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Effect of Hydrologic Restoration on the Habitat of The Cape Sable Seaside Sparrow, Annual Report of 2004-2005

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Annual Report of 2004-2005

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Summary

The major activities in Year 3 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 4 presentations, two at the CSSS – fire planning workshops at Everglades National Park (ENP), one at the Society of Wetland Scientists' meeting in Charleston, SC, and a fourth at the Marl Prairie/CSSS performance measure workshop at ENP. We started field work in the third week of January and continued till June 3, 2005. Early in the field season, we completed vegetation surveys along two transects, B and C (~15.1 km). During April and May, vegetation sampling was completed at 199 census sites, bringing to 608 the total number of CSSS census sites with quantitative vegetation data. We updated data sets from all three years, 2003-05, and analyzed them using cluster analysis and ordination as in previous two years. However, instead of weighted averaging, we used weighted-averaging partial least square regression (WA-PLS) model, as this method is considered an improvement over WA for inferring values of environmental variables from biological species composition. We also validated the predictive power of the WA-PLS regression model by applying it to a sub-set of 100 census sites for which hydroperiods were "known" from two sources, i.e., from elevations calculated from concurrent water depth measurements onsite and at nearby water level recorders, and from USGS digital elevation data. Additionally, we collected biomass samples at 88 census sites, and determined live and dead aboveground plant biomass. Using vegetation structure and biomass data from those sites, we developed a regression model that we used to predict aboveground biomass at all transects and census sites. Finally, biomass data was analyzed in relation to hydroperiod and fire frequency.

In 2005, eight species were added to the existing plant species list. With several unknown taxa from previous years now identified, our list of vascular plant species currently numbers 182. Cluster analysis based on the composite 2003-2005 data set identified the same ten groups that had been recognized from a partial data set in 2004. Distinct assemblages in the NMS ordination of the same data supported the classification, and also indicated that the assemblages can be broadly grouped into two broad categories: 'wet-prairie' and 'marsh'. In general, wet prairies had higher species richness and shallower soils than marshes. Other than the tall *Cladium*- and *Spartina*-dominated marshes, consistent differences in canopy height and cover between prairie and marsh vegetation types were not observed. Wet-prairie vegetation is concentrated in the eastern half of the study area where most birds have been found in recent years, while marsh communities are prevalent in the western and southeastern areas. The WA-PLS model was better than the WA model in predicting inferred hydroperiod. Vegetation-inferred hydroperiod was strongly correlated with water depth-based hydroperiod, suggesting that vegetation composition can be an excellent tool for inferring hydrologic conditions in remote portions of the Everglades. Inferred-hydroperiod was a strong predictor of CSSS occurrence. In sites with hydroperiod ranging between 90 and 150 days, CSSS occupancy was ~50% and at the sites with hydroperiods between 150 and 240 days >30%. The occupancy was <20% at sites with both shorter and longer hydroperiod. Based on the census sites where biomass data were collected, plant height and cover were strong predictors of plant biomass; in turn, plant biomass at a given site was related to the hydrologic conditions and the fire history of the area.

Three years of study have enabled us to present a detailed account of spatial variation in vegetation structure and composition in relation to current hydrologic conditions, but the research has not yet fully addressed how rapidly vegetation would change in response to hydrologic alterations in CSSS habitat. While re-sampling in 2006 of sites surveyed in 2003 may partially address this question, a full understanding of the rate of vegetation change 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 third 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 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 second annual report in November 2004, we carried out a number of activities. The most significant of these included several presentations, planning for the Year 3 field season, purchasing of necessary supplies, sampling along transects and at census points, and data analysis. Before vegetation sampling began in the third week of January 2005, we focused on presentations of Year 2 results and preparation for the third year of sampling. Mike Ross and Jay Sah made a presentation at the Cape Sable seaside sparrow (CSSS) Symposium-2004 at Everglades National Park (ENP) on December 7-8. Our presentation was based primarily on the results reported in the second annual report, but also included results from an analysis of vegetation cover data from 85 census plots that were within the areas burned between 1992 and 2003. Fire maps prepared by David LaPuma for ENP were used to characterize the burned plots. During the rest of December 2004 and in the first 2 weeks of January 2005, we completed planning and purchased some supplies for the upcoming field works. There was little change in FIU sampling personnel. Serge Thomas, who was occasionally involved in vegetation sampling in the last two years, was no longer in our sampling team. In the USGS team, Jim Snyder recruited David Hagyari as a replacement of Sara Robinson.

We commenced vegetation sampling on January 14 and continued through June 3. During this time we sampled 132 points on Transects B and C, and 199 census points distributed throughout the marl prairies of ENP and Big Cypress National Preserve (BCNP) (**Table 1**). Due to the homogeneity of the terrain, we sampled at 200 m intervals along the northern 4.2 km of Transect B. Along the remainder of Transect B (6.9 km) and the entire length (4 km) of Transect C we sampled every 100 m, as we had for the other four transects. On March 28, three weeks after transect sampling was complete (and at about the same time as in 2003 and 2004), we began the vegetation survey at the CSSS census points, using BCNP (Bill Evans, pilot) for helicopter service. After three weeks, however, delays in the transfer of money from ENP to FIU caused a brief interruption in sampling. Work began again on April 22, with Biscayne Helicopter providing most of the transportation for the rest of field season. The interruption in sampling at census points delayed the end of vegetation sampling by about one week. In 2003 and 2004, we had completed vegetation sampling on May 30 and 26, respectively, while we concluded sampling on June 3 in 2005.

Among 199 census sites that we sampled in 2005, 94 were from sub-population A, and 44, 19, 10, 19 and 13 were from sub-populations B, C, D, E and F, respectively (Table

1). In sub-population A, 17 sites were sampled in an area that ENP planned to burn later in the spring. This group brought to 66 the total number of sites within the planned fire boundary that were sampled in 2003-05. As it turned out, conditions prevented burning in this area in 2005, but if the fire takes place as rescheduled in 2006, the pre-burn vegetation data from these plots will serve as an excellent baseline to investigate the effects of fire on vegetation and to monitor post-burn vegetation recovery. Annual re-sampling at two census points burned in 2003 near the Everglades Park road was continued for a third year in 2005. In general, structural and compositional vegetation parameters recorded at both transect and census sites in 2005 were the same as in the first two 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 3 field season (Jan 14 – June 3, 2005)

Transect/ Census points	Sub-population	# of sampling points
Transect	B	91
	C	41
Census sites	A	94
	B	44
	C	19
	D	10
	E	19
	F	13

In the second week of June, Jay Sah made another presentation at the 26th Annual Meeting of Society of Wetland Scientists, June 5-10, Charleston, SC, during a special symposium entitled 'Everglades Ecology and Restoration'. The presentation was primarily based on results described in the Year 2 report, but also included 2005 data recorded in two burned sites. The audience for the presentation was a diverse one representing different fields of wetland ecology and restoration.

While the preparation of this Year 3 report was in progress, Mike Ross and Jay Sah jointly made two additional presentations, one at the Cape Sable seaside sparrow Symposium-2005 on December 7-8, and another at the Marl Prairies/CSSS Performance Measures Workshop on January 19-20, 2006, both organized at ENP. These two presentations included the results from our analyses of vegetation data collected during three years (2003-05). In the first presentation, we also included preliminary results from our work on woody plant dynamics in prairies in sub-population B and from an analysis of biomass data collected at 88 census sites in 2005. The results from the biomass analysis were presented in relation to fire frequency in CSSS habitat. ENP fire data from 1981 to 2005 were used to estimate fire frequency at the CSSS census sites. The second presentation was in a more interactive environment where participants were discussing criteria to be used for the development of Marl Prairies/CSSS performance measures. On the first day of the workshop, Mike and Jay also led a group of ten participants on a visit to vegetation survey sites in sub-population B. In the workshop, vegetation-hydroperiod relationships derived in

our analysis were acknowledged by participants to be a useful tool in the development of Marl Prairies and CSSS performance measures.

In the third week of January 2005, we also started Year 4 field work, which we expect to complete by the last week of May, 2006.

2.2 Analytical methods

Data treatment described in this Report includes several analyses. Some are similar in kind to those done in 2003 and 2004 (classification and ordination), while others differ slightly in approach. For example, we used weighted averaging partial least square (WA-PLS) regression instead of simple weighted averaging (WA). WA-PLS is an improved method in comparison to WA for inferring values of environmental variables from biological species composition (Ter Braak and Juggins 1993; Ter Braak et al. 1993). In addition, we also added one more step in the analysis: a cross-validation of the WA-PLS regression model based on a sub-set of 100 sites from the calibration data set with known hydroperiods. In all our analyses, we updated the input files to include the entire 2003-2005 data set.

Hydroperiod estimation

We estimated hydroperiods at 291 survey plots along six transects using elevation data from topographic surveys and water level data from nearby stage recorders. Hydroperiod estimates for Transects A, D and F were arrived at from topographic surveys in conjunction with water level records at NP205, EVER4 and RG2, respectively. For sites on Transect E, we used water level records from two recorders, CR2 and A13, located near the eastern and western ends of the transect, respectively. Since the mean annual difference in water level at these two recorders in six years (1997-2003) was 18.3 cm, the estimate of mean water level at each plot on Transect E was calculated on the basis of a distance-weighted average of stage at the recorders at each end of the 5-km transect. Thus, for a given day, water level at a point 100 meters west of CR2 was calculated as 98% of stage recorded at CR2 plus 2% of stage at A13, at the west end of the transect. In this way, water level at meter 2500 in the middle of transect was influenced equally by both recorders. A similar approach was applied to calculate the hydroperiods for points at Transect C and B. Hydroperiods for points along Transect C were calculated by applying the weighted averaging procedure described above to stage records from NTS1 & R3110. Transect B, which may be divided into northern and southern sections that meet at the Old Ingraham Highway, was handled slightly differently. Hydroperiods of points in the northern section were calculated from water level records at DO2 and CR3, located near the northern and southern ends of the section. Hydroperiods for points along the southern section of Transect B were calculated from water level records at CR3 and NP46, situated at the northeast and southwest ends of the section. .

Vegetation classification and ordination

We used hierarchical agglomerative cluster analysis to define grouping of all 608 sites sampled in 2003, 2004 and 2005. In this method, clusters are formed hierarchically from

the bottom up by grouping objects based on their mutual similarity or dissimilarity (Legendre and Legendre 1998; McCune and Grace 2002). To reduce the influence of rare species, we eliminated species that were present in less than 12 sites (2% of total), resulting in a matrix of 608 sites and 94 species. We then developed the site-by-site dissimilarity matrix based on species cover data that was first relativized by plot total. We used the Bray-Curtis dissimilarity as our distance measure, and the flexible beta method to calculate relatedness among groups and/or individual sites (McCune and Grace 2002). In the first step, a group is formed between two sites depending on the minimum distance between them. Then the dissimilarity matrix is updated to reflect also the distance between the new group and all other sites, and a new group is formed between two sites or groups of sites present in this matrix. These steps are repeated until all the sites are in one group. Using the same initial dissimilarity matrix, we also performed non-metric multidimensional scaling (NMS) ordination to visualize relationships among plant communities among census sites. In NMS ordination, sites are plotted as points in a space of 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. The performance of an ordination is expressed in term of 'stress', which is a measure of goodness-of-fit of the non-parametric regression of distance between pair of points in the ordination diagram and the corresponding sample-to-sample dissimilarities (Clarke 1993). The NMS ordination with the lowest stress value is usually the best representation of the relationship among sites. Prior to the analyses, we performed an outlier analysis in which samples that had an average distance (Bray-Curtis) 3.0 standard deviations greater than the overall mean distance among all samples were considered to be outliers. Six plots --- four *Spartina*-dominated plots from the Cape Sable area and one each in sub-population A and H (Stair step area) --- were identified as outliers, and therefore eliminated from the ordination. After performing the ordination, cluster groups were superimposed on the ordination diagram to check consistency in relationships among different plant communities in both analyses. The cluster analysis was done with PC-ORD 4.0 (McCune and Mefford 1999), and the NMS ordination with PRIMER 5.0 (Plymouth Marine Laboratory, UK).

Weighted averaging partial least square regression and calibration

The training-data set with which we developed WA-PLS regression model was the species cover data plus hydroperiod estimates from 291 plots on six topographically-surveyed transects. Vegetation in Transect A was sampled in 2003 and on Transects D, E & F in 2004. Transects B & C were sampled in 2005.

In developing the WA-PLS models, species cover were fourth square root transformed, which down weights the influence of very dominant species. Mean hydroperiod was calculated across different time periods (i.e., years preceding vegetation sampling). When mean annual values of the 1 to 6 year periods preceding vegetation sampling were evaluated, the five-year period yielded the best model. Thus, for Transect A, sampled in 2003, we used hydroperiod from 1997-98 to 2001-02 hydro-years. In our analysis, we considered a period from May 1st to April 30th as a hydro-year, as described in Sklar et al. (2002). For Transects D, E and F, sampled in 2004, we used hydroperiod for 1998-2003, while hydroperiod for 1999-2004 hydro-years was used for Transects B and C. The

performance of the models was judged by the improvement in R^2 value and RMSEP (root mean square error of prediction). RMSEP was estimated by a leave-one-out (jackknife) cross-validation procedure, in which a vegetation-hydroperiod model is developed from all samples except one, and consequently applied to predict the hydroperiod of the left-out point on the basis of its vegetation. Each point in the training set data is left out once, resulting in the number of models to be developed in estimating RMSEP equaling the number of sample sites. For instance, in our data set of 291 sites, 291 WA-PLS models were developed from sets of 290 sites, and then applied to the left-out site to predict its hydroperiod. RMSEP was estimated on the basis of predicted and observed hydroperiods for those sites. Finally, observed *vs* predicted hydroperiods were plotted to visualize the fitness of the model. We used the C_2 program of Juggins (2003) to develop WA-PLS model.

Additionally, we used an independent data set to evaluate the model. The data set consisted of a set of 100 census sites for which hydroperiods could be calculated separately from direct measurements of water depth and from a digital elevation map produced by USGS. At each point, we took three measurements of water levels on November 4, 7 or 9, 2005. Assuming a flat water surface between the site and nearest stage recorder, we used mean water level measured at a site to estimate the ground elevation. The site elevations were then used to calculate hydroperiod. To reduce the uncertainty associated with the "flat water surface" assumption, we used only sites that were within 1.5 km of a stage recorder. If a site was close to more than one stage recorder, the nearest one was considered as the reference recorder. Finally, the best WA-PLS model was applied to the calibration data set that included the vegetation data from 608 census plots (179 surveyed in 2003, 230 in 2004, and 199 in 2005). The predicted hydroperiods for those sites were termed 'vegetation-inferred hydroperiods', and were superimposed on the vegetation ordination diagram to illustrate the relationship between vegetation and hydrology. We also mapped their distribution in the marl prairies to illustrate the spatial pattern of hydrologic conditions in CSSS habitat.

Biomass estimation

In conjunction with the vegetation survey, we also collected biomass samples from about 44% of the 199 census sites sampled in 2005. At each site, we collected from two 0.25 m^2 quadrats, at 17 and 41 m from the origin of the 60 x 1 m belt transect. Those quadrats were among the ones for which both structure and species composition data were collected. We clipped the plants in each quadrat and also collected all aboveground materials including periphyton and dead plant material. The materials were bagged together, returned to the lab, and separated into periphyton and live and dead plants. These were oven-dried at 70°C to constant weight, and dry weight was recorded. Step-wise regression was applied to select structural variables that contributed to the best model for predicting aboveground plant biomass. The model was then applied to estimate biomass at 608 census sites.

Hydroperiods, fire and biomass

We obtained annual fire data for 25 years (1981-2005) from Everglades National Park in 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 not

complete, 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 these three variables.

3. Results

3.1 Vegetation

The locations of the six transects, as well as the census points sampled in 2003, 2004 and 2005 are detailed in **Figure 1**. With the 3-years of sampling throughout the range of Cape Sable seaside sparrow habitat, our sampling network is well-distributed and covers most of the short-hydroperiod grasslands peripheral to Shark and Taylor Sloughs in the Everglades.

During the course of the 2005 field season, we identified eight new plant species within or adjacent to the vegetation plots. We were also able to identify seven new taxa that were unidentified last year, bringing our composite species list of vascular plants to 182 (**Appendix 1**). Among them, 14 are identified only to genus. For some taxa, we have adopted a new name based on the Integrated Taxonomic Information System (ITIS). One major change was for muhly grass. During the last two years, we used *Muhlenbergia filipes*, but now we are using *Muhlenbergia capillaris* var. *filipes*.

The cluster analysis based on the composite 2003-2005 set of 608 census plots identified the same ten groups that had been recognized based on data collected through 2004 (**Figure 2**). The NMS ordination of the same data (**Figure 3**) clarifies the relations among different vegetation types within the CSSS habitat matrix. After removing six outliers discussed in Methods, stress was reasonably low (16.0), suggesting that the 2-axis solution provides a good representation of site relationships. As in the ordinations produced on the basis of earlier data sets (Ross et al. 2003, 2004), a 'V' shaped pattern is evident, with the mono-dominant *Cladium* marsh at the fulcrum of the 'V' and prairie and marsh types aligned along the right and left arms, respectively. Within this alignment, marsh vegetation types are fairly well separated from each other. *Eleocharis-Rhynchospora* marsh is arrayed at the extreme end of the marsh arm, and *Paspalum-Cladium* marsh is loosely distributed between the two arms. In contrast, two prairie types, *Muhlenbergia* and *Schizachyrium* prairies, exhibit considerable overlap, indicating that they share a number of common species.

The distinctive composition of the ten communities is evident in **Table 2**, which summarizes, by vegetation type, the mean cover of the 25 most abundant plant species in CSSS grasslands. **Table 3** lists mean values for three measures of diversity --- mean species richness, the Shannon-Weaver diversity index (H'), and evenness (E) (Shannon & Weaver 1949) --- for the 10 vegetation types. In the Everglades, wet prairies are more diverse plant communities than marshes. Among the marsh types, *Paspalum-Cladium* marsh is more heterogeneous than others and has the highest species richness. Among the wet prairies, *Muhlenbergia* wet prairie has the highest species richness and species diversity.

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Table 2: Mean species cover (%) in herb stratum of ten vegetation types, as defined in Figure 2. Means are based on 608 census plots sampled in 2003, 2004 and 2005. Species listed are the 25 most abundant across all sites.

Species	Vegetation types									
	Muhlenbergia **WP**	*Schizachyrium* **WP**	*Schoenus* **WP**	*Cladium* **WP**	*Cladium* **Marsh**	*Cladium Rhynchospora* **Marsh**	*Rhynchospora Cladium* **Marsh**	*Eleocharis Rhynchospora* **Marsh**	*Paspalum-Cladium* **Marsh**	*Spartina* **Marsh**
Cladium jamaicense	12.12	12.76	9.44	21.96	33.83	10.99	3.57	3.05	3.77	2.11
Schizachyrium rhizomatum	4.95	15.78	2.20	3.25	0.12	0.04			0.88	0.09
Muhlenbergia capillaris var. *filipes*	14.99	3.03	3.12	3.06	0.23	0.00			0.62	
Rhynchospora tracyi	0.34	0.33	0.32	0.38	0.80	4.13	9.22	2.04	1.72	0.73
Eleocharis cellulosa	0.03	0.03	0.01	0.11	0.88	2.44	3.13	17.73	0.33	8.87
Schoenus nigricans	0.93	0.46	18.02	0.76	0.14	0.01				
Bacopa caroliniana	0.04	0.02	0.03	0.09	0.33	1.84	2.15	1.69	0.30	
Paspalum monostachyum	0.66	1.66	0.00	0.61	0.04	0.04	0.00	0.02	3.48	0.01
Panicum tenerum	0.19	0.41	0.15	0.42	0.25	0.77	0.37	0.47	0.90	
Spartina bakeri	0.02			0.00	0.04		0.04	0.01	0.32	32.69
Centella asiatica	0.45	0.76	0.30	0.59	0.09	0.04	0.00		2.97	0.04
Panicum virgatum	0.14	0.77	0.05	0.50	0.20	0.24	0.16	0.07	1.38	0.09
Rhynchospora microcarpa	0.47	0.42	0.30	0.35	0.15	0.16	0.45	0.01	1.00	0.03
Panicum hemitomon	0.01	0.03	0.00	0.02	0.08	0.44	1.19	1.59	0.56	
Crinum americanum	0.04	0.09	0.08	0.09	0.18	0.53	0.84	0.38	0.52	0.01
Pluchea rosea	0.23	0.49	0.05	0.34	0.29	0.23	0.04	0.02	0.47	0.00
Sagittaria lancifolia	0.12	0.00	0.06	0.07	0.14	0.32	0.49	1.54	0.02	
Cassytha filiformis	0.26	0.50	0.46	0.22	0.17	0.10	0.01		0.11	
Hymenocallis palmeri	0.14	0.14	0.15	0.08	0.06	0.11	0.60	0.36	0.09	0.00
Rhynchospora inundata				0.02	0.10	0.15	0.79	0.01	0.01	
Rhynchospora divergens	0.31	0.15	0.18	0.09	0.01	0.01	0.00		0.03	
Leersia hexandra	0.00	0.07	0.00	0.03	0.04	0.15	0.19	0.02	0.15	
Eragrostis elliottii	0.13	0.11	0.12	0.08	0.03	0.03	0.05		0.15	
Pontederia cordata var. *lanciifolia*				0.00	0.09	0.29	0.01		0.00	
Aristida purpurascens	0.25	0.15	0.13	0.07	0.01	0.00			0.00	

Table 3: Mean species richness, evenness, and diversity in herb stratum of ten vegetation types. Means are based on 608 census plots sampled in 2003, 2004 & 2005. Number of plots per type is presented in Figure 2. S = number of species per plot (60x1m). H' = Shannon's diversity (Shannon and Weaver 1949), and E = H'/$\log_n$(S).

Vegetation type	Species richness	Shannon's diversity index (H')	Evenness (E)
Eleocharis-Rhynchospora marsh	11.0	1.259	0.530
Rhynchospora-Cladium marsh	13.7	1.689	0.654
Cladium-Rhynchospora marsh	15.8	1.564	0.578
Cladium marsh	14.5	0.646	0.245
Spartina marsh	8.6	0.700	0.361
Paspalum-Cladium marsh	21.9	2.104	0.690
Cladium wet prairie	23.0	1.318	0.425
Schoenus wet prairie	23.4	1.507	0.476
Schizachyrium wet prairie	24.3	1.551	0.488
Muhlenbergia wet prairie	26.7	1.573	0.482

Figure 4 illustrates mean values of five structural variables in the ten major vegetation types present in CSSS habitat. In the wet-prairie communities, *Cladium*-dominated prairies were more open than others. Among the marsh types, *Spartina* marsh had the tallest canopy and the greatest crown cover. Except the tall *Cladium*- and *Spartina*-dominated marshes, there were not noticeable differences in canopy height and cover between prairies and marsh vegetation types. This suggests that the use of remote sensing to distinguish even broad groupings of prairie and marsh vegetation types based on only crown height and cover will be a difficult proposition. However, the Cape Sable seaside sparrow is apparently able to make such a distinction, favoring prairies over marshes despite the subtle differences in plant morphology and community structure between these two coarsely defined groups.

Now that we have completed three years of vegetation sampling, the spatial distribution of vegetation types within our sampling network (**Figure 5**) provides a fairly complete representation of the current status of vegetation structure and composition throughout the range of sparrow habitat. Wet-prairie vegetation is concentrated in the eastern half of the study area where most birds have been found in recent years, while marsh communities are prevalent in the western and southeastern areas (Sub-populations A & D). In Sub-population A, where sparrow populations are currently very low, wet prairies are present only on the higher ground along a central ridge that runs from the northeast to the southwest corner of the area. This habitat needs to be protected from any further decline in its potential for reestablishment of the robust number of sparrows that once were present. Marsh communities are also present in the southern and southwestern portions of Sub-population B, which are close to Florida Bay and to Shark Slough, respectively.

3.2 Soils

In CSSS habitat, prairie and marsh sites are distinguished as clearly by soil depth as by recent hydrology. Prairie vegetation occurs almost exclusively where soil depth is 40 cm

or less, while marsh vegetation is usually found on soils deeper than 30 cm (**Figure 6**). The deepest soils were observed on Cape Sable, where soil depth exceeded 1.5 meters at all sites sampled. Though the variation in soil depth values among marsh sites is much higher than among prairies sites (**Figure 7**), soil depth increases monotonically with hydroperiod. The deeper soil in marsh sites, with their longer hydroperiods, reflects higher volumetric rates of soil accumulation over the long term, particularly as peat formation becomes dominant over marl formation. It seems certain that hydroperiod affects the aggradative (production), degradative (oxidation and decomposition), and re-distributional (deposition and erosion) components of soil accumulation in a complex manner, but our current understanding of this balance is incomplete.

3.3 Topography

Broad-scale topographic surveys for Transects A, C, D, and F were presented in the 2002-03 Report and for Transects B & E in the 2003-04 Report. Finer-scale, within-plot topographic surveys were completed at the time of initial vegetation sampling. This year we completed the vegetation survey and plot level topographic surveys on Transects B and C.

On Transect D, elevations estimated by surveying from a benchmark located 400 m from the southwestern end of the transect did not match water conditions observed in the field. We were not able to verify these surveyed elevations independently, since we could not locate any benchmark at the northeastern end of the 2.5 km transect. We therefore estimated elevations based on a correction factor derived from water elevations observed at a subset of sites on the same day. We made two measurements of water level at eight randomly selected sites along the Transect D on November 7, 2005. We estimated elevation of the water surface at each site, based on the water level value recorded at stage recorder EVER-4 at the northeast end of the transect on that day, and assuming a flat water surface throughout the 2.5 km stretch. Measured water depth at each site was subtracted to calculate ground elevation. Then we calculated the mean difference between ground elevations determined as described above and those obtained from the initial topographic survey, and applied it as a correction factor to adjust the surveyed ground elevations at each point along Transect D. On average, the water elevation-derived ground elevations were 4.4 cm lower than the initial survey-derived ones.

3.4 Vegetation-hydrology relationships

Based on the assumption that a reasonably flat water table exists over short distances in the Everglades, elevations across our transects are directly related to hydroperiod, defined here as the annual, discontinuous period of flooding, expressed in days per year. Hydroperiod gradients along Transect A were described in the 2002-03 report, and along Transects D, E & F in the 2003-04 report. **Figure 8** illustrates hydroperiods along the two transects, B and C, that were surveyed this year. Two sections of transect B, one to the north and the other to the south of the Old Ingraham highway differed in hydroperiod. Averaged over the five year period that preceded vegetation sampling, mean hydroperiod was shorter, with more spatial variability, in the northern section than in the southern section, where

hydroperiods generally exceeded 240 days. With a few exceptions, hydroperiod along Transect C varied narrowly, between 150 and 210 days of flooding per year.

Hydrologic variation within the CSSS habitat influences the nature of the resident plant communities. To understand the effects of scale on vegetation pattern, and how the CSSS may respond to this hierarchy of scales, we can now examine vegetation-hydrology relationships at smaller scales than are presented in **Figure 5**, i.e., variation at 100-meter intervals or even within-plot variation. With the completion of surveys on Transects B and C, we can now describe detailed vegetation pattern along six transects that together stretch 30.8 km in length. The vegetation type best represented by each plot was determined by running a separate classification analysis, i.e., inserting a row representing its species abundances along with species cover data from the 608 census plots, and determining which unit it grouped with most closely in the cluster analysis. The vegetation patterns illustrated in **Figure 9** represent a fresh analysis for all transects, superceding results presented on the basis of partial data sets in earlier Reports.

Vegetation types along Transect C, D & F were relatively uniform (**Figure 9**). Along Transect C and F, prairies were dominant, while most of the vegetation on Transect D was one marsh type or another. Vegetation on Transect A, B and E was more heterogeneous. Along Transect A, a gradient in vegetation from wet prairie communities on the east to marsh communities on the west was consistent with the elevation gradient primarily responsible for the differences in hydrological regimes. Along transect B and E, prairies were dominant in most locations, but marshes were present locally at the low elevation sites. Mean total cover was also lower along Transect E than Transects D or F, though recent fire in Transect D left a few sites sparsely vegetated. Mean cover on the lower section of Transect B immediately south of the Ingraham Highway was very high, which is probably due to presence of more fertile soil in the abandoned agriculture fields.

Vegetation and hydrology data collected at 291 sites along the six transects were used in weighted averaging (WA) regression methods to determine species' hydroperiod optima and tolerances. A total of 115 species that occurred in at least 2 plots had optimum hydroperiods ranging from 3 to 9 months (**Table 4**). The median was 206 days. Prairie species like *Muhlenbergia capillaris, Schizachyrium rhizomatum,* and *Schoenus nigricans* have shorter optimum hydroperiod (<206 days), while most of species that are abundant in marshes, e.g., *Rhynchospora* spp., *Eleocharis cellulosa, Panicum hemitomum*, etc. have optimum hydroperiods >220 days. *Cladium jamaicense* exhibited an intermediate hydroperiod optimum (215 days) with a wide tolerance.

We used the same sets of vegetation and hydrology data to develop the weighted averaging partial least square (WA-PLS) regression models. Different hydrologic lag periods (hydroperiod means based on stage records of 1-6 years prior to sampling) were tested, and the best model was based on hydroperiod calculated from a 5-year record prior to vegetation sampling. The R^2 (0.87) and the root mean squared error of prediction (26.8) indicated that WA-PLS regression model was useful in predicting hydroperiods for CSSS census sites for which detailed hydrologic data were not available (**Figure 10**).

Table 4: Species hydroperiod optima and tolerances, as estimated by weighted averaging regression, based on species cover collected at 291 sites along six transects.

Species name	Species Code	Occurrence (n)	Estimated Hydroperiod	
			Optimum	Tolerance
Aeschynomene pratensis var. pratensis	AESPRA	19	228	47
Agalinis linifolia	AGALIN	50	219	45
Agalinis spp.	AGASPP	34	248	39
Aletris bracteata	ALEBRA	6	148	46
Andropogon glomeratus var. glomeratus	ANDGLO	3	168	43
Andropogon virginicus var. virginicus	ANDVIR	86	200	58
Angadenia berterii	ANGBER	11	136	47
Annona glabra	ANNGLA	44	203	64
Aristida purpurascens	ARIPUR	136	179	48
Asclepias lanceolata	ASCLAN	19	195	39
Asclepias longifolia	ASCLON	20	195	48
Aster adnatus	ASTADN	3	150	44
Aster bracei	ASTBRA	197	213	50
Aster dumosus	ASTDUM	141	223	47
Bacopa caroliniana	BACCAR	125	242	39
Calopogon tuberosus	CALTUB	5	174	35
Cassytha filiformis	CASFIL	160	212	58
Casuarina glauca	CASGLA	2	208	27
Centella asiatica	CENASI	202	193	48
Cephalanthus occidentalis	CEPOCC	2	205	18
Chiococca parvifolia	CHIPAR	7	118	50
Chrysobalanus icaco	CHRICA	3	159	80
Cirsium horridulum	CIRHOR	44	142	46
Cladium jamaicense	CLAJAM	291	215	51
Coelorachis rugosa	COERUG	13	223	32
Conocarpus erectus	CONERE	2	172	2
Crinum americanum	CRIAME	88	251	38
Cyperus haspan	CYPHAS	5	189	79
Dichanthelium aciculare	DICACI	12	159	20
Dichromena colorata	DICCOL	20	186	58
Dichanthelium dichotomum	DICDIC	27	200	35
Dichanthelium spp.	DICSPP	12	177	41
Dyschoriste angusta	DYSANG	40	163	55
Eleocharis cellulosa	ELECEL	83	253	24
Eleocharis geniculata	ELEGEN	8	198	39
Eragrostis elliottii	ERAELL	183	212	55
Erianthus giganteus	ERIGIG	52	242	37
Erigeron quercifolius	ERIQUE	16	219	49

Species name	Species Code	Occurrence (n)	Estimated Hydroperiod	
			Optimum	Tolerance
Eupatorium leptophyllum	EUPLEP	55	191	39
Eupatorium mikanioides	EUPMIK	46	213	35
Eustachys petraea	EUSPET	2	181	8
Evolvulus sericeus	EVOSER	2	116	14
Flaveria linearis	FLALIN	7	116	47
Fuirena breviseta	FUIBRE	33	203	53
Helenium pinnatifidum	HELPIN	79	235	48
Heliotropium polyphyllum	HELPOL	39	143	52
Hymenocallis palmeri	HYMPAL	195	205	51
Hyptis alata	HYPALA	32	207	47
Ipomoea sagittata	IPOSAG	99	215	47
Iva microcephala	IVAMIC	30	161	58
Juncus megacephalus	JUNMEG	2	250	7
Justicia angusta	JUSANG	62	228	48
Leersia hexandra	LEEHEX	62	245	42
Linum medium var. texanum	LINMED	20	145	49
Lobelia glandulosa	LOBGLA	17	207	49
Ludwigia alata	LUDALA	2	259	14
Ludwigia microcarpa	LUDMIC	67	216	45
Ludwigia repens	LUDREP	15	231	52
Magnolia virginiana	MAGVIR	2	181	2
Mecardonia acuminata var. peninsularis	MECACU	5	108	37
Melanthera nivea	MELNIV	18	133	54
Metopium toxiferum	METTOX	2	225	72
Mikania scandens	MIKSCA	91	206	44
Mitreola petiolata	MITPET	38	227	54
Muhlenbergia capillaris var. filipes	MUHCAP	224	198	49
Myrica cerifera	MYRCER	33	182	57
Nymphoides aquatica	NYMAQU	5	216	56
Oxypolis filiformis	OXYFIL	71	221	40
Panicum dichotomiflorum	PANDIC	26	231	56
Panicum hemitomon	PANHEM	36	248	32
Panicum rigidulum	PANRIG	30	221	50
Panicum tenerum	PANTEN	278	217	52
Panicum virgatum	PANVIR	187	227	46
Paspalidium geminatum var. geminatum	PASGEM	15	238	26
Paspalum monostachyum	PASMON	113	215	50
Peltandra virginica	PELVIR	29	236	36
Persea borbonia	PERBOR	8	190	41
Phyla nodiflora	PHYNOD	86	192	44
Phyla stoechadifolia	PHYSTO	8	196	22
Piriqueta caroliniana	PIRCAR	25	158	55

Species name	Species Code	Occurrence (n)	Estimated Hydroperiod	
			Optimum	Tolerance
Pluchea rosea	PLUROS	237	209	51
Polygala grandiflora var. leiodes	POLGRA	55	167	50
Polygonum hydropiperoides	POLHYD	4	257	18
Pontederia cordata var. lanciifolia	PONCOR	8	256	22
Proserpinaca palustris	PROPAL	47	229	53
Rhynchospora divergens	RHYDIV	88	175	54
Rhynchospora inundata	RHYINU	16	256	35
Rhynchospora microcarpa	RHYMIC	222	212	52
Rhynchospora tracyi	RHYTRA	220	220	51
Sabatia grandiflora	SABGRA	2	91	44
Sabal palmetto	SABPAL	7	209	44
Sagittaria lancifolia var. lancifolia	SAGLAN	73	231	44
Samolus ebracteatus	SAMEBR	8	169	17
Schoenolirion albiflorum	SCHALB	6	236	46
Schoenus nigricans	SCHNIG	101	196	63
Schizachyrium rhizomatum	SCHRHI	205	199	54
Schinus terebinthifolius	SCHTER	2	176	3
Scleria verticillata	SCLVER	2	91	44
Setaria parviflora	SETPAR	38	204	46
Sisyrinchium angustifolium	SISANG	13	123	57
Solanum blodgettii	SOLBLO	2	126	67
Solidago stricta	SOLSTR	130	188	47
Spartina bakeri	SPABAK	12	184	34
Spermacoce terminalis	SPETER	3	122	8
Spiranthes spp.	SPISPP	3	232	75
Taxodium distichum var. imbricarium	TAXDIS	5	272	14
Teucrium canadense	TEUCAN	45	191	32
Thalia geniculata	THAGEN	3	241	2
Typha domingensis	TYPDOM	2	242	1
Utricularia cornuta	UTRCOR	8	219	36
Utricularia foliosa	UTRFOL	9	258	32
Utricularia purpurea	UTRPUR	26	246	32
Utricularia radiata	UTRRAD	2	219	41
Utricularia subulata	UTRSUB	55	217	38
Vernonia blodgettii	VERBLO	53	154	53

The predictive power of the WA-PLS regression model was further validated by applying the model to a sub-set of 100 census sites for which hydroperiod could be calculated from elevations estimated from water depth measurements and from the USGS digital elevation model **(Figure 11)**. The fairly strong correlation ($R^2 = 0.66$) between vegetation-inferred hydroperiod and water depth-derived hydroperiods indicated that the WA-PLS regression model developed in this study can be used to predict hydroperiod at remote sites for which water level data are not available. However, caution must be used in interpreting such predictions, and the use of the model should be restricted to the range of hydrologic conditions and vegetation types used to develop it. The relatively strong performance of the model in comparison to the USGS elevation-based hydroperiod suggests that vegetation composition in the Everglades is more useful than coarse estimates of elevation in describing recent hydrologic conditions in localized areas.

Vegetation-hydrology relationships within the range of CSSS habitat was further explored by superimposing the contours of inferred hydroperiod on the site ordination already presented in **Figure 3.** Marsh and wet prairies sites are arranged along a gradient of decreasing inferred hydroperiod (**Figure 12**). Inferred hydroperiods in marsh sites generally exceeded 210 days, while wet prairie hydroperiods were shorter, ranging from slightly above 210 to as low as 60 days. *Paspalum-Cladium* marsh and *Schoenus* wet prairie had a much wider range of inferred hydroperiod than other vegetation types.

Since our survey now includes good representation from throughout the recent range occupied by the CSSS, the spatial expression of hydrologic conditions predicted from existing vegetation provides a more complete view of habitat conditions (**Figure 13**). Sites with inferred hydroperiod shorter than seven months are concentrated mostly in the eastern Everglades, to the south and southwest of Long Pine Key, and on a narrow strip running from northeast to the southwest in sub-population A. Longer inferred hydroperiods at a few sites along the southern and western periphery of sub-population B habitat suggest that vegetation and hydrology in those areas may not be now suitable for CSSS. In contrast, vegetation at several sites in the northern periphery of sub-population D was indicative of shorter hydroperiods than sites immediately to the south. The utility of vegetation-inferred hydroperiods in manifesting hydrological variation in remote areas where a formal network of water measurements is absent opens the possibility that historical records of vegetation can also be used to reconstruct past hydrologic regimes via a similar approach.

3.5 Recent CSSS habitat usage

Figure 14 divides CSSS habitat into 30-day ranges of inferred hydroperiod, presenting the percentage of sites per group in which CSSS were recorded at least once in the three years prior to vegetation sampling. For example, for sites surveyed in 2005, only those where a CSSS was recorded at least once during the 2002-2004 surveys were included. Sparrows were observed at nearly 50% of sites with inferred hydroperiod between 90 and 120 days, and at 30% or more up to a hydroperiod of 240 days. Birds were observed at 20% of sites with hydroperiods of 60-90 and 240-270 days, suggesting that vegetation and hydrologic conditions on those sites are marginally suitable for the species. CSSS were recorded at very few sites with hydroperiods greater than 270 days. While the present study

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provides the general pattern of habitat use in relation to vegetation and hydrology, it should be noted that the location of sparrow and vegetation census points may have differed by as much as a few hundred meters. Now that the survey points are permanently marked and both vegetation and bird groups are focused on the same locations, analysis of CSSS habitat use in relation to vegetation and hydrology can be done with more precision in the future.

3.6 Plant biomass, hydrology and response to fire

Mean aboveground plant biomass at the sampled sites was 515 g/m^2, with dead plant materials constituting about 3/4th of the total. Among the sampled sites, marsh and wet prairie sites did not differ in mean total biomass (ANOVA: $F_{1,85}$ = 1.25, p = 0.27; Mean ± SD.: 478 ± 277 and 561 ± 310 g/m^2, respectively). At those sites, total plant cover and mean crown height were both significantly related to total biomass (**Figure 15**), and explained 55% and 16% of variation in the biomass data, respectively. We used both variables to predict the biomass for CSSS census and transect sites at which we have completed vegetation sampling in last three years. The above ground plant biomass in the prairies and marshes within the range of CSSS habitat varied from 129 to 1320 g/m^2. *Spartina* marsh and *Cladium* marsh had the highest biomass.

Total biomass in prairies and marshes are also affected by fire history, though the relationship is complex with variability indicative of the influence of external factors, including hydrology. The data presented in **Figure 16** indicate a curvilinear relationship across all sites, with biomass increasing with time since fire through age 15, and then decreasing. As fire frequency is much lower in wet conditions (**Figure 17**), biomass in marshes with longer hydroperiod tends to be controlled by hydrology rather than fire. For instance, biomass was very low in marsh sites with hydroperiods longer than 10 months, though they had not burned for several decades or more (**Figure 18**). Annual re-sampling at two census plots burned in 2003 also revealed that post-fire biomass recovery rate was different in wet prairie and marsh sites (**Figure 19**). Species number recovered to pre-burn level by Year 2 after fire in both sites, with species turnover (species gained plus species lost, expressed as a percentage of initial species number) higher in wet prairie (31 and 27) than marsh (18 and 12) (**Figure 20**). These preliminary results from the analysis of biomass, hydrology and fire from a cross-section of sites should be interpreted with caution. Collection of additional biomass samples in 2006 field season will help to improve the plant-structure and biomass model, and thus the prediction of total biomass throughout the range of CSSS habitat. In the long run, however, full understanding of the relationship will only come from application of an improved allometric prediction model to long-term monitoring data from individual sites of known fire history.

4. Conclusions & questions

Vegetation pattern in CSSS habitat is the manifestation of several interacting environmental factors, including hydrology, fire and soil characteristics. The CSSS population's response to hydrologic changes may be direct, for example, nesting behavior in breeding season, or indirect, mediated through the changes in vegetation in their habitat.

Based on our three years of vegetation study, we have so far presented a detailed account of spatial variation in vegetation structure and composition in relation to current hydrologic conditions. In the Year 2 report (Ross et al. 2004), we also described vegetation change from an analysis of qualitative vegetation observations recorded by the sparrow census team in 1981 and annually from 1992 to 2004. However, no study has yet fully addressed the question of how rapidly vegetation would change in response to an alteration in existing hydrological regimes in CSSS habitat. This question is important, with implications for restoration efforts that would modify the current hydrologic regimes to restore CSSS habitat in sub-populations A and D, where vegetation in recent years has changed to wetter types in response to hydrologic change (Ross et al. 2004). While re-sampling in 2006 of sites surveyed three years earlier will address the question to some extent, a full understanding of the rate of vegetation change will need the sites to be monitored at various time scales. In a long-term study 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. However, they pointed out that the results could not be generalized, and would depend as well on several other factors, including fire. In the prairies, repeated burning may reduce the relative proportion of sawgrass biomass (Herndon and Taylor 1986), though it is not yet known how hydrologic alteration aimed at maintaining lower water level or shorter hydroperiod in marshes, in conjunction with fire, will affect the process of prairie restoration. Recent studies have shown that after 3-4 years of fire in prairies, burned and unburned sites do not differ significantly in vegetation composition (Lockwood et al. 2005), but post-fire vegetation recovery may be affected by both pre- and post-fire hydrologic conditions. If water level increases at a burned site to submerge the residual vegetation, recovery may take different trajectory than at sites where hydrologic conditions remain unchanged. Moreover, since prairies and marshes differ in species composition and soil characteristics, the synergistic effects of hydrology and fire on these communities may differ as well.

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Appendix 1: List of species identified within or adjacent to census or transect plots in three years of study. Reference Codes: (1) Godfrey and Wooten 1979, 1981; (2) Long and Lakela 1976; (3) Wunderlin 1998; (4) Correll and Correll 1982; (5) Lellinger 1985. Scientific name: 6. Species added in 2005; 7. Unidentified specimens are now identified; 8. Scientific name changed.

CLASS	FAMILY	SCIENTIFIC NAME	AUTHOR CITATION	REF	SPCODE	ALTERNATE NAME
DICOT	FABACEAE	*Acacia pinetorum*[6]	F.J. Herm.	3	ACAPIN	
PTERIDOPHYTE	PTERIDACEAE	*Acrostichum aureum*	L.	5	ACRAUR	
PTERIDOPHYTE	PTERIDACEAE	*Acrostichum danaeifolium*	Langsd. & Fisch.	5	ACRDAN	
DICOT	FABACEAE	*Aeschynomene pratensis* var. *pratensis*	Small	2	AESPRA	
DICOT	SCROPHULARIACEAE	*Agalinis linifolia*	(Nutt.) Britton	1	AGALIN	
DICOT	SCROPHULARIACEAE	*Agalinis maritima*	(Raf.) Raf.	1	AGAMAR	
DICOT	SCROPHULARIACEAE	*Agalinis purpurea*	(L.) Pennell	1	AGAPUR	
DICOT	SCROPHULARIACEAE	*Agalinis* spp.[7]			AGASPP	
MONOCOT	LILIACEAE	*Aletris bracteata*	Northr.	3	ALEBRA	1,2 A. farinosa L. (misapplied)
MONOCOT	POACEAE	*Andropogon glomeratus* var. *glomeratus*	(Walt.) Britton et al.	2	ANDGLO	
MONOCOT	POACEAE	*Andropogon virginicus* var. *virginicus*	L.	1	ANDVIR	
PTERIDOPHYTE	SCHIZAEACEAE	*Anemia adiantifolia*	(L.) Sw.	5	ANEADI	
DICOT	APOCYNACEAE	*Angadenia berterii*	(A. DC.) Miers	2	ANGBER	3 A. berteri (A. DC.) Miers
DICOT	ANNONACEAE	*Annona glabra*	L.	1	ANNGLA	
MONOCOT	POACEAE	*Aristida purpurascens*	Poir.	2	ARIPUR	
DICOT	ASCLEPIADACEAE	*Asclepias lanceolata*	Walt.	1	ASCLAN	
DICOT	ASCLEPIADACEAE	*Asclepias longifolia*	Michx.	1	ASCLON	
DICOT	ASTERACEAE	*Aster adnatus*	Nutt.	2	ASTADN	
DICOT	ASTERACEAE	*Aster bracei*	Britton ex Small	3	ASTBRA	1 A. tenuifolius L.; 2 A. tenuifolius var. aphyllus R.W. Long
DICOT	ASTERACEAE	*Aster dumosus*	L.	1	ASTDUM	
DICOT	ASTERACEAE	*Aster* spp.[7]			ASTSPP	

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CLASS	FAMILY	SCIENTIFIC NAME	AUTHOR CITATION	REF	SPCODE	ALTERNATE NAME
DICOT	ASTERACEAE	*Baccharis* spp.		1	BACSPP	
DICOT	SCROPHULARIACEAE	*Bacopa caroliniana*	(Walt.) Robins.	1	BACCAR	
DICOT	SCROPHULARIACEAE	*Bacopa monnieri*	(L.) Pennell	1	BACMON	
PTERIDOPHYTE	BLECHNACEAE	*Blechnum serrulatum*	L.C. Rich.	5	BLESER	
DICOT	URTICACEAE	*Boehmeria cylindrica*[6]	(L.) Sw.	3	BOECYL	
DICOT	SCROPHULARIACEAE	*Buchnera floridana*	Gand.	1	BUCFLO	
MONOCOT	ORCHIDACEAE	*Calopogon tuberosus*	(L.) Britton et al.	1	CALTUB	
DICOT	EUPHORBIACEAE	*Caperonia castaneifolia*	(L.) A. St.-Hil.	1	CAPCAS	
DICOT	LAURACEAE	*Cassytha filiformis*	L.	2	CASFIL	
DICOT	CASUARINACEAE	*Casuarina glauca*	Sieber ex Spreng.	2	CASGLA	
DICOT	APIACEAE	*Centella asiatica*	(L.) Urban	1	CENASI	
DICOT	RUBIACEAE	*Cephalanthus occidentalis*	L.	1	CEPOCC	
DICOT	EUPHORBIACEAE	*Chamaesyce adenoptera subsp. pergamena*	(Bertol.) Small/(Small) D.G. Burch	2	CHAADE	3 C. pergamena (Small) Small
DICOT	RUBIACEAE	*Chiococca parvifolia*	Wullschl. ex Griseb.	4	CHIPAR	2 C. pinetorum Britton; 3 C. alba (L.) Hitchc.
DICOT	CHRYSOBALANACEAE	*Chrysobalanus icaco*	L.	1	CHRICA	
DICOT	ASTERACEAE	*Cirsium horridulum*	Michx.	1	CIRHOR	
MONOCOT	CYPERACEAE	*Cladium jamaicense*	Crantz	1	CLAJAM	
MONOCOT	POACEAE	*Coelorachis rugosa*	(Nutt.) Nash	3	COERUG	1,2 Manisuris rugosa (Nutt.) Kuntze
DICOT	COMBRETACEAE	*Conocarpus erectus*	L.	1	CONERE	
DICOT	ASTERACEAE	*Conoclinium coelestinum*	(L.) DC.	1	CONCOE	
MONOCOT	AMARYLLIDACEAE	*Crinum americanum*	L.	1	CRIAME	
MONOCOT	CYPERACEAE	*Cyperus haspan*	L.	1	CYPHAS	
MONOCOT	CYPERACEAE	*Cyperus polystachyos*	Rottb.	1	CYPPOL	
MONOCOT	CYPERACEAE	*Cyperus* spp.[7]			CYPSPP	
MONOCOT	POACEAE	*Dichanthelium aciculare*	(Desv. ex Poir.) Gould & C.A. Clark	3	DICACI	
MONOCOT	POACEAE	*Dichanthelium dichotomum*	(L.) Gould	3,4	DICDIC	1Panicum dichotomum L

CLASS	FAMILY	SCIENTIFIC NAME	AUTHOR CITATION	REF	SPCODE	ALTERNATE NAME
MONOCOT	POACEAE	*Dichanthelium* spp.			DICSPP	
MONOCOT	CYPERACEAE	*Dichromena colorata*	(L.) Hitchc.	1	DICCOL	
MONOCOT	POACEAE	*Digitaria villosa*	(Walter) Pers.	2	DIGVIL	3 D. filiformis (L.) Koeler var. filiformis
DICOT	RUBIACEAE	*Diodia virginiana*	L.	1	DIOVIR	
DICOT	ACANTHACEAE	*Dyschoriste angusta*	(A. Gray) Small	1	DYSANG	2 D. oblongifolia (Michx.) Kuntze var. angusta (A. Gray) R.W. Long
MONOCOT	POACEAE	*Echinochloa* spp.[6]			ECHSPP	
MONOCOT	CYPERACEAE	*Eleocharis cellulosa*	Torr.	1	ELECEL	
MONOCOT	CYPERACEAE	*Eleocharis geniculata*	(L.) Roem. & Schult.	1	ELEGEN	2 E. caribaea (Rottb.) S.F. Blake
DICOT	ACANTHACEAE	*Elytraria caroliniensis* var. *angustifolia*	(J.F. Gmel.) Pers./(Fern.) Blake	1	ELYCAR	
MONOCOT	POACEAE	*Eragrostis elliottii*	S. Wats.	1	ERAELL	
MONOCOT	POACEAE	*Erianthus giganteus*	(Walt.) Muhl.	1	ERIGIG	3 Saccharum giganteum (Walt.) Pers.
DICOT	ASTERACEAE	*Erigeron quercifolius*	Lam.	2	ERIQUE	
MONOCOT	ERIOCAULACEAE	*Eriocaulon* spp.			ERISPP	
DICOT	ASTERACEAE	*Eupatorium leptophyllum*	DC.	1	EUPLEP	
DICOT	ASTERACEAE	*Eupatorium mikanioides*	Chapm.	1	EUPMIK	
MONOCOT	POACEAE	*Eustachys petraea*	(Sw.) Desv.	3	EUSPET	1,2 Chloris petraea Sw.
DICOT	CONVOLVULACEAE	*Evolvulus sericeus*	Sw.	1	EVOSER	
DICOT	ASTERACEAE	*Flaveria linearis*	Lag.	1	FLALIN	
MONOCOT	CYPERACEAE	*Fuirena breviseta*	(Coville) Coville	1	FUIBRE	
MONOCOT	CYPERACEAE	*Fuirena scirpoidea*	Michx.	1	FUISCI	
DICOT	SCROPHULARIACEAE	*Gratiola ramosa*	Walter	1	GRARAM	
DICOT	NYCTAGINACEAE	*Guapira discolor*	(Spreng.) Little	4	GUADIS	2 Pisonia discolor Spreng.
DICOT	ASTERACEAE	*Helenium pinnatifidum*	(Nutt.) Rydb.	1	HELPIN	
DICOT	BORAGINACEAE	*Heliotropium polyphyllum*	Lehm.	1	HELPOL	

CLASS	FAMILY	SCIENTIFIC NAME	AUTHOR CITATION	REF	SPCODE	ALTERNATE NAME
DICOT	MALVACEAE	*Hibiscus grandiflorus*	Michx.	1	HIBGRA	
DICOT	HYDROPHYLLACEAE	*Hydrolea corymbosa*	J. Macbr. ex Elliott	1	HYDCOR	
MONOCOT	AMARYLLIDACEAE	*Hymenocallis palmeri*	S. Wats.	2	HYMPAL	
DICOT	CLUSIACEAE	*Hypericum cistifolium*[6]	Lam.	3	HYPCIS	
MONOCOT	HYPOXIDACEAE	*Hypoxis wrightii*	(Baker) Brackett	2	HYPWRI	
DICOT	LAMIACEAE	*Hyptis alata*	(Raf.) Shinners	1	HYPALA	
DICOT	AQUIFOLIACEAE	*Ilex cassine*	L.	1	ILECAS	
DICOT	CONVOLVULACEAE	*Ipomoea sagittata*	Poir.	1	IPOSAG	
DICOT	ASTERACEAE	*Iva microcephala*	Nutt.	1	IVAMIC	
MONOCOT	JUNCACEAE	*Juncus megacephalus*	M.A. Curtis	1	JUNMEG	
MONOCOT	CYPERACEAE	*Juncus roemerianus*	Scheele	1	JUNROE	
DICOT	ACANTHACEAE	*Justicia angusta*	(Chapm.) Small	3	JUSANG	1,2 Justicia ovata (Walt.) Lindau
DICOT	MALVACEAE	*Kosteletzkya virginica*	(L.) Presl.	1	KOSVIR	
DICOT	COMBRETACEAE	*Laguncularia racemosa*	(L.) C.F. Gaertn.	1	LAGRAC	
MONOCOT	POACEAE	*Leersia hexandra*	Sw.	1	LEEHEX	
DICOT	ASTERACEAE	*Liatris* spp.[6]			LIASPP	
DICOT	LINACEAE	*Linum medium var. texanum*	(Planch.) Britt./(Planch.) Fern.	1	LINMED	
DICOT	CAMPANULACEAE	*Lobelia glandulosa*	Walt.	1	LOBGLA	
DICOT	ONAGRACEAE	*Ludwigia alata*	Elliott	1	LUDALA	
DICOT	ONAGRACEAE	*Ludwigia microcarpa*	Michx.	1	LUDMIC	
DICOT	ONAGRACEAE	*Ludwigia repens*	Forst.	1	LUDREP	
DICOT	ONAGRACEAE	*Ludwigia* spp.[7]			LUDSPP	
PTERIDOPHYTE	SCHIZAEACEAE	*Lygodium microphyllum*	(Cav.) R. Br.	5	LYGMIC	
DICOT	LYTHRACEAE	*Lythrum alatum var. lanceolatum*	Pursh/(Elliott) T. & G. ex Rothr.	1	LYTALA	
DICOT	MAGNOLIACEAE	*Magnolia virginiana*	L.	1	MAGVIR	
DICOT	SCROPHULARIACEAE	*Mecardonia acuminata var. peninsularis*	(Walt.) Small/(Pennell) Rossow	1,2	MECACU	
DICOT	MYRTACEAE	*Melaleuca quinquenervia*	(Cav.) S.T. Blake	1	MELQUI	

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DICOT	ASTERACEAE	*Melanthera nivea*[8]	(L.) Small	3	MELNIV	2 M. angustifolia A. Rich.; 2M. parvifolia Small
DICOT	ANACARDIACEAE	*Metopium toxiferum*	(L.) Krug & Urb.	1	METTOX	
DICOT	ASTERACEAE	*Mikania scandens*	(L.) Willd.	1	MIKSCA	Mikania batatifolia DC.
DICOT	LOGANIACEAE	*Mitreola petiolata*	(J.F. Gmel.) Torr. & A. Gray	3	MITPET	1,2 Cynoctonum mitreola (L.) Britton
MONOCOT	POACEAE	*Muhlenbergia capillaris* var. *filipes*[8]	M.A. Curtis	2	MUHCAP	1 M. capillaris (Lam.) Trin.; 3 M. capillaris var. filipes (M.A. Curtis) Chapm. ex Beal
DICOT	MYRICACEAE	*Myrica cerifera*	L.	1	MYRCER	
DICOT	MYRSINACEAE	*Myrsine floridana*	A. DC.	4	MYRFLO	1,2 M. guianensis (Aubl.) Kuntze; 3 Rapanea punctata (Lam.) Lund.
DICOT	MENYANTHACEAE	*Nymphoides aquatica*	(S.G. Gmel.) Kuntze	1	NYMAQU	
DICOT	APIACEAE	*Oxypolis filiformis*	(Walt.) Britt.	1	OXYFIL	
MONOCOT	POACEAE	*Panicum dichotomiflorum*	Michx.	1	PANDIC	
MONOCOT	POACEAE	*Panicum hemitomon*	Schult.	1	PANHEM	
MONOCOT	POACEAE	*Panicum rigidulum*	Nees	1	PANRIG	
MONOCOT	POACEAE	*Panicum tenerum*	Beyr. ex Trin.	1	PANTEN	
MONOCOT	POACEAE	*Panicum virgatum*	L.	1	PANVIR	
DICOT	VITACEAE	*Parthenocissus quinquefolia*	(L.) Planch.	2	PARQUI	
MONOCOT	POACEAE	*Paspalidium geminatum* var. *geminatum*	(Forst.) Stapf	1	PASGEM	
MONOCOT	POACEAE	*Paspalum blodgettii*	Chapm.	2	PASBLO	1 P. caespitosum Flugge
MONOCOT	POACEAE	*Paspalum monostachyum*	Vasey ex Chapm.	1	PASMON	
MONOCOT	ARACEAE	*Peltandra virginica*	(L.) Schott & Endl.	1	PELVIR	
DICOT	LAURACEAE	*Persea borbonia*	(L.) Spreng.	1	PERBOR	
MONOCOT	POACEAE	*Phragmites australis*	(Cav.) Trin. Ex Steud.	1	PHRAUS	
DICOT	VERBENACEAE	*Phyla nodiflora*	(L.) Greene	1	PHYNOD	
DICOT	VERBENACEAE	*Phyla stoechadifolia*	(L.) Small	1	PHYSTO	

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CLASS	FAMILY	SCIENTIFIC NAME	AUTHOR CITATION	REF	SPCODE	ALTERNATE NAME
DICOT	EUPHORBIACEAE	*Phyllanthus caroliniensis*	Walt.	1	PHYCAR	2 P. caroliniensis subsp. saxicola (Small) G.L. Webster
DICOT	EUPHORBIACEAE	*Phyllanthus* spp.[7]			PHYSPP	
DICOT	LENTIBULARIACEAE	*Pinguicula pumila*	Michx.	1	PINPUM	
DICOT	TURNERACEAE	*Piriqueta caroliniana*	(Walter) Urb.	2	PIRCAR	
DICOT	ASTERACEAE	*Pityopsis graminifolia*[6]	(Michx.) Nutt.	3	PITGRA	2 Heterotheca graminifolia (Michx.) Shinners
DICOT	ASTERACEAE	*Pluchea odorata*	(L.) Cass.	1	PLUODO	
DICOT	ASTERACEAE	*Pluchea rosea*	Godfrey	1	PLUROS	
DICOT	POLYGALACEAE	*Polygala balduinii*	Nutt.	1	POLBAL	
DICOT	POLYGALACEAE	*Polygala grandiflora* var. *leiodes*	Walt./Blake	2	POLGRA	
DICOT	POLYGONACEAE	*Polygonum hydropiperoides*	Michx.	1	POLHYD	
MONOCOT	PONTEDERIACEAE	*Pontederia cordata* var. *lanciifolia*	L./(Muhl.) Torr.	1	PONCOR	
MONOCOT	POTAMOGETONACEAE	*Potamogeton illinoensis*	Morong	1	POTILL	
DICOT	HALORAGACEAE	*Proserpinaca palustris*	L.	1	PROPAL	
DICOT	RUBIACEAE	*Randia aculeata*	L.	2	RANACU	
DICOT	RHIZOPHORACEAE	*Rhizophora mangle*	L.	1	RHIMAN	
MONOCOT	CYPERACEAE	*Rhynchospora divergens*	Chapm. ex M.A. Curtis	1	RHYDIV	
MONOCOT	CYPERACEAE	*Rhynchospora inundata*	(Oakes) Fern.	1	RHYINU	
MONOCOT	CYPERACEAE	*Rhynchospora microcarpa*	Baldw. ex Gray	1	RHYMIC	
MONOCOT	CYPERACEAE	*Rhynchospora tracyi*	Britt.	1	RHYTRA	
DICOT	ACANTHACEAE	*Ruellia caroliniensis*	(J.F. Gmel) Steud.	2	RUECAR	
MONOCOT	ARECACEAE	*Sabal palmetto*	(Walt.) Lodd. ex Schult. & Schult.	1	SABPAL	
DICOT	GENTIANACEAE	*Sabatia grandiflora*	(Gray) Small	1	SABGRA	
MONOCOT	ALISMATACEAE	*Sagittaria lancifolia* var. *lancifolia*	L.	1	SAGLAN	
DICOT	SALICACEAE	*Salix caroliniana*	Michx.	1	SALCAR	

CLASS	FAMILY	SCIENTIFIC NAME	AUTHOR CITATION	REF	SPCODE	ALTERNATE NAME
DICOT	PRIMULACEAE	*Samolus ebracteatus*	Kunth.	1	SAMEBR	
DICOT	APOCYNACEAE	*Sarcostemma clausum*	(Jacq.) Roem. & Schult.	1	SARCLA	
DICOT	SAURURACEAE	*Saururus cernuus*	L.	1	SAUCER	
DICOT	ANACARDIACEAE	*Schinus terebinthifolius*	Raddi	1	SCHTER	
MONOCOT	POACEAE	*Schizachyrium rhizomatum*	(Swallen) Gould	1	SCHRHI	
MONOCOT	LILIACEAE	*Schoenolirion albiflorum*	(Raf.) R.R. Gates	3	SCHALB	1,2 S. elliottii Feay ex A. Gray
MONOCOT	CYPERACEAE	*Schoenus nigricans*	L.	1	SCHNIG	
MONOCOT	CYPERACEAE	*Scleria verticillata*	Muhl. ex. Willd.	1	SCLVER	
MONOCOT	ARECACEAE	*Serenoa repens*	(W. Bartram) Small	1	SERREP	
DICOT	AIZOACEAE	*Sesuvium portulacastrum*	(L.) L.	1	SESPOR	
MONOCOT	POACEAE	*Setaria parviflora*	(Poir.) Kerguelen	3	SETPAR	1,2 S. geniculata P. Beauv.
DICOT	SAPOTACEAE	*Sideroxylon reclinatum* var. *austrofloridense*[8]	Michx./(Whetstone) Kartesz & Gandhi	3	SIDREC	1 Bumelia reclinata (Michx.) Vent.
DICOT	SAPOTACEAE	*Sideroxylon salicifolium*[8]	(L.) Lam.	3	SIDSAL	2 Dipholis salicifolia (L.) A. DC.; 4Bumelia salicifolia (L.) Sw.
MONOCOT	IRIDACEAE	*Sisyrinchium angustifolium*	Mill.	3	SISANG	2 S. atlanticum Bickn.
DICOT	SOLANACEAE	*Solanum blodgettii*	Chapm.	2	SOLBLO	3 S. verbascifolium L.; 4 S. donianum Walp.
DICOT	ASTERACEAE	*Solidago* spp.[7]			SOLSPP	
DICOT	ASTERACEAE	*Solidago stricta*	Ait.	1	SOLSTR	
MONOCOT	POACEAE	*Spartina bakeri*	Merr.	1	SPABAK	
DICOT	RUBIACEAE	*Spermacoce terminalis*	(Small) Kartesz & Gandhi	3	SPETER	2 Borreria terminalis Small
MONOCOT	ORCHIDACEAE	*Spiranthes* spp.[7]			SPISPP	
DICOT	ACANTHACEAE	*Stenandrium dulce* var. *floridanum*	(Cav.) Nees/A. Gray	2	STEDUL	1 S. floridanum (Gray) Small
DICOT	EUPHORBIACEAE	*Stillingia aquatica*	Chapm.	1	STIAQU	
GYMNOSPERM	CUPRESSACEAE	*Taxodium distichum* var. *imbricarium*	(L.) L.C./(Nutt.) Croom		TAXDIS	

CLASS	FAMILY	SCIENTIFIC NAME	AUTHOR CITATION	REF	SPCODE	ALTERNATE NAME
DICOT	LAMIACEAE	*Teucrium canadense*	L.	1	TEUCAN	
MONOCOT	MARANTACEAE	*Thalia geniculata*	L.	1	THAGEN	
PTERIDOPHYTE	THELYPTERIDACEAE	*Thelypteris palustris var. pubescens*	Schott/(Laws.) Fern.	5	THEPAL	
MONOCOT	TYPHACEAE	*Typha domingensis*	Pers.	1	TYPDOM	
DICOT	LENTIBULARIACEAE	*Utricularia cornuta*	Michx.	1	UTRCOR	
DICOT	LENTIBULARIACEAE	*Utricularia foliosa*	L.	1	UTRFOL	
DICOT	LENTIBULARIACEAE	*Utricularia gibba*[6]	L.	1	UTRGIB	2 U. biflora Lam.
DICOT	LENTIBULARIACEAE	*Utricularia purpurea*	Walt.	1	UTRPUR	
DICOT	LENTIBULARIACEAE	*Utricularia radiata*	Small	1	UTRRAD	
DICOT	LENTIBULARIACEAE	*Utricularia spp.*			UTRSPP	
DICOT	LENTIBULARIACEAE	*Utricularia subulata*	L.	1	UTRSUB	
DICOT	ASTERACEAE	*Vernonia blodgettii*	Small	1	VERBLO	
DICOT	FABACEAE	*Vicia acutifolia*	Elliott	1	VICACU	
DICOT	VITACEAE	*Vitis rotundifolia*	Michx.	1	VITROT	
MONOCOT	XYRIDACEAE	*Xyris* spp.[6]			XYRSPP	
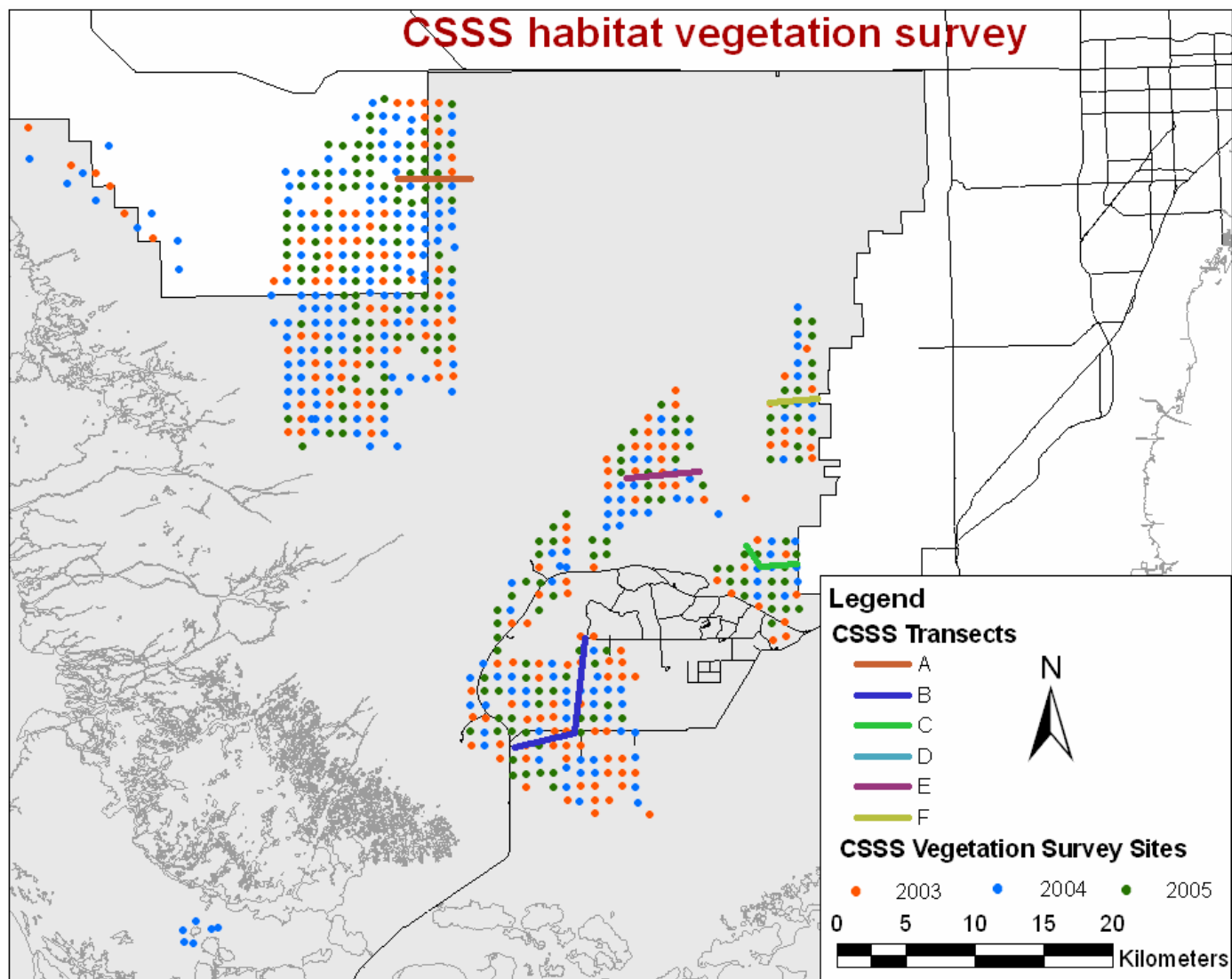
Figure 1: Location of CSSS vegetation survey census sites and transect
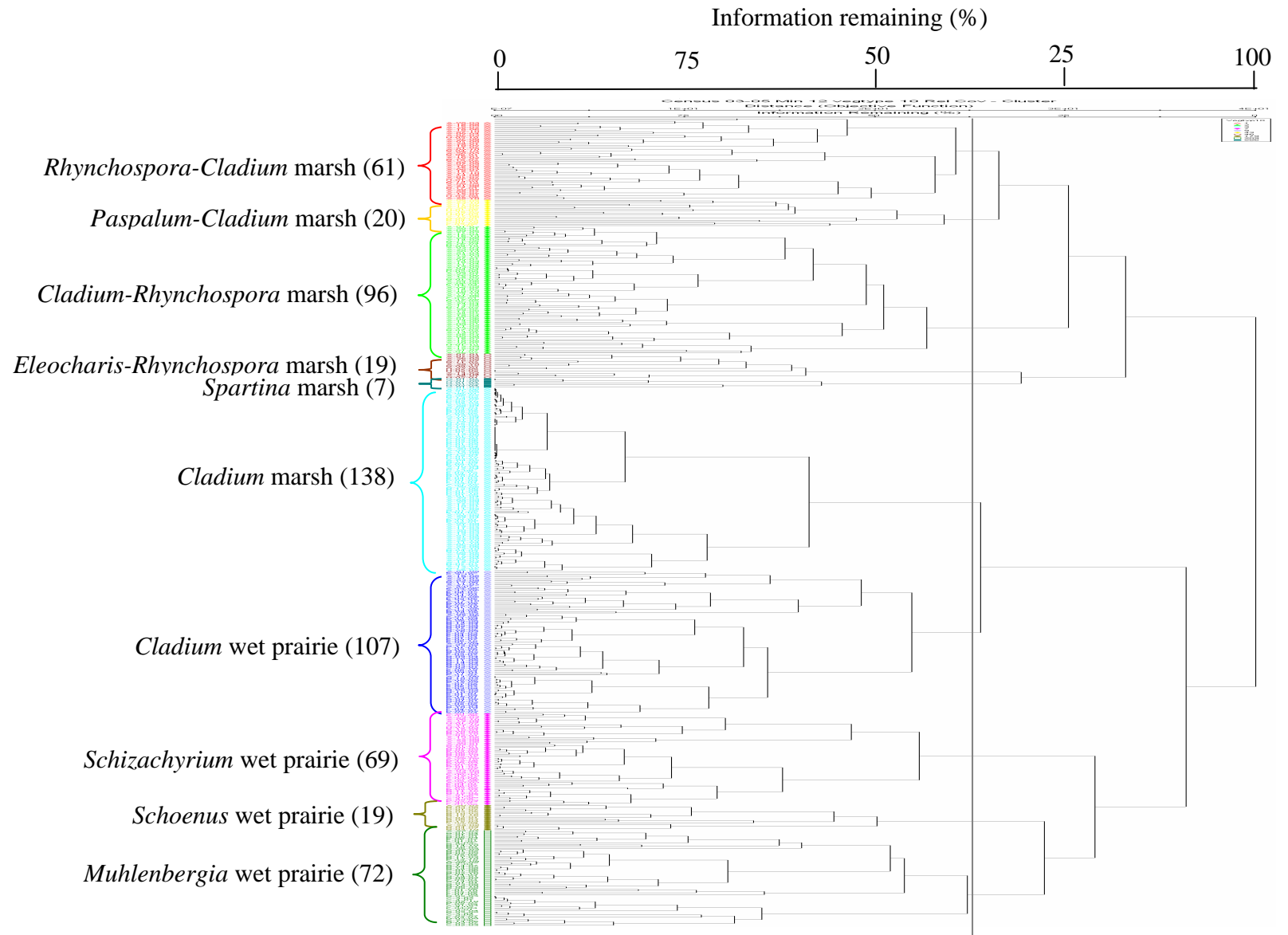
Figure 2: Vegetation types identified through cluster analysis of species cover values at 608 census sites sampled in three years (2003-05). Numbers in parentheses are number of sites sampled in each type. Information remaining (%) is based on Wishart's objective function, following McCune and Grace (2002).
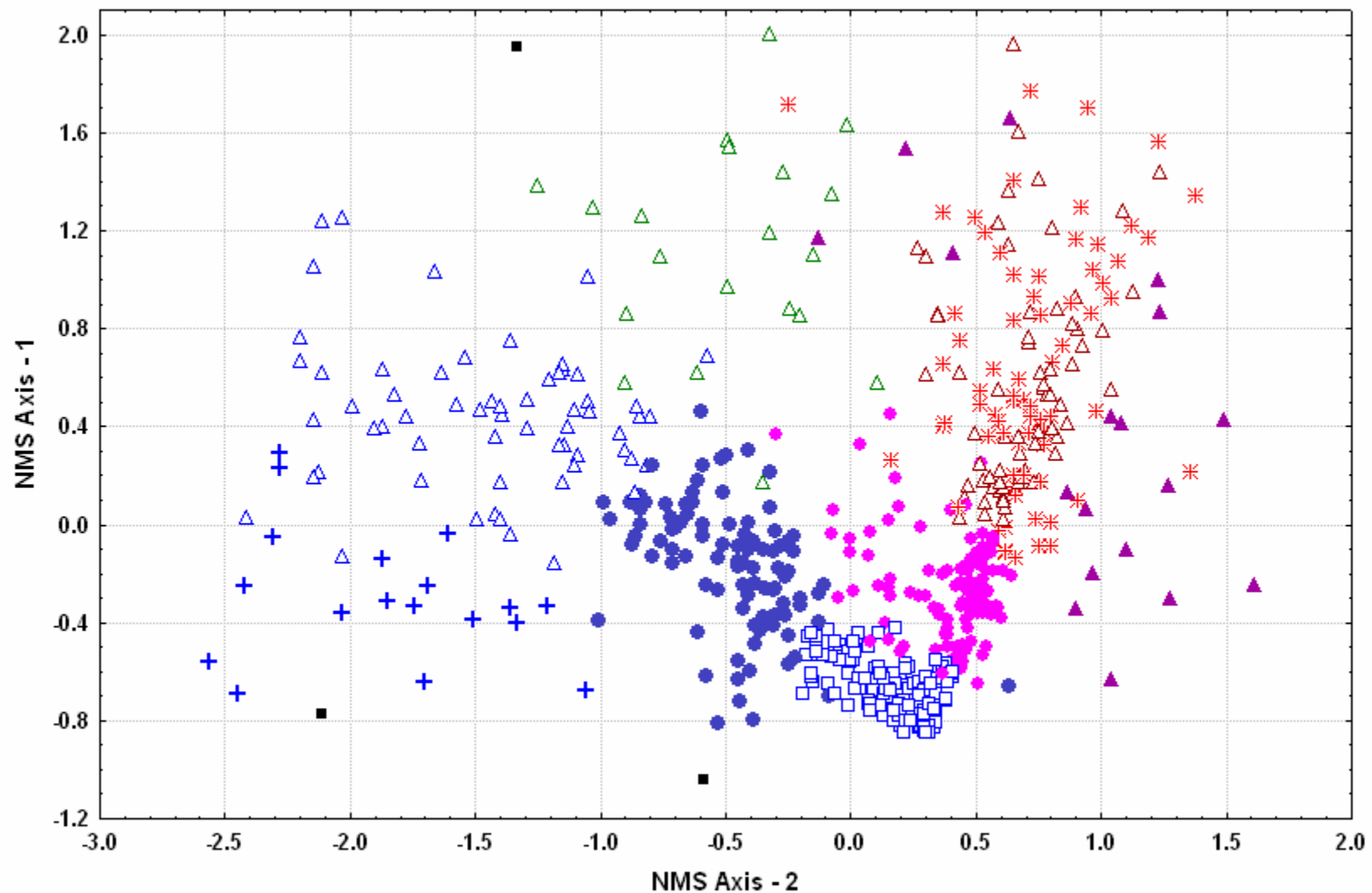
Figure 3: Site scores from 2-axis non-metric multidimensional scaling (NMS) ordination, based on relative cover at 608 census plots sampled in three years (2003-05). **+** *Eleocharis-Rhynchospora* marsh △ *Rhynchospora-Cladium* marsh ● *Cladium-Rhynchospora* marsh ☐ *Cladium* marsh ■ *Spartina* marsh △ *Paspalum-Cladium* marsh ● *Cladium* wet prairie (WP) △ *Schizachyrium* WP ▲ *Schoenus* WP ✳ *Muhlenbergia* WP
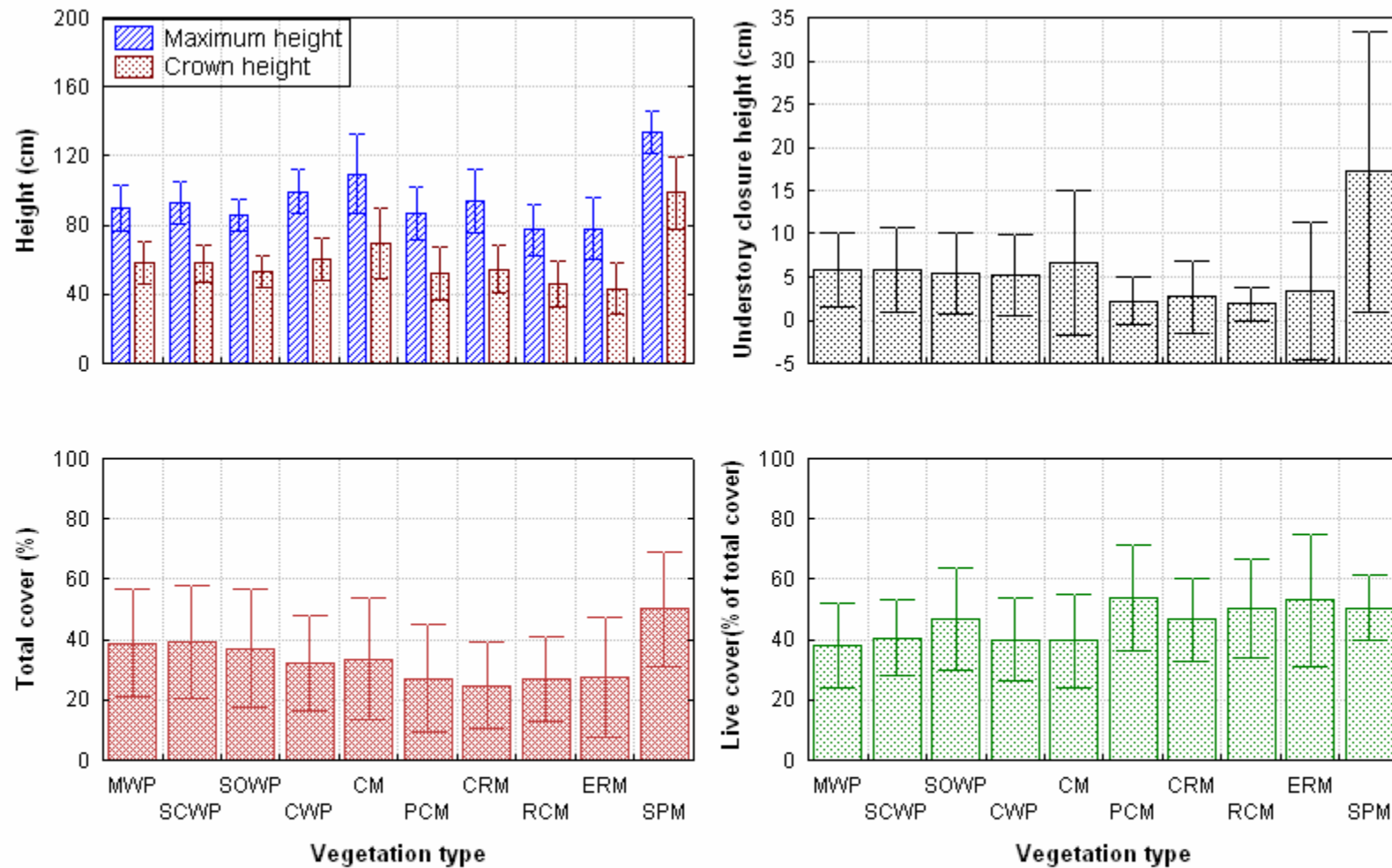
Figure 4: Mean (±1 S.D.) for five important structural variables in herb stratum of eight vegetation types, based on census plots sampled in three years (2003-05). MWP = *Muhlenbergia* wet prairie; SCWP = *Schizachyrium* wet prairie; SOWP = *Schoenus* wet prairie; CWP = *Cladium* wet prairie; CM = *Cladium* marsh; PCM= *Paspalum-Cladium* marsh; CRM = *Cladium-Rhynchospora* marsh; RCM = *Rhynchospora-Cladium* marsh; ERM = *Eleocharis-Rhynchospora* marsh; SPM = *Spartina* marsh
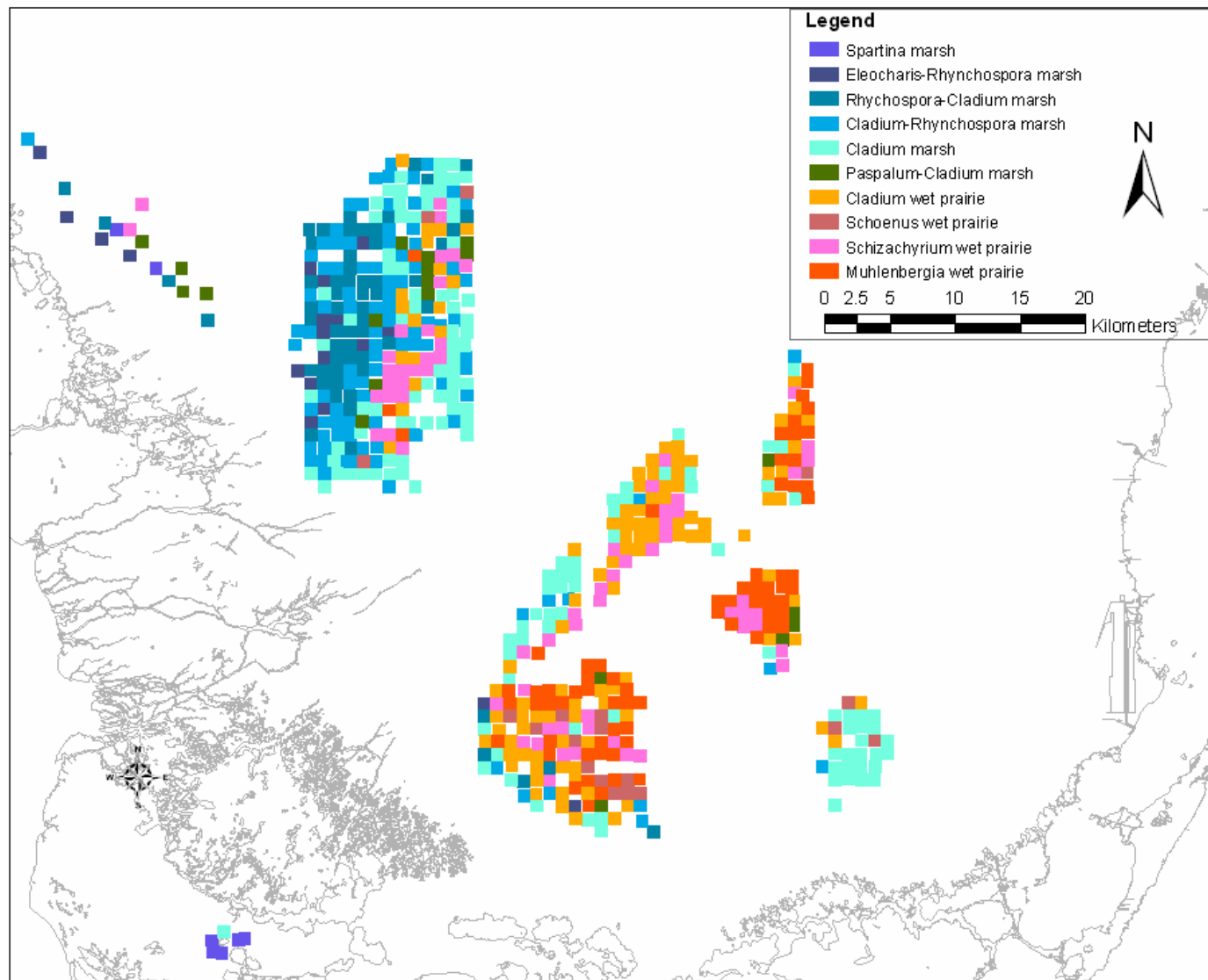
Figure 5: Distribution of vegetation types within recent range of CSSS, based on census plots sampled in three years (2003-05)
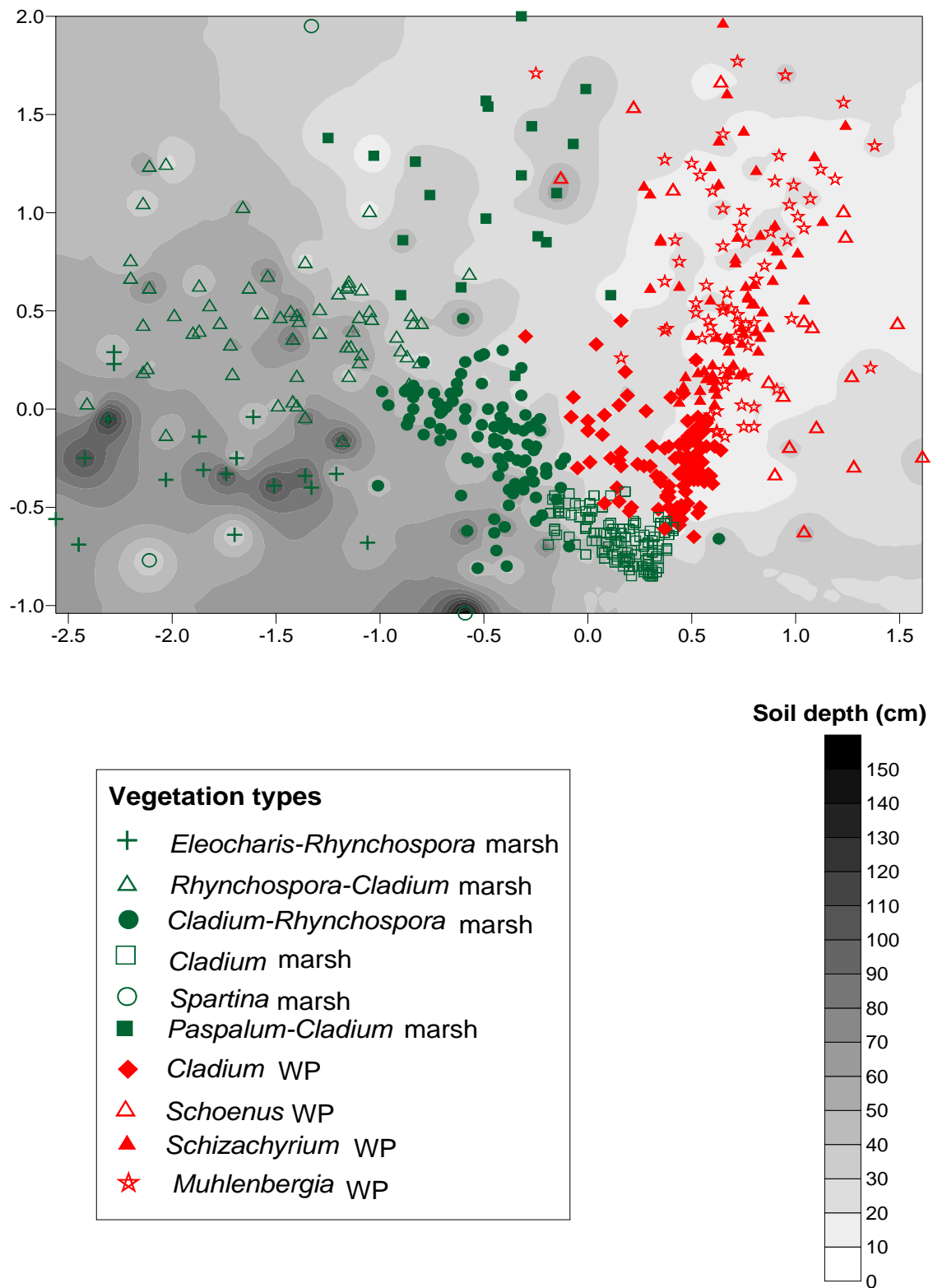
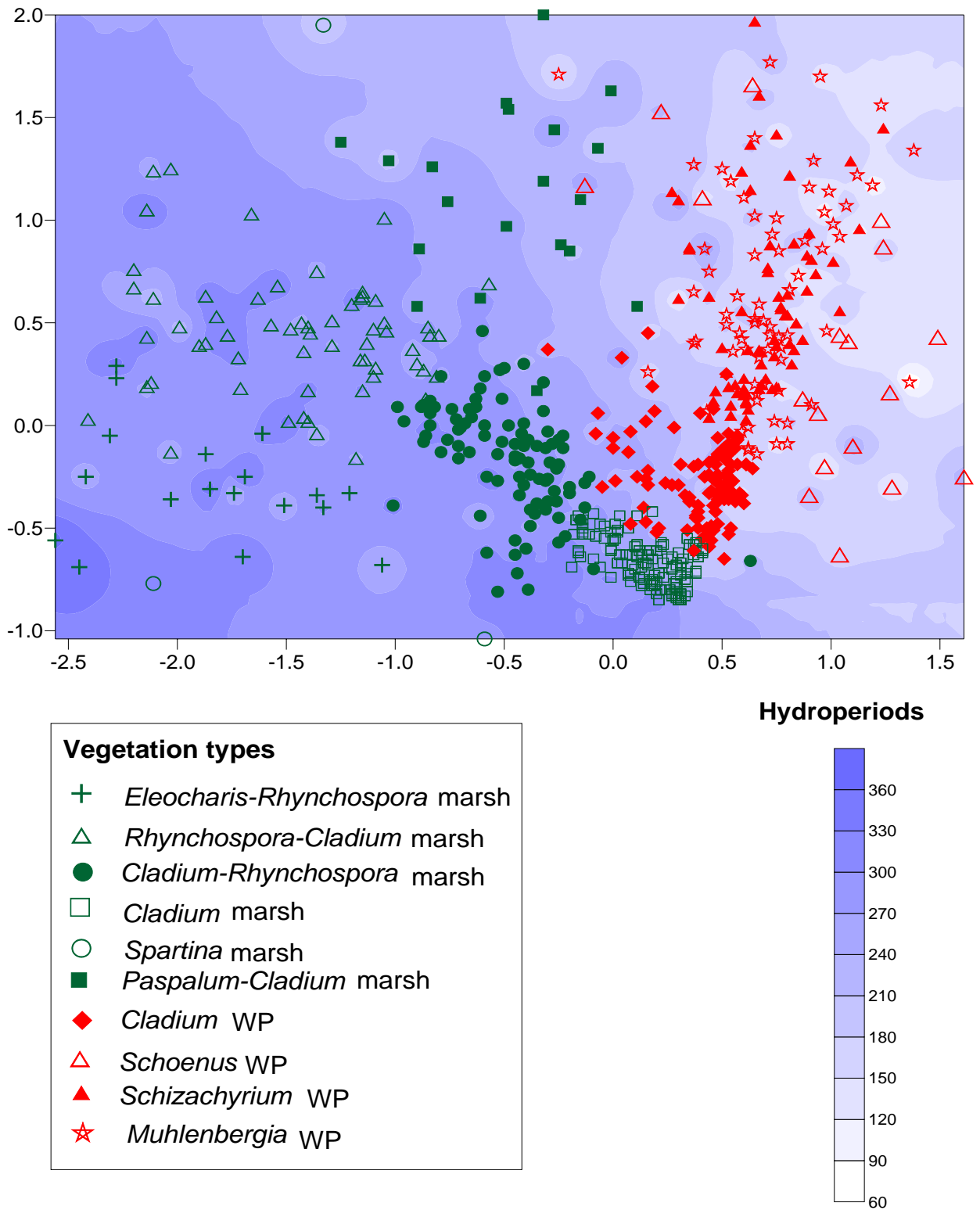**Figure 6:** Relationship of vegetation type to soil depth in CSSS landscape, as indicated by their co-variation in NMS ordination space.
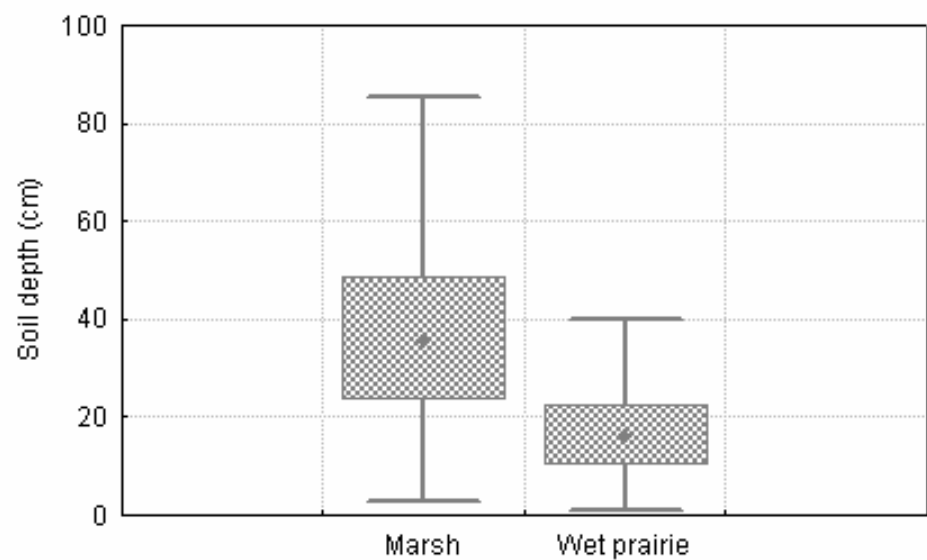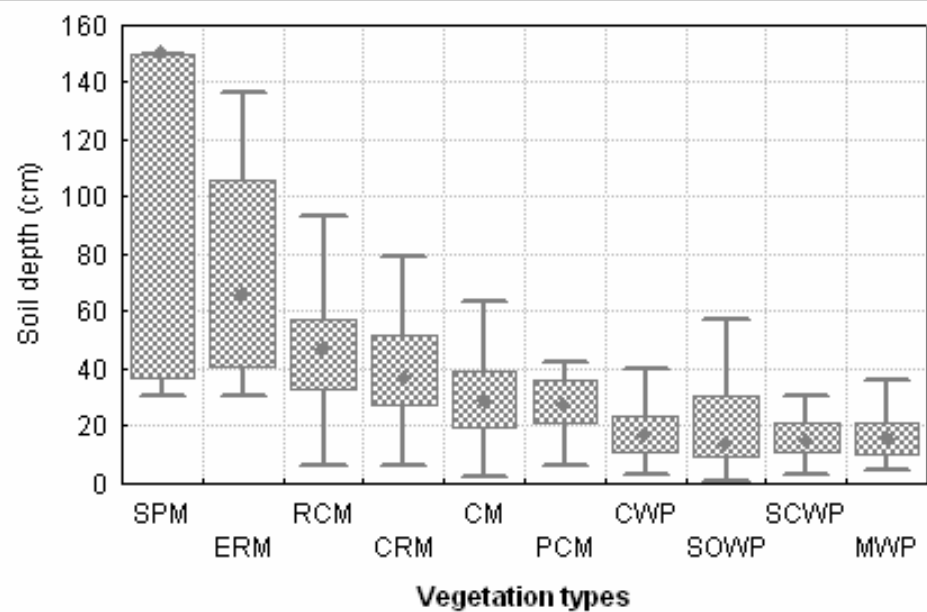
**Figure 7**: Soil depth at the CSSS census sites surveyed in three years (2003-05).
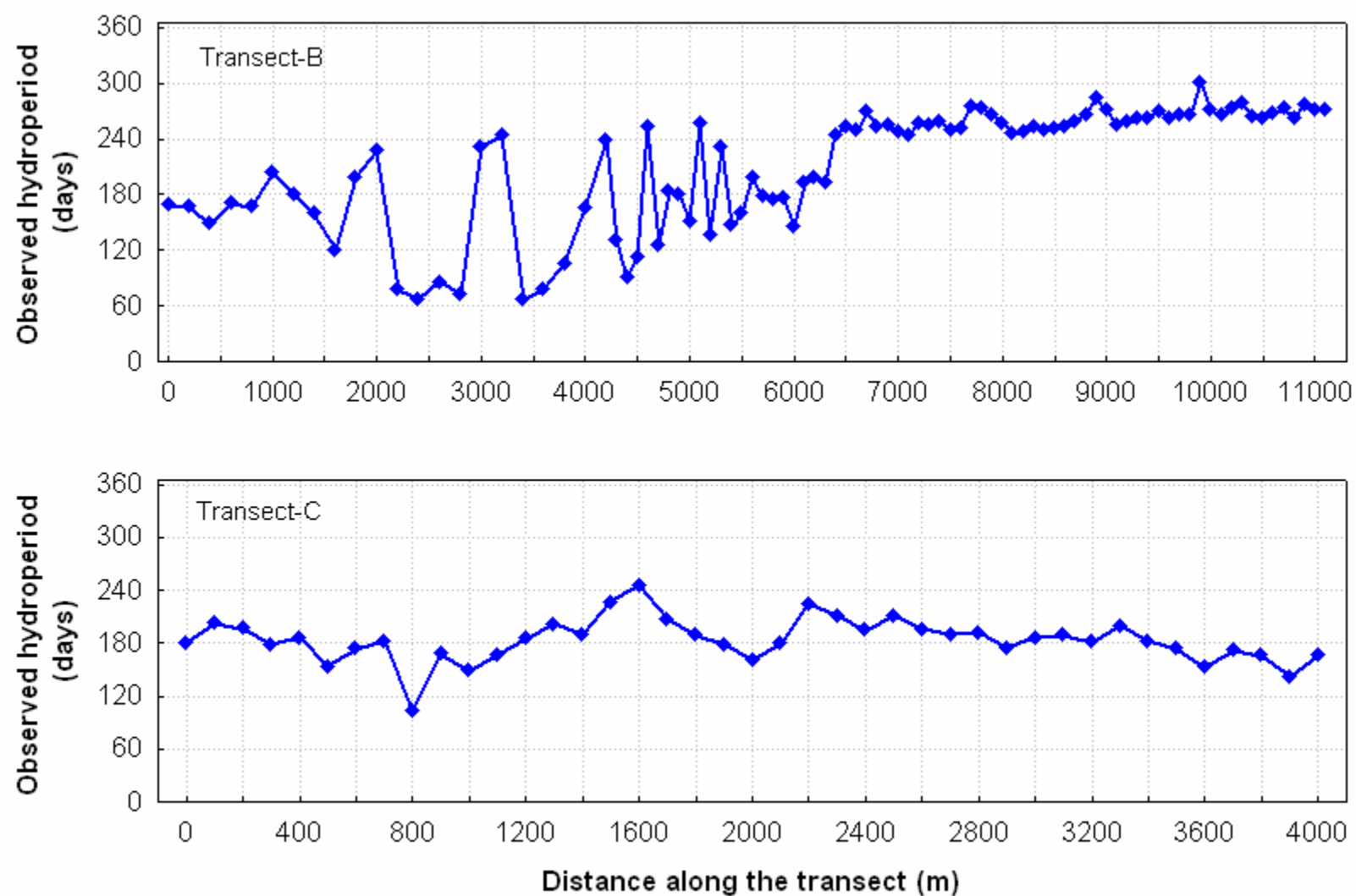
Figure 8: Mean hydroperiod (days) at the vegetation survey sites along Transects B and C. Hydroperiods are calculated from mean elevation of 10 compositional sub-plots and respective stage recorders, and averaged over five years prior to vegetation sampling.
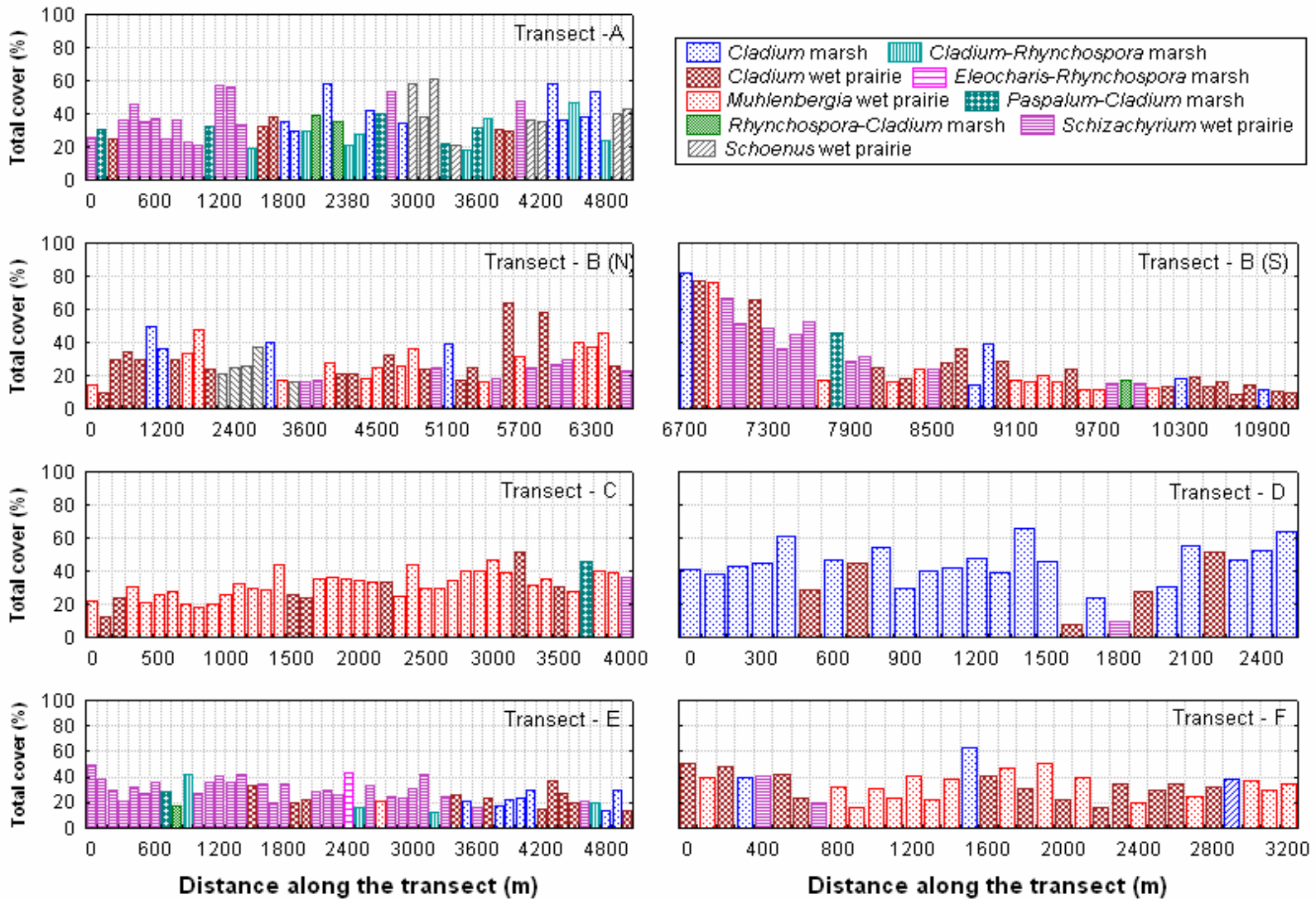
Figure 9: Vegetation type and total herb stratum vegetation cover along 6 transects. Transect B has two sections, northern (N) and southern (S) that meet at the Old Ingraham Highway.
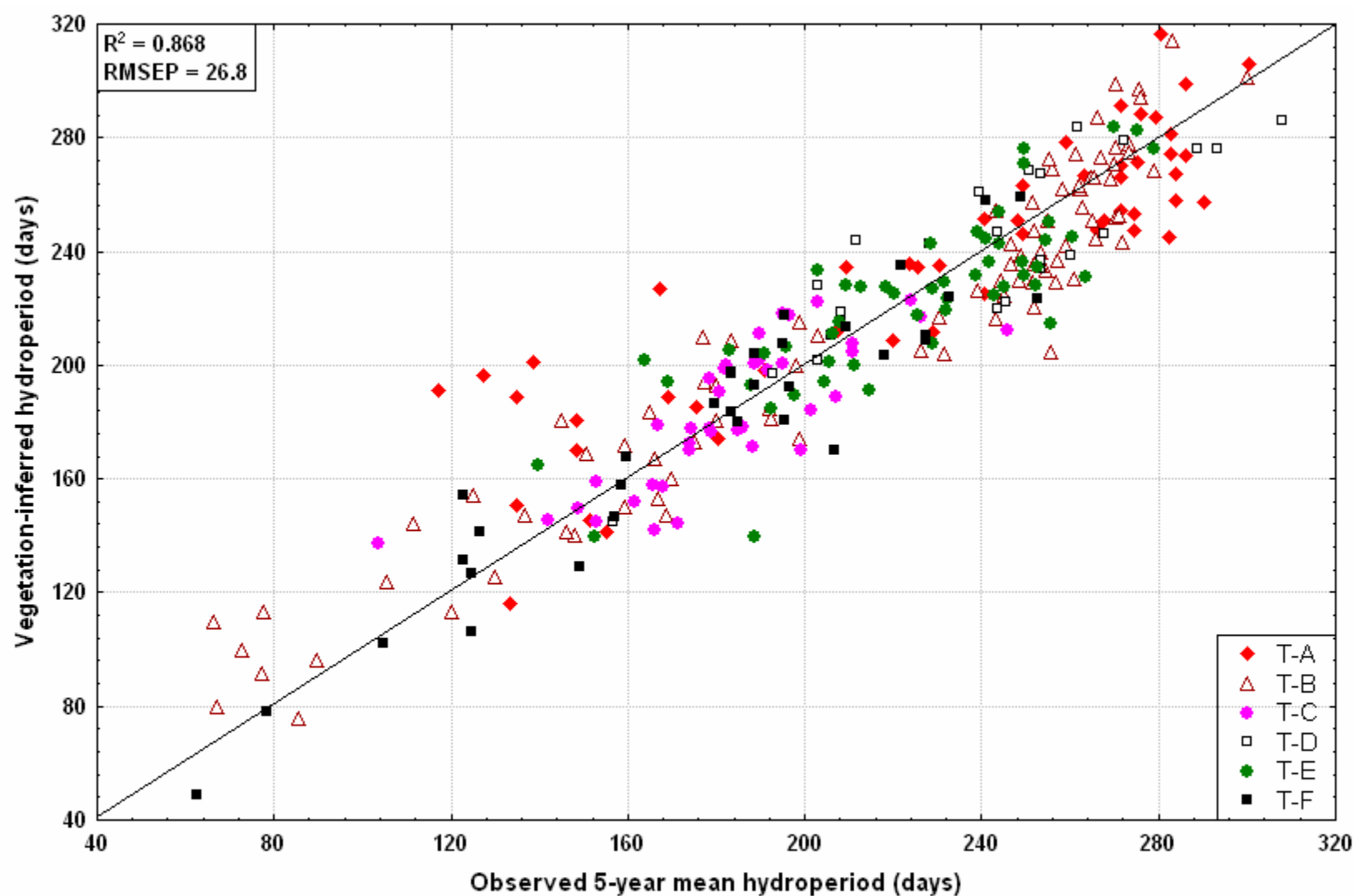
Figure 10: Observed vs inferred hydroperiods at 291 locations along Transects A, B, C, D, E, and F. Inferred values are derived from leave-one-out procedure in WAPLS regression, C^2 program (Juggins 2003)

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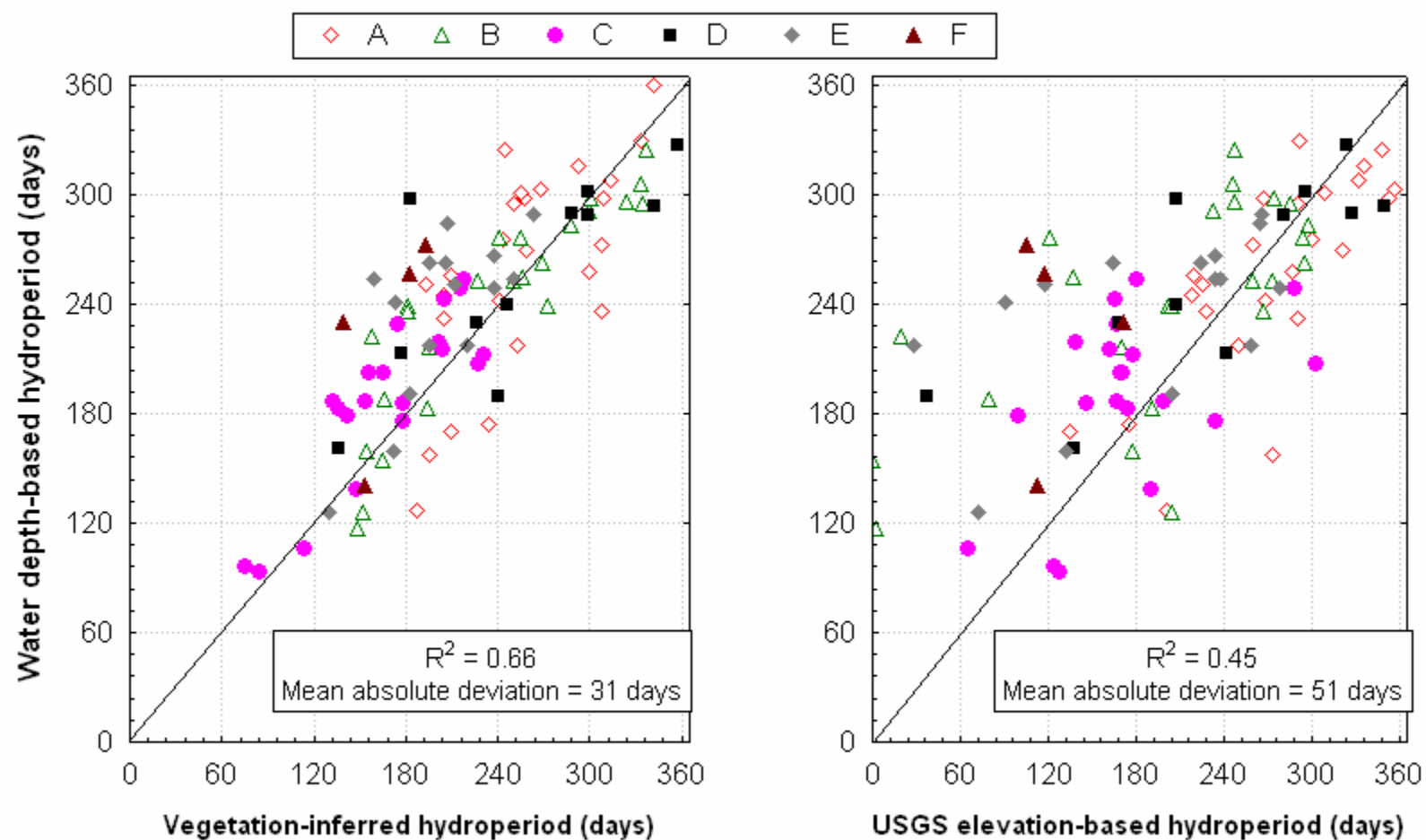
Figure 11: Scatter diagrams showing the relationship of water depth-based hydroperiod with (a) vegetation-inferred, and (b) USGS elevation-based hydroperiods.

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Figure 12: Relationships of vegetation type to inferred hydroperiod in the CSSS landscape as indicated by their co-variation in NMS ordination space.
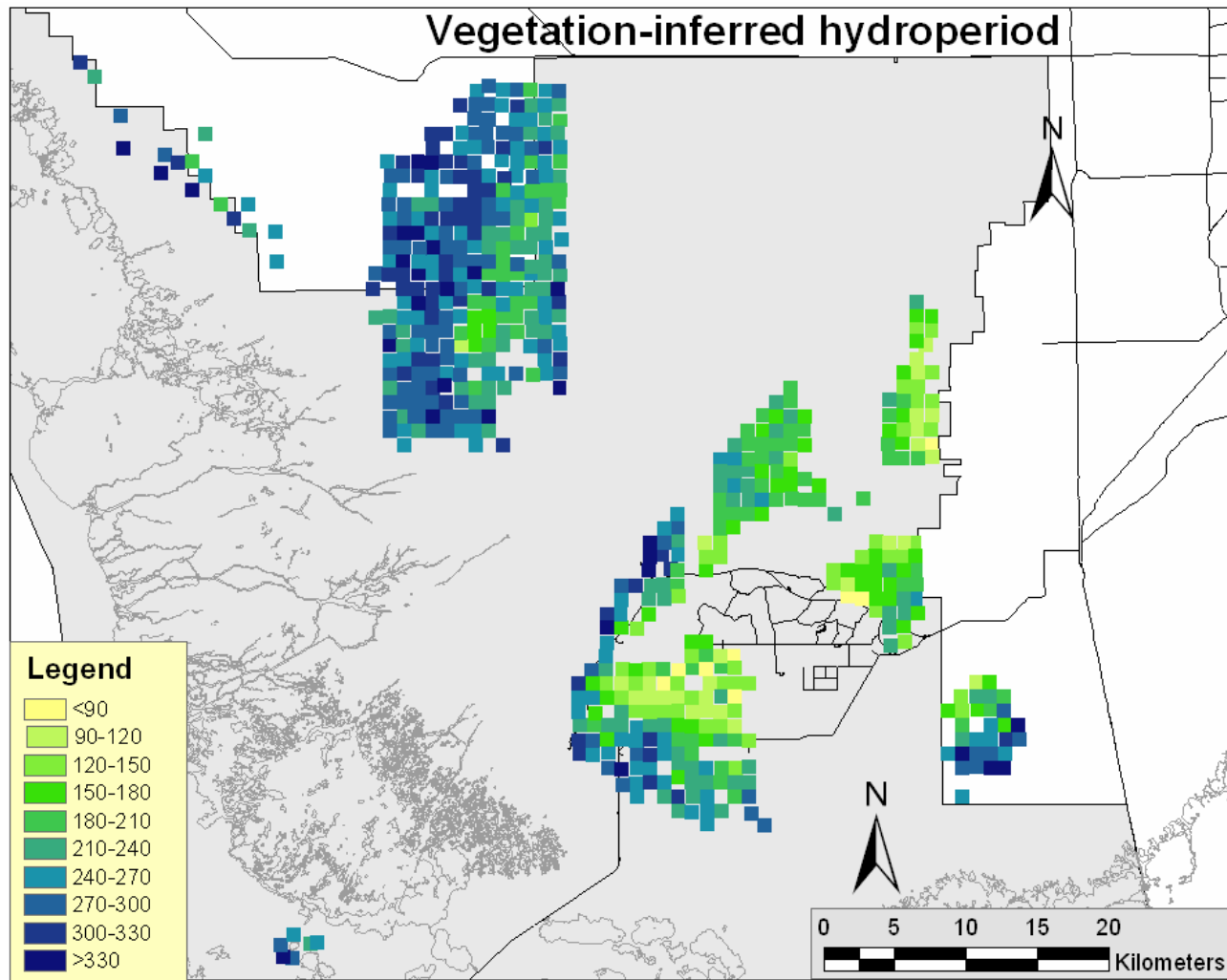
Figure 13: Distribution of vegetation-inferred hydroperiods within the range of CSSS habitat, based on 608 census sites sampled in 2003, 2004 and 2005.
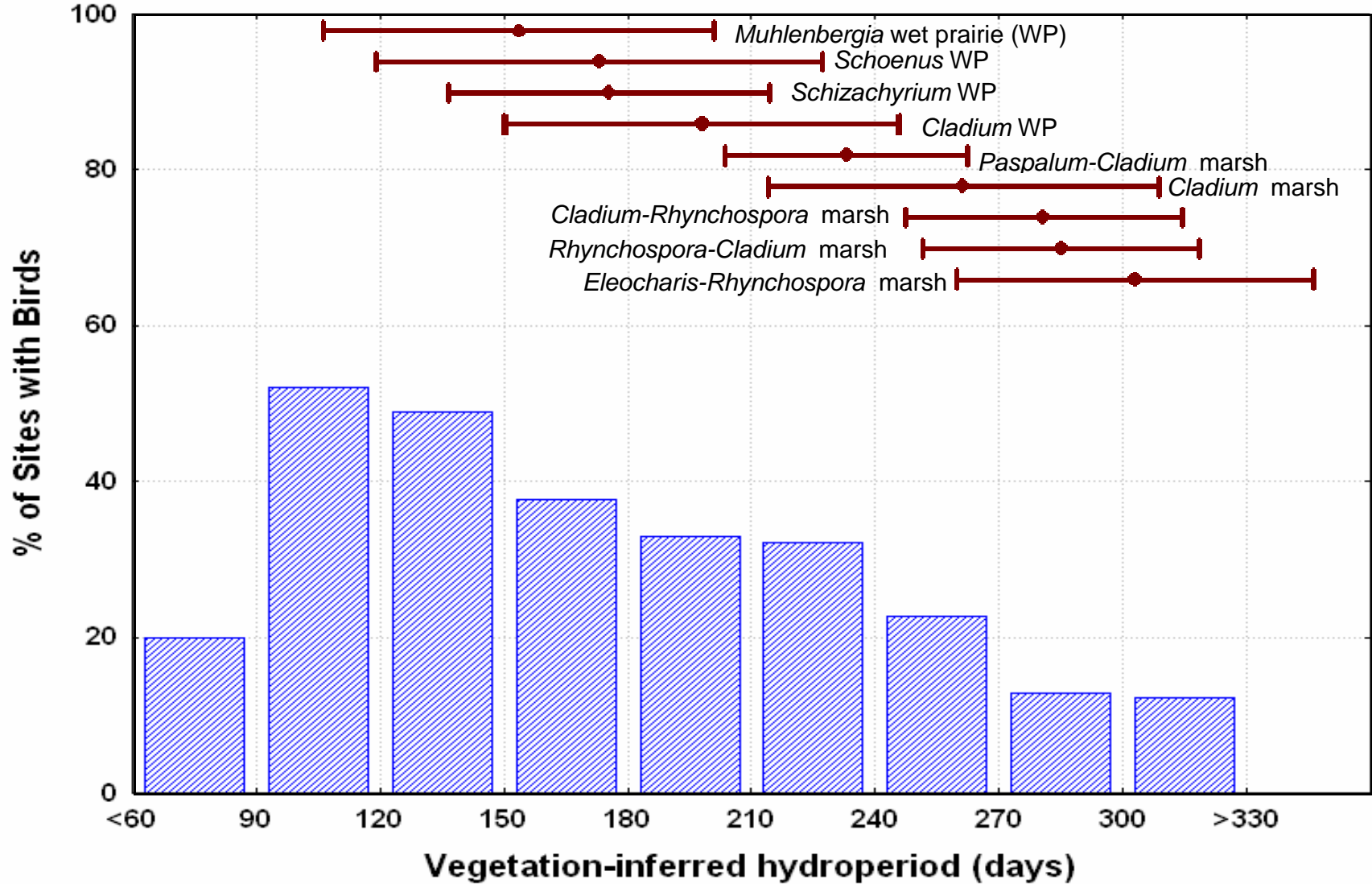
Figure 14: Percentage of census locations, subdivided into 30-day increments of inferred hydroperiod, in which CSSS were observed at least once during 3 years prior to vegetation sampling. Data are based on 608 sites sampled in three years (2003-05). Mean (± 1 SD) inferred hydroperiod for nine vegetation types among 2003-05 vegetation census plots are superimposed.
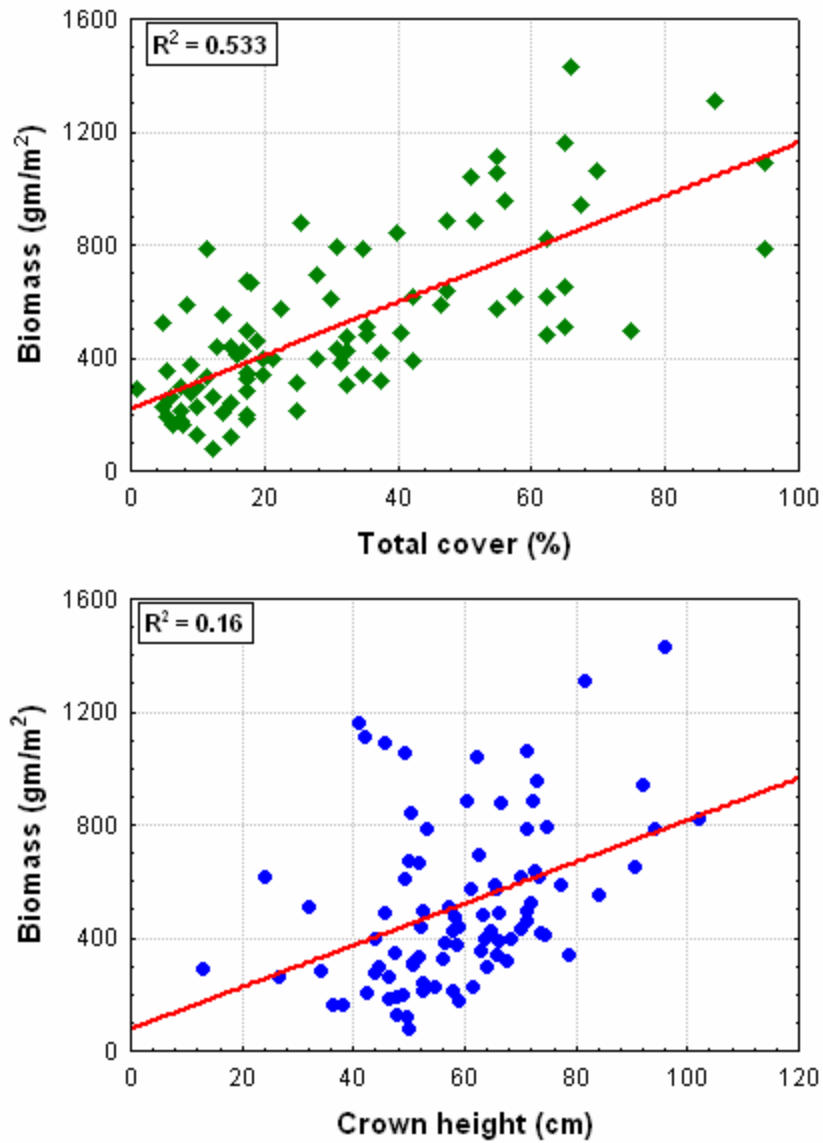
Figure 15: Scatter plots showing aboveground biomass in relation to crown cover and height. Data are based on 88 CSSS census sites sampled in 2005.
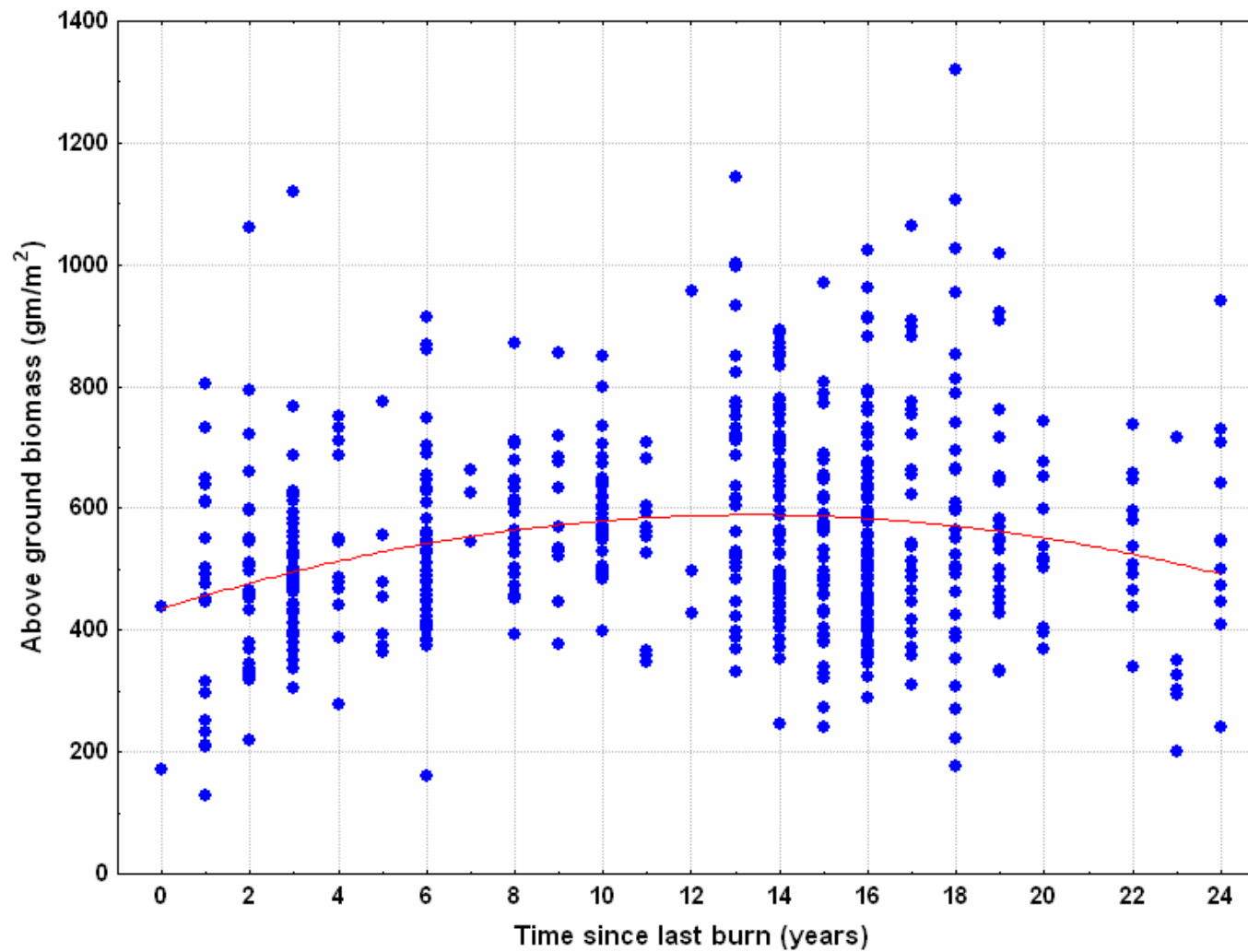
Figure 16: Aboveground biomass in relation to time since last fire in wet prairies and marshes within CSSS habitat. Time since last fire is calculated from fire data (1980-2005) received from ENP. Aboveground biomass was predicted from crown cover and height at 293 transect and 608 census sites sampled in three years (2003-2005)
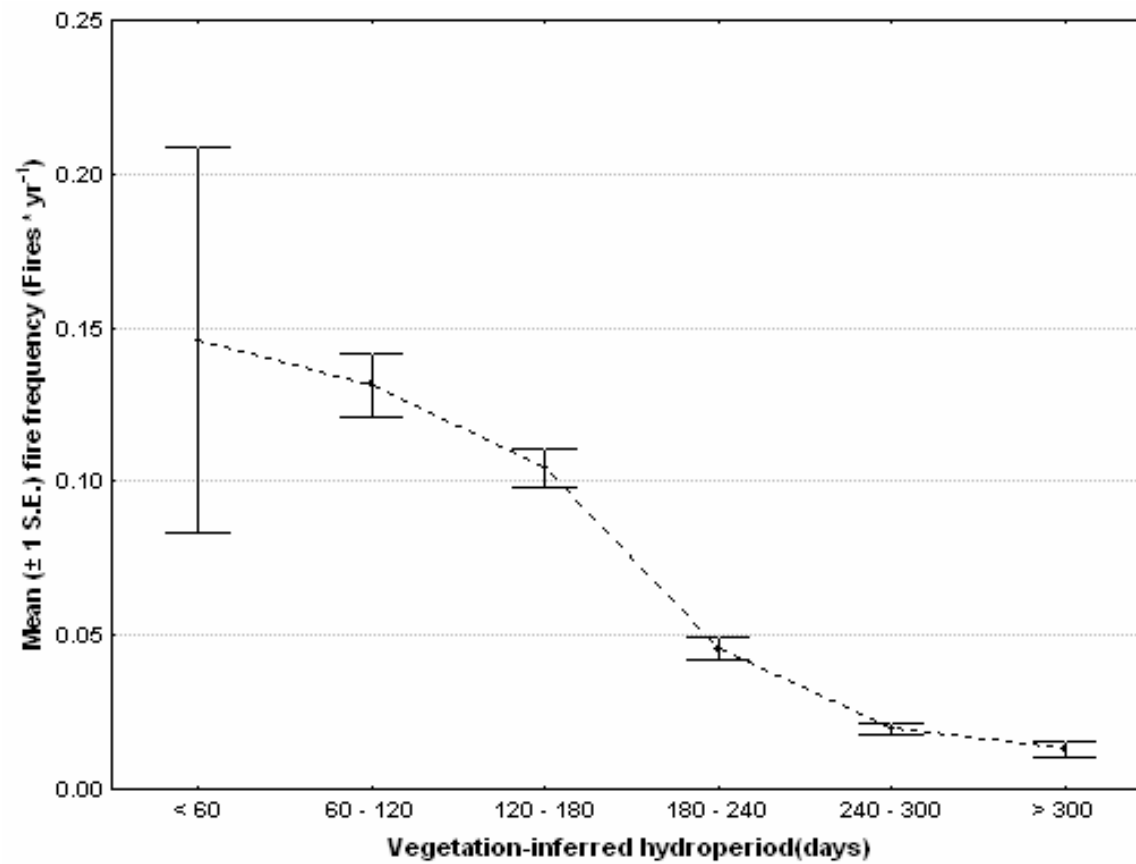
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Figure 17: Fire frequency in relation to vegetation-inferred hydroperiod in wet prairies and marshes within CSSS habitat. Fire frequency is based on fire data (1980-2005) received from ENP.
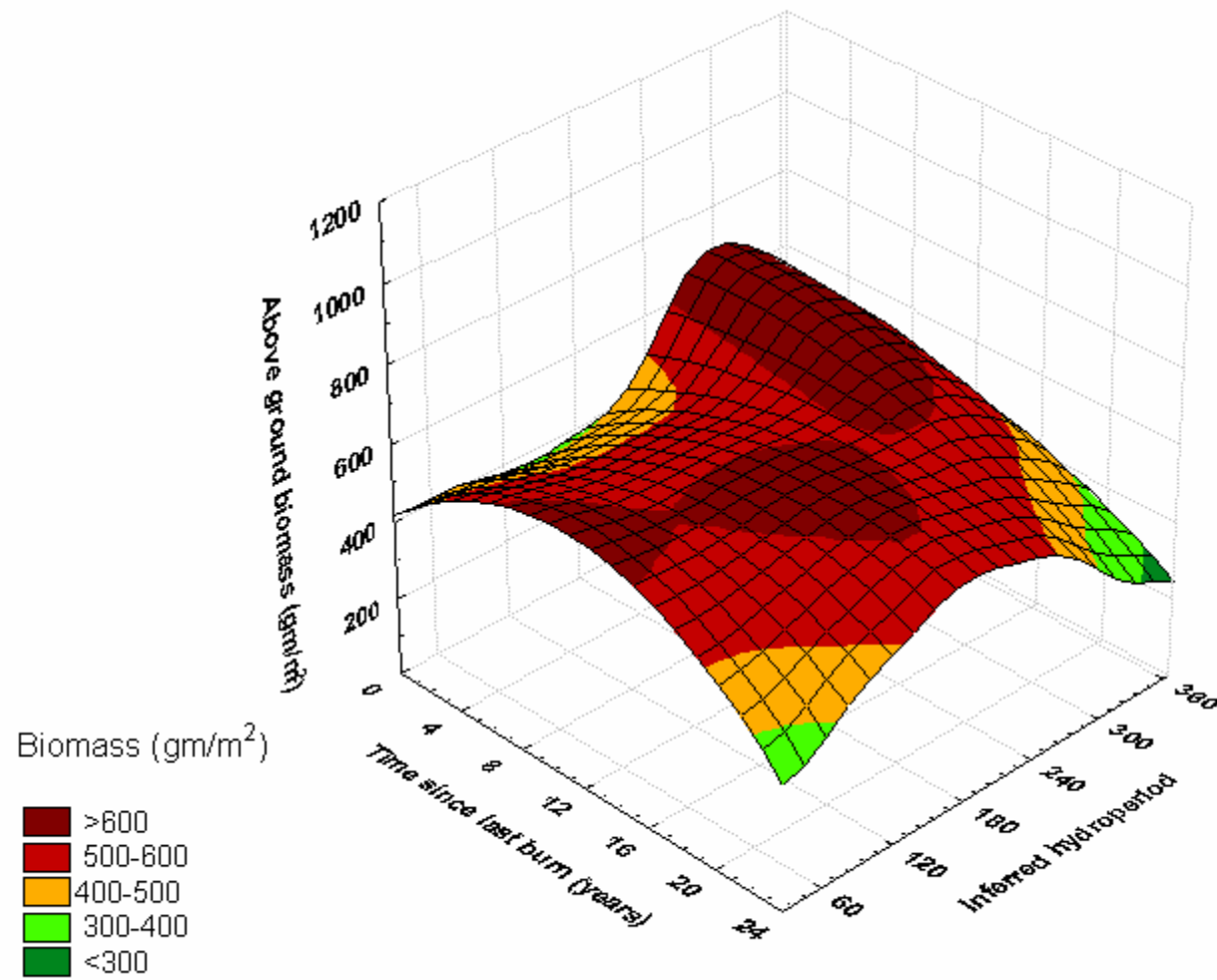
Figure 18: Surface plot showing the relationship among aboveground biomass, time since last fire and inferred-hydroperiod in wet prairies and marshes within CSSS habitat.
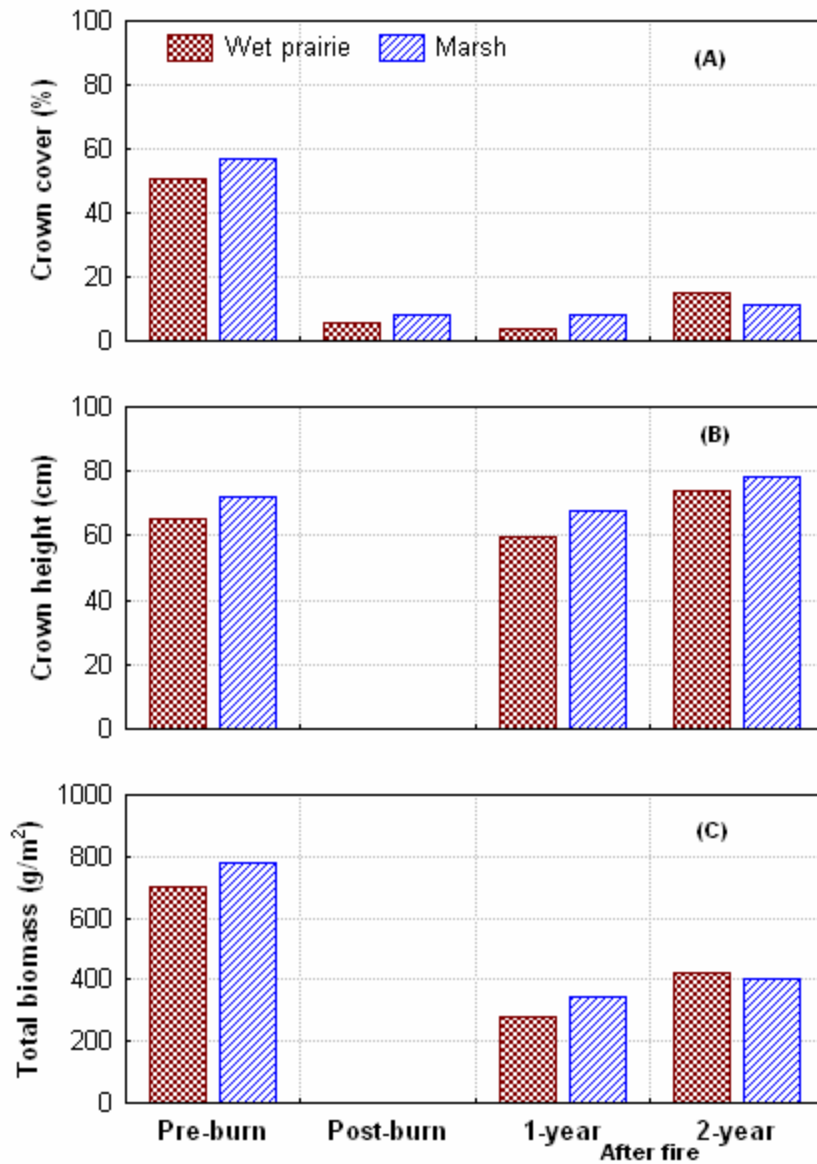
Figure 19: Mean crown cover (A), height (B), and total biomass (C) in one wet prairie and one marsh site burned in 2003, and sampled annually in 2003, 2004 and 2005.
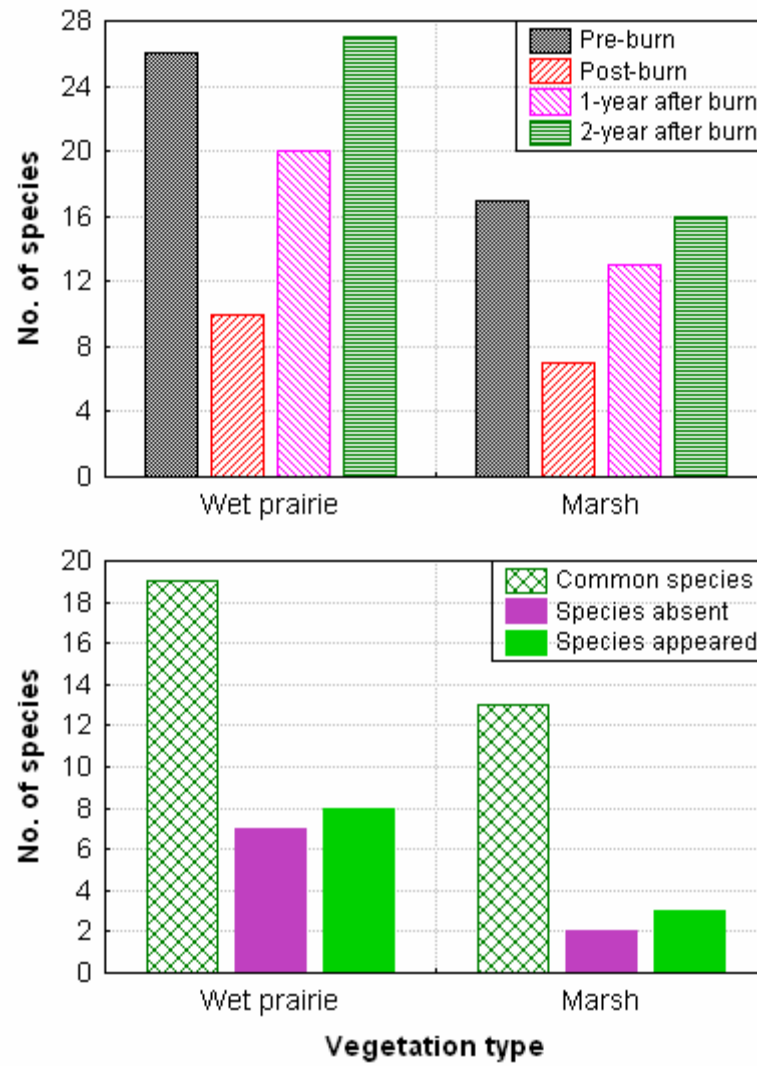
Figure 20: Change in number of species in one wet prairie and one marsh site burned in 2003 and sampled annually in 2003, 2004 and 2005. (A) Total number of species (B) Species turnover.