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

Annual Report of 2005-2006
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Summary

The major activities in Year 4 on 'Effect of hydrologic restoration on the habitat of the Cape Sable seaside sparrow (CSSS)' included presentations, field work, data analysis, and report preparation. During this period, we made 3 presentations, one at the Greater Everglades Ecology and Restoration meeting at Orlando, one at the Fire Ecology Congress at San Diego, CA, and one at the CSSS – fire planning workshops at Everglades National Park (ENP). We started field work in the third week of January, and continued till May 31, 2006. Early in the 2006 field season, we re-surveyed vegetation along Transect A and the burned sites along Transect D which were first surveyed in 2003 and 2004, respectively. Maintaining the consistency in time frame as in previous years, we re-surveyed vegetation at 191 census points during April and May. The census sites included 172 sites sampled in 2003, 14 burned sites sampled in either 2004 or 2005, and 5 sites sampled for the first time in 2006. We also collected biomass samples at an additional 88 census sites, bringing the total number of sites at which biomass were collected to 166. We measured live and dead biomass, and used vegetation structure and biomass data from those sites to re-develop a regression model that we applied to predict aboveground biomass at all transects and census sites. Vegetation data analysis focused mostly on the change in vegetation structure and composition in three years from 2003 to 2006. Analysis was done on two sets of sites. The first set included sites which were not burned for at least three years before the 2006 survey, and the second set included sites that were burned in 2001, 2003 or 2005. Soil samples collected over a three year period were analyzed for pH, total carbon, nitrogen and phosphorus, and organic carbon. The change in vegetation structure and composition, species richness, and above ground biomass at the unburned sites in three years was analyzed by comparisons among vegetation types arranged along the hydrologic gradient and among CSSS sub-populations. Vegetation change at the burned sites was analyzed by vegetation type and in relation to time since last fire. Soil nutrient data for the CSSS census sites was analyzed in relation to vegetation type. Counts of Cape Sable seaside sparrow were compared between 2003 and 2006 and were related to vegetation cover and time since last fire.

Vegetation composition within CSSS habitat did not change much in terms of relative cover of species. However, mean plant cover and absolute cover of several major species, including *Cladium jamaicense, Schizachyrium rhizomatum, Schoenus nigricans,* and *Muhlenbergia capillaris*, was significantly lower in 2006 than in 2003. At the same time, the mean cover of *Eleocharis cellulosa*, which is an indicator of wet sites in the Everglades, increased, suggesting that at least some sites became wetter in three years. It was also evidenced by the increase in 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. In particular, vegetation in the wet prairies along the eastern edge of sub-population E, the central part of sub-population A, and the southern part of sub-population B were indicative of slightly wetter conditions in 2006 than three years earlier. At unburned sites, plant cover, species richness, and above ground biomass were lower in 2006 than in 2003. 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 killed most plants, including sawgrass culms, resulting

in very low cover during 2006 survey, and the appearance of a new suite of species that were absent in pre-fire vegetation survey. Across all sites, species richness exhibited a hump-shaped relationship with biomass, though the relationship varied among vegetation types arranged along hydrology gradient. Soil organic carbon and nitrogen were higher at marsh sites and in sub-population A than prairie sites and other sub-populations. Total phosphorus in soil was much higher in sub-population A, but did not differ significantly between marsh and wet prairies sites.

Re-survey of sites sampled three years ago revealed that mean plant cover decreased even at sites that were not burned for three years prior to the vegetation re-sampling in 2006. The decrease in plant cover could be attributed to a change in hydrologic regimes, disturbances like hurricane, which impounded significant amounts of water in 2005, or to observer error. Though three year average of mean daily water level at several stage recorders was higher for 2006 than for 2003, it is not clear at present whether such a difference in water level could have significant effect on plant cover within such time scale, as there is limited understanding yet regarding how rapidly vegetation changes in response to hydrologic alterations in CSSS habitat. Additionally, very low plant cover and a change in species composition at sites flooded after fire in 2005 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 2006 of sites surveyed in 2003, along with burned sites surveyed in 2004 and 2005, has answered many questions regarding vegetation change in response to hydrology and fire. However, a full understanding of the causes and rates of change in vegetation structure and composition will require a long-term database covering a broader range of time series and environmental conditions.

1. Introduction

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

2. Methods

2.1 Presentations and field work

After the completion of our third annual report in March 2006, we carried out a number of activities. The most significant of these included several presentations, re-sampling of sites previously sampled in the Year 1 or burned in 2003 and 2005, and data analysis.

We began Year 4 field work before submitting the 3rd year report, i.e., in the third week of January 2006 and continued till the last week of May, 2006. While the field work was going on, Mike Ross and Jay Sah made a presentation at the Marl Prairies/CSSS Performance Measures Workshop on March 19-20, 2006, organized at ENP.

In the 4th year of field work, there was little change in FIU sampling personnel. Franco Tobias, who was occasionally involved in vegetation sampling in the third year, was no longer in our sampling team. Instead, Nilesh Timilsina joined our team and carried out most of field preparation, and also accompanied the field crew for vegetation sampling. Erin Hanan and Nabin Acharya, who both worked as part-time research assistants in Dr. Ross’ lab, occasionally accompanied the FIU team. In the USGS team, Jim Snyder recruited Beyte Barrios as a replacement of David Hagyari.

We commenced vegetation sampling on January 18 and continued through May 31, 2006. Transect A, the transect initially surveyed in 2003, was re-surveyed between February 1 and March 1, 2006. On March 27, three and half weeks after we had completed transect sampling, we began vegetation sampling at the CSSS census points first surveyed in 2003. Vegetation re-sampling at census points was done at the same as in 2003 to assure that any change in vegetation composition between two sampling periods would not be confounded by any seasonal variation in species abundance. Most of the vegetation sampling was done using BCNP helicopter service (Bill Evans, pilot). From the beginning of May, however, Biscayne Helicopter provided most of the transportation for the rest of field season because BCNP helicopter remained engaged in or stood by for fire related work within the Preserve. We completed the sampling of census points on May 31, 2006.

During the field work in 2006, we re-sampled the 51 points on Transects A, and 172 of the 179 census points sampled in 2003 (**Table 1**). Seven census sites sampled in the Stairstep area of western ENP in 2003 were not re-sampled in 2006. At the same time, five sites (4 in sub-population A and 1 in sub-population E) scheduled for sampling in 2003 but missed for various reasons were sampled for the first time in 2006. This brought the total number of census sites where the quantitative vegetation data are available to 613, thoroughly scattered throughout all six sub-populations **(Figure 1)**. Moreover, we re-sampled an additional 20 transects sites (18 on Transect D, 2 on Transect B) and 14 census sites that were sampled for the first time in 2004 or 2005, and were burned either in 2003 or 2005. Burned sites were re-sampled to learn more about vegetation recovery after burning and to assess the effects of the fire-hydrology interaction on vegetation.

Among the 191 census sites sampled in 2006, 70 were from sub-population A, and 67, 10, 13, 21 and 10 were from sub-populations B, C, D, E and F, respectively **(Table 1**). In sub-population A, four sites were sampled for the first time, while two burned sites sampled initially in 2005 were re-sampled in 2006. In sub-population B, nine sites that were burned in 2003 or 2005 and sampled in 2004 or 2005 were re-sampled this year. In population D, besides the 10 sites sampled in 2003, three sites sampled in 2004 or 2005 were also re-sampled in 2006, and in sub-population E, one site was first sampled this year. Annual re-sampling at two census points burned in 2003 near the Everglades Park road was continued for a fourth year in 2006. In general, structural and compositional vegetation parameters recorded at both transect and census sites in 2006 were the same as in the first three years of the study. 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 4 field season (Feb 1 – May 31, 2004)

Transect/ Census sites	**Sub-population**	**First-time sampled**				**# of sites sampled**
		2003	**2004**	**2005**	**2006**	
Transect	A	51				51
	B			2		2
	D		18			18
Census sites	A	64		2	4	70
	B	58	8	1		67
	C	10				10
	D	10	2	1		13
	E	20			1	21
	F	10				10

After the field work was completed, we made three presentations. In the first week of June, Jay Sah gave a presentation, entitled ‘Vegetation-environment relationships and their implications for Cape Sable seaside sparrow populations in Everglades marl prairies’ at the 2006 Greater Everglades Ecosystem Restoration Conference, June 5-9, 2006, Buena Vista Palace, Orlando, FL. The presentation was primarily based on results described in the Year 3 report, but also included 2006 data recorded along Transect A and in two woody plant plots, one each in sub-populations B and D. The audience for the presentation was a diverse one representing different fields of wetland ecology and restoration.

Jay Sah gave another presentation, entitled ‘Assessing the interactions of fire and hydrology on marl prairie vegetation in the southern Everglades, Florida, USA’ at the 3rd International Fire Ecology and Management Congress, November 13-17, 2006, San Diego, CA. This presentation was primarily based on the 2006 data, focusing on the results from an analysis of biomass and vegetation change in the sites which were burned between 2001 and 2005. In the presentation, the effect on vegetation of the interaction between fire and hydrology was emphasized.

We presented the 4th year results also at the Cape Sable seaside sparrow (CSSS) Symposium-2006 at Everglades National Park (ENP) on December 5-6. First Mike Ross outlined two presentations, one by Rachel King and the other by Jay Sah. Rachel’s presentation was on woody plants in Cape Sable habitat and Jay’s presentation described the results from an analysis of soil nutrients, biomass estimation and vegetation change.

2.2 Analytical methods

Vegetation change

We used a non-metric multidimensional scaling (NMS) ordination (Kruskal, 1964) to visualize temporal change in vegetation composition between two 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 often proportional to 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 among sites. We used Analysis of Similarity (ANOSIM), a nonparametric multivariate analytical 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 places or times are no larger than differences between one replicate and another within any place or time. When R is near 1, there are likely to be real differences in samples from differing locations and/or times.

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 three year period before the 2006 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 considered as burned, we adapted a slightly different criterion. Recent studies have shown that for vegetation in prairies, return to the initial condition usually requires 3-4 years following fire (Lockwood et al. 2005). We therefore considered the sites which had burned within three years of either the 2003 or 2006 sampling as burned sites. That included those sites which were burned in 2001, 2003 and/or 2005 (no sites burned in 2002 or 2004 were sampled this year). Consequently, the grouping of burned sites on the basis of time since last fire yielded six groups: pre-burn, post-burn, and 1, 2, 3 and 5 years after burn. Two-way analysis of similarity (ANOSIM) was used to examine the differences in vegetation composition among these different groups within each vegetation type.

Soil characteristics

Soil samples were collected from vegetation sampling sites on Transect A, D and F and 359 census sites. Samples were analyzed for pH, total carbon, inorganic carbon, total nitrogen and total phosphorus at the Soil and Water Laboratory at the Institute of Food and Agricultural Science (IFAS), University of Florida – Tropical Research and Education Center, Homestead, FL. Soil pH was determined by using EPA Method 150.1, total carbon and nitrogen by EPA 440.0, total phosphorus by EPA 365.2 and inorganic carbon by the method of weight loss described in Soil Survey Laboratory Method 61E c. We used box plots, scatter plots, and mapping with ArcGIS to examine pattern in soil physical and chemical characteristics within the CSSS habitat.

Biomass estimation

In Year 3, estimation of biomass at transect and census sites was based on a regression equation developed from samples collected at eight-eight 2005 census sites. To improve the model, we collected biomass samples from an additional 88 census sites sampled in 2006 (Year 4). Biomass collection followed the same methodology described in Year 3 Annual Report (Ross et al. 2006). At each site, we harvested above ground biomass from two 0.25 m^2 quadrats, at 17 and 41 m from the origin of the 60 x 1 m belt transect. Structure and species composition data were collected concurrently at these two plots. We clipped the plants in each quadrat and collected all aboveground materials including periphyton and dead plant material. Materials were bagged together, returned to the lab, and separated into periphyton and live and dead plants. These were oven-dried at 70^{o}C to constant weight, and dry weight was recorded.

We applied step-wise regression to select structural variables that produced the best model for predicting aboveground plant biomass. Before analysis, biomass data were square-root transformed to approximate the normal distribution. Percent plant cover values were first expressed as fractions between 0 and 1, and then were arcsine-square root transformed, as suggested in Sokal and Rohlf (1995). The Akaike Information Criteria (AIC) was used for model selection, and the model with lowest AIC was selected (Akaike 1974). This model was then used to estimate biomass at both transects and CSSS census sites sampled between 2003 and 2006. As the Levene's test indicated that these data did not satisfy the assumption of homogeneity of variance, we used nonparametric methods (Mann-Whitney U and Kruskal-Wallis ANOVA) to test differences in biomass between wet prairie (WP) and marsh (M), and among vegetation types, respectively.

Hydroperiod, fire and biomass

We obtained annual fire data for 25 years (1981-2005) from Everglades National Park in a geo-spatial format. We also received fire data from Big Cypress National Preserve for the northwestern section of sub-population A. However, the fire data from Big Cypress were incomplete and limited to a subset of years scattered through the 25-year period. We used ArcGIS to create a fire map, and to calculate fire frequency and time since last fire. We graphed biomass in relation to fire and inferred hydroperiod in order to visualize the relationships among the three variables.

3. Results

3.1 Vegetation change

Both burned and unburned sites were sampled in 2006. For vegetation analysis purpose, we considered sites that were not burned for three years prior to 2006 vegetation sampling as unburned. By this criterion, all 51 sites on Transect-A, and 149 of 186 census sites re-sampled in 2006, were considered unburned. Burned sites were those experiencing fire within three years prior to either the 2003 or 2006 sampling date. Burned sites included 52 census sites, and 18 and 2 sites on Transect-D and Transect-B, respectively.

Vegetation change at unburned sites

Transect A: Expressed in terms of relative species cover, vegetation composition along Transect A did not differ significantly between 2003 and 2006 (ANOSIM: Global R = 0.022, p-value = 0.065). In the NMS ordination (**Figure 2**), the position of the sites are summarized by vegetation type and year. Within a type, ordination scores for Axis 1, which is strongly correlated (r = 0.668; p = 0.009) with hydroperiod, were usually similar in the two years. In contrast, along Axis 2, which is negatively correlated with total cover, group positions for 2006 samples were consistently separated from the corresponding groups sampled in 2003. Exploring this trend further, **Table 2** indicates that total ground cover as well as the mean absolute cover of several major species was significantly lower in 2006 than in 2003. In three years, total cover decreased from 36.3% to 23.9%, though the proportion of green cover remained the same. The mean cover of *Cladium jamaicense* was 13.2% and 9.8% in 2003 and 2006, respectively. Other major species whose cover significantly different in two sampling years were *Panicum tenerum*, *Schoenus nigricans* and *Paspalum monostachyum*. The mean cover of *Rhynchospora tracyi* on the Transect A increased between 2003 and 2006.

Table 2: Mean cover (%) of major species in 2003 and 2006 on Transect A, and the p-values from the pair-wise t-test between years.

Species	Mean cover (%)		p-value (pair-wise t-test)
	2003	2006	
Cladium jamaicense	13.20	9.80	<0.001
Schoenus nigricans	3.98	2.03	0.012
Schizachyrium rhizomatum	3.69	4.17	0.114
Paspalum monostachyum	2.83	2.02	0.038
Panicum tenerum	1.38	0.28	<0.001
Rhynchospora tracyi	1.36	2.57	<0.001
Panicum virgatum	1.15	1.06	0.522

The changes in cover at the sites on the Transect A did not seem to be limited to the species that are indicative of either wetter or drier environments, and were also not significantly correlated with observed hydroperiod, averaged over 3, 4 or 5 years prior to vegetation sampling. The weak relationship between changes in absolute cover of major species and observed hydroperiod suggests that such changes were not solely caused by changes in hydrology. Vegetation inferred hydroperiods also did not significantly differ between 2003 and 2006 (Pairwise t-test: $n = 51$, $p = 0.114$).

Census sites: Species composition at unburned marsh and wet prairie sites did not change significantly in the three years between 2003 and 2006 (**Figure 3:** ANOSIM - Global R = 0.006, p-value = 0.083). However, vegetation change over the period was primarily signified by a decrease in total plant cover and in mean cover of several major species throughout the CSSS habitat **(Figure 4)**. In three years, total plant cover decreased from 40.7% to 27.7%. The mean cover of *Cladium jamaicense* was 19.8% and 14.6% in 2003 and 2006, respectively. Other major species whose mean cover was significantly different in two sampling years were *Panicum tenerum*, *Muhlenbergia capillaris* var. *filipes*, *Schoenus nigricans* and *Schizachyrium rhizomatum*. Mean cover of *Eleocharis cellulosa* increased while the cover of *Bacopa caroliniana* and *Rhynchospora tracyi* did not change significantly.

Total plant cover decreased in all six sub-populations and within eight out of the 10 vegetation types described for CSSS habitat (Ross et al. 2006). The other two vegetation types, *Eleocharis-Rhynchospora* marsh and *Spartina* marsh, were not represented among unburned sites sampled in both 2003 and 2006. The decrease in total cover was highest in Sub-population D, and it was higher in all four wet prairie types than the marshes (**Figure 5a & 5b**). Change in the cover of major species across the vegetation types showed mixed results. Among the three major species indicative of longer hydroperiod in CSSS habitat, cover of *E. cellulosa* and *R. tracyi* either increased or remain unchanged across all vegetation types, while cover of *C. jamaicense* decreased in six vegetation types and remained unchanged in *Rhynchospora-Cladium* and *Cladium-Rhynchospora* marsh (**Figure 6**). **Figure 7** places these patterns in a spatial perspective. Mean cover of *E. cellulosa* increased in all sub-populations while *C. jamaicense* decreased throughout the area. However, the magnitude of change in their cover varied greatly among sub-populations. In sub-population D, the cover of *C. jamaicense* decreased by 50%, twice as much as in other sub-populations. The cover of *R. trayci* showed a similar, mixed trend. In contrast, three major prairie species (*M. capillaris* var. *filipes*, *S. nigricans* and *S. rhizomatum*) decreased in cover in almost all vegetation types **(Figure 6)** and in all sub-populations in which those species were present (**Figure 7**).

Species richness

Like plant cover, mean species richness (the number of species per site) also decreased significantly (Pair wise t-test: $n = 149$, $p < 0.001$) over the three years, from 15.3 species per plot in 2003 to 12.6 in 2006. However, there were some sites where species richness either increased or did not change **(Figure 8)**. Mean species richness decreased uniformly in all eight vegetation types, and in all sub-populations but D (**Figure 9a & b**).

Vegetation change at burned sites

Among the 257 sites at which vegetation was re-sampled in 2006, 72 sites were considered as burned sites. However, in an outlier analysis based on Bray-Curtis dissimilarity, two sites in Sub-population A were identified as outliers, probably because the sites were recorded within the fire boundary of a 2005 fire, but were not burned at all. Non-metric multidimensional scaling (NMDS) ordination was used to illustrate the change in vegetation composition at the burned sites. For this ordination, we used absolute cover of species to illustrate the change in species cover after fire. In the ordination space, the groups were not well separated (Stress 0.18), though the sites were arranged along two major gradients, hydrology and time since last fire. The gradients became more obvious when the centroids of vegetation types x time since last fire were plotted in the ordination space. Sites sampled immediately after fire (Post-burn) were far apart from pre-burn sites (**Figure 10a**), indicating strong differences in vegetation composition Time since last fire had a significant effect on vegetation composition (ANOSIM: $R = 0.223$; $p = 0.001$). Unburned sites, represented here by Pre-burn sites, significantly differed from burned sites in vegetation composition even after 5 years of fire (**Table 3**). Burned sites after 2, 3 and 5 years of fire did not differ in vegetation composition. Similar results were found by Lockwood et al. (2005). **Figure 11** depicts this pattern at two sites that we have surveyed on an annual basis following a fire in 2003. Mean plant cover at these sites also was similar after three years to the pre-burn level (**Figure 11**).

Table 3: *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	5-Year
Pre-burn	0.006	0.001	0.001	0.001	0.001
Post-burn		0.694	1.000	0.002	0.022
1-Year			0.403	0.017	0.440
2-Year				0.601	0.668
3-Year					0.303

The results from the present analysis needs to be interpreted cautiously, as the sites representing various stages of post-fire recovery were not the same, and they included a range of vegetation types which in general are arranged along a hydrologic gradient in prairies and marshes. The nature of the relationship between time since fire and vegetation cover were different among vegetation types. *Schizachyrium* and *Muhlenbergia* wet prairies showed higher compositional variability before and after fire than did *Cladium* wet prairie and marsh sites (**Figure 10**). Similar results were reported from the survey of one wet prairie and one marsh site burned in 2003 (Ross et al. 2004, 2006). At those sites, site-related differences in compositional recovery between wet prairie and marsh were still maintained after three years of fire (**Figure 12**).

The possible reason for differences in post-fire recovery could be the interaction between hydrology and fire. All sites burned in August 2005 were wet prairie sites, which were flooded immediately after fire by a rise in water level of more than a foot on the occasion of Hurricane Katrina (**Figure 13**), which appeared to have killed most plants. In these sites, vegetation was very sparse even one year after fire (**Figure 14**). At these sites, vegetation cover may not only take longer than expected to return to pre-burn condition, recovery may take on a different trajectory in terms of species composition. For instance, preliminary analysis showed that 17 species that were present before the 2005 fire were not present during the 2006 survey, whereas 11 new species were found (**Table 4**). Change in species composition is further confirmed by a shift in rank abundance curves after the August fire (**Figure 15**). The relative cover of a few dominant species decreased greatly, whereas the relative cover of several minor species, especially *Centella asiatica*, *Pluchea rosea*, and *Iva microcephala*, increased. In contrast, at sites burned in May 2005, water level increased gradually, providing ample opportunity for the re-growth of plants after fire, and resulting in a rapid recovery of vegetation cover. Though the relative cover of *Cladium jamaicense*, the most dominant species in *Cladium* marsh, decreased at those sites too, not a single species that was absent in the pre-burn vegetation survey appeared after fire. In contrast, 14 species that were present prior to this fire were absent in 2006. The timing of the surveys may be at issue, as the surveys at these sites were done in January, and some species might not have had enough opportunity to germinate due to persisting high water level. Therefore, the conclusion from this comparison should be interpreted cautiously, as it is not yet clear whether the differences among the 2 sets of sites burned at different time of year are due to differences in vegetation type (marsh in May burn, wet prairies in August-burned sites), timing of survey, or post-burn flooding of August burned sites. But the re-constitution of these communities after fire will be a fascinating topic to examine further. Repeated annual sampling at the burned sites experiencing different hydrologic regimes both before and after fire will help to elucidate the effects of fire and hydrology more completely.

3.2 Plant biomass, hydrology and response to fire

Biomass estimation

Mean aboveground plant biomass at 166 census sites, half sampled in 2005 and the other half in 2006, was 480 g/m^2, with dead plant materials constituting about 3/4 of the total. Total plant cover and mean crown height were both significantly correlated to with biomass (**Figure 16**). After we applied square-root and arcsine-square root transformations to biomass and plant cover data, respectively, we used step-wise regression and selected the model with crown cover and height as primary structural variables for predicting biomass. The selected the model is:

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

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

The improved regression model was used to re-estimate the biomass for CSSS census and transect sites previously reported (Ross et al. 2005). Above ground plant biomass in the prairies and marshes within the range of CSSS habitat varied from 117 to 1684 g/m^2, and the predicted mean biomass from the 2005 and improved regression models did not differ significantly.

Table 4: List of the species that were present only in either pre-burn or 2006 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**	**Pre-burn**	**2006**
Agalinis linifolia	+			
Agalinis purpurea			+	
Agalinis spp.			+	
Annona glabra				+
Aristida purpurascens	+		+	
Asclepias longifolia				+
Aster spp.				+
Cassytha filiformis	+		+	
Cephalanthus occidentalis			+	
Chamaesyce adenoptera subsp. *pergamena*			+	
Chiococca parvifolia			+	
Chrysobalanus icaco	+			
Dichanthelium aciculare				+
Dichanthelium spp.				+
Eragrostis elliottii	+			
Erianthus giganteus			+	
Erigeron quercifolius			+	
Eupatorium leptophyllum				+
Justicia angusta	+			
Leersia hexandra				+
Lobelia glandulosa	+		+	
Ludwigia microcarpa	+			
Mitreola petiolata	+			
Myrica cerifera			+	
Nymphoides aquatica			+	
Oxypolis filiformis	+			
Panicum hemitomon				+
Persea borbonia			+	
Pityopsis graminifolia			+	
Proserpinaca palustris	+			
Rhynchospora divergens	+			
Ruellia caroliniensis				+
Sabal palmetto			+	
Schoenolirion albiflorum				+
Spermacoce terminalis				+
Stenandrium dulce var. *floridanum*			+	
Taxodium distichum var. *imbricarium*	+			
Utricularia foliosa	+			
Unidentified-01			+	

Biomass, hydrology and fire

Total biomass in prairies and marshes is affected by both hydrology and fire. In general, wet prairies had significantly higher mean biomass than marshes (Mann-Whitney U test: p <0.008). However, among 10 vegetation types, *Spartina* marsh had the highest biomass (**Figure 17**). Fire history also has a significant effect on the total biomass in prairies and marsh, though the relationship is complex and is influenced by hydrology. For instance, a curvilinear relationship between time since last fire and biomass across all sites (**Figure 18a**) illustrates that many marsh sites have very low biomass despite being unburned for more than two decades. In contrast, biomass at prairie sites, in general, shows an asymptotic relationship with time since last fire. Despite a definite trend observed in total biomass across the sites burned in different years, sites burned in the same year exhibited significant variation in biomass. Large variability in biomass across both marsh and prairie sites burned in a particular year is attributable to micro-topographic variation in burned areas, and differences in hydrologic conditions and fire behavior. Marsh sites showed higher variability than wet prairies sites. We applied boundary line analysis to estimate the magnitude of variation across the sites burned in the particular year. Prairie sites have at least 380 gm/m^2 biomass after 6-8 years of fires. However, two different types of models fitted to upper and lower 1% of data points suggest that at the prairie sites, variability in biomass across sites changed with time since last fire (**Figure 18b**). Moreover, sites unburned for more than two decades did not exhibit high biomass values, suggesting that either these sites had different physical characteristics (e.g., wetter than the others), or that biomass accumulation takes on a different trajectory in very old stands.

Change in biomass

In concurrence with vegetation cover dynamics discussed earlier, mean above ground plant biomass at the sites sampled in both 2003 and 2006 also decreased over the three year period. At census sites sampled in both years and not burned at least three years prior to the 2006 sampling, the mean (± SD) plant biomass was 529 ± 195 g/m^2 and 419 ± 131 g/m^2 in 2003 and 2006, respectively. Biomass decreased across all vegetation types as well as in all six sub-populations (**Figure 19**). Sites along Transect A, which had not burned in more than a decade, also showed a similar trend. The mean biomass at those sites decreased from 482 ± 108 to 399 ± 81 g/m^2. Since the biomass is estimated from the cover value, the reason for biomass decrease could be the same as it was for the decrease in cover value, i.e., a change in hydrologic regimes and/or a direct or indirect impact of the 2005 hurricane events. The possible role of events associated with the 2005 hurricane season in the change of vegetation cover and biomass is also supported by the fact that the mean above ground biomass, directly measured by harvesting technique at 88 randomly selected sites in each of 2005 and 2006, was also lower in the latter year. At these unburned sites, mean biomass was 573 and 453 g/m^2 in 2005 and 2006, respectively.

Species richness and biomass

The relationship between species richness and biomass is generally represented by a unimodal curve, with maximum species richness occurring at intermediate level of biomass or productivity (Grime 1973; Rosenzweig 1995). Within the marl prairies of southern Everglades as well, species richness demonstrated a hump-shaped relationship with biomass across all the sites (**Figure 20a**). The relationship was maintained within vegetation types, for example *Schoenus* wet prairie that included a relatively wide range of hydroperiods (**Figure 20b**). Within vegetation types in which the hydrologic gradient was narrower, the relationship was positive, negative or non-existent depending on the hydrology and biomass. The relationship was positive within the wettest marsh sites characterized by low aboveground biomass (**Figure 20c**), and negative within less frequently flooded marsh sites of higher biomass (**Figure 20d**). Within the short hydroperiod prairie sites, the relationship between species richness and biomass was not detected, suggesting the influence of other factors such as fire.

3.3 Vegetation and Soils

Soils in the marl prairie landscape within the recent range of CSSS habitat exhibit great variability in their physical and chemical characteristics, owing primarily to variation in micro-topography, hydrology and vegetation. We analyzed soil samples collected at 463 CSSS vegetation sampling sites, for pH, total carbon (TC), inorganic carbon (IC), total nitrogen (TN) and total phosphorus (TP). Percent of organic carbon (OC) was obtained by subtracting IC from TC. At the CSSS census sites, soil pH ranged between 6.7 and 8.1, and did not differ significantly among vegetation types ($F_{8,347} = 1.4$, $p = 0.213$). Mean total carbon was 15.7 ± 3.0%. On average, organic carbon constituted half (51.5%) of the total carbon, however its proportion in the soil varied greatly among vegetation types and throughout the range of CSSS habitat (**Figure 21**). Soil organic carbon ranged between 1.1 and 29.4%, and in general, marsh sites had significantly higher organic carbon than prairie sites ($F_{1, 354} = 20.5$; $p < 0.001$). Patterns of total nitrogen in the soils paralleled that of organic carbon ($r = 0.94$), and its amount varied from 0.32 to 3.09%.

Soil organic carbon and total nitrogen were higher at the sites in Sub-population A than in other sub-populations (**Figure 22**). The high organic carbon at the sites in the Sub-population A is in concurrence with the prevailing marsh vegetation at those sites. The absence of fire in the area for more than one and half decades also might have contributed to the accumulation of organic carbon. Not all existing marsh sites within CSSS habitat have high organic carbon. For instance, sites with marsh vegetation on Transect D have lower organic carbon than marsh sites on Transect A (**Figure 23a**), and organic carbon on three transects (A, D, and F) together exhibited no significant relationship ($R^2 = 0.017$; $p = 0.17$) with mean hydroperiod (average of 5 years), which is generally high at the marsh sites. In contrast, soil organic carbon at those sites is significantly related to time since last fire and fire frequency (**Figure 23b**). Even on Transect A, unburned sites (OC = 14.1%) had significantly higher ($F_{1,45} = 23.2$, $p < 0.001$) soil organic carbon than the sites burned at least once in 25 years (OC = 9.1%).

Soil total phosphorus (TP) differed significantly ($F_{8,448} = 3.60$, $p<0.001$) among vegetation types (**Figure 24a**), though wet prairies and marshes did not differ in soil phosphorus. Total phosphorus in soil was not significantly related to vegetation inferred hydroperiod. In contrast, phosphorus content in soil co-varied with organic carbon, showing a significant and positive relationship ($R^2 = 0.587$, $p<0.01$) (**Figure 24b**). Within the CSSS habitat, phosphorus content in soil took on an interesting spatial pattern. Sites in sub-population A had much higher soil phosphorus than the sites in all other sub-populations, and soils at the sites in sub-population D had the lowest mean phosphorus content (**Figure 25**).

It should be kept in mind that P concentration is expressed here on a mass basis. If one wanted to know the concentration of P on a volumetric basis, or wanted to quantify the amount of P stored in a soil of given depth, some measure of bulk density would also be needed. In our study, field bulk density was not measured. However, because the density of organic materials is much lower than that of the mineral components of the soil, bulk density almost certainly decreases with the organic carbon content of a soil. In other words, **Figure 24b** illustrates a strong relationship between OC and P contents of soils, but the shape or even direction of the function would likely look very different were concentrations expressed per-unit-volume. In the next year, we plan to develop calibrations that will allow us to express the P concentrations of Everglades marl prairie soils on either a mass or volume basis. Moreover, since CSSS favored wet prairie vegetation is dominant in the area with low organic carbon, probably due to relatively shorter hydroperiod and/or frequent fire, the restoration of CSSS habitat in the marsh vegetation dominated areas which show great variability in organic carbon, would need the mixed and cautionary approach.

3.4 Vegetation change, hydrology and Cape Sable seaside sparrow

Vegetation change at the CSSS census sites over the three-year period 2003-2006, was marked by an increase in wetness of some sites, and a decrease in crown cover at the unburned sites. At burned sites, plant cover increased or decreased, depending on the time since last burn and the hydrologic conditions in the post-burn period. Another notable difference in vegetation structure between 2003 and 2006 was the relatively low mean total species cover in the latter year in almost all vegetation types and sub-populations. The difference in mean plant cover was significant among sites which were not burned for at least three years before 2006 sampling. The differences in plant cover between the two sampling events could be attributed to a change in hydrological regime, to disturbance such as hurricane related events in 2005, or to observer error. In general, vegetation-inferred hydroperiod, the hydroperiod for a site predicted from vegetation composition using Weighted Averaging Partial Least Square (WAPLS) regression model (See Ross et al. 2006 for details), increased during the period, suggesting that at least some sites became wetter in 2006 than in 2003. Further evidence for hydrologic change was the increase in mean cover of *Eleocharis cellulosa*, an indicator of wet conditions in marl prairies (**Figure 4**). In particular, the wet prairies along the eastern edge of sub-population E, the central part of sub-population A, and the southern part of sub-population B had vegetation indicative of slightly wetter conditions in 2006 than three years earlier (**Figure 26**). An analysis of real time hydrologic data for some stage recorders within CSSS habitat, for example NP205, revealed that mean hydroperiod averaged over three years was higher prior to 2006 than to the 2003 survey (**Figure 27**). Though the wettest marsh has lower plant cover than other marsh and prairie sites, it is not clear at present that the relatively small increase in mean hydroperiod could be responsible for the significant reduction in mean plant cover observed over the three-year period, particularly when the decrease in cover was observed in all vegetation types throughout the CSSS habitat. Currently, understanding of how rapidly vegetation changes in response to hydrologic alterations in marl prairies is limited. In Taylor Slough, Armentano et al. (2006) demonstrated that an observable change in prairie and marsh vegetation may occur within 3-4 years in response to hydrology, but their conclusion was based on a long-term study within slough where water level increased on average by 40 cm in contrast to 2-3 cm in current study. Moreover, they cautioned about generalizing too far from their results, and pointed out that vegetation change was also affected by several other factors, including fire. Results of one-year post fire vegetation survey at the sites burned in 2005 revealed that some combinations of natural and/or anthropogenic disturbances, especially fire and hurricane-caused post-fire flooding, are capable of delaying vegetation recovery and alter vegetation composition. However, to fully understand the effect of such an interaction, these sites need to be studied closely in the next few years.

When vegetation cover at the permanent sites is monitored repeatedly, there is always a chance for observer error to become incorporated in the visual estimation of plant cover. However, in the 2003-2006 surveys, the influence of observers' visual estimates on the species cover was most unlikely to be substantial, as differences of the almost the same magnitude were detected for total plant cover estimated by two independent methods carried out by different teams of observers. These were total crown cover estimates and cumulative species cover estimates in 30 and 10 0.25 m^2 quadrats per site, respectively. While there were few changes in the team members who took the structural measurements, the same three people conducted species cover estimates in more than 90% of compositional plots in both years. However, annual variation in species cover estimates by the same or different observers is not uncommon (Kennedy and Addison 1987; Helm and Mead 2004), and might be confounded with other errors in this study too.

We examined sparrow occurrence at the census sites in relation to vegetation structure present in 2003 and 2006. Out of 149 un-burned sites, sparrow populations were surveyed in both 2003 and 2006 at only 97 sites, and birds were sighted at only 36% of the sites in either 2003 or 2006. Three sites had the same number of birds in both years, whereas at 32 sites, sparrow counts in 2006 were different from those in 2003. Thirteen sites where birds were sighted in 2003 had no birds in 2006. At 12 sites, birds were recorded in both 2003 and 2006, but the number of birds sighted differed between years. The differences in bird count in 2003 and 2006 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 2006 were wetter than in 2003 (**Figure 28**), particularly when hydroperiod was close to or above 270 days. Moreover, these analyses suggest that sites can become "too dry", from the perspective of vegetation, with fewer birds in 2006 than 2003 (**Figure 29**). 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 2001, 2003, or 2005, and were surveyed for vegetation in both 2003 and 2006. Forty-seven percent of sites that were burned in 2001 had sparrows at least one of the three years prior to burn, whereas only 21% of sites burned in 2003 were occupied **(Figure 30)**. At those sites, however, bird returned at more than 67% of sites within 4-5 years of fire. The same may not be true at the sites which burned in 2005, as the immediate flooding of the sites after fire has killed most of the vegetation (see section 3.1 and Figure 12), and plant cover may not return to a level that is favorable for the sparrows to colonize again soon.

4. Conclusions

Marl prairie vegetation in the southern Everglades is primarily shaped by the interplay of hydrology, fire, nutrients and periodic natural disturbances, including hurricanes. Re-survey in 2006of vegetation composition and structure at sites sampled three years earlier has revealed that even at sites that were not burned for three years prior to re-sampling, mean plant cover was less in 2006 than in 2003. Though it is unclear at present what exactly caused the decrease in mean plant cover as well as the cover of several major species, we hypothesized that reduced plant cover could be attributed to a change in hydrologic regimes, hurricane-related events, or to observer's error. The three-year average of mean daily water level at several stage recorders was higher prior to 2006 than 2003, suggesting that at least some sites might have become wetter in recent years. Wetter conditions were also evidenced by an increase in mean cover of *Eleocharis cellulosa*. Though the *E. cellulosa* and *Rhynchospora tracyi* dominated marsh sites in marl prairies have the lowest crown cover, it is uncertain that such relatively small increase in mean water level could have caused significant reduction in mean plant cover within three years, particularly when the decrease in cover was observed in all vegetation types at both nutrient-poor and nutrient-rich sites throughout the CSSS habitat. Currently, there is limited understanding regarding how rapidly vegetation changes in response to hydrologic alterations in marl prairies. Moreover, a combination of natural and/or anthropogenic disturbances, e.g., the fire and hurricane-related events in 2005, can also affect vegetation structure and composition. For instance, very low plant cover and a change in species composition at the sites flooded after fire in 2005 suggests that post-fire hydrology can significantly affect the rate and course of vegetation recovery process. In summary, re-sampling in 2006 of sites surveyed in 2003 and burned sites surveyed in 2004 and 2005 has partially answered the questions regarding vegetation change in response to hydrology and fire, but a full understanding of the causes and rate of change in vegetation structure and composition will require a long-term database covering a broader time series and wider range of environmental conditions.

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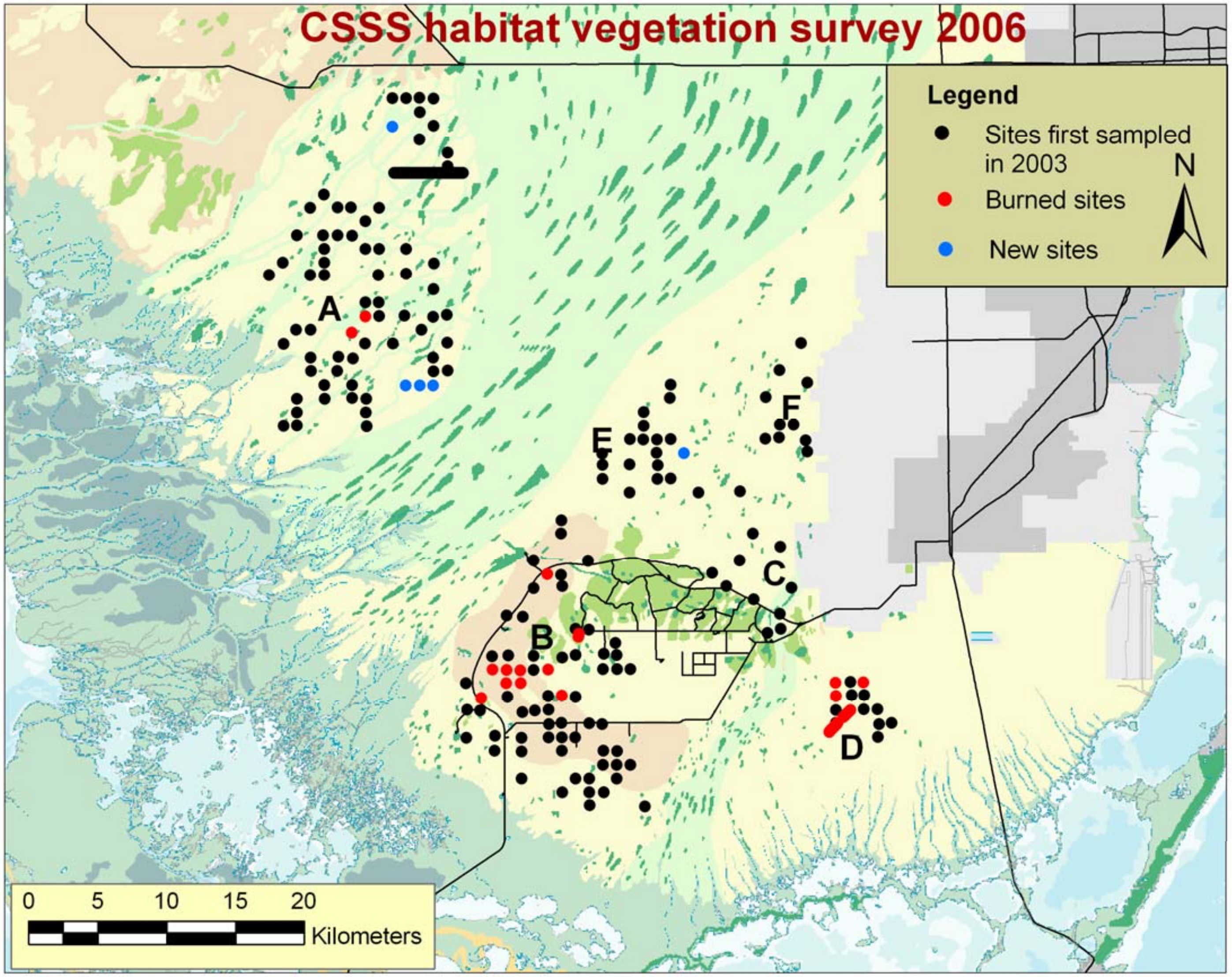


Figure 1: Location of sites within the Cape Sable seaside sparrow habitat sampled for vegetation in 2006.

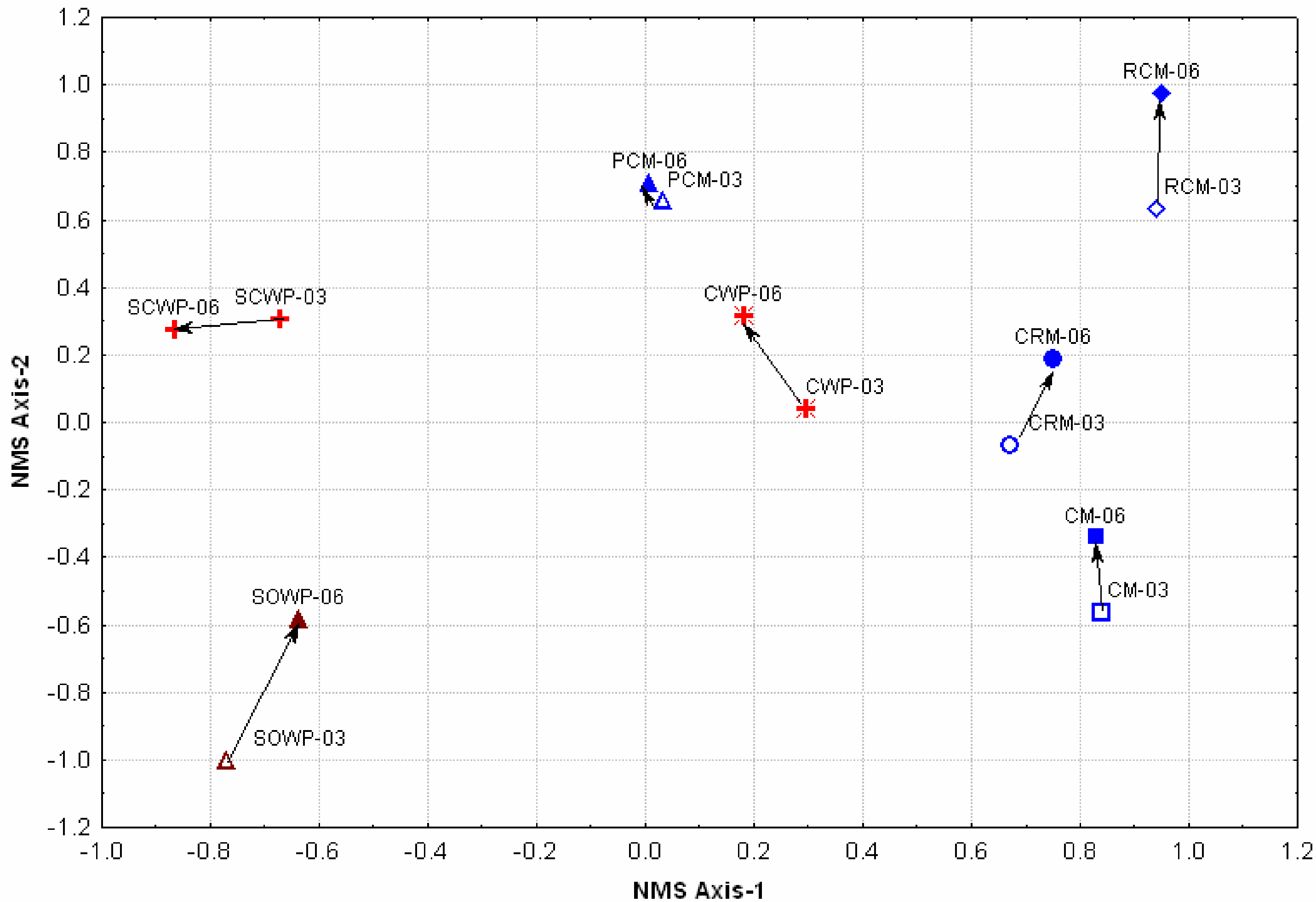


Figure 2: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on relative cover at 51 plots on Transect-A. Points in ordination space represent centroids of the sites, grouped into vegetation types by years. Arrows show the shift in site position in ordination space due to dissimilarity in vegetation structure and composition between 2003 and 2006. CM = *Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; RCM=*Rhynchospora-Cladium* marsh; PCM = *Paspalum-Cladium* marsh; CWP = *Cladium* wet prairie; SCWP = *Schizachyrium* wet prairie; SOWP = *Schoenus* wet prairie; MWP = *Muhlenbergia* wet prairie

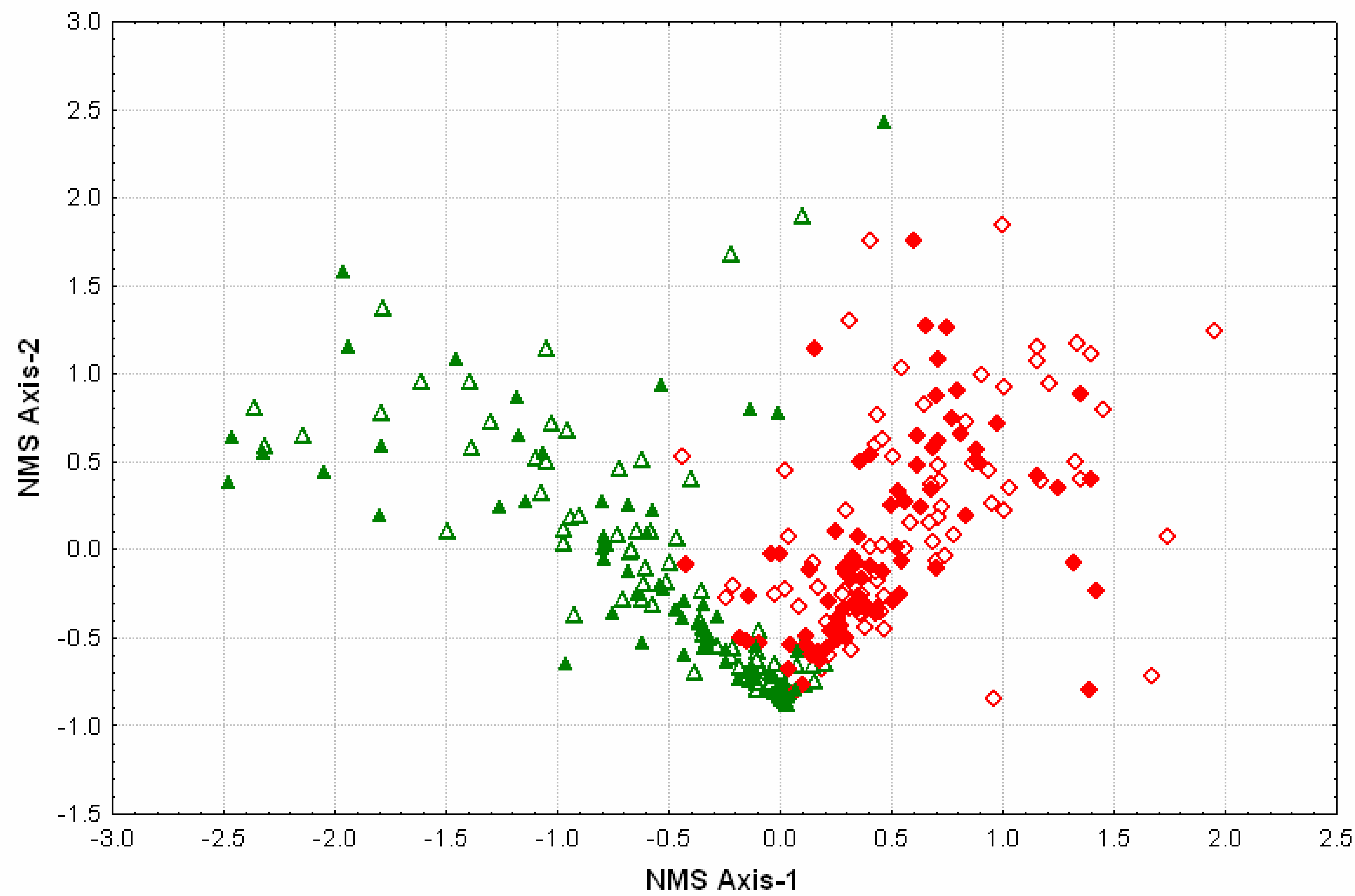


Figure 3: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on relative cover of species at 149 unburned CSSS census sites sampled in both 2003 and 2006. The figure illustrates distinct grouping between marsh (green) and wet prairie (red) are easily distinguishable regardless of years sampled, but samples from 2003 (open) and 2006 (closed) appear to be randomly dispersed within the swarm of marsh and prairie points.

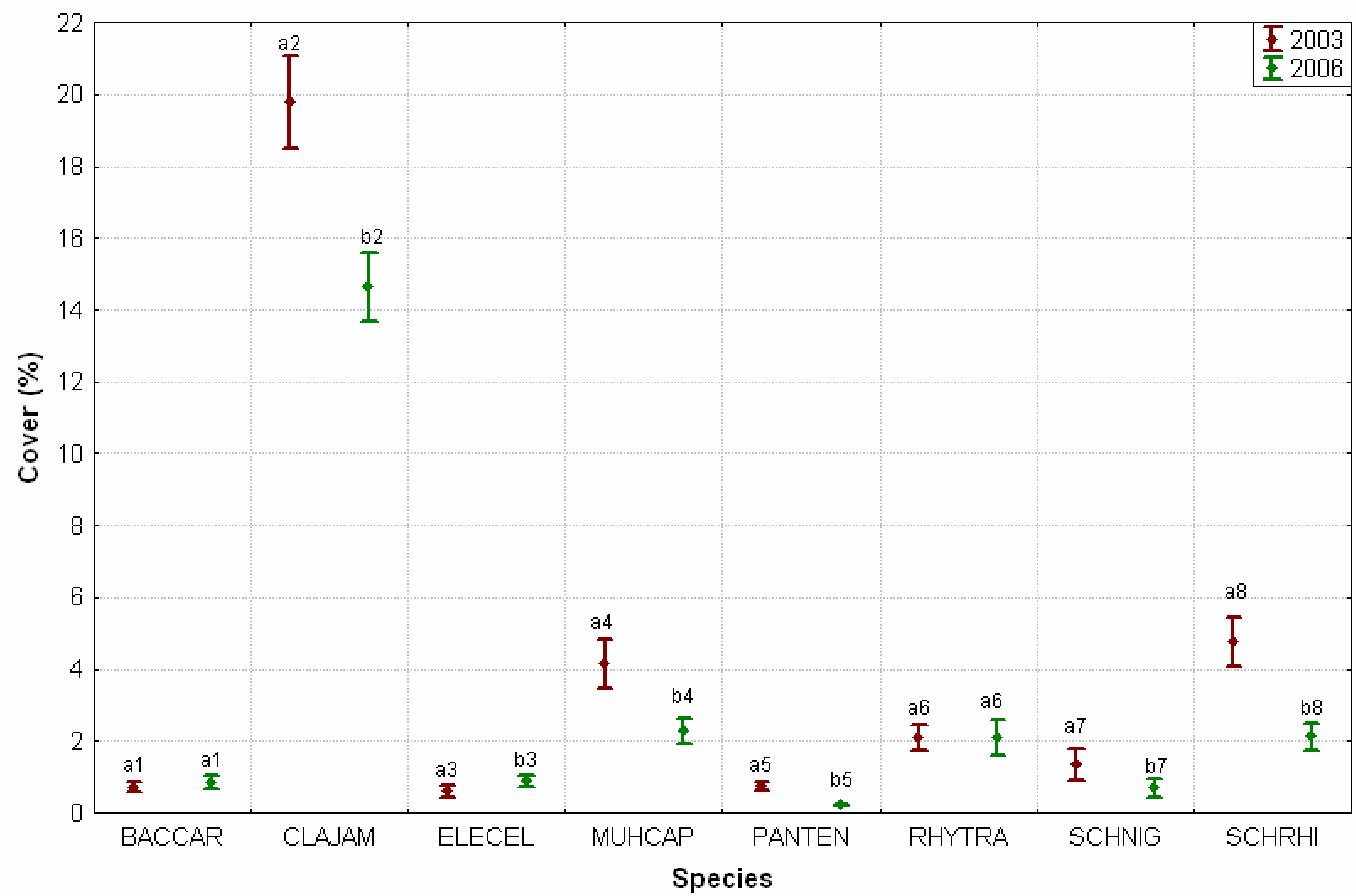


Figure 4: Mean (± 1 S.E.) cover of major species (mean cover >0.5%) in 149 CSSS census sites which were not burned for 3 years prior to vegetation sampling. Different roman letters indicate significant difference (pair wise t-test; $p < 0.05$) in cover of the particular species between two sampling years, 2003 and 2006. The number associated with the letter indicates particular species: 1) *Bacopa caroliniana*, 2) *Cladium jamaicense*, 3) *Eleocharis cellulosa*, 4) *Muhlenbergia capillaris* var. *filipes*, 5) *Panicum tenerum*, 6) *Rhynchospora trayci*, 7) *Schoenus nigricans*, and 8) *Schizachyrium rhizomatum*.

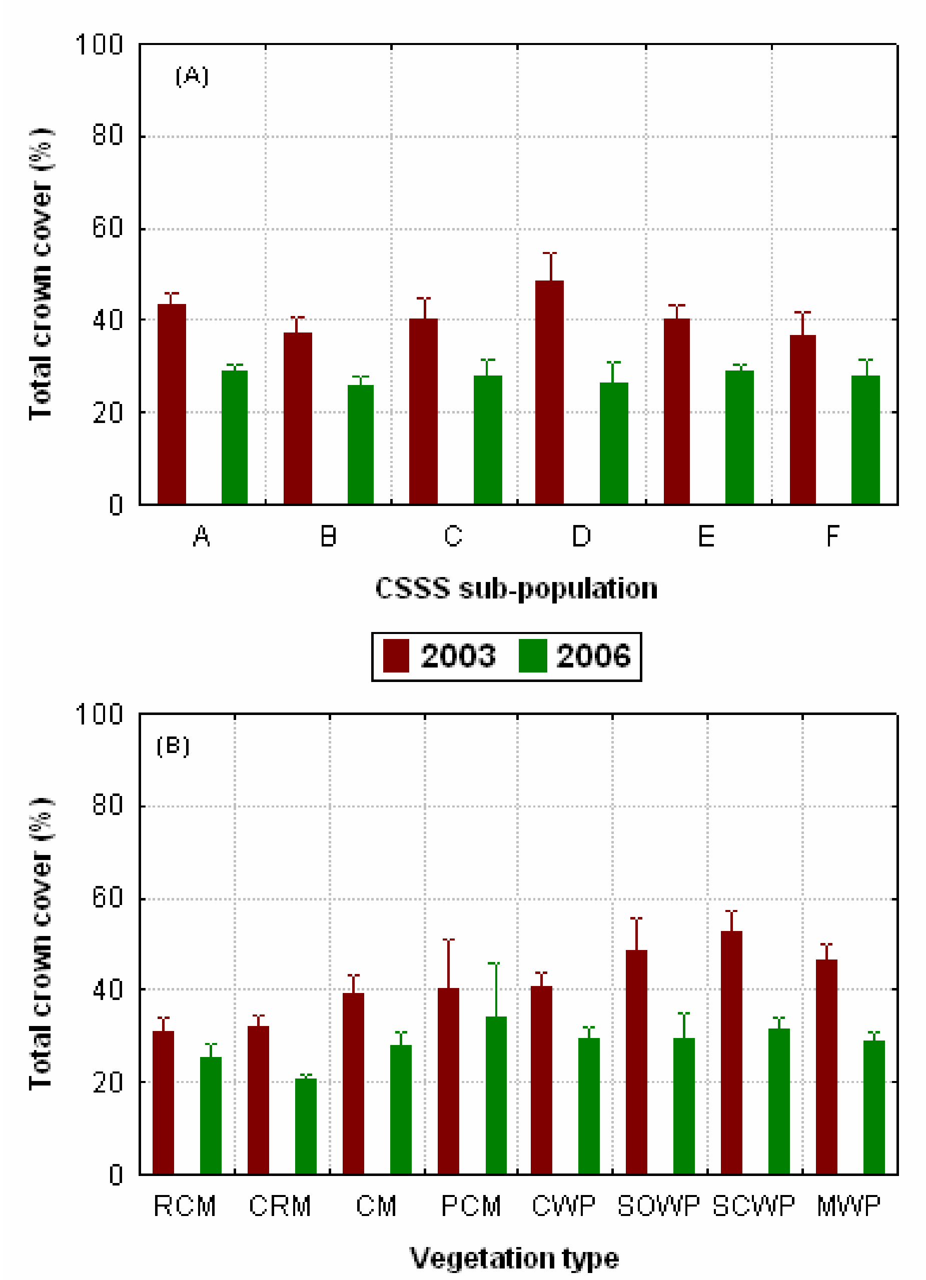


Figure 5: Mean (± 1 S.E.) crown cover at the unburned CSSS census sites sampled in both 2003 and 2006. Total crown cover is averaged over (A) CSSS subpopulations, and (B) Vegetation types. RCM = *Rhynchospora-Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; CM = *Cladium* marsh; PCM = *Paspalum-Cladium* marsh; CWP = *Cladium* wet prairie; SOWP = *Schoenus* wet prairie; SCWP = *Schizachyrium* wet prairie; MWP = *Muhlenbergia* wet prairie.

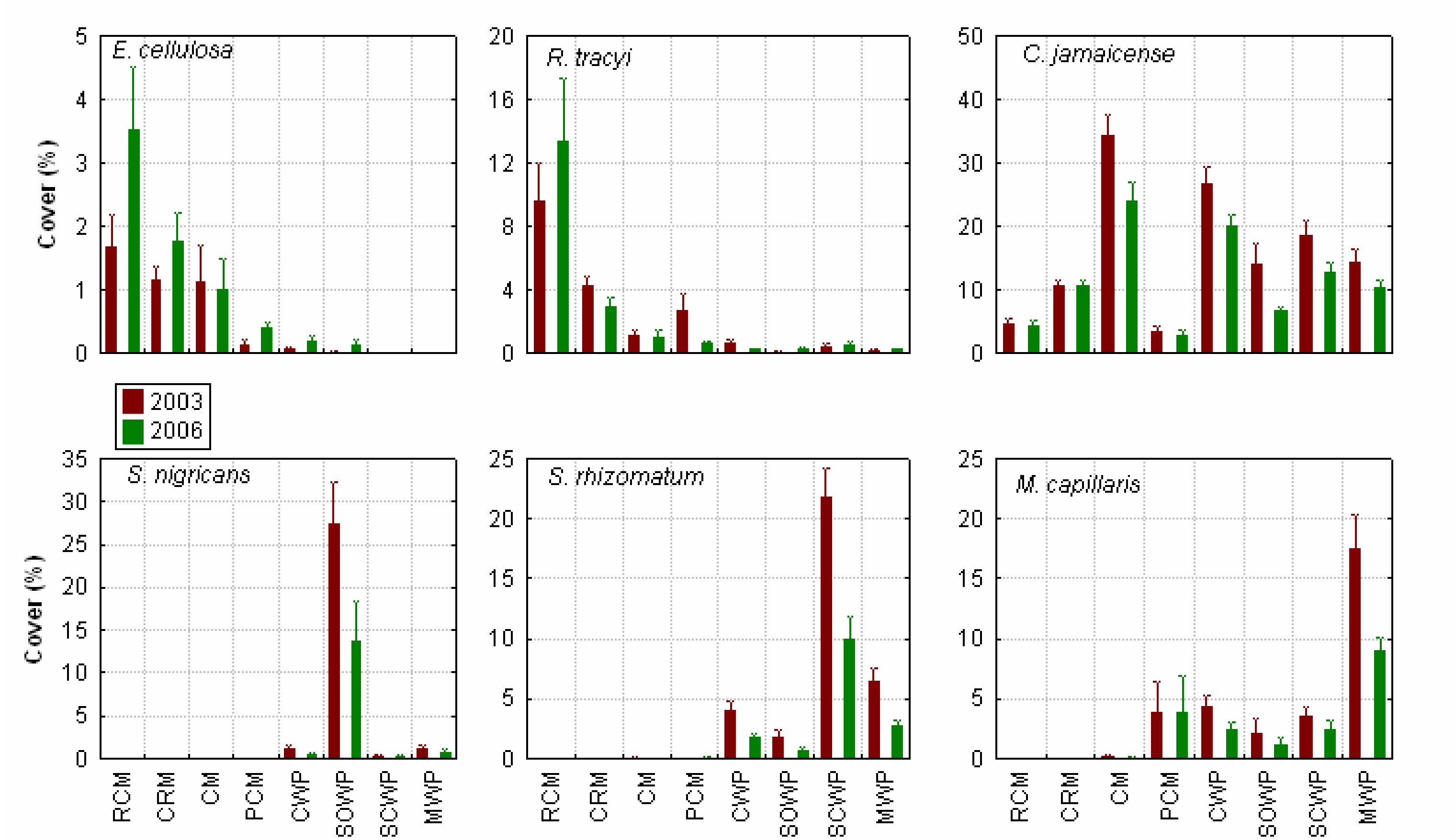


Figure 6: Mean (± 1 S.E.) cover of six major species at the unburned CSSS census sites sampled in both 2003 and 2006. Cover of species is averaged over vegetation types in which the particular species in present either in 2003 or 2006. RCM = *Rhynchospora-Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; CM = *Cladium* marsh; PCM = *Paspalum-Cladium* marsh; CWP = *Cladium* wet prairie; SOWP = *Schoenus* wet prairie; SCWP = *Schizachyrium* wet prairie; MWP = *Muhlenbergia* wet prairie.

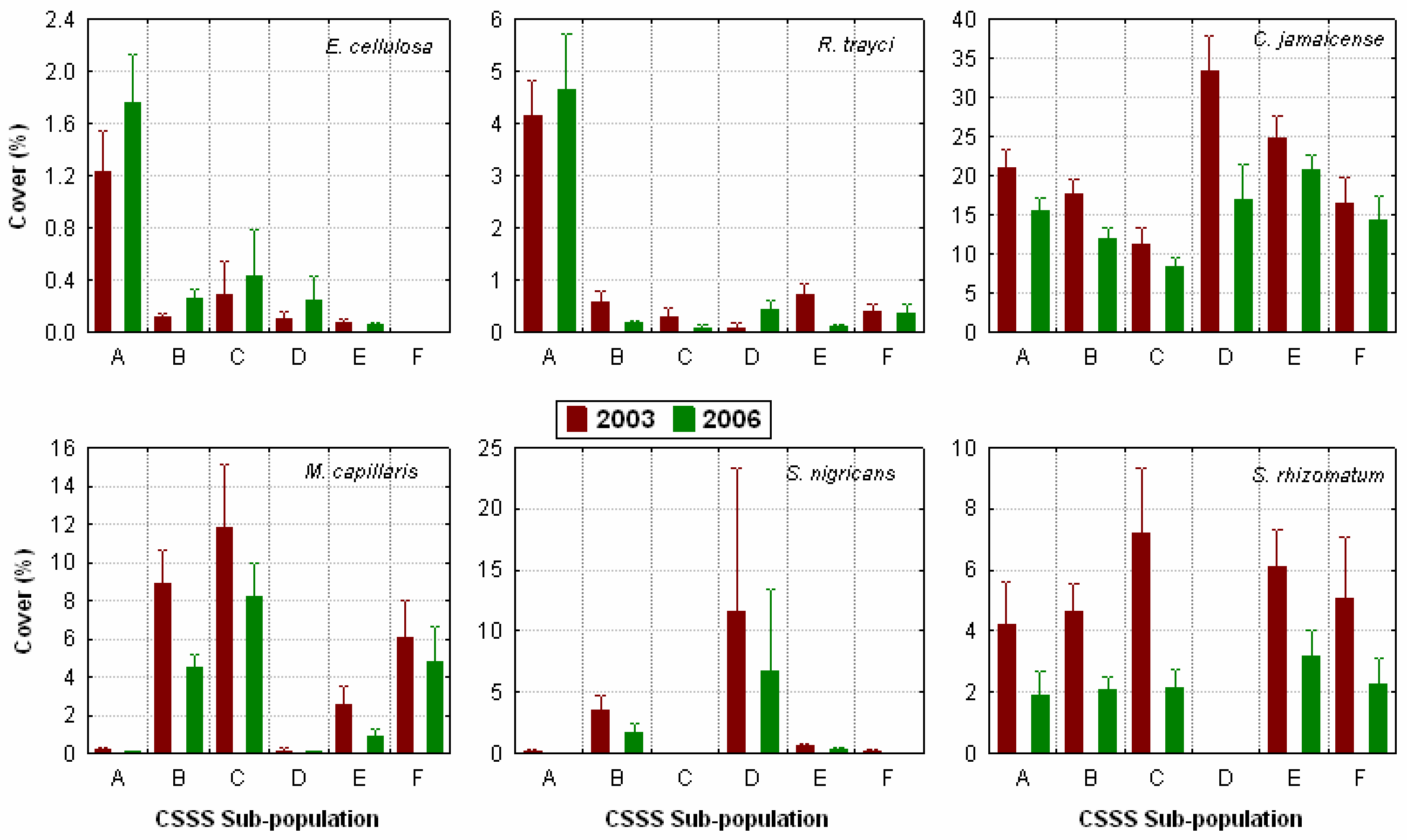


Figure 7: Mean (± 1 S.E.) cover of six major species at the unburned CSSS census sites sampled in both 2003 and 2006. Cover of species is averaged over CSSS sub-populations in which the particular species in present either in 2003 or 2006.

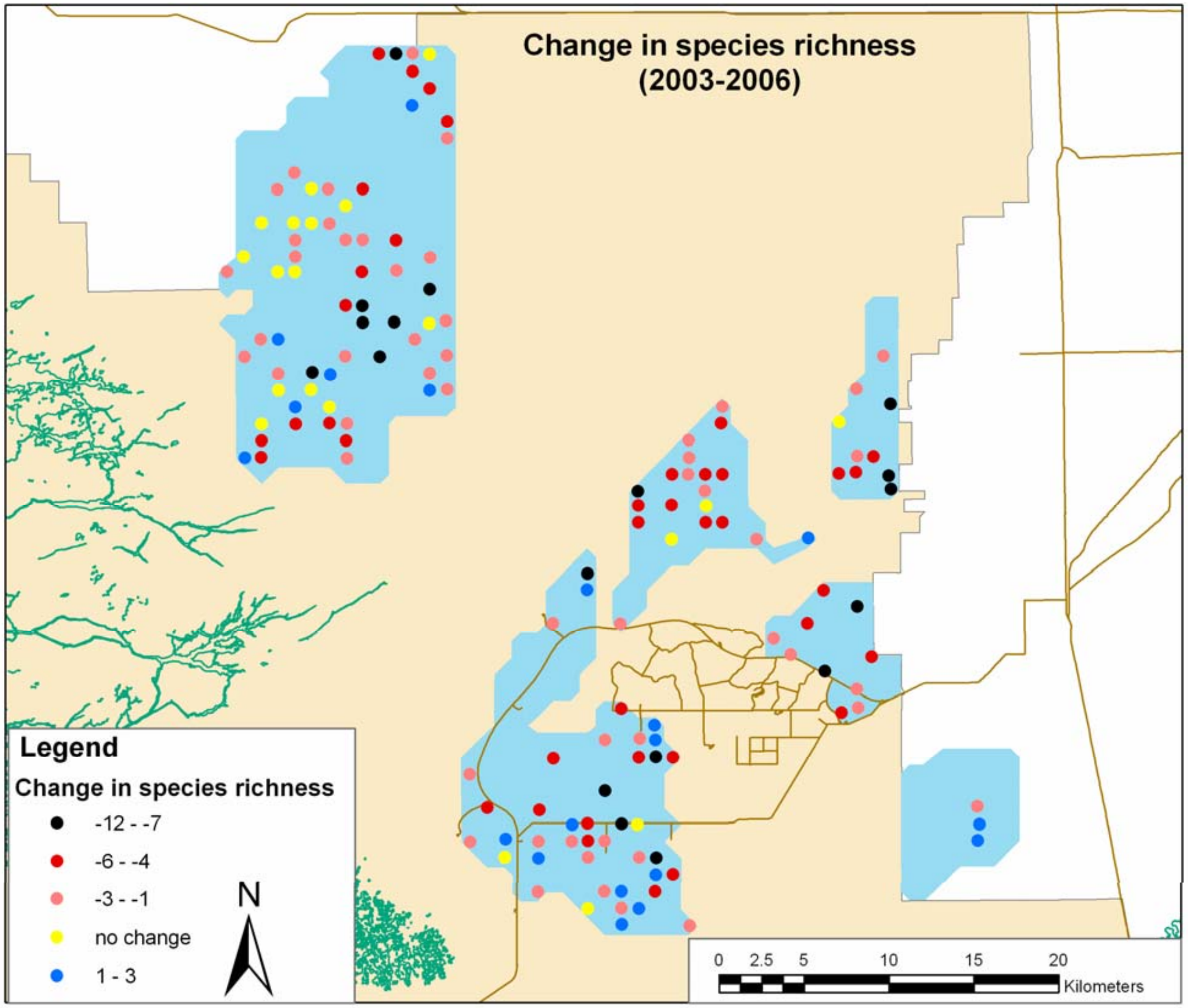


Figure 8: Change in species richness (number of species per site) between 2003 and 2006 sampling.

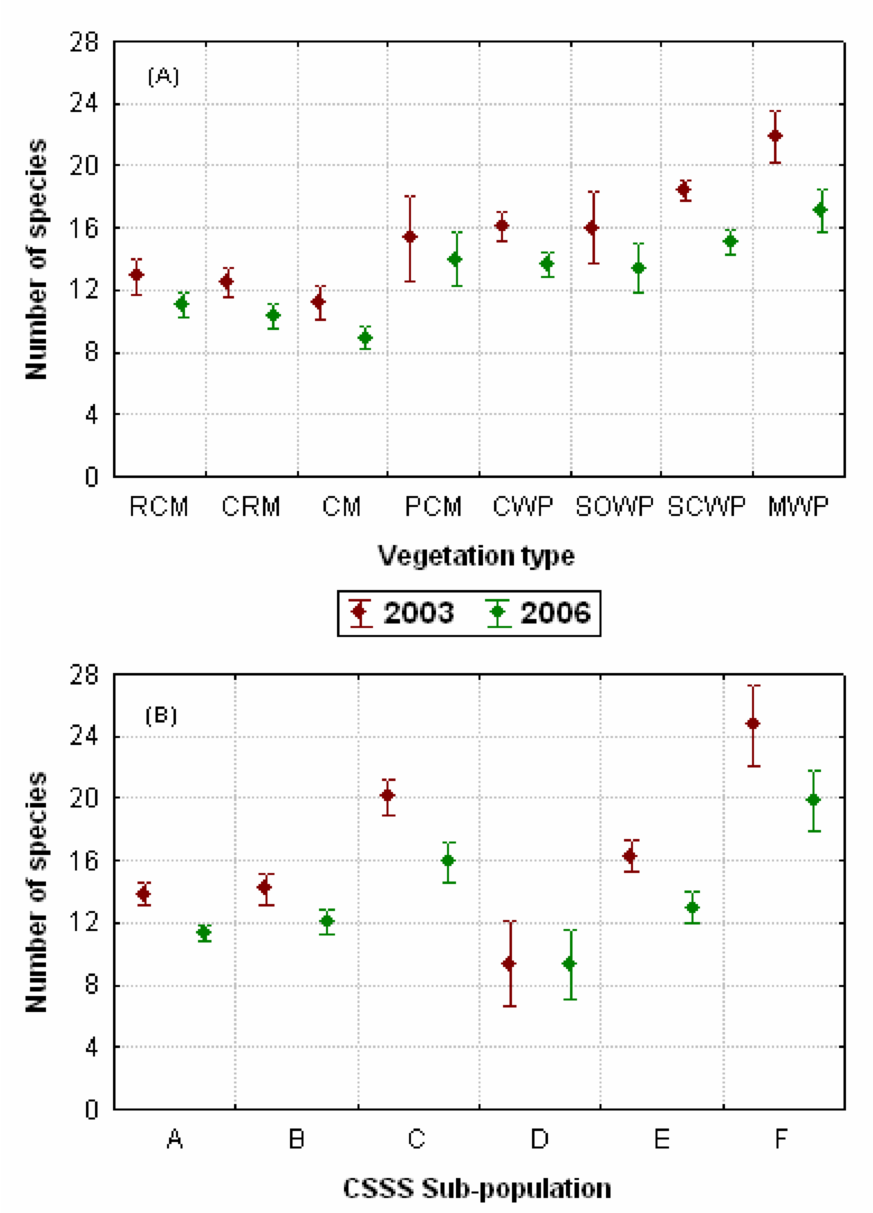


Figure 9: Mean (± 1 S.E.) species richness (number of species per site) in 2003 and 2006 samplings. Number of species is averaged over (A) vegetation types, and (B) CSSS subpopulations. RCM = *Rhynchospora-Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; CM = *Cladium* marsh; PCM = *Paspalum-Cladium* marsh; CWP = *Cladium* wet prairie; SOWP = *Schoenus* wet prairie; SCWP = *Schizachyrium* wet prairie; MWP = *Muhlenbergia* wet prairie.

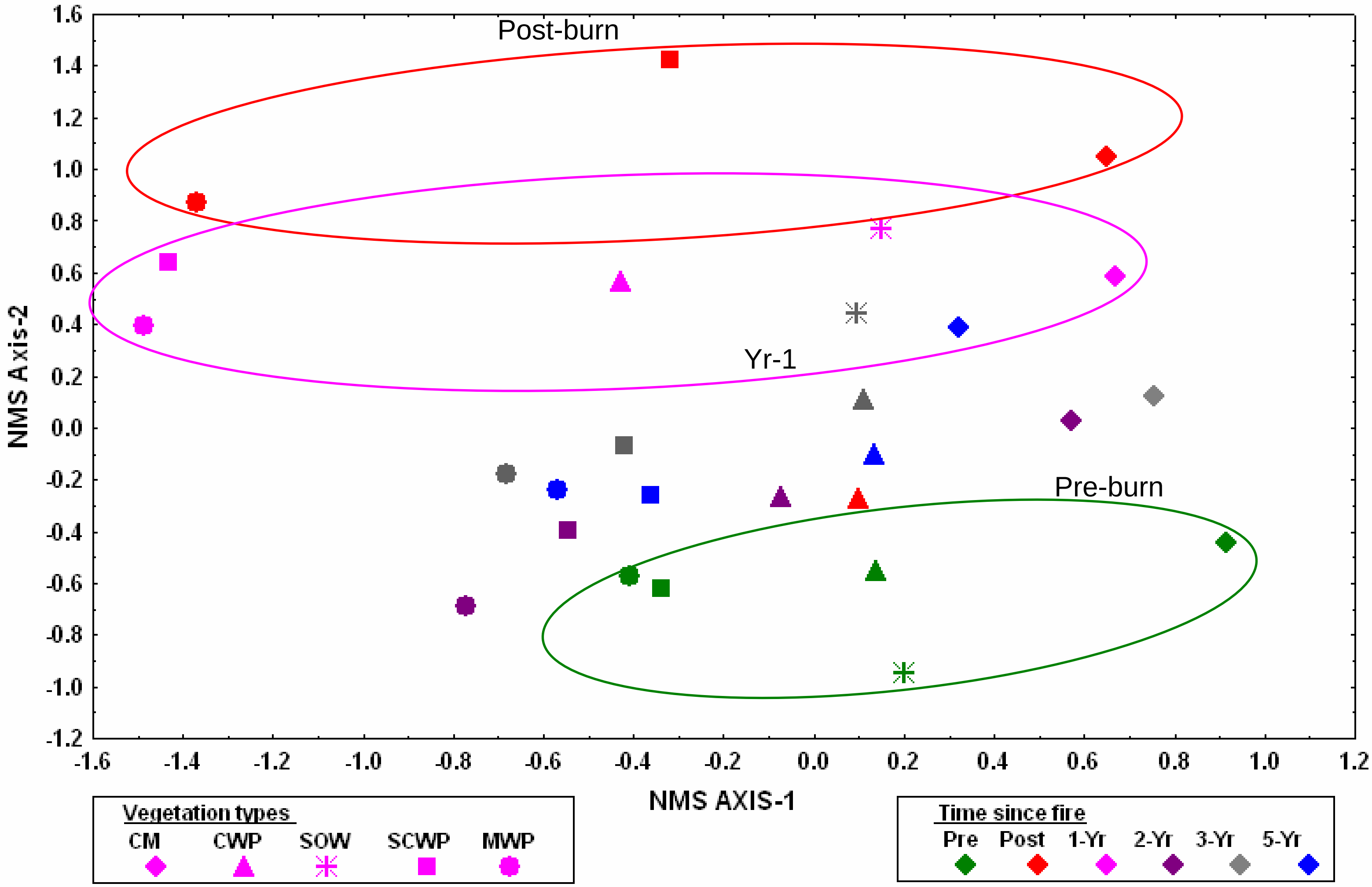


Figure 10: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on total cover at 70 sites burned in 2001, 2003 or 2005 and sampled in 2003, 2004 or 2005 and again in 2006. Points in ordination space represent centroids of sites, grouped by vegetation type and time since last burn. CM = *Cladium* marsh; CWP = *Cladium* wet prairie; SCWP = *Schizachyrium* wet prairie; SOWP = *Schoenus* wet prairie; MWP = *Muhlenbergia* wet prairie

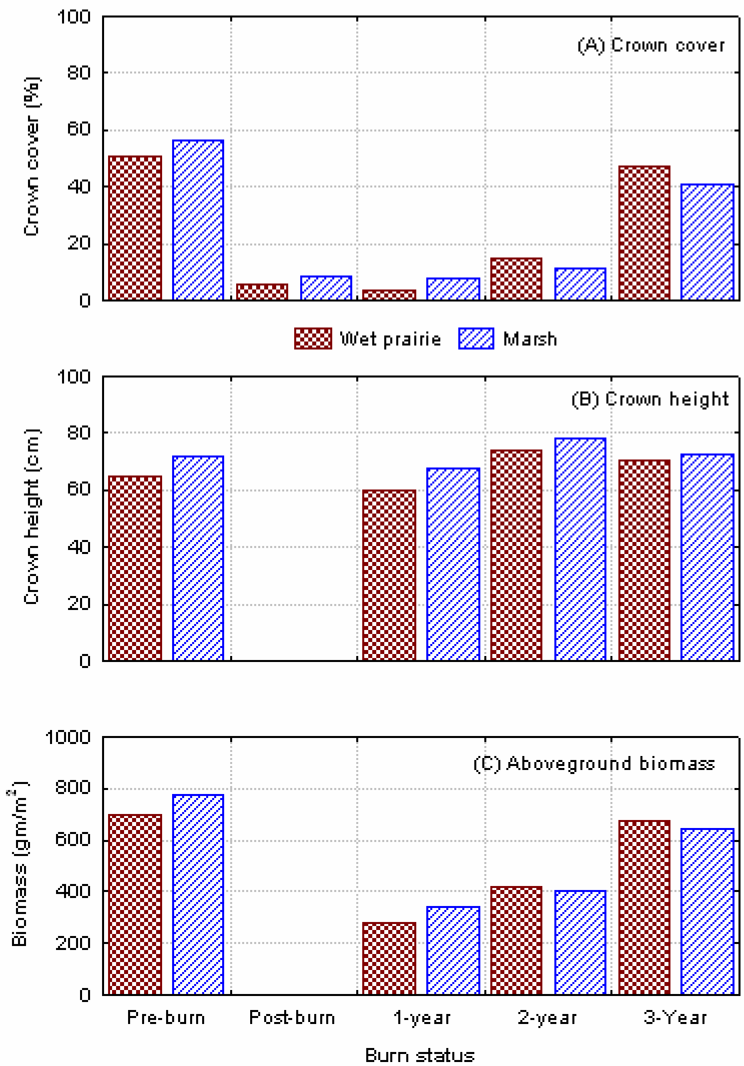


Figure 11: Mean crown cover (A), height (B), and total biomass (C) in one wet prairie and one marsh site burned in 2003, and sampled within one month after fire and annually thereafter.

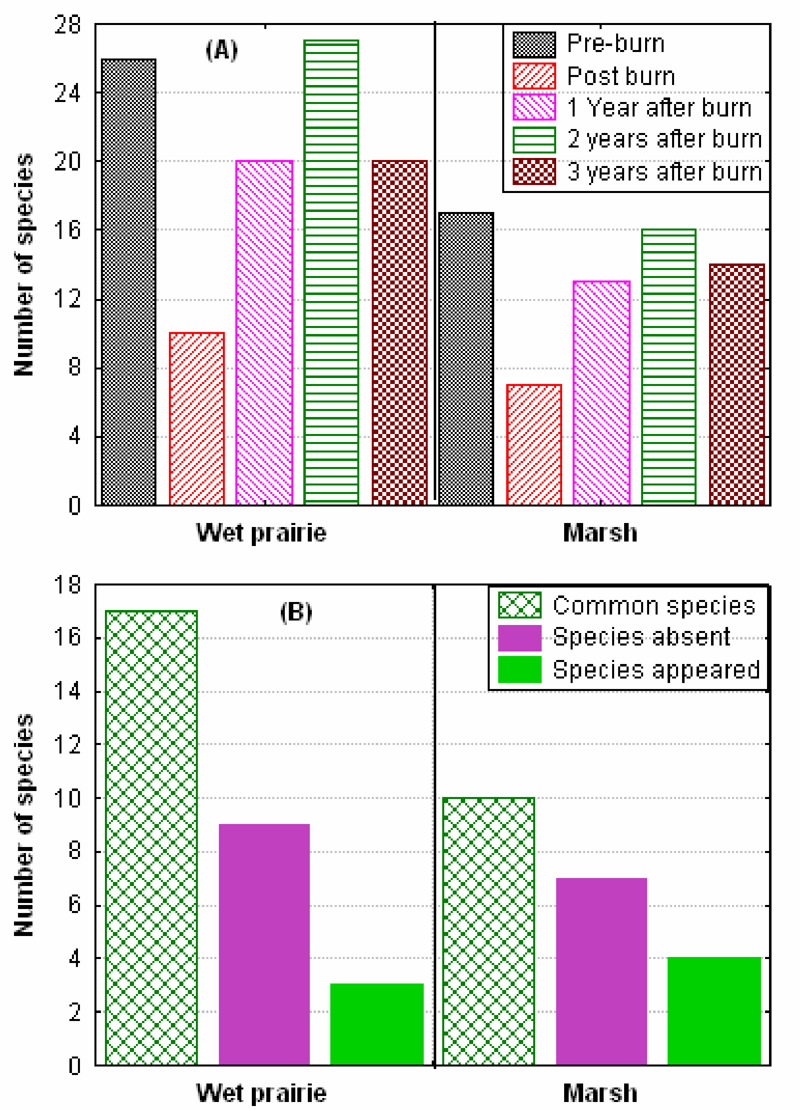


Figure 12: Change in number of species in one wet prairie and one marsh site burned in 2003 and sampled within one month after fire, and annually thereafter. (A) Total number of species (B) Species turnover.

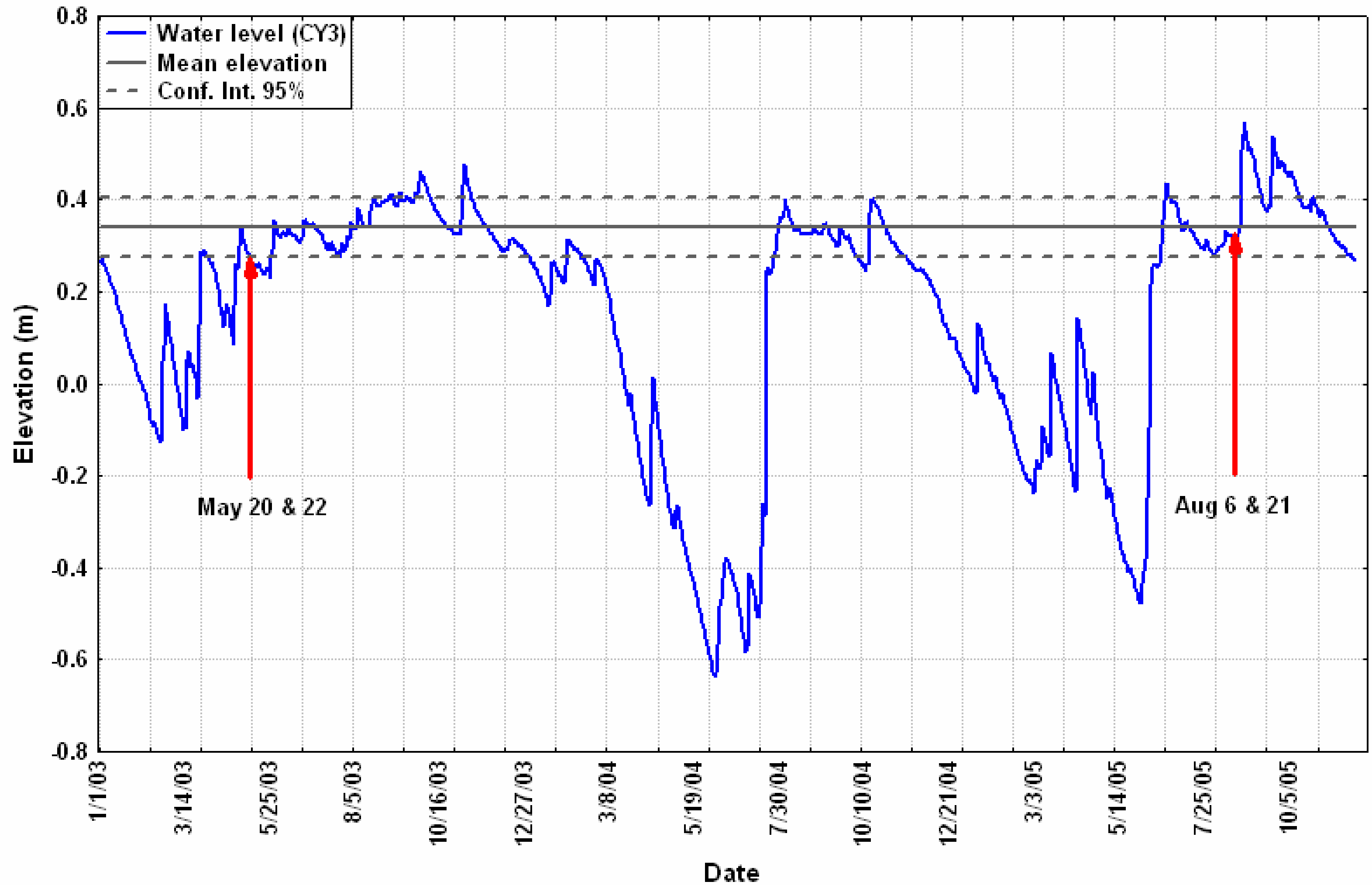


Figure 13: Mean daily water level (m, NAVD 1988) at the stage recorder CYP-3, located in CSSS Sub-population-B and mean ground elevation at the CSSS sites within 1.5 km radius from the stage recorder. Arrows represent the 4 burn dates (2 in 2003 and 2 in 2005). In 2005, hurricane Katrina (on August 25) dumped more than 3" of rain in South Florida within 5 hours.

Figure 14: A CSSS census site, mahog-011 (FIU ID: B-11-03, UTM: 519435, 2805281) 2 weeks and 15 months after fire showing a foot of standing water and very sparse vegetation, respectively.

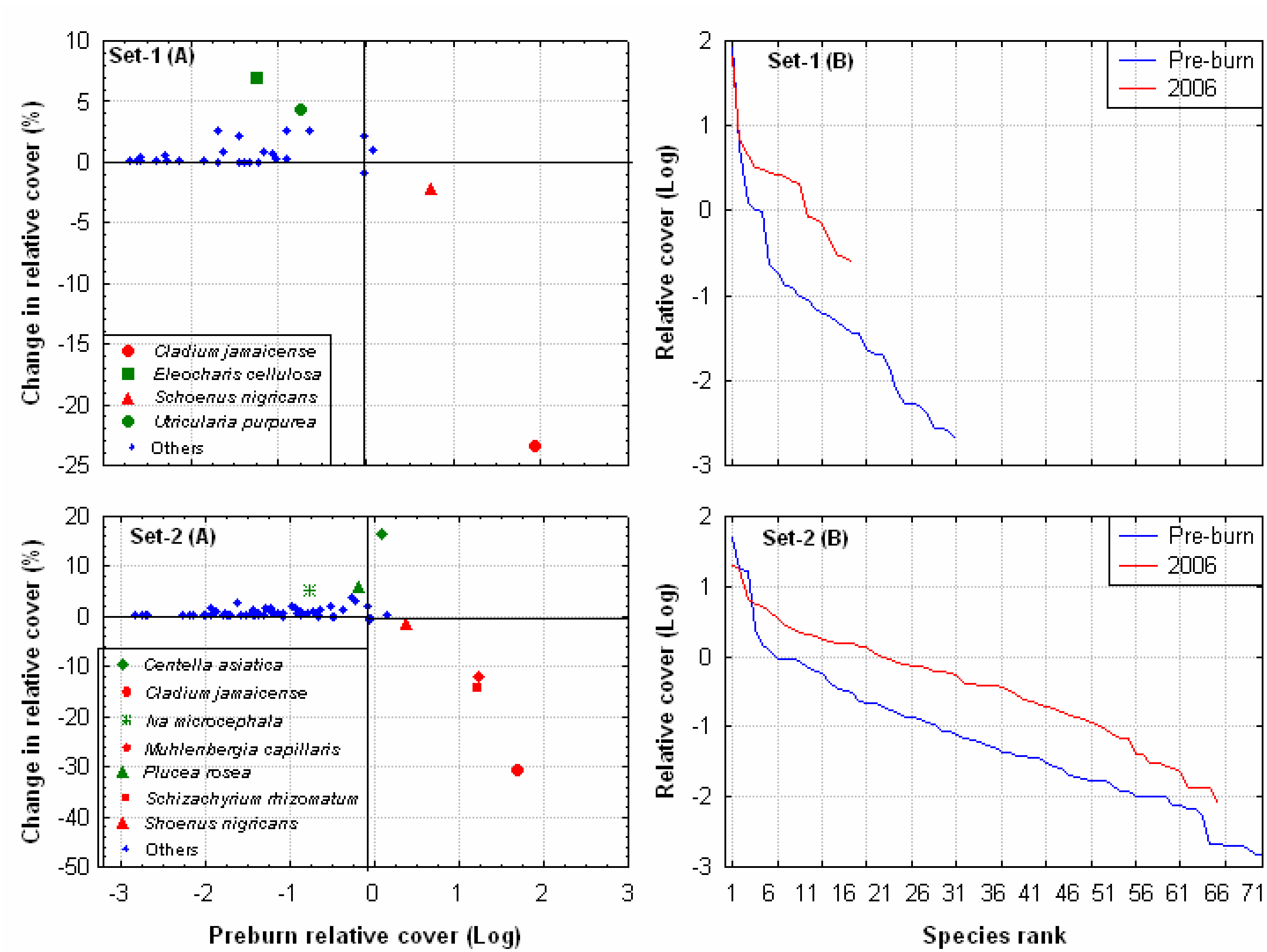


Figure 15: Change in the relative cover of species (A) and species rank abundance (B) at the sites burned in May 2005 (Set-1) and August 2005 (Set-2).

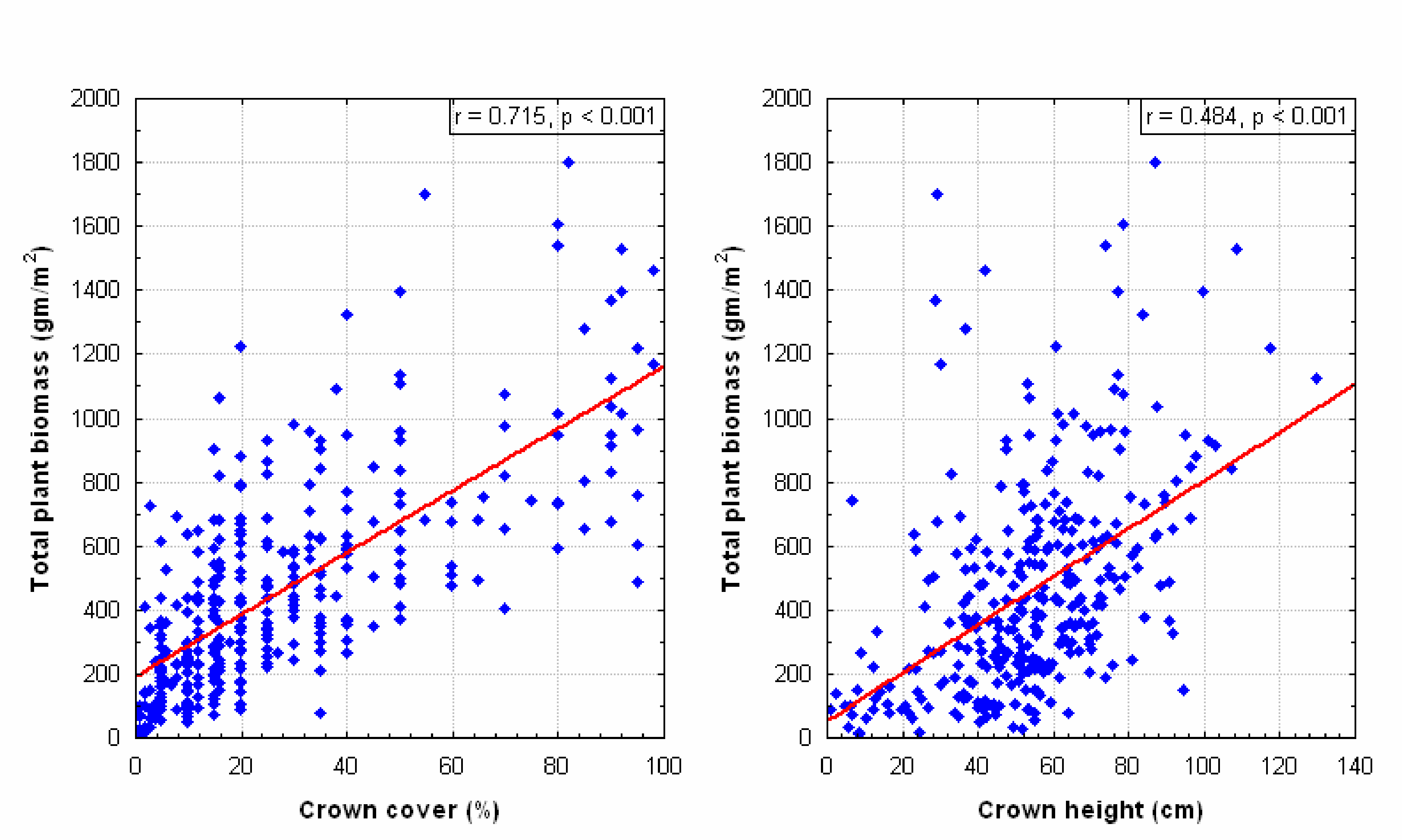


Figure 16: Scatter plots showing aboveground biomass in relation to crown cover and height. Data are based on 166 CSSS census sites sampled in 2005 and 2006.

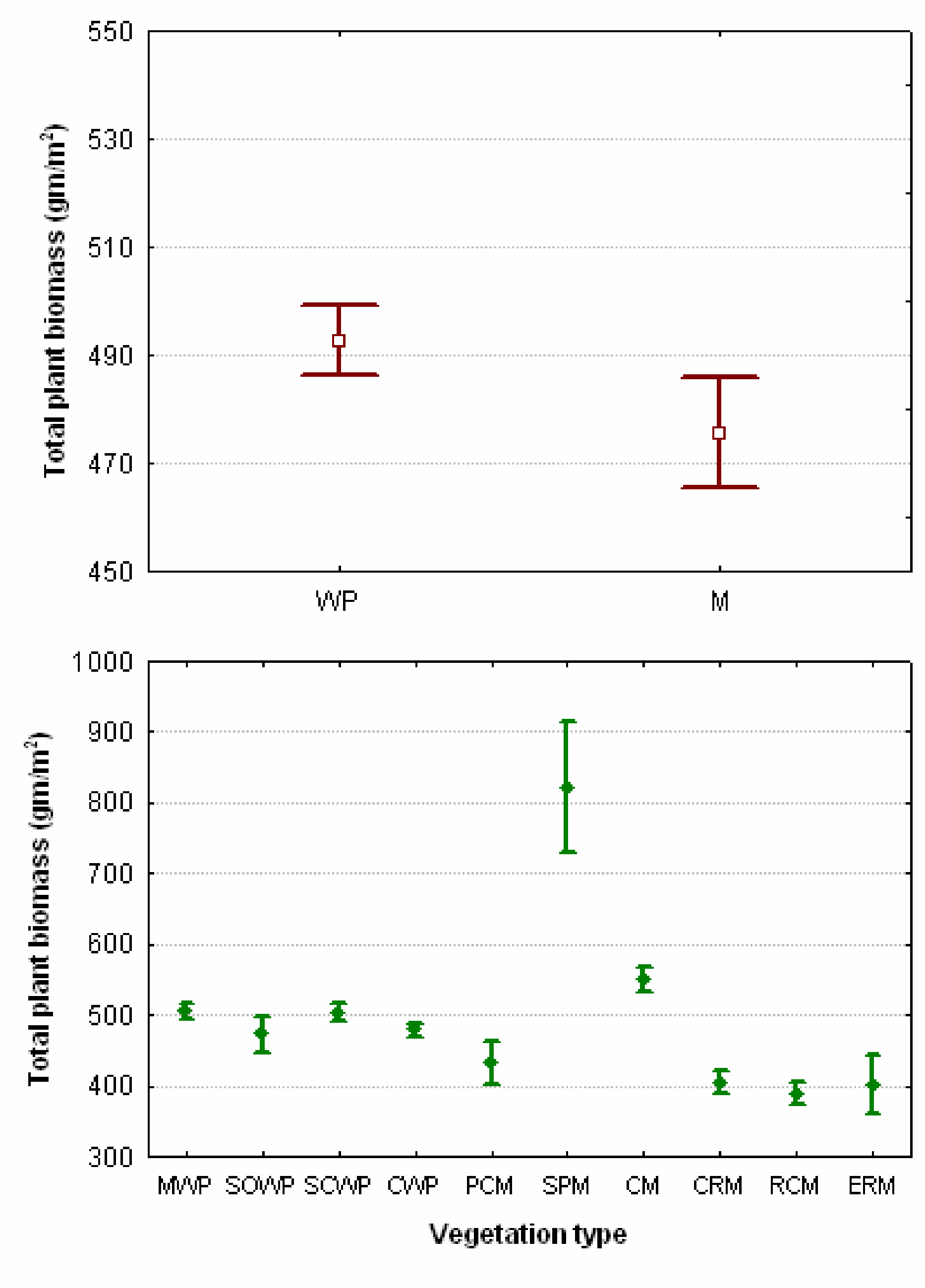


Figure 17: Total plant biomass at the transect and CSSS census sites sampled for vegetation over three years, 2003 to 2005.

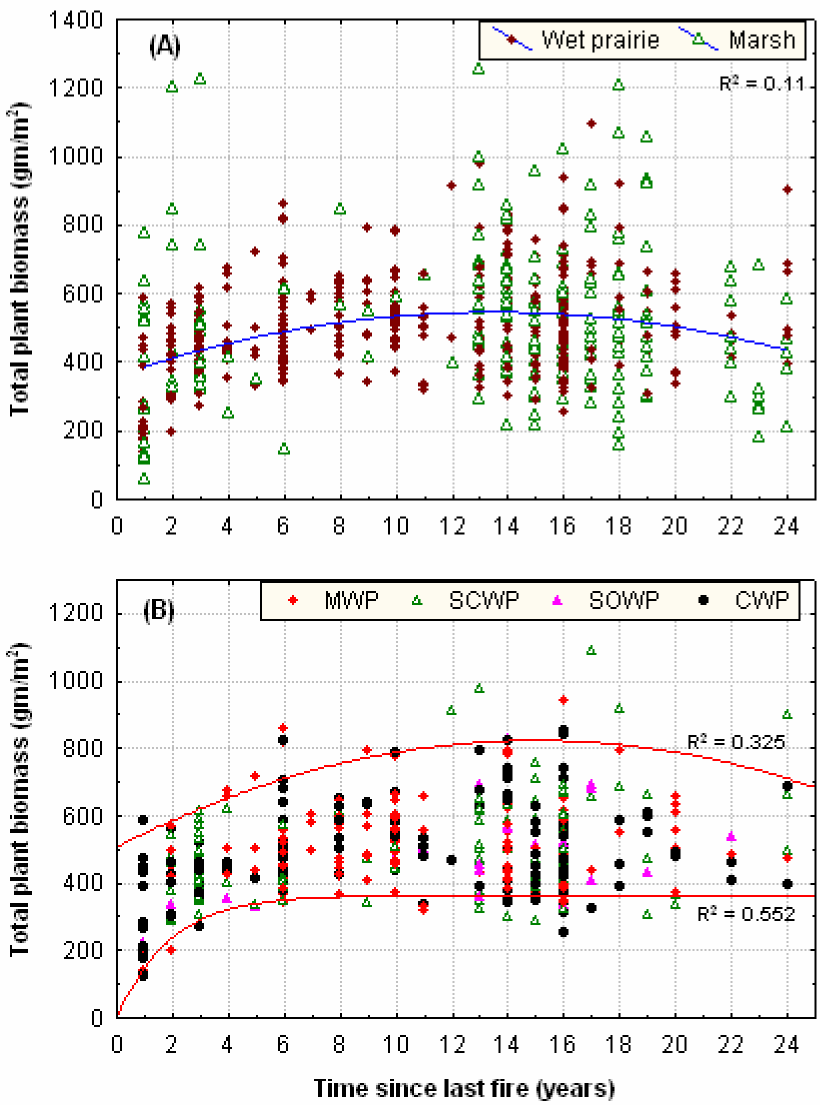


Figure 18: Total plant biomass in the wet prairie and marsh sites at which vegetation was surveyed over three years 2005-2006 within CSSS habitat. Biomass was re-estimated using the regression equation developed from the biomass samples collected at 166 sites in 2005 and 2006. (A) Total biomass in the wet prairie and marsh sites in relation to time since last fire. (B) Total biomass in the wet prairie sites showing the upper and lower boundary lines fitted to 99 and 1 percentile data points.

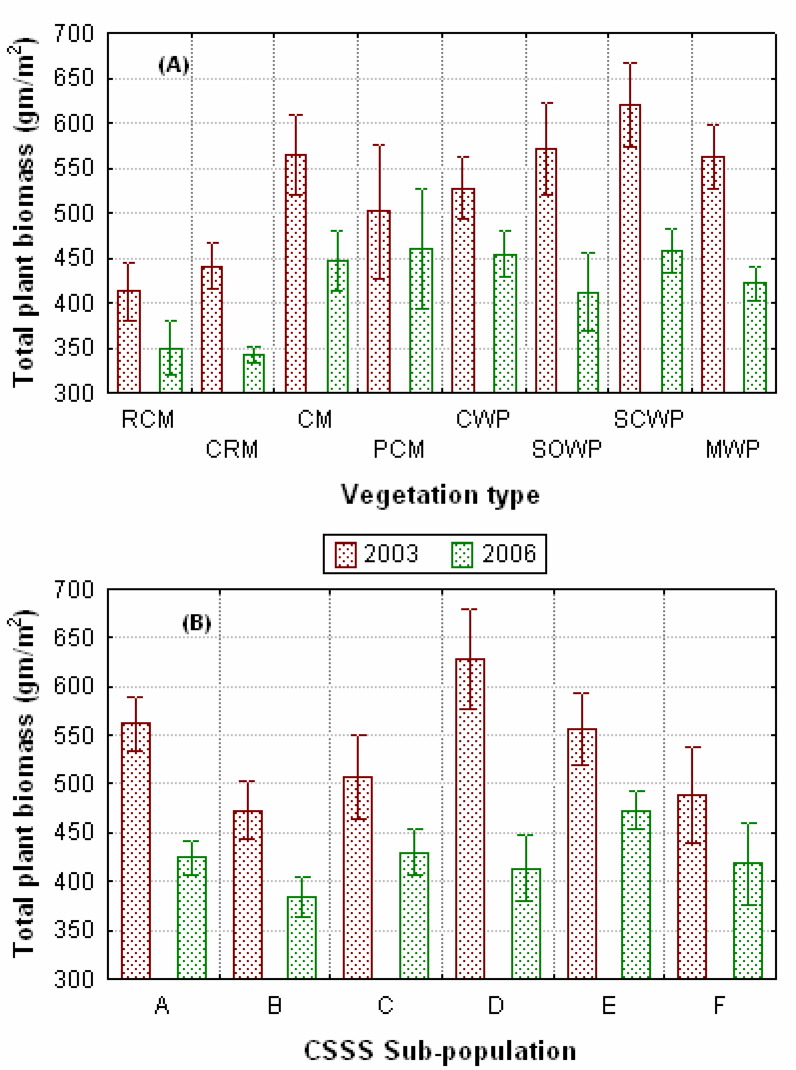


Figure 19: Mean (± 1 S.E.) total plant biomass at the unburned CSSS census sites sampled in both 2003 and 2006. Total crown cover is averaged over (A) Vegetation types, and (B) CSSS subpopulations. RCM = *Rhynchospora-Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; CM = *Cladium* marsh; PCM = *Paspalum-Cladium* marsh; CWP = *Cladium* wet prairie; SOWP = *Schoenus* wet prairie; SCWP = *Schizachyrium* wet prairie; MWP = *Muhlenbergia* wet prairie.

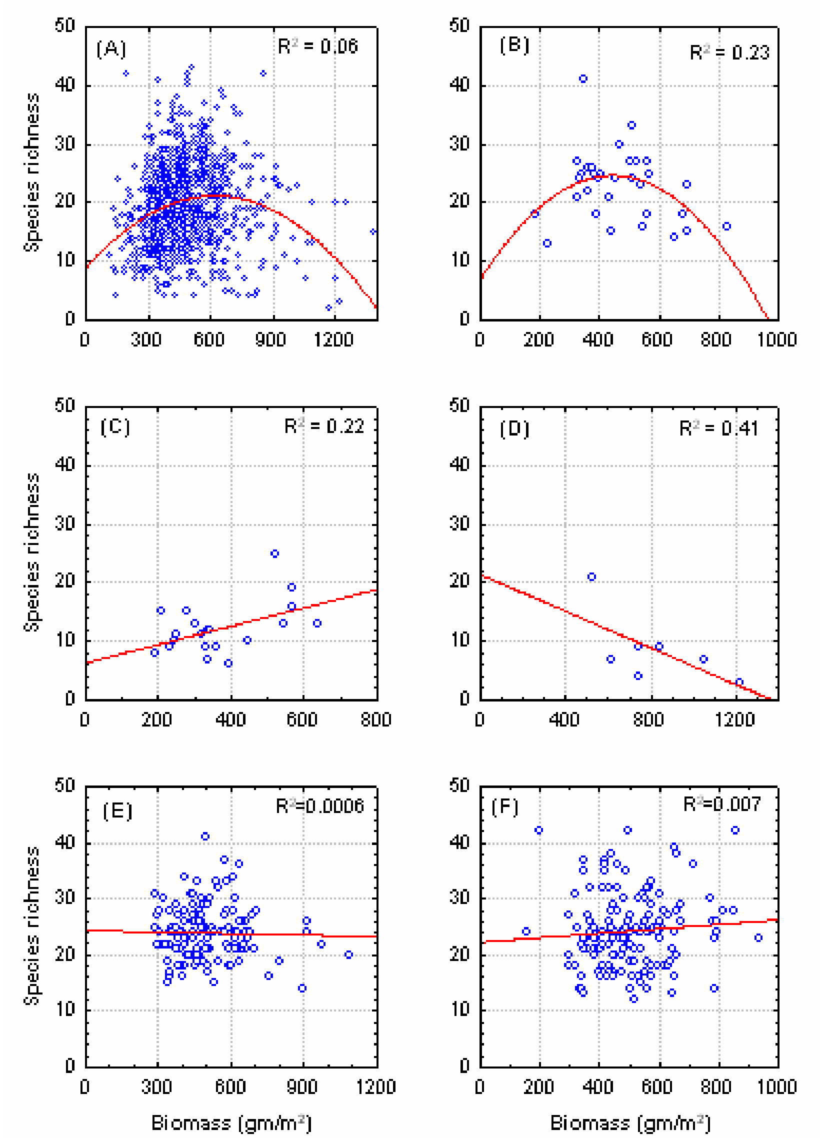


Figure 20: Species richness in relation to biomass at CSSS vegetation sampling sites. (A) All transect and census sites, (B) *Schoenus* wet prairie, (C) *Eleocharis-Rhynchospora* marsh, (D) *Spartina* marsh, (E) *Schizachyrium* wet prairie, and (F) *Muhlenbergia* wet prairie

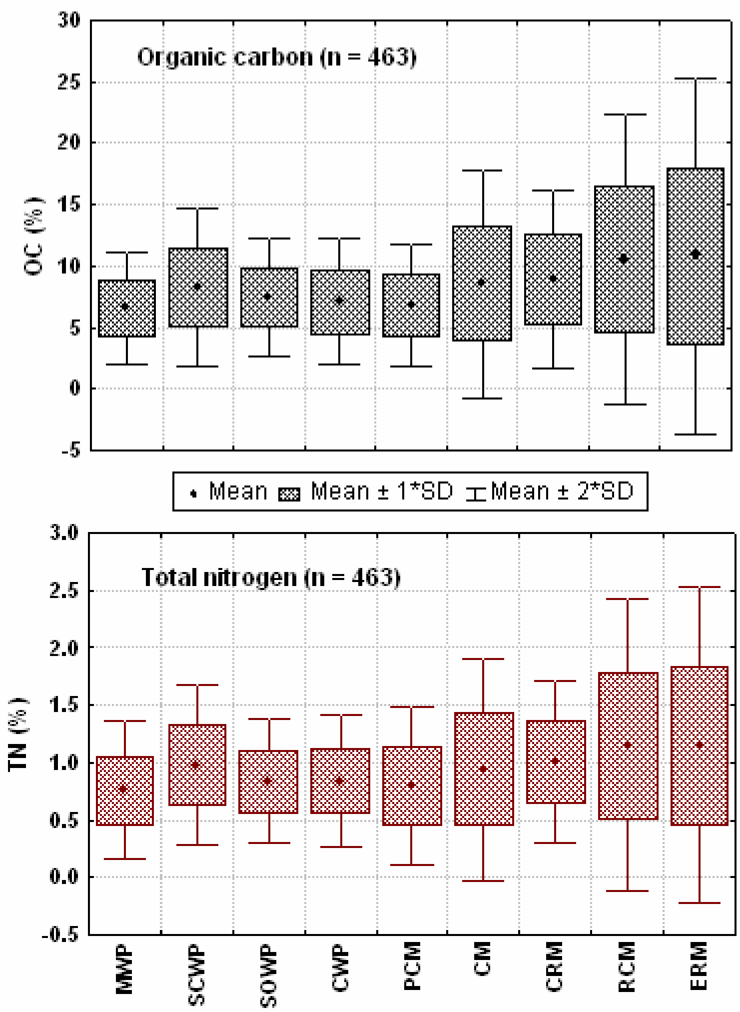
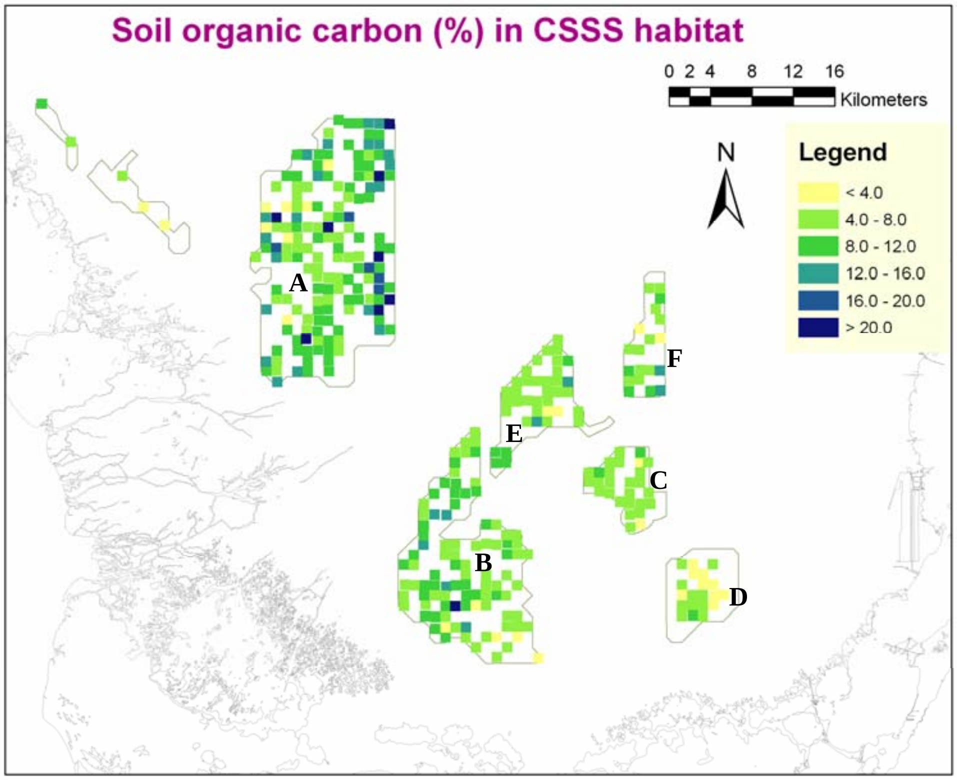


Figure 21: Box plots showing the mean (± SD) organic carbon (OC) and total nitrogen (TN) in 9 vegetation types at 463 CSSS transect and census sites sampled over three years, 2003, 2004 and 2005. ERM = *Eleocharis-Rhynchospora* marsh, RCM = *Rhynchospora-Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; CM = *Cladium* marsh; PCM = *Paspalum-Cladium* marsh; CWP = *Cladium* wet prairie; SOWP = *Schoenus* wet prairie; SCWP = *Schizachyrium* wet prairie; MWP = *Muhlenbergia* wet prairie.



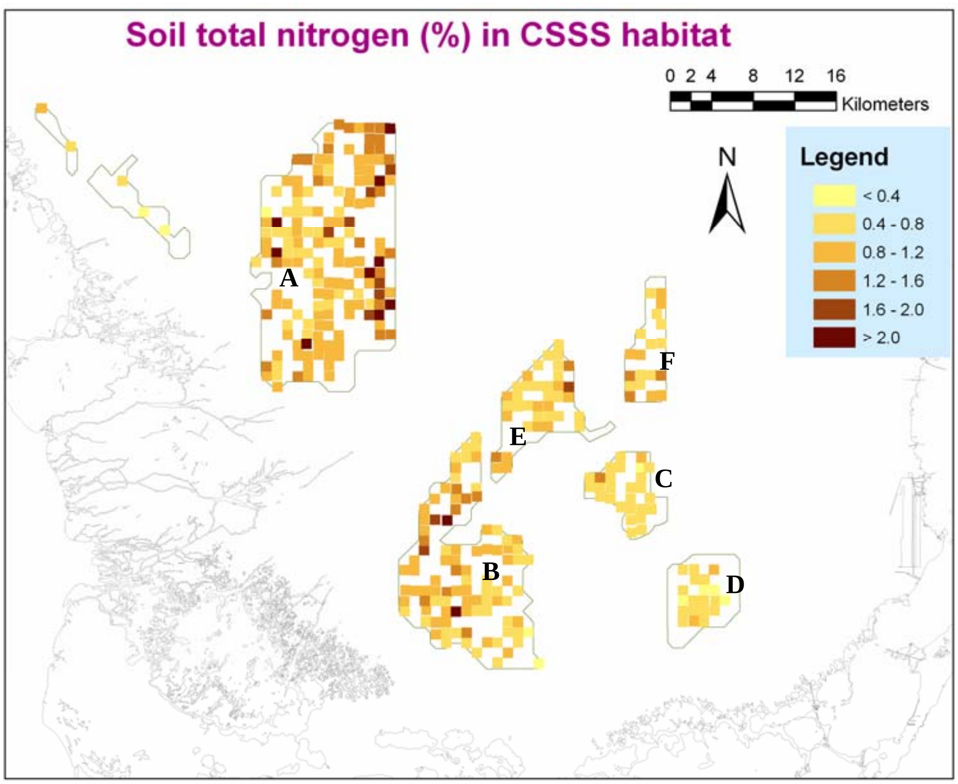


Figure 22: Soil organic carbon (OC) and total nitrogen (TN) at the CSSS census sites. Roman letters indicate six CSSS sub-population areas.

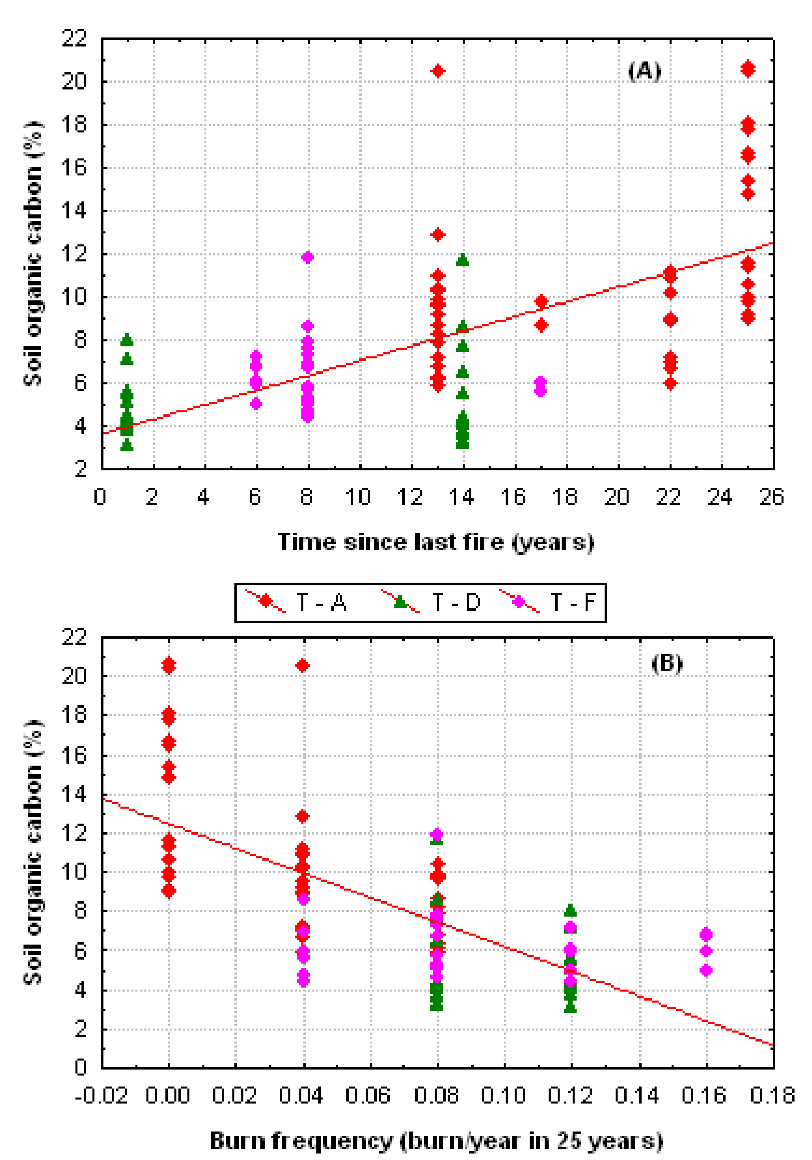


Figure 23: Soil organic carbon (OC) in relation to time since last fire (A) and burn frequency (B) at CSSS vegetation sites on Transects A, D & F. Sites not burned in 1980 and later have been assigned time since last fire 25 years and fire frequency of '0'.

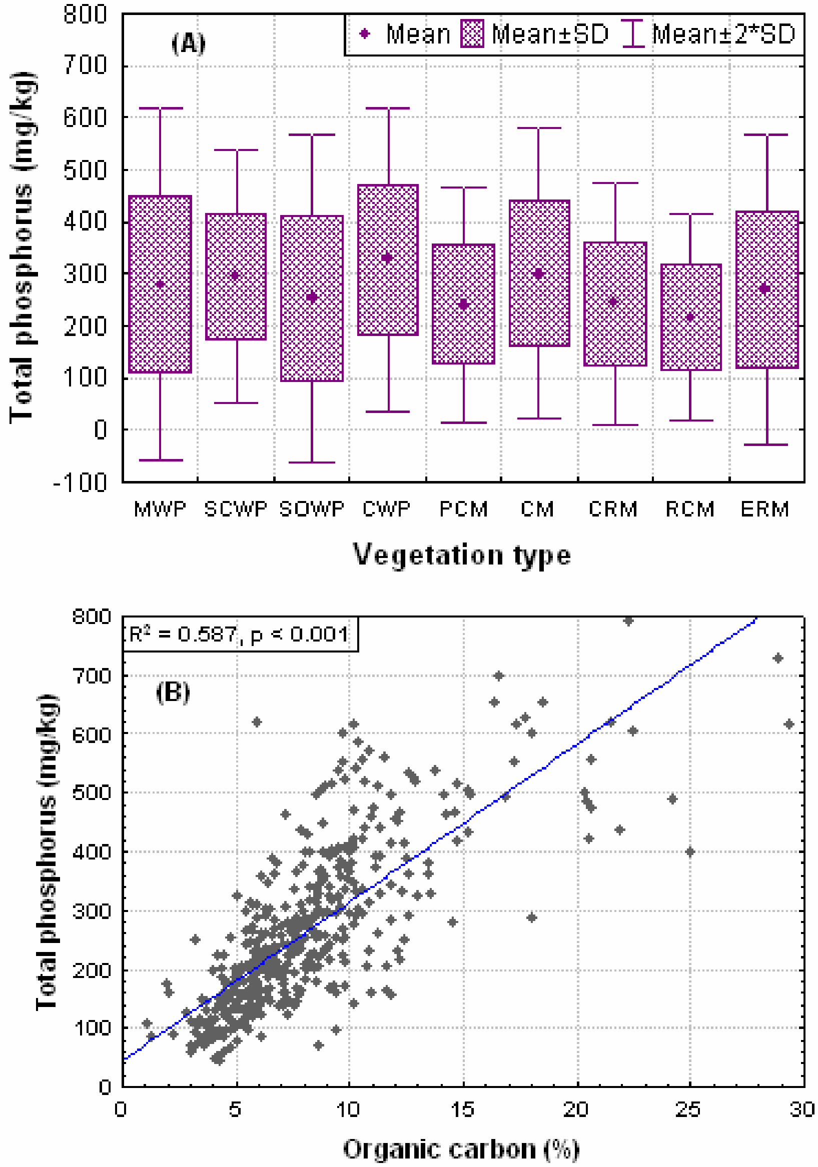


Figure 24: (A) Box plots showing the mean (± SD) soil total phosphorus (TP) in 9 vegetation types, and (B) the relationship between organic carbon (OC) and total phosphorus (TP) at 463 CSSS transect and census sites sampled over three years, 2003, 2004 and 2005. ERM = *Eleocharis-Rhynchospora* marsh, RCM = *Rhynchospora-Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; CM = *Cladium* marsh; PCM = *Paspalum-Cladium* marsh; CWP = *Cladium* wet prairie; SOWP = *Schoenus* wet prairie; SCWP = *Schizachyrium* wet prairie; MWP = *Muhlenbergia* wet prairie.

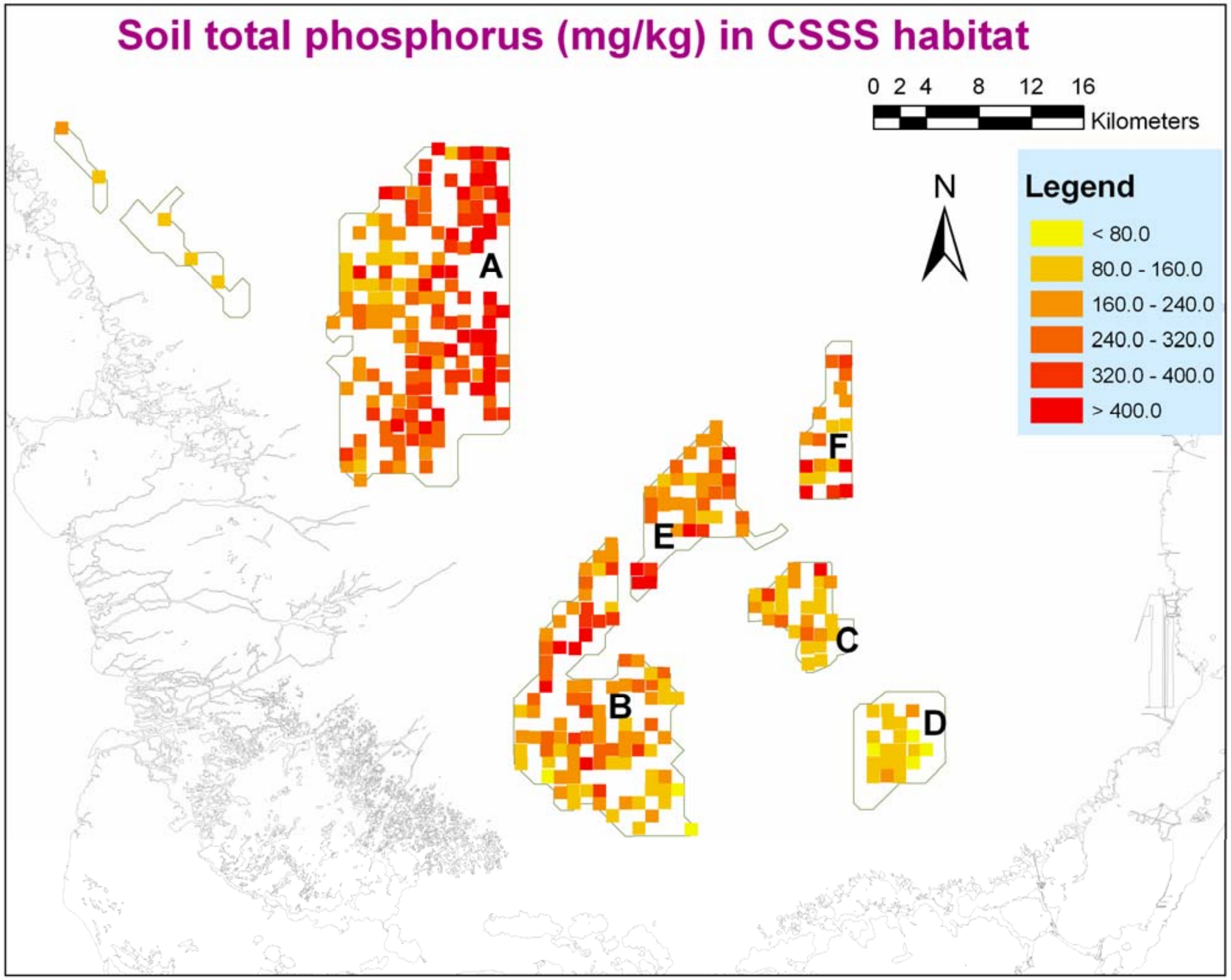


Figure 25: Soil total phosphorus (TP) at the CSSS census sites. Roman letters indicate six CSSS sub-population areas.

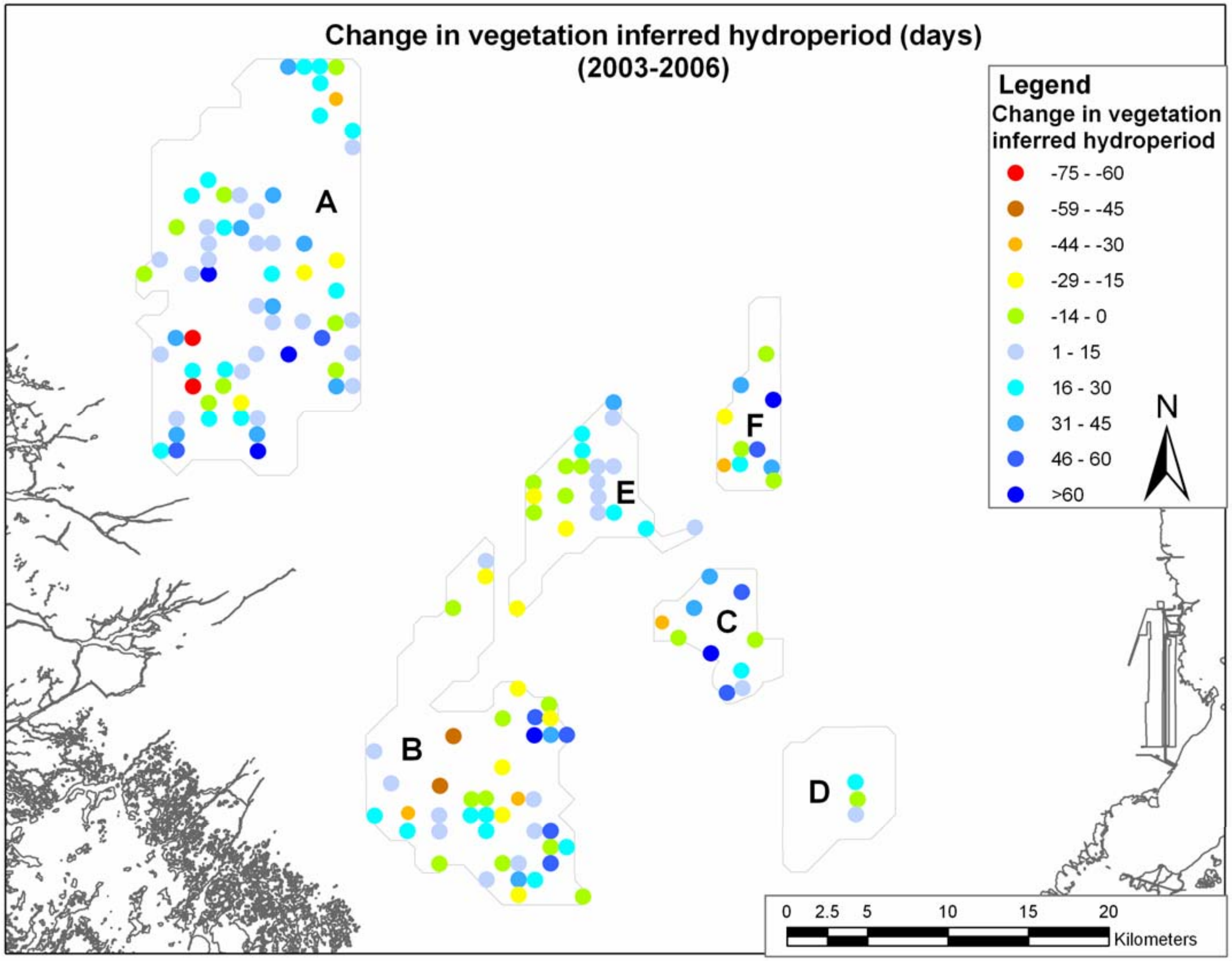


Figure 26: Change in vegetation inferred hydroperiod (days) at the sites which were sampled in both years, 2003 & 2006, and were not burned at least for 3 years prior to 2006 sampling. Roman letters indicate six CSSS sub-population areas.

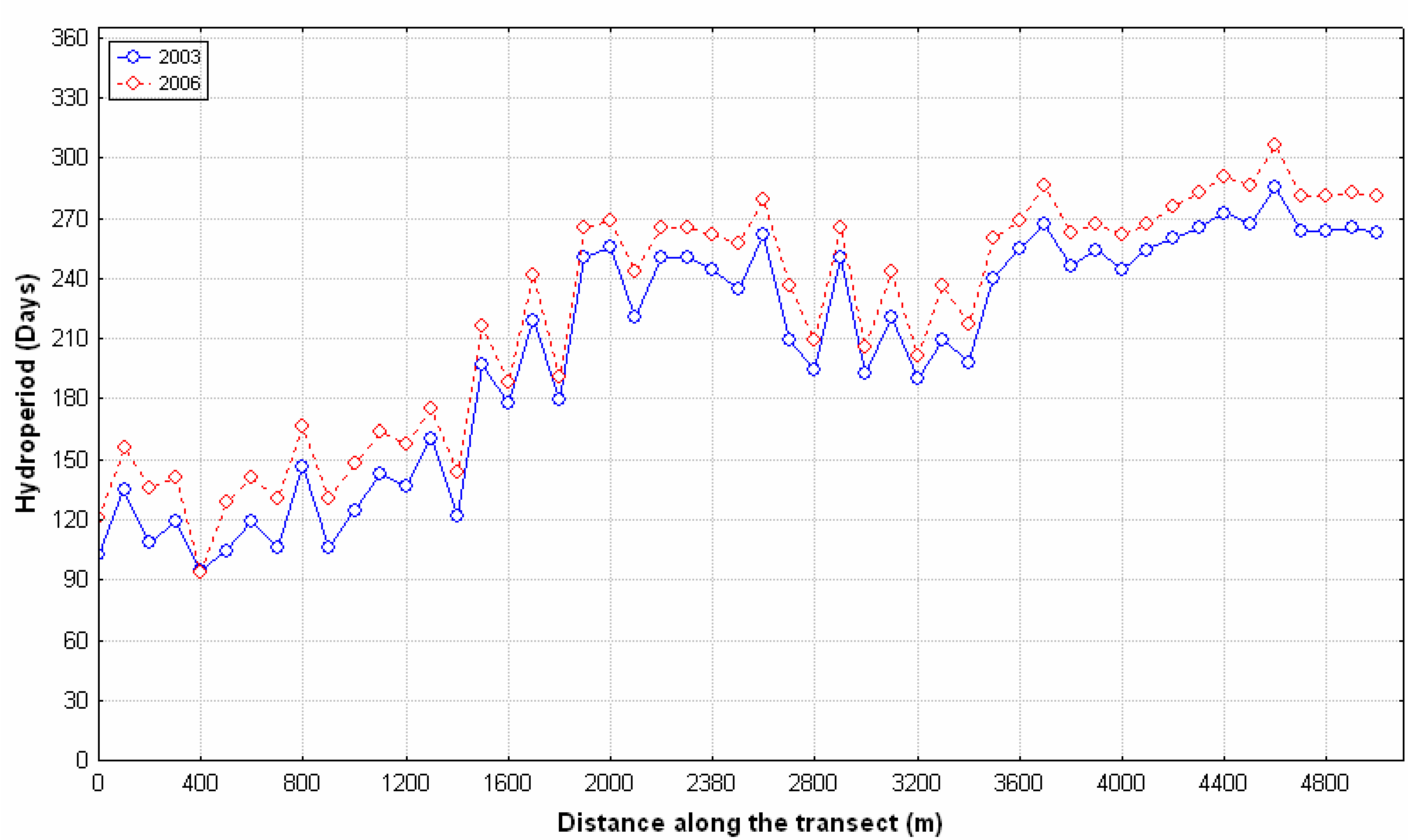


Figure 27: Mean hydroperiod (days) averaged over three years prior to vegetation sampling in 2003 and 2006 at the sites along the Transect A. Hydroperiod for the sites were calculated using mean elevation at the sites and water level data recorded at NP205.

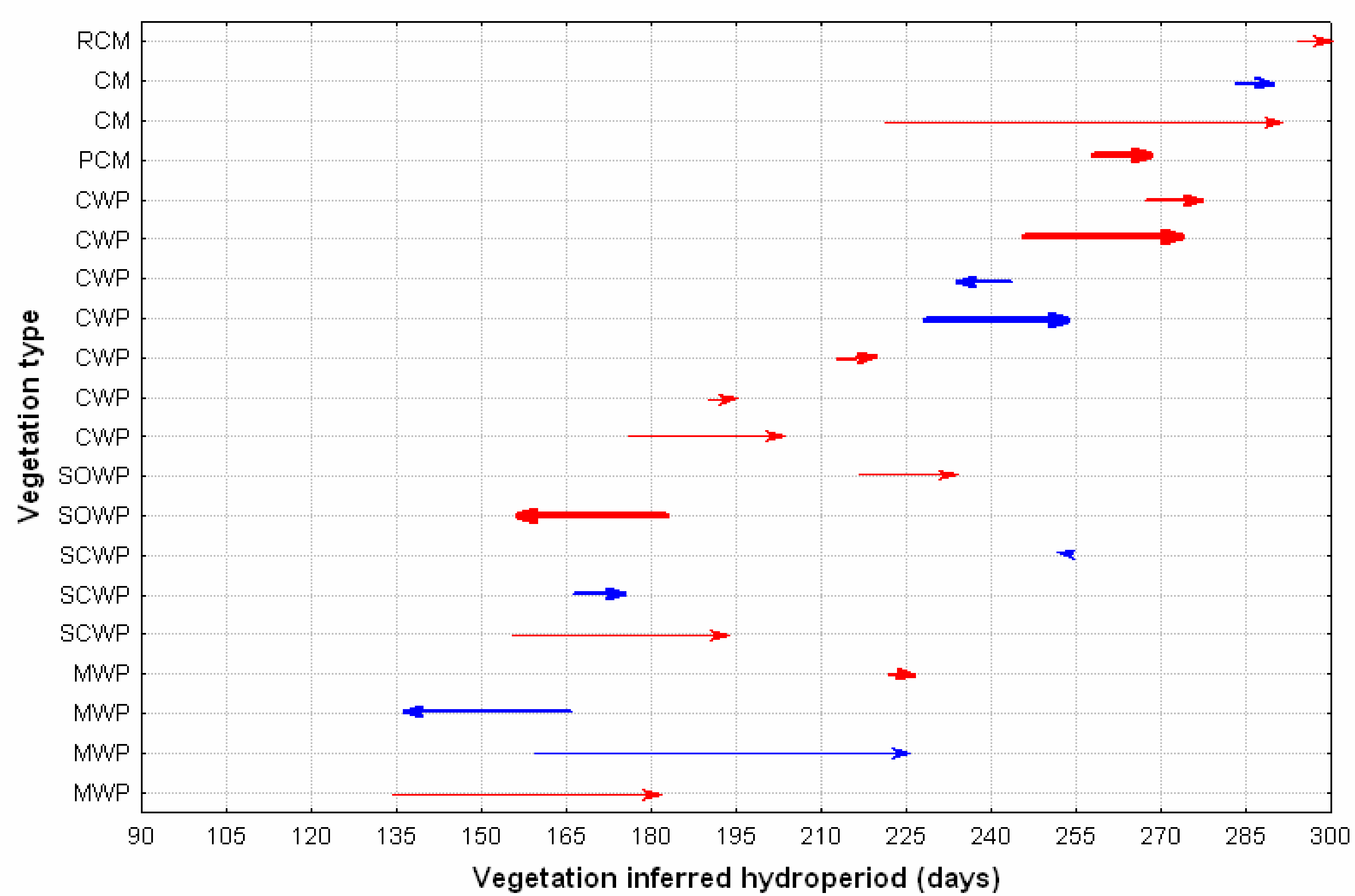


Figure 28: Change in CSSS counts with a change in vegetation inferred hydroperiod (days) at the sites which were sampled in both years, 2003 & 2006, and were not burned at least for 3 years prior to 2006 sampling. Only those sites, at which CSSS population was surveyed in both years, and the count was '0' in either 2003 or 2006 are included. Blue and red lines show gain and loss in CSSS numbers, respectively. The thickness of line indicates the CSSS count as 1, 2, and 3 that were gained or lost in increasing order.

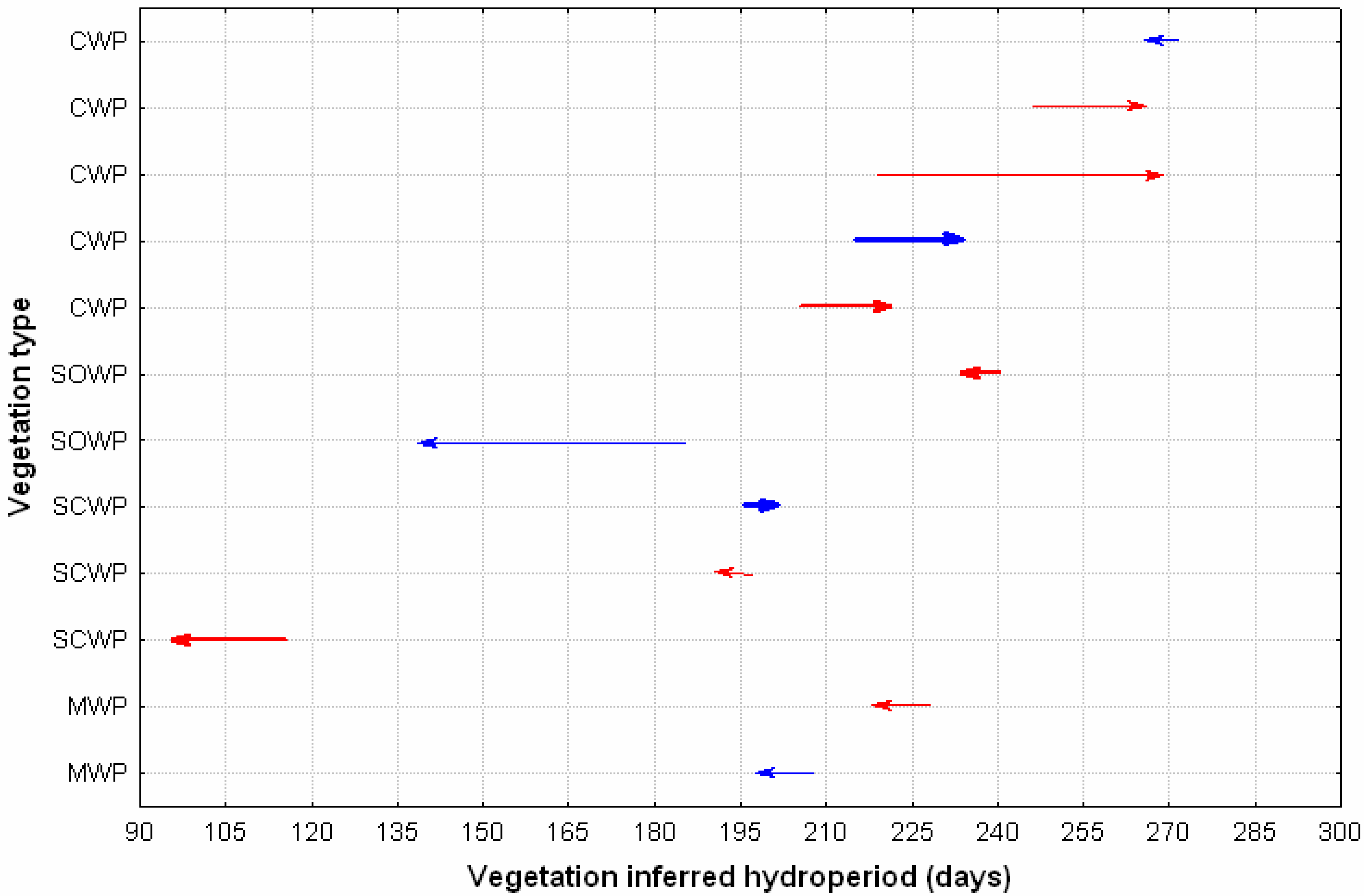


Figure 29: Change in CSSS counts with a change in vegetation inferred hydroperiod (days) at the sites which were sampled in both years, 2003 & 2006, and were not burned at least for 3 years prior to 2006 sampling. Only those sites, at which CSSS population was surveyed in both years and had bird counts 1 or more in both 2003 and 2006, are included. Blue and red lines show gain and loss in CSSS numbers, respectively. The thickness of line indicates the CSSS count as 1, 2, and 3 that were gained or lost in increasing order.

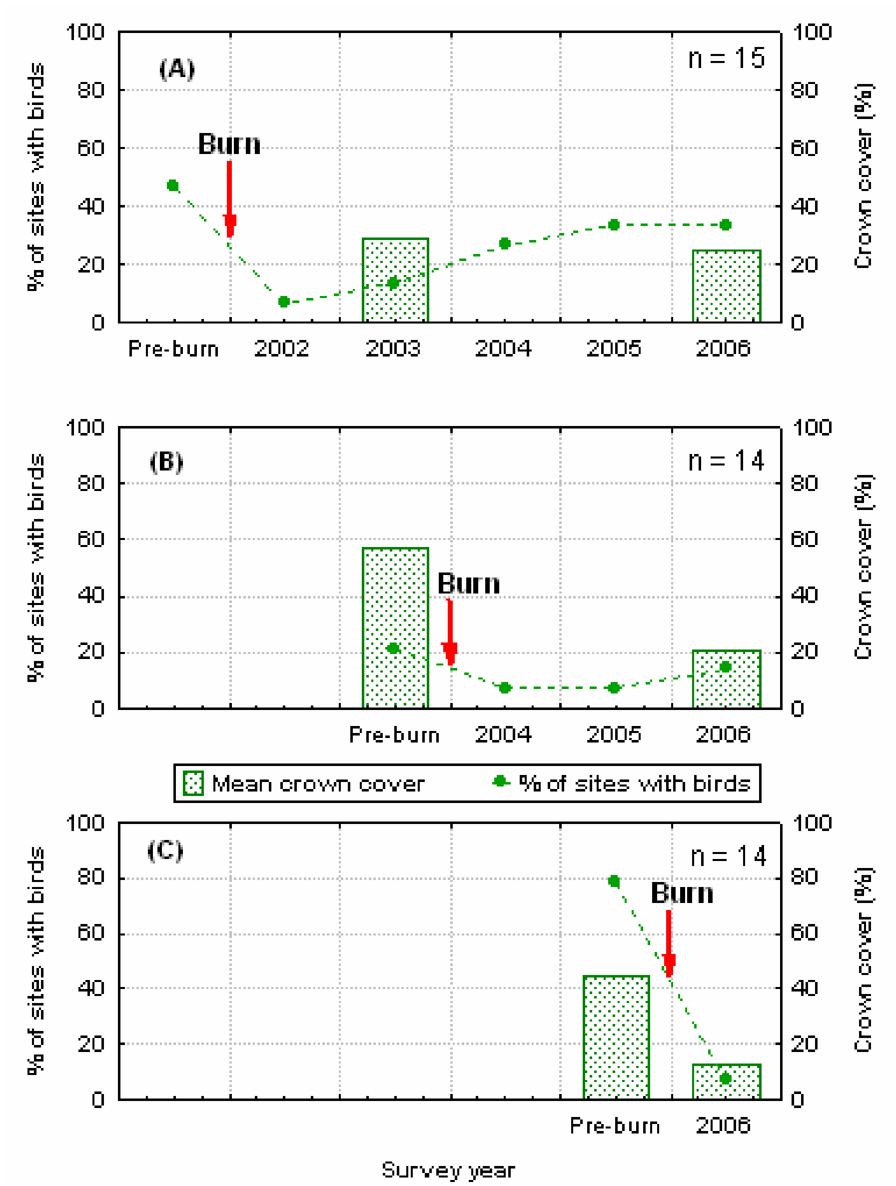


Figure 30: Mean crown cover and % of sites with birds observed at sites burned in 2001 (A), 2003 (B) or 2005 (C). At the sites burned in 2001 or 2003, vegetation survey was done in both 2003 & 2006. Vegetation in sites burned in 2005 was surveyed in 2003, 2004 or prior to the fire in 2005; all of these sites were resurveyed in 2006. 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.