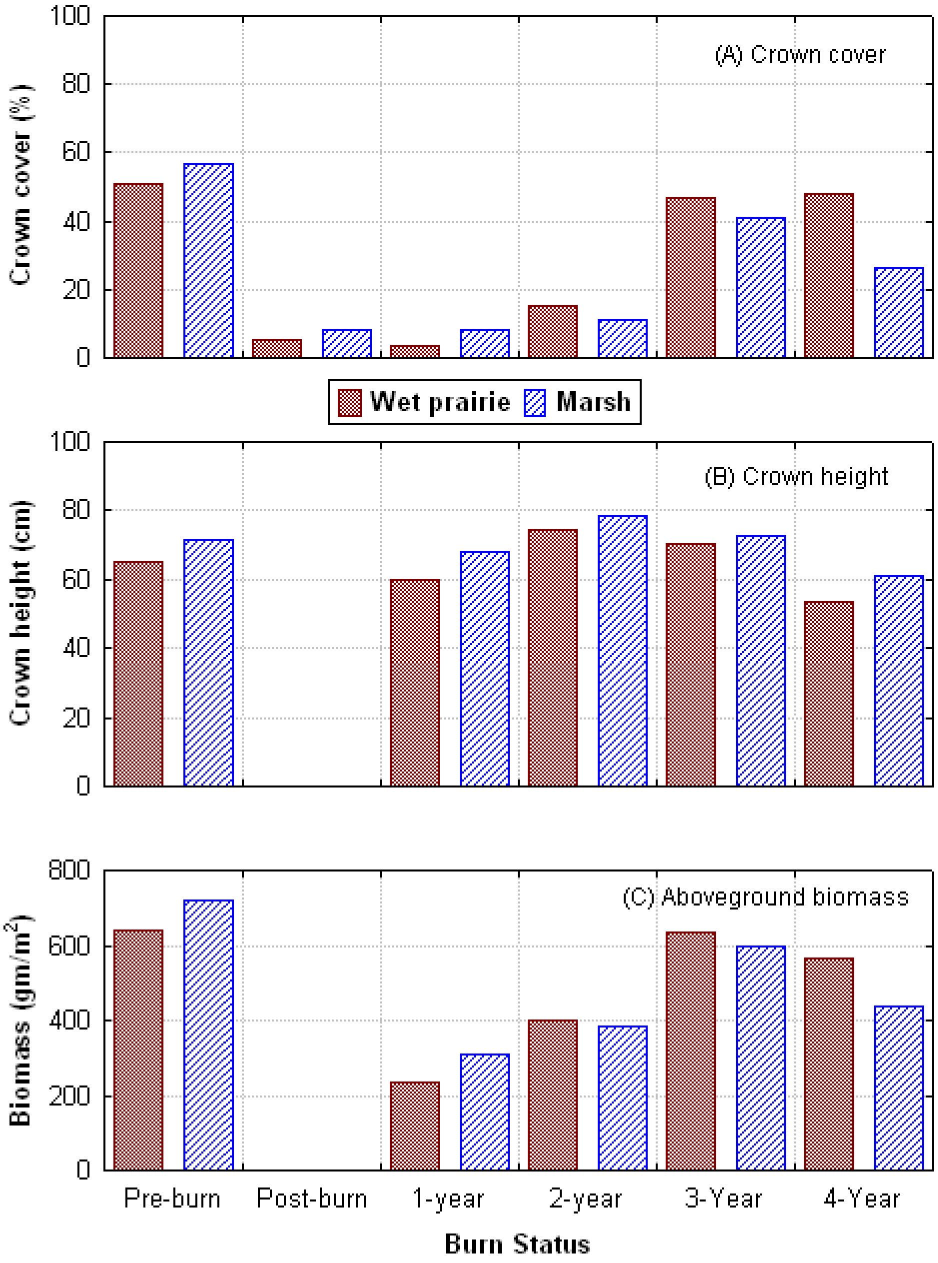

Figure 12: Mean crown cover (A), height (B), and total biomass (C) in one wet prairie and one marsh site burned in 2003, and sampled within one month after fire and annually thereafter.

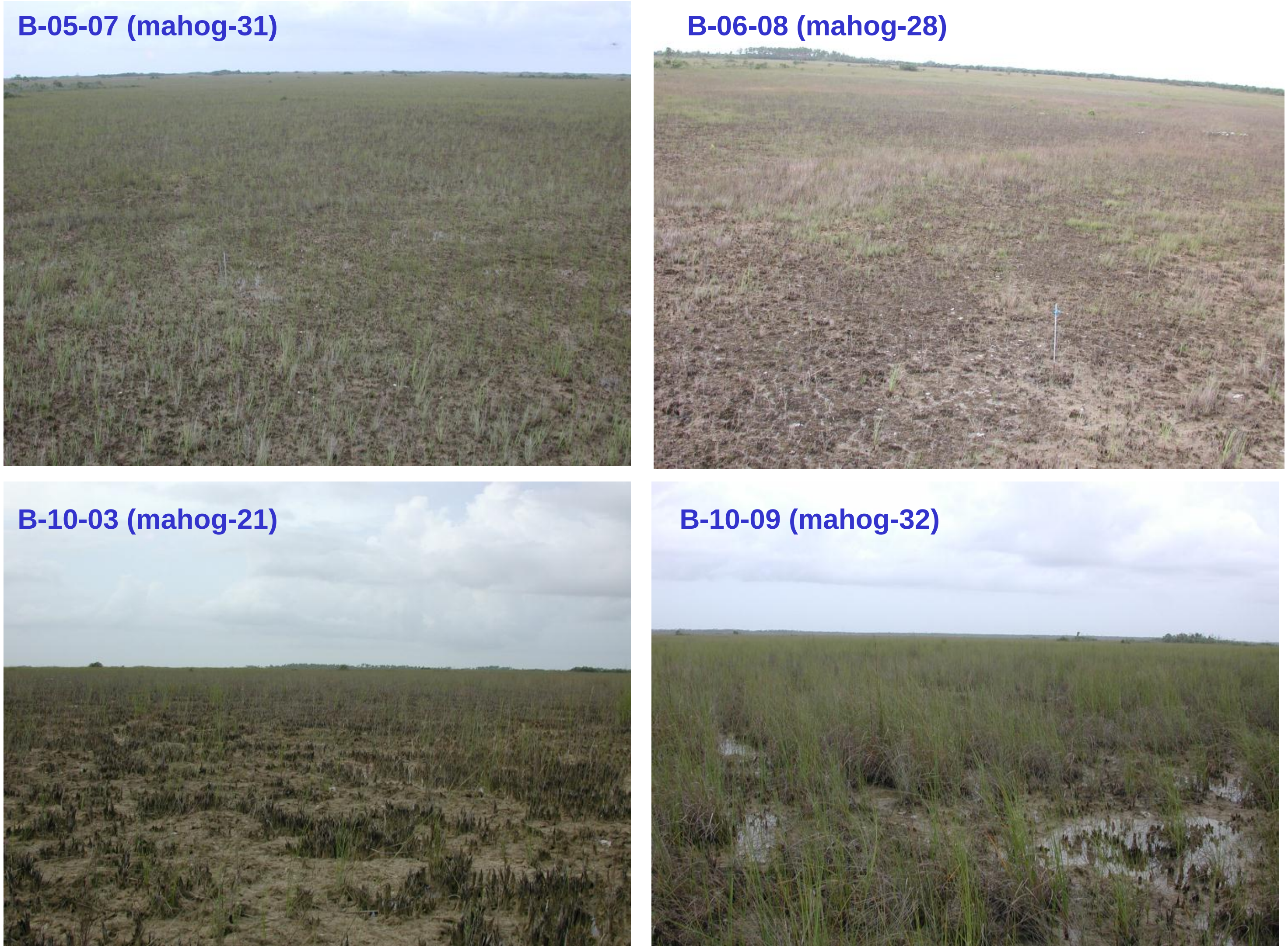

Figure 13: Four CSSS census sites 2 years after fire showing very sparse vegetation.

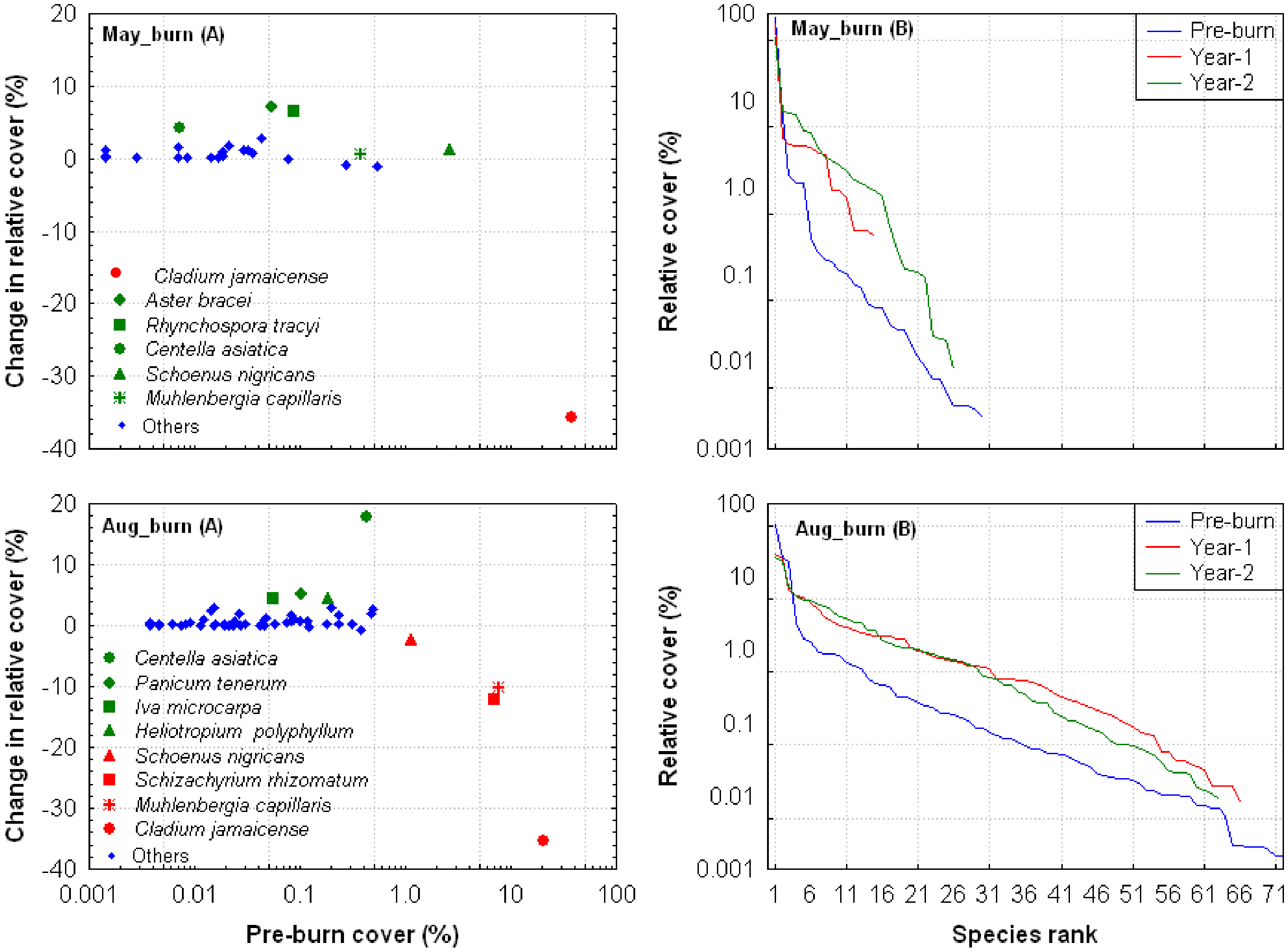

Figure 14: Change in the relative cover of species (A) and species rank abundance (B) at the sites burned in May 2005 (May_burn) and August 2005 (Aug_burn).

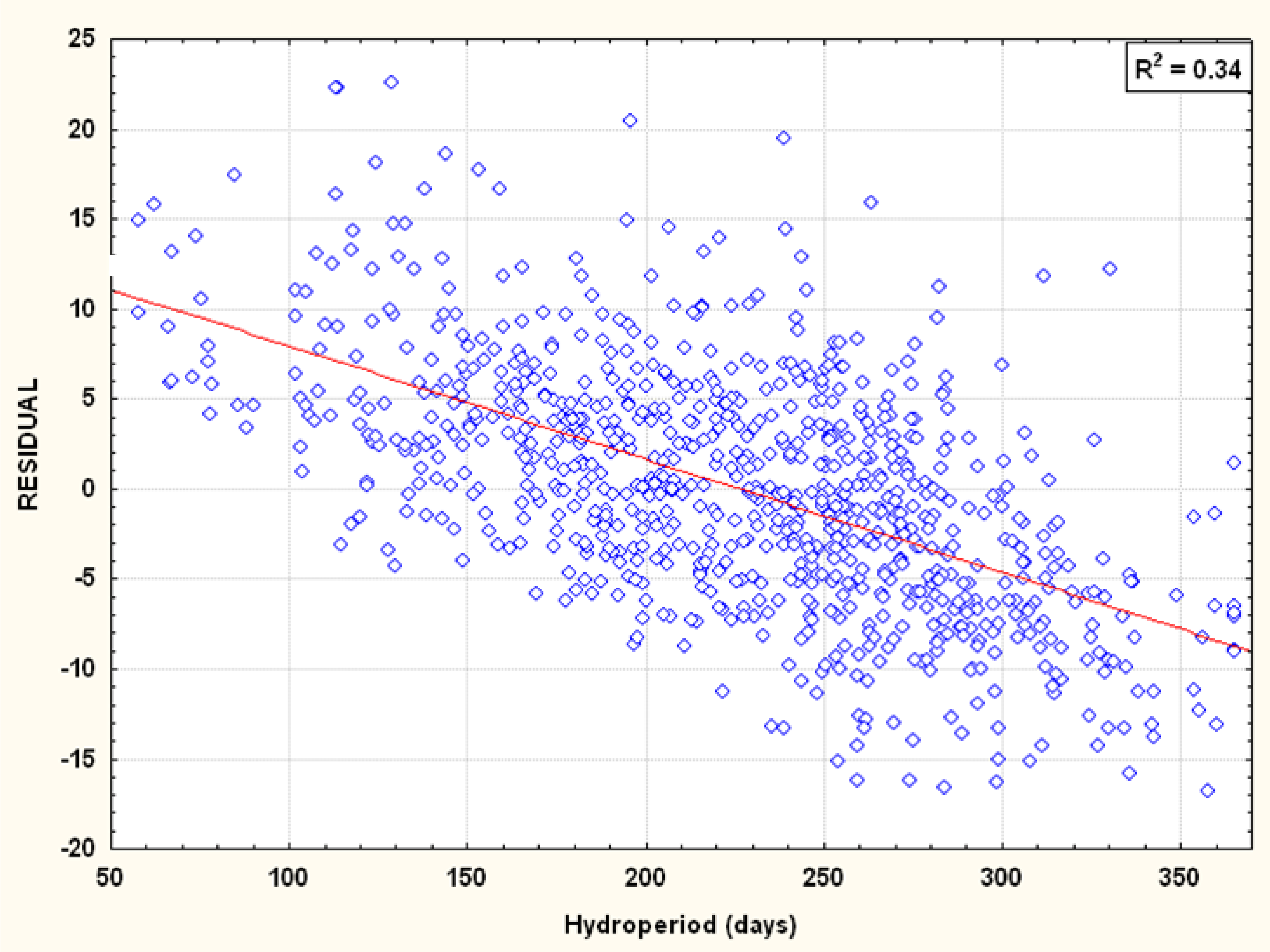

Figure 15: Relationship between vegetation-inferred hydroperiod and species richness after partialling out the effects of biomass.

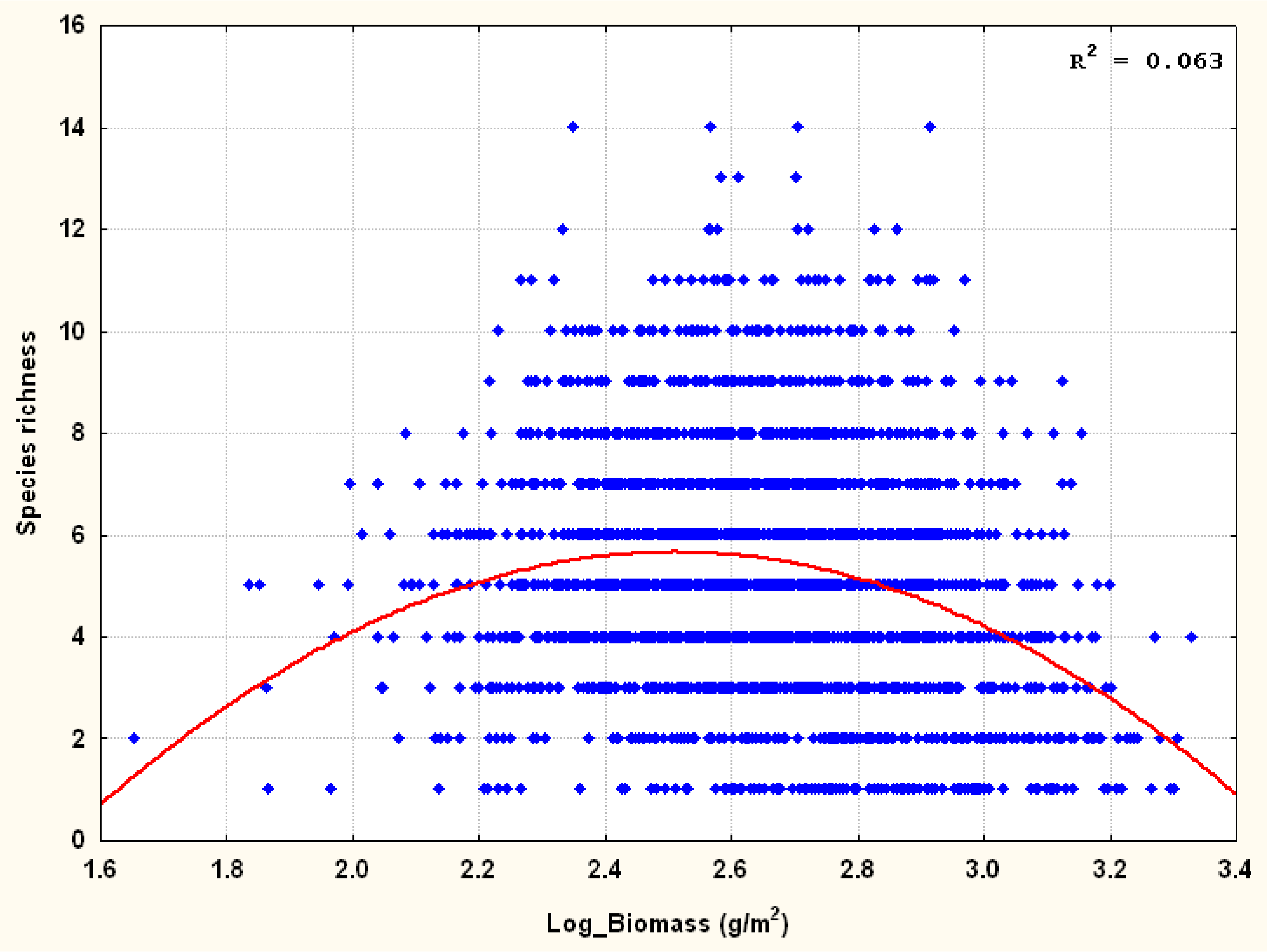

Figure 16: Relationship between total plant biomass in sub-plots surveyed at each site along on six transects in 2003, 2004 and 2005. Biomass was estimated at sub-plot level using the regression equation developed from the biomass samples collected at 166 sites in 2005 and 2006

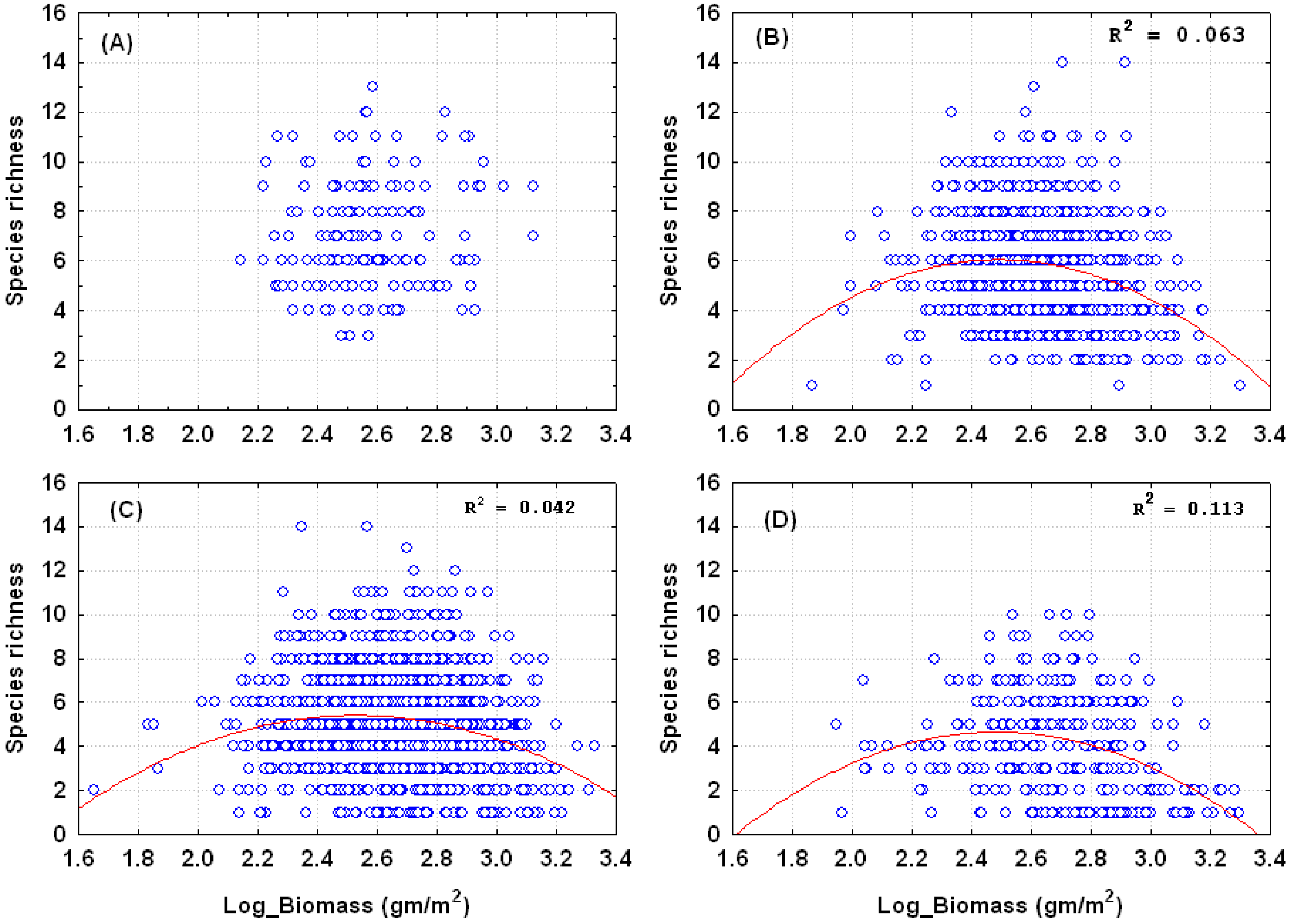

Figure 17: Species richness in relation to biomass (log) in CSSS vegetation sampling transects. Sampling units (0.25 m^2) are grouped in four groups with equal range of hydroperiod (<90, 90-180, 180-270, and >270 days) (A) <90 days, (B) 90-180 days, (C) 180-170 days, and (D) >270 days.

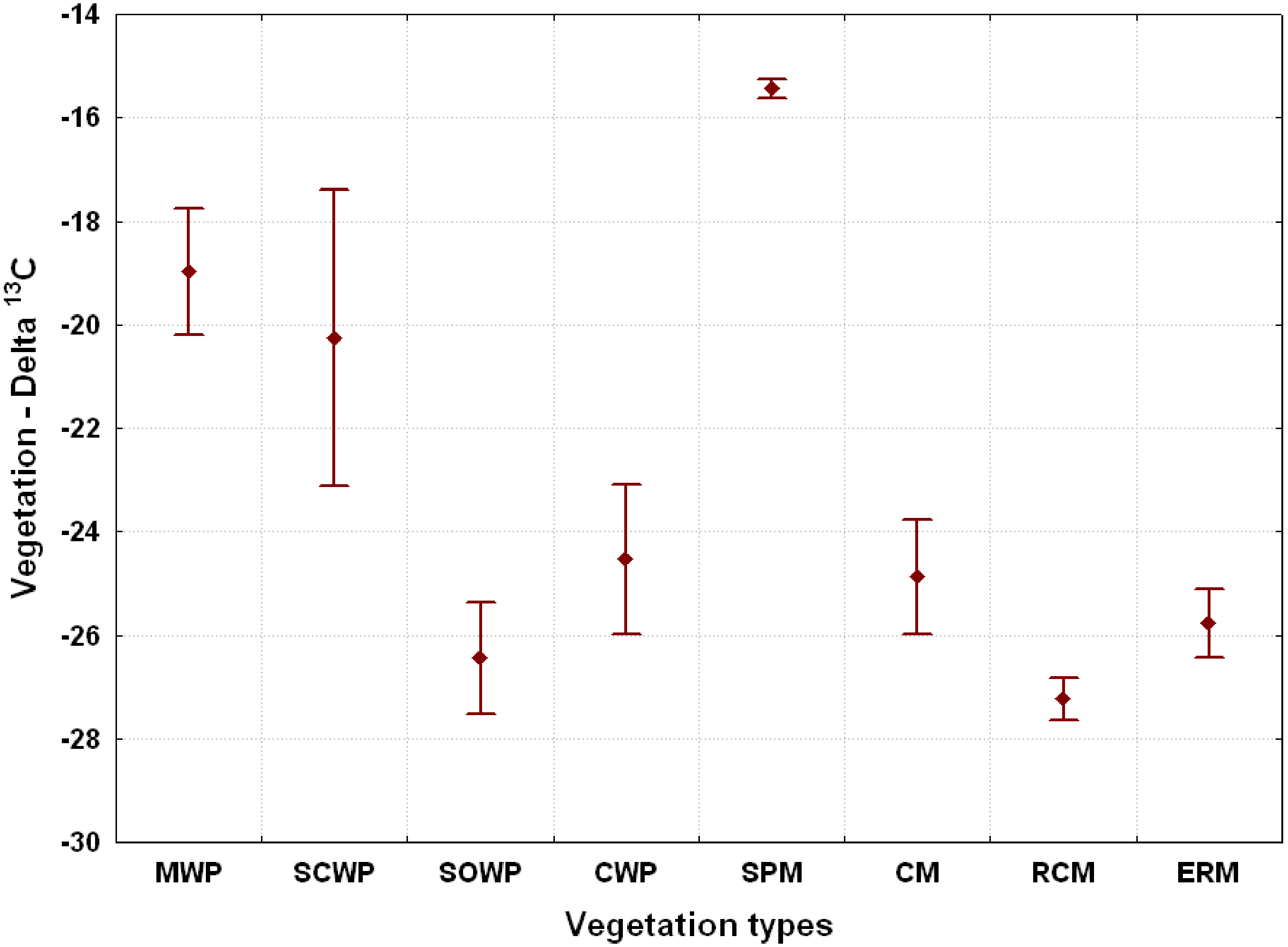

Figure 18: Mean δ^{13}C values of above ground plant materials in eight of ten vegetation types identified by Ross et al. (2006) within CSSS habitat. MWP = Muhlenbergia wet prairie; SCWP = *Schizachyrium* wet prairie; SOWP = Schoenus wet prairie; CWP = *Cladium* wet prairie; SPM = *Spartina* marsh; CM = *Cladium* marsh; RCM = *Rhynchospora-Cladium* marsh; ERM = *Eleocharis-Rhynchospora* marsh.

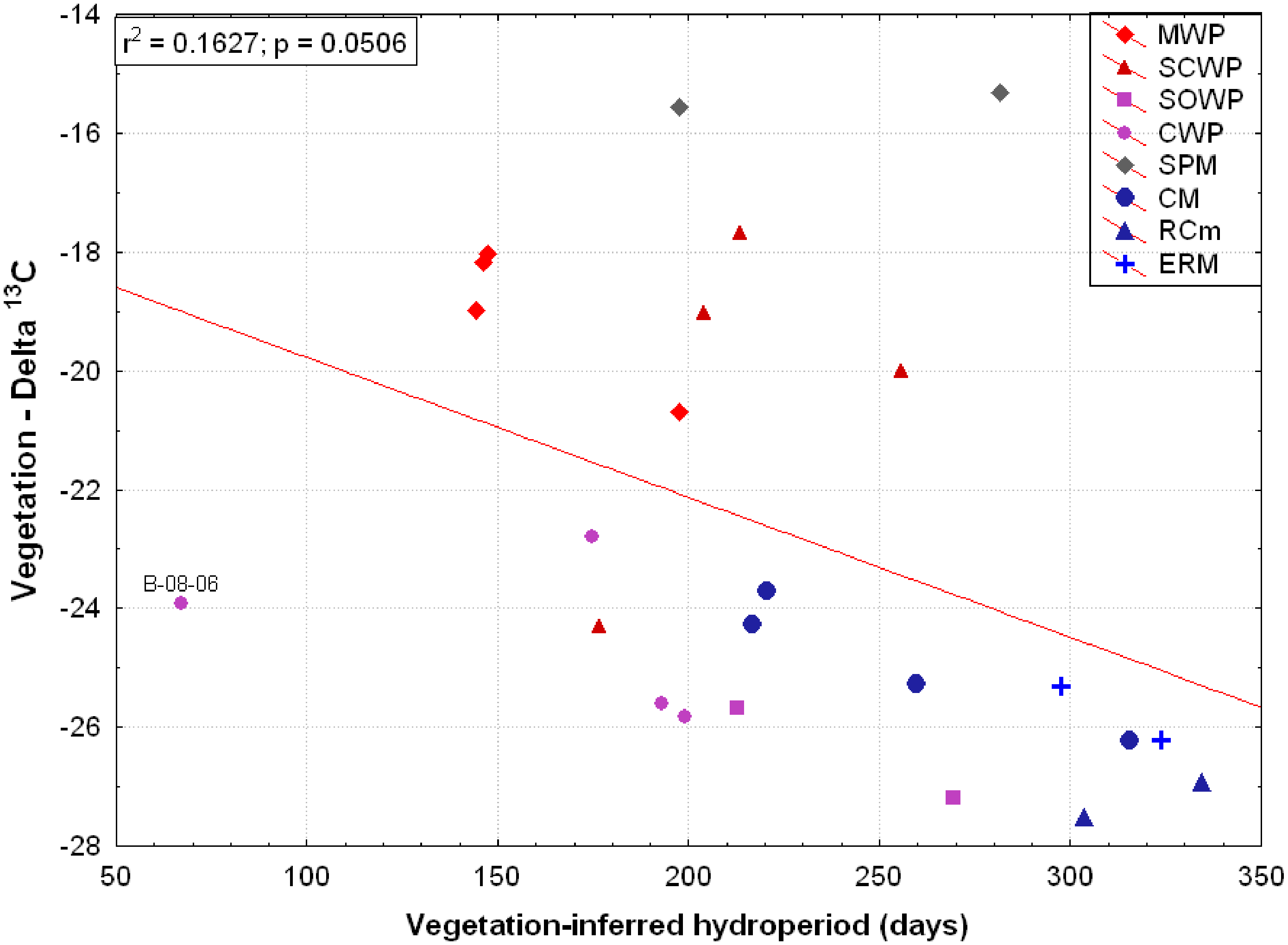

Figure 19: Mean δ^{13}C values of above ground vegetation in relation to hydroperiod at 24 vegetation survey sites within CSSS habitat in Everglades marl prairie.

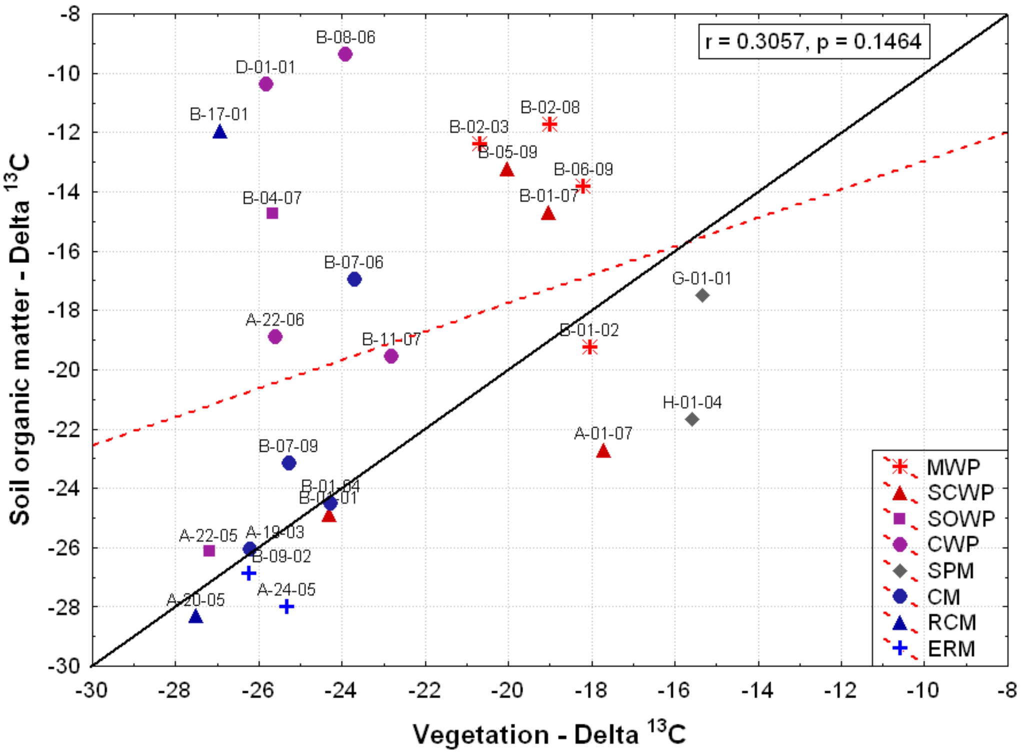

Figure 20: Relationship between δ^{13}C values of above ground vegetation and soil organic matter at 24 CSSS vegetation survey sites. Solid line is the 1:1 curve, dashed line is best fit.

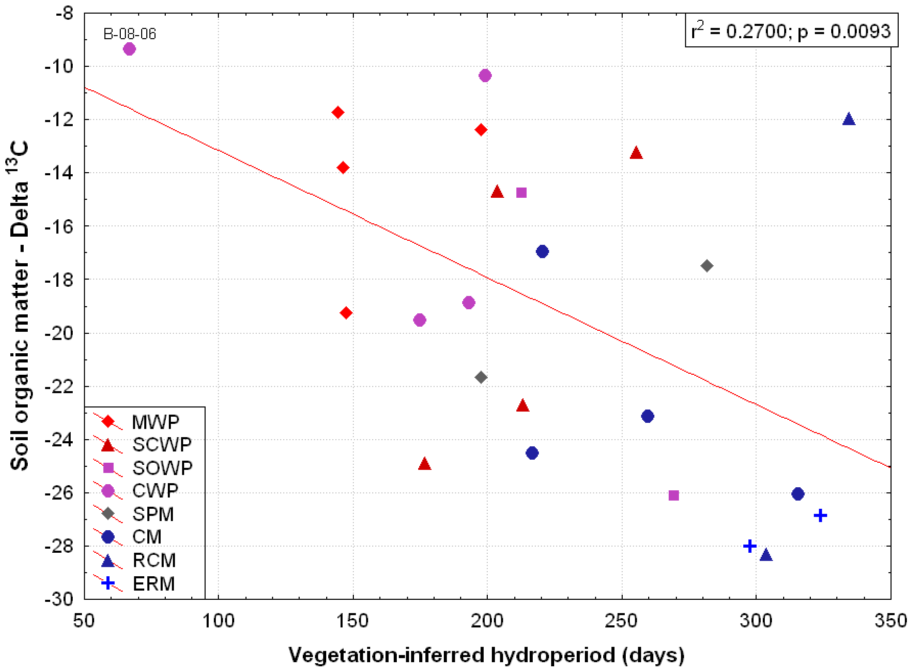

Figure 21: Mean δ^{13}C values of soil organic matter in relation to hydroperiod at 24 vegetation survey sites within CSSS habitat in Everglades marl prairie.

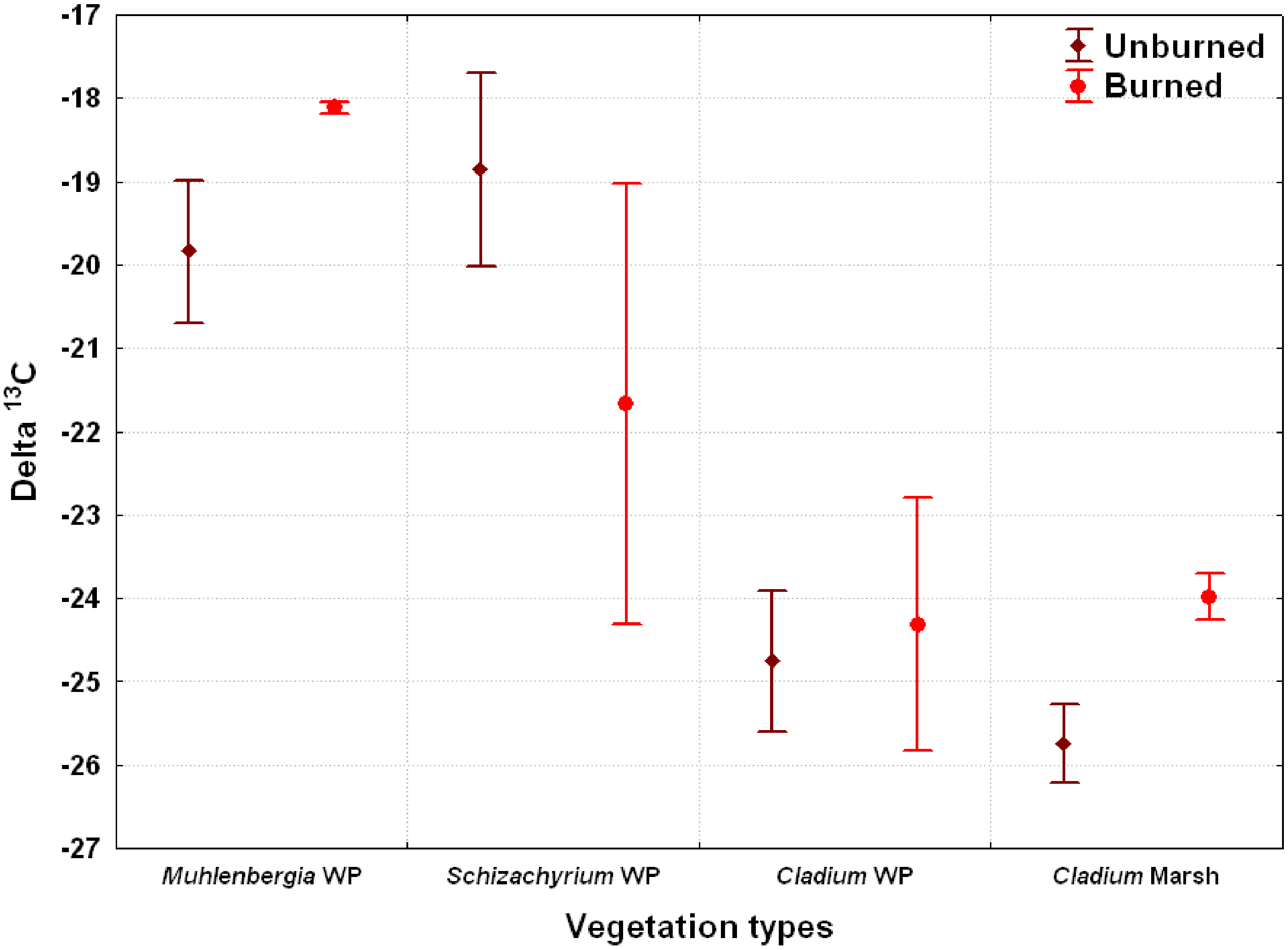

Figure 22: Mean δ^{13}C values of above ground vegetation in burned and unburned sites in 4 vegetation types within CSSS habitat in Everglades marl prairie.

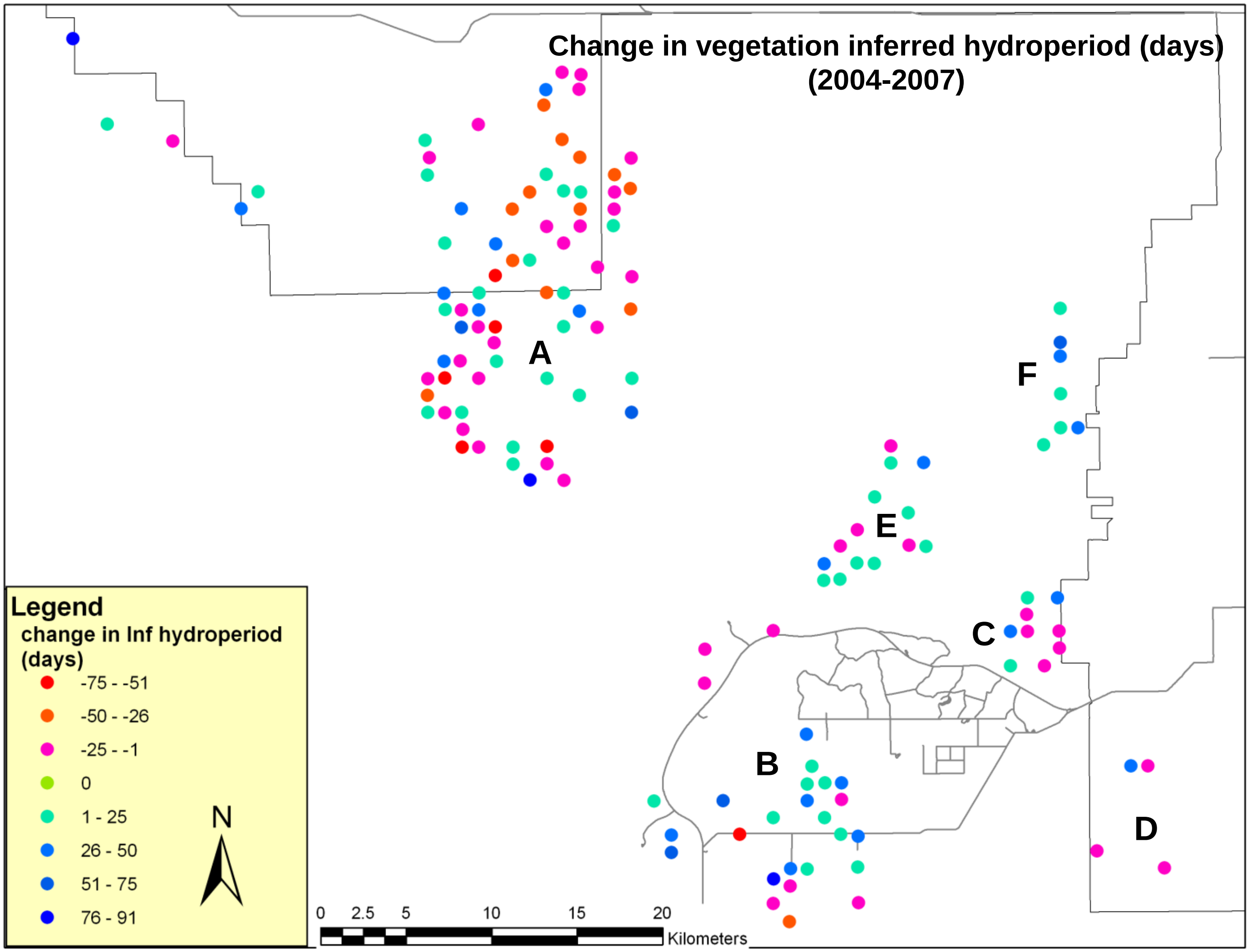

Figure 23: Change in vegetation inferred hydroperiod (days) at the sites which were sampled in both years, 2004 & 2007, and were not burned at least for 4 years prior to 2007 sampling. Roman letters indicate six CSSS sub-population areas.

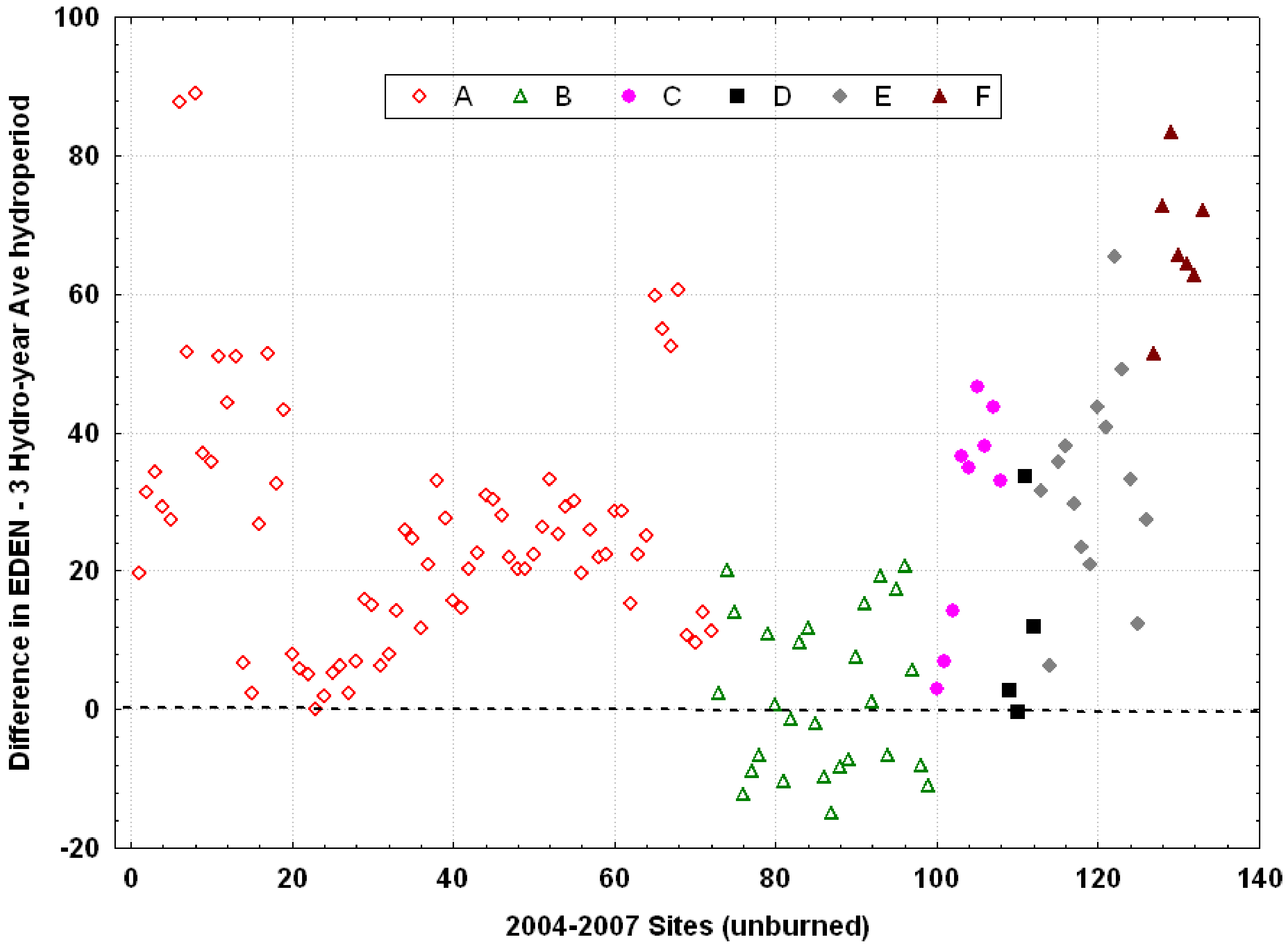

Figure 24: Mean hydroperiod (days) averaged over three years prior to vegetation sampling in 2004 and 2007. Hydroperiod for the sites were calculated using USGS ground elevation and water surface elevation data obtained from Everglades Depth Estimation Network (EDEN). .

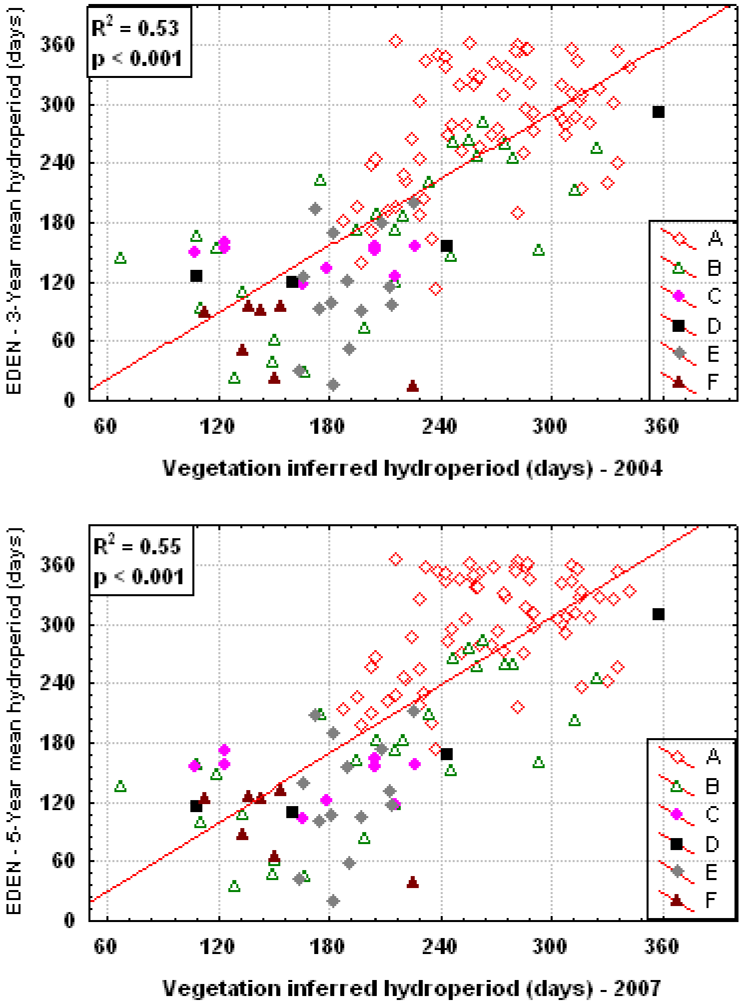

Figure 25: Relationships between hydroperiod inferred from vegetation data gathered at the sites in both 2004 and 2007 and the hydroperiod estimated using from USGS ground elevation and water surface elevation data obtained from the Everglades Depth Estimation Network (EDEN).

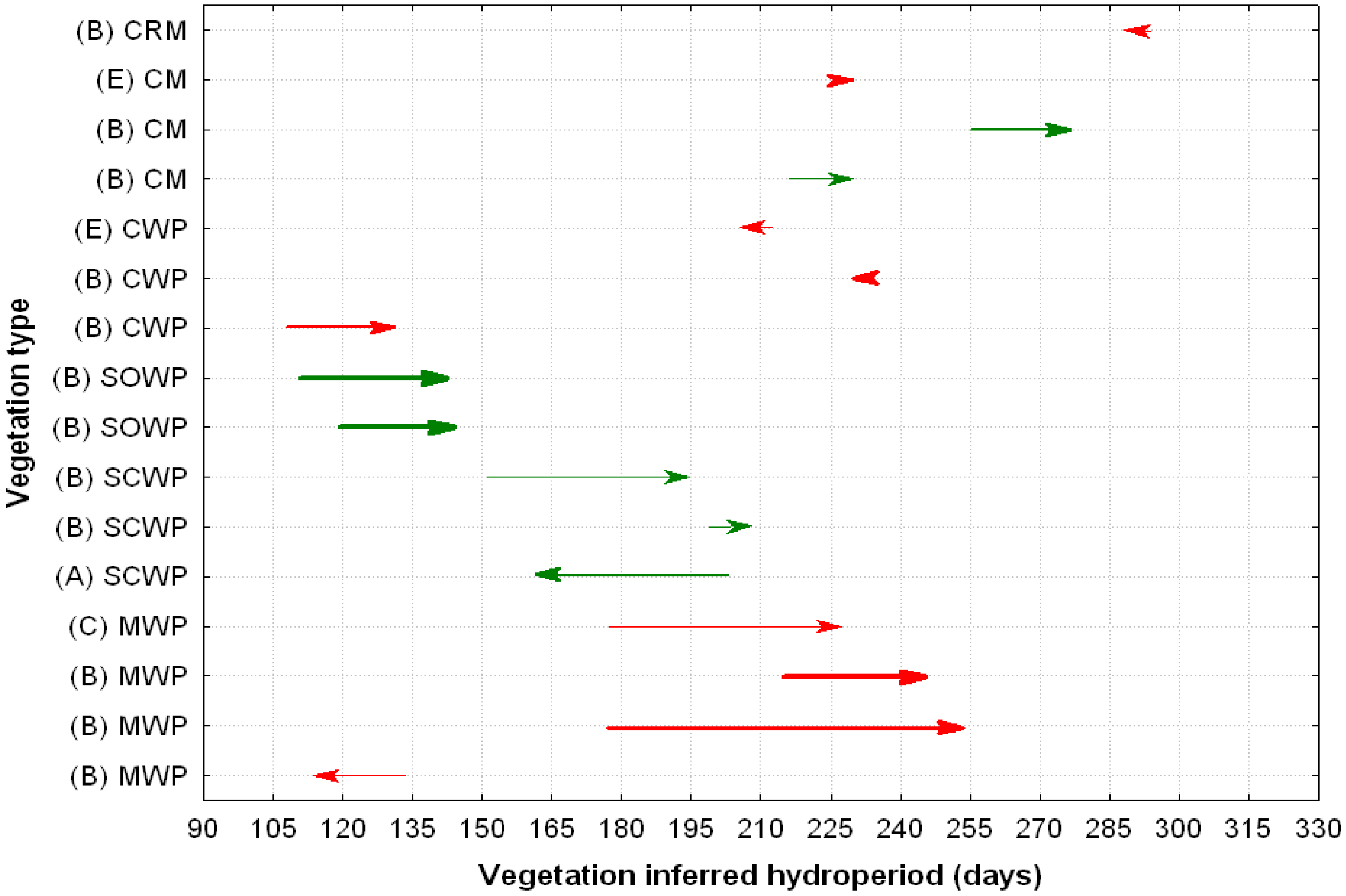

Figure 26: Change in CSSS counts with a change in vegetation inferred hydroperiod (days) at the sites which were sampled in both years, 2004 & 2007, and were not burned at least for 4 years prior to 2007 sampling. Only those sites, at which CSSS population was surveyed in both years, and the count was '0' in either 2004 or 2007 are included. Green and red lines show gain and loss in CSSS numbers, respectively. The thickness of line indicates the CSSS count as 1, 2, 3, and >3 that were gained or lost in increasing order.

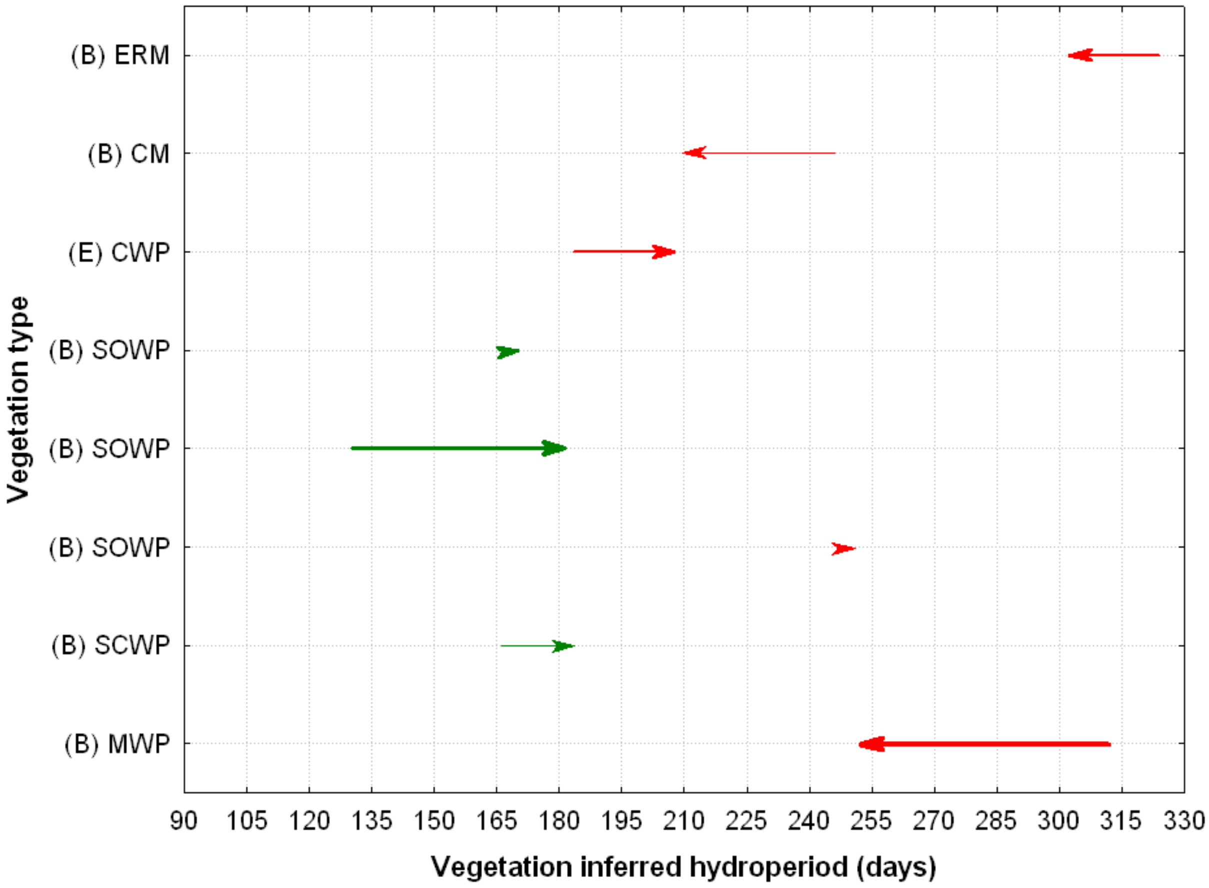

Figure 27: Change in CSSS counts with a change in vegetation inferred hydroperiod (days) at the sites which were sampled in both years, 2004 & 2007, and were not burned at least for 4 years prior to 2007 sampling. Only those sites, at which CSSS population was surveyed in both years and had bird counts 1 or more in 2004 and 2007, are included. Green and red lines show gain and loss in CSSS numbers, respectively. The thickness of line indicates the CSSS count as 1, 2, 3 and 4 that were gained or lost in increasing order.

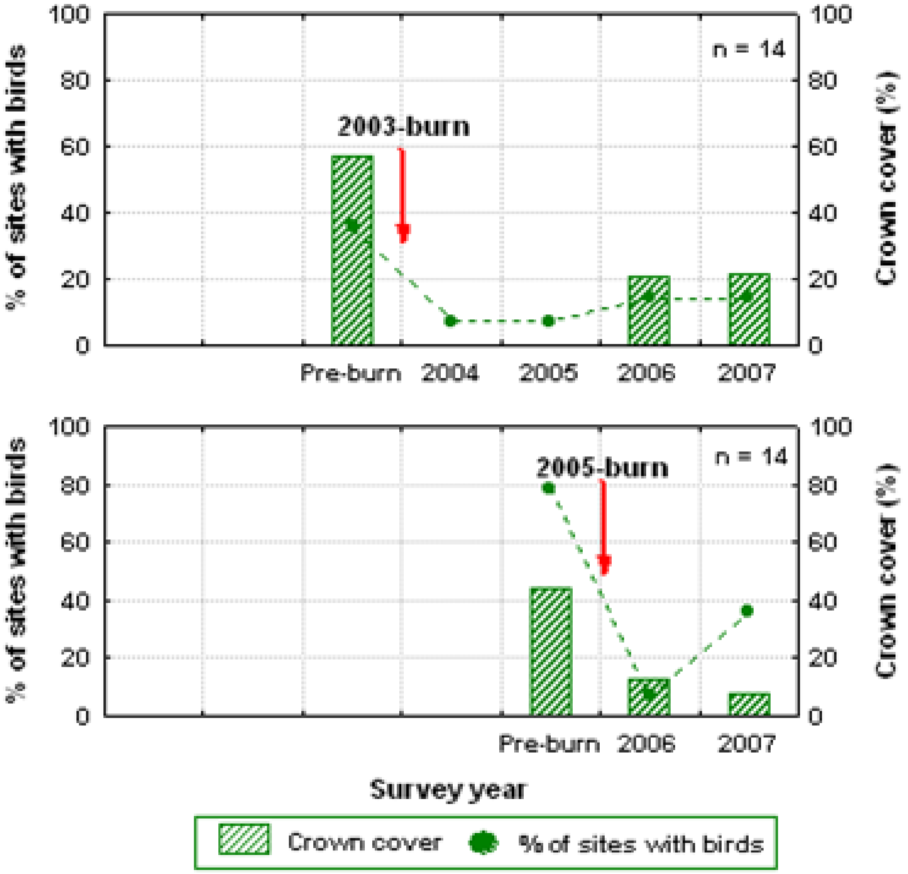

Figure 28: Mean crown cover and % of sites with birds observed at sites burned in 2003 (A) or 2005 (B). At the sites burned in 2003 vegetation survey was done in 2003, 2006 and 2007. Vegetation in sites burned in 2005 was surveyed in 2003, 2004 or prior to the fire in 2005; all of these sites were resurveyed in 2006 and 2007. Pre-burn bird data represent the number of sites in which sparrows were observed in any of the three years prior to fire. Post-burn percentages are based on sites where birds were present in any year after fire.