

1-2010

Cape Sable Seaside Sparrow Habitat – Vegetation Monitoring: FY 2009 - Final Report

Jay P. Sah

Southeast Environmental Research Center, Florida International University

Michael S. Ross

Southeast Environmental Research Center, Florida International University

James R. Snyder

USGS, Florida Integrated Science Center, Big Cypress National Preserve Field Station

Pablo L. Ruiz

Southeast Environmental Research Center, Florida International University

Susana Stofella

Southeast Environmental Research Center, Florida International University

See next page for additional authors

Follow this and additional works at: <https://digitalcommons.fiu.edu/sercrp>



Part of the [Earth Sciences Commons](#), and the [Environmental Sciences Commons](#)

Recommended Citation

Sah, Jay P.; Ross, Michael S.; Snyder, James R.; Ruiz, Pablo L.; Stofella, Susana; Colbert, Nate; Hanan, Erin; Lopez, Lawrence; and Camp, Michael, "Cape Sable Seaside Sparrow Habitat – Vegetation Monitoring: FY 2009 - Final Report" (2010). *SERC Research Reports*. 91.

<https://digitalcommons.fiu.edu/sercrp/91>

This work is brought to you for free and open access by the Southeast Environmental Research Center at FIU Digital Commons. It has been accepted for inclusion in SERC Research Reports by an authorized administrator of FIU Digital Commons. For more information, please contact dcc@fiu.edu.

Authors

Jay P. Sah, Michael S. Ross, James R. Snyder, Pablo L. Ruiz, Susana Stofella, Nate Colbert, Erin Hanan, Lawrence Lopez, and Michael Camp

Cape Sable seaside sparrow habitat – Vegetation Monitoring

(Contract # W912EP-09-C-0024)

FY 2009 – Final Report



Submitted to:

Susan Conner

U. S. Army Corps of Engineers

701 San Marco Blvd.

Jacksonville, FL 32207

Ph. (904) 232-1782

Email: susan.l.conner@usace.army.mil

**Jay P. Sah¹, Michael S. Ross¹, James, R. Snyder²,
Pablo L. Ruiz¹, Susana Stoffella¹, Nate Colbert¹,
Erin Hanan¹, Lawrence Lopez¹ and Michael Camp²**

1. Southeast Environmental Research Center

Florida International University, Miami FL 33199

2. USGS, Florida Integrated Science Center

Big Cypress National Preserve Field Station, Ochopee, FL 34141

January, 2010

Cape Sable seaside sparrow habitat –Vegetation Monitoring (2009)

Summary

This document summarizes the activities that were accomplished in FY 2009 on the research project “**Cape Sable seaside sparrow habitat – Vegetation Monitoring**”, a collaborative effort among the US Army Corps of Engineers, Florida International University, and the US Geological Survey. The major activities in 2009 included field work, data analysis and presentations. The results of 2009 field work were presented at the 4th International Congress of Fire Ecology and Management, Savannah, GA from November 30 to Dec 5, 2009 and at the Cape Sable seaside sparrow (CSSS) Fire Meeting, held at the Krome Center, Homestead, FL on December 8, 2009.

Field sampling was conducted between March 23 and June 3, 2009, during which we re-surveyed 234 sites: 191 Census sites, 3 sites on Transect B, 7 sites on Transect D, and 33 sites on Transect F. The number of sites sampled in 2009 was higher than in any previous year, primarily because a large number of sites burned in Mustang Corner fire and three other wild fires in 2008 were included in 2009 sampling. At all sites surveyed in 2009, we recorded structural and compositional vegetation parameters following the methods used in previous years (2003-2008) and tagged shrubs and trees (woody plants > 1 m) present in the 5 x 60 m plots. In addition, for the first time, we measured height of sawgrass (*Cladium jamaicense*) stubble in the compositional plots at the sites that were burned in 2008. Field data were entered by field crews, and were thoroughly checked by Jay Sah (Co-PI) to ensure that the data were complete, correct, and compliant with sampling methodologies. The data are stored under a project folder on a shared network drive maintained by the Southeast Environmental Research Center (SERC) at FIU. The shared network drive is backed up daily.

We used a non-metric multidimensional scaling (NMS) ordination to visualize temporal change in vegetation composition, and Analysis of Similarity (ANOSIM), to quantify differences in vegetation composition between two sampling years (2005 and 2009) at unburned sites, and sites burned in 2008. For a group of sites burned in 2005, we used trajectory analysis to quantify the rate of vegetation change in relation to time since last fire. In general, vegetation composition (i.e., the relative cover of species) within CSSS habitat did not change significantly across all sub-populations. Nevertheless, in sub-population A, the vegetation in the eastern part of the sub-population indicated a drying trend during the 4 year period, while vegetation in the western part indicated slightly wetter conditions in 2009 than 2005. This spatial pattern was consistent with a change in 4-year average hydroperiod estimated from EDEN data. The increase in hydroperiod in western part of sub-population A could be due to an increased run-off in upstream basin and flow across the FMB-Monroe section of the Tamiami Trail in recent years. Across all sites, changes in wetness affected species richness, which decreased with increases in vegetation-inferred hydroperiod. In summary, re-survey of a sub-set of sites sampled for the first time in 2005 revealed that vegetation composition and structure changed at some sites depending on their locations within the CSSS habitat, and at the burned sites, changes in species composition varied with time since last fire and post fire hydrology conditions.

Table of Contents

Summary	ii
1. Background	1
2. Methods	2
2.1 Field Sampling	
2.2 Data entry and management	3
2.3 Analytical Methods	3
3. Results and Discussions	5
3.1 Vegetation change at unburned sites	5
3.1.1 Vegetation change, hydrology and species richness	5
3.1.2 Vegetation change and hydrology in sub-population A	6
3.2 Vegetation change at burned sites	8
4. Fire and flooding interactions: vegetation dynamics trajectories in the marl prairies	10
4.1 Introduction	10
4.2 Methods	11
4.2.1 Field sampling	11
4.2.2 Data analysis	11
4.3 Results and Discussions	12
5. Vegetation, hydrology, and CSSS population (2009)	17
References	19
Figures (1-28)	22-47

Cover photo: Sparse vegetation in 4th year after fire at a Cape Sable seaside sparrow vegetation monitoring site burned in 2005 and flooded by Hurricane Katrina within 7 days after fire. (Photo: Jay Sah).

Cape Sable seaside sparrow habitat – Vegetation Monitoring (2009)

1. Background

The Cape Sable seaside sparrow (CSSS), a federally endangered species, has remained the focus of several water management operations in the Everglades. To monitor vegetation responses to changes in hydrologic regime and fire events within the sparrow habitat, FIU-USGS researchers initiated a vegetation study in 2002 with funding from U.S. Army Corps of Engineers (USACE). In the first three years (2003-2005), a detailed account of spatial variation in vegetation composition and structure in relation to hydrology and fire history were documented (Ross et al. 2006). Since 2006, sub-sets of sites in each of six sparrow sub-populations (A-F) have been re-visited annually to address the spatio-temporal changes in vegetation in response to fire events and changes in hydrologic regime. The sub-set sampled each year includes both unburned and burned sites. Burned sites are sampled to assess the vegetation recovery process following fire, and generally, they are sampled 1, 2 and 4 years after fire. However, when some events, such as hurricane-caused post-fire flooding in 2005, provide an opportunity to learn more about vegetation response to fire-hydrology interactions, the sites are sampled annually.

This document summarizes the works accomplished during FY 2009. The major activities in 2009 included field work, data analysis, and presentations. Field sampling was accomplished between March 23 and June 3, 2009, and the data were processed in the remaining part of the year. Later, once the data were analyzed, Jay Sah (Co-PI) presented the results at the 4th International Fire Ecology and Management Congress, Savannah, GA from 30 Nov to 4 Dec, 2009, and at the Cape Sable seaside sparrow (CSSS) Fire Meeting 2009, held on December 8 at the Krome Center, Homestead, Florida.

In Section 2 of the report, general methods are described, including field preparation and vegetation sampling, data entry and management, and data analysis. In Section 3, sub-sections 3.1 and 3.2 describe the results from the sampling of unburned and burned sites, respectively. For the unburned sites, differences in vegetation composition and cover of major species between two surveys are first described. Since sub-population A has been the pivot of water management strategies intended to manage CSSS habitat west of Shark Slough, an analysis of vegetation and hydrologic pattern in relation to changes in water flow pattern across Tamiami Trail, particularly the section between Forty Mile Bend and Monroe Station, is presented in a separate sub-section (Sec. 3.1.2). For the burned sites, the general results are presented in the sub-section 3.2. The sites burned in 2005 have been annually sampled for four years after fire, leading us to analyze the data using trajectory analysis. The results of such analyses are presented in a separate section (Sec. 4) that includes introduction, methods, and results and discussion. Finally, Section-5 examines the sparrow population recorded in 2009 in relation to vegetation and hydrologic changes between two surveys.

2. Methods

2.1 Field sampling

In 2009, the 7th year of field work, there was slight change in FIU sampling personnel. Brooke Shamblin, who worked as a botanist on the project during the two previous years, left FIU for a position elsewhere. Instead, Nate Colbert joined our team, and was a member of the field crew for vegetation sampling. Other FIU participants were the same in 2009 as in 2007 and 2008. There was a change in USGS sampling team. T. J. Hilton who was part of the field crew in 2008 was no longer with USGS in 2009. Instead, Michael Camp joined the team for vegetation sampling.

Before we commenced field sampling, we organized a staff meeting, involving PIs, Co-PI, and all staff, to prepare the logistics for sampling vegetation and entering data during the 2009 field season scheduled. In the meeting, we went over field logistics required to accomplish the vegetation sampling, and made a list of needed acquisitions. Pablo Ruiz, Scientific Research Manager, who is responsible for our team's purchasing needs, procured the necessary supplies. We inspected our equipment, sampling frames, etc. and repaired them, if necessary. Nate Colbert, Lawrence Lopez and Michael Camp attended the OAS-required S-271 helicopter crewmember training course between March 30 and April 3, 2009. Finally, since two new staff has been in the pivot of were integrated, we also held a practice field exercise to train them how to carry out their duties in the field, and to calibrate their cover estimates against those of experienced staff.

We commenced vegetation sampling on March 23 and continued through June 3, 2009. Our endeavor was to carry out vegetation re-sampling at all the sites in the same months as in the previous surveys, so that any change in vegetation composition between the two sampling periods would not be confounded by seasonal variation in species abundance. In 2009, we re-surveyed 234 sites: 191 Census sites, 3 sites on Transect B, 7 sites on Transect D, and 33 sites on Transect F. Census sites included 124 unburned and 67 burned sites (**Figure 1**). While all sites sampled on Transects B and D were burned sites, only 24 of 33 sites on Transect F were burned, and the rest of the sample sites were unburned for at least four years. The number of sites sampled in 2009 was higher than in any previous year, primarily because of the large number of sites that were burned in the Mustang Corner (East Everglades) fire and three other 2008 wildfires. Vegetation in plots burned in 2008 was very sparse (**Figure 2**).

Unburned sites included a sub-set of sites initially sampled in 2005 (**Table 1**). With the re-sampling of these census sites, the 2nd round of vegetation sampling at census sites is completed. The availability of pre-burn vegetation data for all burned sites re-sampled in 2009 greatly assisted us in assessing vegetation recovery more precisely than in previous surveys.

In 2009, we recorded structural and compositional vegetation parameters at both unburned and burned transect and census sites following the methods used in previous years (2003-2008). As done for the first time in 2008, we also tagged all shrubs and trees (woody plants > 1 m) present in the 5 x 60 m plots. Tagging will allow us to track the fate of these individuals when these plots are re-sampled next. In 2009, we initiated measurements of the

height of sawgrass (*Cladium jamaicense*) stubble in the compositional plots at the sites that were burned in 2008. We measured height of 3-5 sawgrass stubbles in at least 5 0.25 m² compositional plots at each site.

Table 1: Number of sites sampled during Year 7 field season (March 23 – June 3, 2009)

Transect/ Census sites	Sub pop	Unburned		Burned								# of sites sampled in 2009
		First-time sampled		First-time sampled				Burn year				
		2004	2005	2003	2004	2005	2006	2005	2006	2007	2008	
Transect	B					3				3		3
	D				7			7				7
	F	9			24						24	33
Census sites	A		61	3	9	7	1		2	2	16	81
	B		34	12	6	2		13	7			54
	C		5			2			2			7
	D		7	1				1				8
	E		12	2	4	1					7	19
	F		5	4	5	8					17	22
Total		133		101								234

2.2 Data entry and management

After sampling was completed, data were entered by the field crews. Data were thoroughly checked by Jay Sah (Co-PI) to ensure that the data were complete, correct, and compliant with sampling methodologies. Wherever there were questionable data, field crews were consulted, and data were corrected. Finally, data were stored under a project folder on a shared network drive maintained by the Southeast Environmental Research Center (SERC) at FIU. The shared network drive is accessible by all staff members. The shared network drive is backed up daily, and archived periodically on backup disks in the PI's offices.

2.3 Analytical methods

To examine change in vegetation composition, analyses were done separately for unburned and burned sites. For unburned sites, we used a non-metric multidimensional scaling (NMS) ordination and Analysis of Similarity (ANOSIM) to quantitatively examine the differences in vegetation composition between two sampling years. The distance between points in the ordination diagram is indicative of the underlying dissimilarity between those points, thus the magnitude of distance between positions of the same site sampled in different years is the measure of periodic vegetation change. In the analysis, we used the Bray-Curtis distance metric as a measure of dissimilarity. ANOSIM, a nonparametric permutation procedure (Clarke 1993), is used to statistically test the differences in vegetation composition between two groups. In this analysis, an R-statistic is generated based on differences of mean rank of distances among groups and within groups. An absolute value of the R-statistic close to 1 suggests a real difference in vegetation composition among groups. In our analysis, the groups were different sampling years.

For burned sites, we adopted a slightly different approach in data analysis. Grouping of these burned sites on the basis of time since last fire yielded five groups: pre-burn, post-burn, and 1, 2, and 4 years after burn. Differences in vegetation composition between pre-burn and different post-burn years were examined using analysis of similarity. Additionally, we used trajectory analysis (Minchin et al. 2005) to analyze data collected at 21 sites burned in 2005, as pre-burn and 4 years of post-burn data were available for analysis. The methods of analysis for these data are described in detail in Section 4.

To assess whether a change in vegetation composition at unburned sites between 2005 and 2009 was in response to periodic differences in hydrology, we used an approach similar to Armentano et al. (2006). We analyzed the differences in mean vegetation-inferred hydroperiod, i.e. the hydroperiod for a site predicted from vegetation composition using a Weighted Averaging Partial Least Square (WAPLS) regression model developed in 2005 (Ross et al. 2006). We considered that significant change in vegetation-inferred hydroperiod between 2005 and 2009 would support the hypothesis that vegetation at the sampled sites changed in four years in response to hydrological changes. Additionally, we also analyzed the changes in hydroperiod estimated from Everglades Depth Estimation Network (EDEN) hydrological data. From the EDEN website (<http://sofia.usgs.gov/eden/models/watersurfacemod.php>), we downloaded water stage data which are available since Jan 1, 2000. We calculated hydroperiod for each hydro-year (May 1-April 30), and analyzed differences in the 4-year mean hydroperiods prior to 2005 and 2009 sampling events.

3. Results and Discussions

3.1 Vegetation change at unburned sites

3.1.1 Vegetation change, hydrology and species richness

In general, vegetation composition, expressed in terms of relative cover of species at unburned sites within CSSS habitat, did not differ significantly in the four years between 2005 and 2009 surveys (**Figure 3**: ANOSIM – Global $R = 0.008$, p -value = 0.073). However, this was not consistent across all sub-populations. In the eastern sub-populations, the differences in vegetation composition between two sampling events in general were not statistically significant. However, there were apparent trends within individual sub-populations. As illustrated by vegetation-inferred hydroperiod (**Figure 4**), the vegetation at the majority of sites in sub-population D was indicative of slightly wetter conditions in 2009 than four years earlier. Moreover, in sub-populations B and E, a few sites, particularly near the Shark Slough, also had become wetter in four years. In contrast, sites in most parts of sub-population B, and along Taylor Slough in sub-population C had become drier or showed little change. The drying trend observed in Taylor Slough appears to extend trends previously noted in other studies. A long-term study of vegetation transects established to monitor the impact of water deliveries by S-332 into Taylor Slough showed that vegetation on three transects downstream of the S-332 structure experienced a change in species composition that indicated drier conditions in 2003 and 2007 than in 1999 (Armentano et al. 2006; Saha et al. 2007).

Between 2005 and 2009, total plant cover, expressed as the sum of individual species cover, did not show significant change in the unburned portions of the CSSS habitat. However, the cover of a few major species (cover >0.5%) showed significant change in four years. Mean cover of sawgrass (*Cladium jamaicense*), the most abundant species within the CSSS habitat, was significantly lower in 2009 than in 2005 (**Figure 5**). In contrast, the mean cover of three major species, water hyssop (*Bacopa caroliniana*), spikerush (*Eleocharis cellulolosa*), and muhly grass (*Muhlenbergia capillaris* var. *filipes*) significantly increased in four years. Cover of *E. cellulosa* almost doubled (from 2.6% to 4.2%) between two surveys. Change in cover of major species was not consistent in all sub-populations. Five major species that changed significantly in one or more sub-populations were *C. jamaicense*, *M. capillaris*, *B. caroliniana*, *E. cellulosa*, and beak rush (*Rhynchospora tracyi*) (**Figure 6**). *B. caroliniana* and *E. cellulosa* increased in cover by almost 50% in sub-population A, indicating wetter condition in 2009 than four year earlier. Nevertheless, such change seems to be spatially differentiated (see details in Section 3.1.2). Mean cover of *E. cellulosa* also increased in sub-population D, though the change was not statistically significant, probably due to low number of sites sampled within the sub-population. However, in this sub-population, cover of *C. jamaicense* significantly decreased. Increase in the cover *E. cellulosa* combined with a decrease in the cover of *C. jamaicense* suggests a wetting trend in the sub-population D. In contrast, at sites in sub-population F, a significant increase in mean cover of *M. capillaris* var. *filipes* in four years indicated drier conditions in 2009 than 2005, a trend also suggested by an observed increase in the cover of bluestem (*Schizachyrium rhizomatum*) and a decrease in the cover of *C. jamaicense*.

Change in species cover, which indicated the hydrologic trend that the sites experienced in recent years, were also reflected in the dynamics of plant species richness in CSSS habitat. Although mean species richness at the unburned sites did not differ significantly between the two surveys, it decreased where vegetation-inferred hydroperiod increased in four years. The sites that became wetter in 2009 had fewer species than before (**Figure 7**), supporting the previous observation that plant species richness is negatively correlated with hydroperiod in the marl prairie landscape (Sah et al. 2008).

3.1.2 Vegetation change and hydrology in sub-population A

In sub-population A, the NMS ordination results revealed that the direction of change in vegetation composition differed among sites (**Figure 8**). Most marsh sites became wetter (shifted toward more hydrophytic vegetation) in five years, whereas the wet prairie sites and a few marsh sites showed mixed results. Vegetation change patterns at both marsh and prairie sites are spatially differentiated within the sub-population, suggesting that vegetation at these sites is responding to spatially variable hydrologic changes in recent years. In the western parts of the sub-population, vegetation-inferred hydroperiod at several sites increased in four years, showing that marsh vegetation present at these sites was indicative of wetter conditions in 2009 than in 2005 (**Figure 9a**). In contrast, relatively shorter vegetation-inferred hydroperiod in 2009 at the sites in the northeastern and southern parts of the sub-population indicated a decrease in wetness. A similar pattern was observed for changes in 4-year average hydroperiod calculated using EDEN water depth data (**Figure 9b**). In this region of the Everglades, the close resemblance between vegetation-inferred and EDEN data-based hydroperiods is remarkable.

The hydrologic and vegetation change patterns in sub-population A track the water level reported at the stage recorder P-34 and NP-205 in recent years (**Figure 10a**). The relatively dry conditions resulted from consistent low water level near NP-205 in the eastern part of this sub-population (East-A) are in concurrence with management efforts to regulate water deliveries from S-12 structures under the operational objective of ISOP/IOP. However, despite such regulated deliveries to keep the sub-population dry, the persistence of much wetter marsh vegetation caused by high water level near P-34 in the western part of the sub-population A (West-A) is inconsistent with sparrow habitat management objectives. In recent years, the difference between NP-205 and P-34 has been relatively low, primarily due to high water level at P-34 (**Figure 10b**). The question is what factors are responsible for the hydrologic anomaly in the West-A in recent years. There are two plausible reasons for the high water level in the areas near P-34: a) increased runoff from the upstream basin, and b) slow drainage of water towards the ocean.

The western parts of the sub-population A comprise shallow sloughs that receive runoff from the water basin intersected by a section of Tamiami Trail, between Forty-Mile Bend and Monroe Station (FMB-Monroe) section, and by the Loop Road (**Figure 11a**). Therefore, in addition to annual variation in rainfall, the hydrologic conditions in the West-A are likely to be also influenced by the spatial and temporal variation in flows through the culvert and bridges on these two roads. Currently, we were not able to obtain and analyze the data for the flow through the culverts and bridges on the Loop Road. However, with the assumption that most of water

flowing in the areas bounded by Tamiami Trail and Loop Road also flow across the latter road into the downstream marsh, an insight into the analytical results of flow pattern through culverts and bridges on the FMB-Monroe section of the Trail will help to explain the observed hydrologic conditions in West-A. A recent analysis of the flow data in relation to rainfall for four periods 1941-1952, 1953-1963, 1964-1991 and 1992-2008, revealed that mean annual rainfall did not differ much among these periods (133.1, 137.7, 128.0, and 139.7 cm, respectively), but the annual runoff per unit rainfall in the FMB-Monroe sub-basin was much higher (approximately twice) in the last period (1992-2008) than in the other periods (Kotun et al. 2009). The last two of the four periods represented the post WCA-3A era, The increased runoff per unit rainfall has been attributed to high stage level in WCA-3A, which in the central part of the impoundment, was almost 30 cm (1 foot) higher in the last (1992-2008) period than in 1964-1991. Kotun et al. (2009) also postulated that water should naturally flow from Mullet Slough, the major drainage in the FMB-Monroe basin, into the WCA-3A. But, the high stage within the conservation area might have caused a backwater effect in Mullet Slough, causing water to flow out of WCA-3A towards Big Cypress National Preserve, and ultimately ending up in increased flow across the Tamiami Trail. Water flow in the most recent period increased at all bridges except the western most (Bridge-96), and the periodic increase in flow was much higher at the bridges in the east, close to the L28 (**Figure 11b**) (Kotun et al. 2009). Determination of whether the water flowing through the culverts and bridges in the eastern portion of FMB-Monroe section is the primary reason for high water level in West-A requires a better understanding of flow pattern across the Loop Road. A detailed study of such flow pattern is warranted in order to understand hydrodynamics of the region. Such study could include use of tracers and an analysis of water budgets that should account for the local rainfall, inflow of water across the Loop Road into the marsh, and outflow towards downstream areas. In addition, spatial and temporal analysis of landscape features, such as woody patches or tree islands, sawgrass strands, and sloughs will also help to understand the broad scale ecological impact of increased flow in this part of the Everglades. It is relevant because a change in volume and rate of water flow in marshes have been impacting the size and orientation of such features in other parts of the Everglades (SCT 2003; Wu et al. 2006).

When supported by additional analysis of flow pattern across the Loop Road, the phenomenon described above may explain why West-A has been persistently wetter in the 1990s and 2000s. However, formulation of effective strategies to improve the sparrow habitat conditions in West-A would require an in-depth analysis to quantify the relative role of important drivers that caused the WCA-3A stage to be consistently high during the period of 1992-2008. The operations of water structures that control the impoundment of water in WCA-3A are influenced by several factors, including rainfall, stages in the WCA-3B and Northeast Shark Slough (NESS), and stage level at NP-205. In general, operations of the structures follow the WCA-3A Rainfall Based Management Plan whose objectives include restoration of a more natural hydro-pattern in Northeast Shark River Slough and Everglades National Park (Pathak and Palermo 2006). When two post-WCA-3A periods (1964-1991 and 1992-2008) were compared, average annual rainfall was relatively high in the latter period (1992-2008). In this period too, the stage in WCA-3A had peaked in 1994-1995 corresponding with the highest rainfall and since then, the stage level showed an overall decreasing trend. However, maximum stage in most years remained above 10 ft NGVD, the threshold at which an increase in flow per unit rainfall occurs when annual maximum stage at WCA3A-4 is high (Kotun et al. (2009). An analysis of the

relative contributions of rainfall and regulatory deliveries on the continuation of WCA-3A stage above the 10 ft threshold is important, particularly when information is emerging that maintenance of NP-205 stage ≤ 6 ft NGVD for a minimum of 60 consecutive days between March 1 and July 15 by controlling delivery through the S12's is inadequate to restore the vegetation throughout the recent range of sub-population A, particularly in West-A. Our vegetation analysis results showed that the vegetation in the West-A has become wetter in recent years (**Figure 9a**), even though NP-205 is maintained at the desired level. It is likely that restricted schedules of S-12s to obtain desired stage level at NP-205 under the IOP plan may have also contributed to the high stage in WCA-3A, resulting in increased water level and deteriorating habitat conditions in the western ranges of the sub-population. If so, while it needs to be carefully examined how an improvement in one part of sub-population A habitat is impacting the other part of the habitat, formulation of management strategies that would maintain both the desired water level at NP-205 and concurrently reduce the water level in West-A is needed to improve the sparrow habitat throughout the range of the sub-population.

The other potential factor influencing the hydrologic conditions in the vicinity of P-34, not far from the coast, could be sea level rise, which in south Florida has been ~ 2.5 mm per year over the last century. It is likely that water drainage towards ocean is being adversely affected by rising water levels near the coast, decreasing the hydrologic gradient and slowing drainage in the dry season. A clear understanding of the effects of sea level rise should include an assessment of spatio-temporal variability in ground water salinity, hydraulic gradients, flow rate, and inward shift of salt tolerant plant species along transects.

3.2 Vegetation change at burned sites

In the Everglades marl prairies, fire plays an important role in modifying vegetation structure and composition, which ultimately influences CSSS population dynamics. In 2009, vegetation was sampled at 101 burned sites, of which 67 were census and 34 transect sites. The number of burned sites sampled in 2009 was higher than in any previous year, primarily because of the large number of sites that burned in four 2008 wildfires. These included the Mustang Corner Fire, which was the largest fire to have burned in Everglades National Park since 1989's Ingraham Fire. Unlike previous years, pre-burn vegetation data was available for all burn sites sampled in 2009. Since several sites were sampled annually during 2006-2009, sequential data were available for post-fire years at those sites. Moreover, the burned sites experienced different pre- and post-fire hydrology conditions, which presumably influenced the fire severity and post-fire vegetation trajectories. For instance, a sub-set of sites burned in 2005 were flooded within 7 to 14 days of the fires, whereas the remainder of the sites burned in 2005 or other years did not experience such immediate flooding stress. At those sites, water level increased gradually, allowing the plants ample opportunity to grow after fire. Therefore, a direct comparison among sites across different years, or different fires within the same year, was intended only to illustrate the general trend of post-fire vegetation dynamics in marl prairie. The trend in vegetation trajectories after fire in relation to post-fire hydrologic conditions was analyzed in detail only for the 2005-burned sites.

Burned sites, including both pre- and post-burn samples, were arranged along two gradients in non-metric multidimensional (NMS) ordination space, i.e. hydrology and time since last fire (**Figure 12a**). However, as we expected, post-fire year sample groups were not well separated in the ordination (stress 0.21), mainly because there was considerable overlap among sites, within both marsh and wet prairie types, representing different post-fire years. The sites differed greatly in burn year, previous fire history, and post fire hydrology, and thus followed different paths of vegetation recovery. In 2005-burned sites, vegetation composition remained significantly different from pre-burn vegetation even four years after fire. In contrast, 2007- and 2008-burned sites did not show that much difference, as was observed in 2005-burned sites, in vegetation composition between pre-burn and two and one year after fire (**Figure 12b**).

At 2008-burned sites, vegetation composition one year after fire differed significantly from pre-burn. The observed trend was consistent across all fires in that year. The mean Bray-Curtis dissimilarity between pre-burn and one year after fire vegetation composition did not differ significantly among fires (**Figure 13**), probably because these fires occurred within a one month interval in the early summer, and all sites did not experience drastic changes in post-fire hydrologic conditions. Likewise, the onset of the rainfall in 2009 was also delayed. However, mean Bray-Curtis dissimilarity between pre-burn and post-fire Year 1 vegetation in 2008-burned sites (62.5%) was significantly less (One-way ANOVA: $F_{1, 83} = 5.12$, $p = 0.02$) than the mean dissimilarity between pre-burn and post-fire Year 4 in 2005-burned sites (71.5%). This suggests that vegetation recovery was extremely slow in 2005-burned sites, many of which were severely impacted by post-fire flooding. Faster recovery at 2008-burned sites was also reflected in the total cover values. In the first year after fire, mean vegetation cover at those sites was 37.2% of pre-burn cover, a value higher than the vegetation cover (30.9% of pre-burn cover) observed at 2005-burned sites three years after fire. However, at the 2008-burned sites also, vegetation cover recovery significantly differed among the four 2008 fires (**Figure 14**). Wet prairie sites in the eastern Everglades, particularly those within the Mustang Corner fire boundary, had a lower rate of vegetation cover recovery than the wet prairie sites within sub-population A. Besides hydrology, vegetation recovery after fire in the wet prairies might have been influenced by fire intensity and soil conditions. In general, sites in the eastern marl prairies have thinner soil with lower organic matter than the wet prairies sites in the west (Ross et al. 2006; Sah et al. 2009). Continued monitoring of vegetation recovery at sites burned in 2008 is important for sparrow habitat management, particularly to clearly understand if fire, in combination with water management, can be used as tool to restore the altered sparrow's habitat

4. Fire and flooding interactions: vegetation dynamics trajectories in the marl prairies

4.1 Introduction

Disturbances are important processes affecting plant community structure and change. Although a post-disturbance community pattern is largely determined by interactions between pre-disturbance community characters, and the nature of the specific disturbance (Foster et al. 1998), a single disturbance event is unlikely to cause a long-term change in the fundamental community characters (Stone 1998). However, multiple interacting disturbances of different physical and/or biological forms often result in changes in community character different from, and less predictable than, the independent effects of each disturbance (Walker and Chapin III 1987; Paine et al. 1998; Turner and Dale 1998; Peters et al. 2004; Collins and Smith 2006; Li et al. 2007). In general, effects of compounding multiple perturbations are controlled by their sequential order (Frelich and Reich. 1998; Fukami 2001), intensity, and spatio-temporal variability (Foster 1988, Foster et al. 1998). At the temporal scale, intervals between disturbances are of absolute importance (Ross et al. 2004), e.g., with short intervals between events, several species influenced by earlier disturbances could be less resistant to the subsequent disturbance. In this study, we examined how post-fire vegetation dynamics in seasonally-flooded wetlands are influenced by various levels of flooding, occurring at varying intervals after fire.

Fire and flooding often occur in sequence, with some interval between them. These disturbances are common in the wetlands, such as floodplains, coastal prairies, and seasonally flooded grasslands (McKee and Baldwin 1999; Lockwood et al. 2003). In seasonally-flooded grasslands, where the probability of wildfire is much high at the onset of the rainy season, there is a likelihood that a wildfire will be closely followed by flooding, thus affecting the trajectories of post-fire vegetation recovery. The chances of such events are high in South Florida, where wildfires caused by natural lightning, are frequent in the rainy season. Moreover, in the rainy season, there is always a possibility of torrential rains associated with tropical storms or hurricanes. In South Florida freshwater wetlands, several researchers have described the plant community level responses to a single form of disturbance (Busch et al. 1998; Armentano et al. 2006), and the studies that included the both fire and flooding, focused primarily on the response of individual species, such as sawgrass (*Cladium jamaicense*) (Herndon et al. 1991), muhly grass (*Muhlebergia capilaris* var. *filipes*) (Snyder et al. 2004), sawgrass (*Cladium jamaicense*) and cattail (*Typha domingensis*) (Ponzio et al. 2004). However, community level responses of Everglades freshwater wetland vegetation to interactive effects of fire and flooding have not been studied.

In a seasonally-flooded wetland, the rate and extent of post-fire vegetation recovery vary depending on vegetation type, soil characteristics, fire intensity, pre- and post-fire hydrologic conditions, etc. Vegetation recovery after a single burn event in some wetlands ends in a return to pre-burn community composition and structure within 3-4 years (Pahl et al. 2003; LaPuma et al. 2007). However, sequential disturbances, such as fire followed by flooding, in the wetlands, may result in changes in community characters by removing dominant species and facilitating the growth of opportunistic species (Zedler and Krecher 2004). Sudden dieback of dominant species may occur when the aerial shoots are burned-off in a fire and are submerged by post-fire flooding, cutting off the oxygen supply to the rhizomes results in death of the plants (Ball 1990;

Herndon et al. 1991; Kirkman and Sharitz 1994; Ponzio et al. 2004). Plants can avoid such a drowning effect by growing enough to maintain their apices above the water level. Therefore, intervals between subsequent disturbances, such as fire followed by flooding, may determine the fate of the plants.

We therefore examined community level responses to interactions of fire and flooding in Southern Everglades marl prairies. The marl prairie landscape, the habitat of the federally listed endangered species, Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*), is a mosaic of seasonally flooded, short hydroperiod wetlands with calcitic marl substrates in the Southern Everglades. Our specific objective was to assess the effects of post-fire hydrology on the trajectory of vegetation recovery. Since development of restoration strategies in Everglades requires a better understanding of vegetation changes in response to management efforts, it is important to understand the effects of interacting multiple disturbances on landscape pattern of plant community characters and their implication on ecosystem management. A deviation in the course of post-fire vegetation recovery will not only increase heterogeneity in the marl prairie landscape mosaic, but may affect the return of CSSS to burned sites.

4.2 Methodology

4.2.1 Field sampling

The study area was in Southern Everglades marl prairies that were burned in 2005 (**Figure 15**). In that year, three major fires burned 1,348 ha of marl prairies within the CSSS habitat. In May, the “Aerojet” fire burned 76.7 ha areas in sub-population D, outside the Everglades National Park, and in August, the “Keyhole” and “Sisal” fires burned 611 and 660 ha areas, respectively, in sub-population B. The areas burned in May (May_burn) remained unflooded for >1 month after fire, and for two months thereafter experienced a gradual increase in water level, while the area burned in August (Aug_burn) were flooded by more than a foot (30 cm) of water by Hurricane Katrina within 7-15 days of fire.

Prior to the 2005 fires, both May-burned and Aug-burned sites were sampled once over the three year period between 2003 and 2005. After the sites burned in 2005, they were sampled annually, between March and May, for four consecutive years. At each sampling site, vegetation was sampled in a N-S oriented, 1 x 60 m rectangular plot beginning 3 m south of a rebar established to permanently mark the sampling site. Nested within the plots were ten 0.25 m² (0.5 x 0.5 m) subplots, arrayed at 6-meter intervals along the baseline (east side) beginning at Meter 5. In each subplot, we recorded ocular estimation of cover (live + dead) of each species. Finally, we recorded any additional species present in the 1 x 60 m plot, and assigned each species a mean cover of 0.01% for the plot as a whole.

4.2.2 Data Analysis

Vegetation data was first summarized by a non-metric multidimensional scaling (NMS) ordination, and differences in vegetation composition between pre-burn and different post-burn

years were examined using analysis of similarity (ANOSIM). For NMS ordination, cover data were relativized by species maxima. Change in post-fire vegetation composition at individual sites was analyzed using trajectory analysis (Minchin et al. 2005). Trajectory analysis allows researchers to test the hypothesis that as a result of management intervention or a disturbance event, community composition is changing along a pre-defined target represented by reference sites or a pre-defined environmental gradient. In this study, we examined the time trajectory of each site along vectors representing time since last fire (TSLF) and hydrologic gradient vectors. To define the TSLF and hydrology (mean annual days per year flooded) vectors, the census and transect sites sampled between 2003 and 2005 in five eastern sub-populations (B-F) were also included in the NMS ordination. The sites sampled in 2003 to 2005 represented a range of 0 to 25 years along TSLF gradient (Ross et al. 2006). Hydrology vector was derived from the sites sampled on the five transects. For those sites, plot level hydroperiod was calculated using water level data obtained from Everglades Depth Estimation Network (EDEN) database for the nearest stage recorders and the mean plot elevation, obtained by surveying in from the nearest vertical control benchmark to each subplot. Hydroperiod was defined as the number of discrete days per year when mean water level was above the ground surface.

In the ordination space, the reference vectors for time since last fire and hydrologic gradients were defined by using vector fitting technique in DECODA (Minchin 1998). In this method, a gradient is defined in the direction through ordination which produces maximum correlation between the measured environmental attribute and the scores of the sampling units along the vector. The statistical significance of such correlations is tested using a Monte-Carlo permutation test with 10,000 random permutations, as samples in the given ordination space are not independent (Minchin 1998). The orientation of the ordination was then rotated so that hydroperiod had the perfect correlation ($r = 1.0$) with axis-1 which was the principal axis.

Two statistics, delta (Δ) and slope, were calculated to quantify the degree and rate of change in vegetation composition along the reference vectors (Minchin et al. 2005). Delta (Δ) measures the total amount of change in the target direction. It was calculated as the projected score (X) at the final time step minus the mean score of pre-intervention time steps (**Figure 16**). Slope measures the mean rate of change in community composition along the target vector. Since NMS ordinations were scaled in half-change units, the rate was mean half change per year, where 1 half-change is the distance between sampling units at which their mean similarity is half of what would be for replicate sampling units with similar species composition and identical coordinates in the ordination space. In our analysis, the slope was calculated as the linear regression coefficient of projected scores on target vector on sampling years since the sites were burned. The statistical significance of both delta (Δ) and slope was tested using Monte Carlo simulations with 10,000 permutations.

4.3 Results and Discussions

Results of non-metric multidimensional scaling (NMS) ordination revealed that the sites were roughly arranged along two gradients in ordination space, i.e. hydrology and time since last fire (**Figure 17**). In general, the sites with vegetation adapted to relatively short hydroperiod had higher species richness than the sites with wetter vegetation, and plant species diversity was high

at the most recently burned sites. Species diversity decreased as the total vegetation cover increased with time since the sites were burned. Between two groups of sites burned in 2005, May-burned sites were dominated by marsh vegetation indicative of wetter conditions than the wet prairie vegetation at the August-burned sites.

In both May_burn and Aug_burn groups, vegetation composition remained significantly different (ANOSIM – $p=0.001$) from pre-burn vegetation even 4 years after fire (**Table 2**), and total plant cover was less than 50 percent of the initial cover (**Figure 18**). The observed pattern in these burned plots is in contrast to findings of other researchers. Several authors reported that vegetation after a single burn in seasonally-flooded wetlands returns to pre-burn conditions within 3-5 years of fire (Werner 1975; Pahl et al. 2003; LaPuma et al. 2007). A similar pattern of vegetation recovery was also reported at two sites burned in spring 2003, and sampled annually for four years thereafter (Sah et al. 2008, 2009). Inconsistency between the present study and earlier research probably results from differences in post-fire hydrologic conditions, as the majority of sites burned in 2005 experienced different levels of flooding after fire.

Differences in species composition between pre-burn and post-fire samples are further confirmed by shifts in rank abundance curves (**Figure 19**). At the Aug_burn sites, where sites were flooded within 7-15 days after fire, the relative cover of dominant species, such as sawgrass (*Cladium jamaicense*), muhly grass (*Muhlenbergia capillaris* var. *filipes*), bluestem (*Schizachyrium rhizomatum*) and black-top sedge (*Schoenus nigricans*) remained considerably lower even four years after fire compared to pre-fire levels. Like most graminoids, these species normally re-sprout and grow rapidly within few weeks of fire, but when their aerial shoots are burned-off and subsequently submerged by post-fire flooding, they may succumb to flooding-induced oxygen deficiency in their rhizomes (Ball 1990; Kirkman and Sharitz 1994; Ponzio et al. 2004). Other Everglades studies have also reported that the synergistic effects of fire and flooding that submerge the remnant culms of plants can be locally detrimental to several species, such as sawgrass (*C. jamaicense*) and muhly grass (*M. capillaris* var. *filipes*) (Herndon et al. 1991; Snyder and Schaffer 2004). A steep decrease in the cover of dominant species usually provides conditions suitable for the growth of opportunistic species (Zedler and Krecher 2004). Persistence of the relatively low cover of dominant species in post-fire years at the Aug_burn sites has also facilitated the growth of other species. Relative cover of several minor species, such as spadeleaf (*Centella asiatica*), southern beakrush (*Rhynchospora microcarpa*), bluejoint panicgrass (*Panicum tenerum*) and rosy camphorweed (*Pluchea rosea*) was higher in post-fire years than in pre-burn samples. Interestingly, at May_burn sites, where water level increased gradually, providing ample opportunity for the re-growth of plants after fire, a large decrease in the relative cover of sawgrass (*C. jamaicense*) was also observed. When leaf meristems of sawgrass are not damaged by fire, the plants are known to grow rapidly, up to 20 to 40 cm in two weeks (Forthman 1973), which helps them to cope with the rising water level. Lower relative cover of sawgrass (*C. jamaicense*) in post-fire years than in pre-burn samples may also be a function of differences in dead materials. Prior to the 2005 fires, the sites had not burned for 14 years, and retained a large component of dead sawgrass. At these sites, the relative cover of spadeleaf (*C. asiatica*), black-top sedge (*S. nigricans*), southern beakrush (*R. microcarpa*) and beakrush (*Rhynchospora tracyi*) all increased. The relative cover of muhly grass (*M. capillaris* var. *filipes*), a C₄ grass, also increased immediately after fire, but decreased in the 4th post-fire year.

In addition to the change in relative cover of species in post-fire years, mean species richness (number of species per site) also changed in both May-burn and Aug_burn groups. While species richness in both the groups declined in the first year after fire, mean number of species in the May-burned plots recovered to pre-fire levels in the following year (**Figure 20**). In contrast, at the Aug-burned plots, the number of species was low in the first two post-fire years. In the 4th year, mean number of species at those sites surpassed the pre-burn level, though the difference was not statistically significant.

Table 2: Global R and *p*-values from analysis of similarity (ANOSIM) testing for among-year differences in vegetation composition before and after fire for two burn groups, May_burn (8 sites) and Aug_burn (13 sites).

Burn group	Sampling event (Before & year after burn)	Year-1	Year-2	Year-3	Year-4
2005 May_burn	Pre-burn	0.642 (0.001)	0.609 (0.001)	0.473 (0.001)	0.378 (0.001)
	Year-1		0.175 (0.006)	0.207 (0.001)	0.247 (0.001)
	Year-2			0.033 (0.227)	0.013 (0.030)
	Year-3				0.046 (0.196)
2005 Aug_burn	Pre-burn	0.718 (0.001)	0.691 (0.001)	0.640 (0.001)	0.521 (0.001)
	Year-1		0.175 (0.008)	0.208 (0.003)	0.326 (0.001)
	Year-2			-0.014 (0.556)	0.075 (0.089)
	Year-3				0.005 (0.350)

Assessment of vegetation recovery dynamics in post-fire years was enhanced by trajectory analysis. The results revealed that only a few sites in Aug_burn groups showed a significant (*p*-value <0.1) shift, expressed as the amount (Δ) and rate (slope) of change, in vegetation composition along a time-since-last-fire (TSLF) vector (**Table 3**); concomitant changes along a hydrology vector were also tested, but found to be non-significant, and are not shown. Because the purpose of the analysis summarized in Table 3 was to examine recovery in vegetation composition since fire, post-fire Year 1 was considered as the base year, and the shift in position of samples along TSLF vector in the ordination space was assessed. In the analysis, the pre-burn samples were positioned in ordination space near the high end of the TSLF vector, so post-burn sites that approached the pre-burn condition were likely to show a significant shift along the TSLF vector. The composition of two reference sites burned in 2003 and sampled annually for four years resembled their pre-burn state by the 4th year after fire.

Table 3: Delta (amount of change in target direction) and slope (rate of change in the target direction in half-changes per year) calculated for 2 sites burned in 2003 and 21 sites burned in 2005. The burned sites were monitored for four years after fire. Time since last fire (TSLF) vector in the non-metric multidimensional scaling (NMS) ordination was the target direction. The base year for change in vegetation was the first year after fire. Statistical significance ($p \leq 0.1$) of delta and slope was tested using Monte Carlo's simulations with 10,000 permutations.

Site	Burn Group	Delta	P-value	Slope	P-value
B-01-01	Ref-2003	0.746	0.000	0.226	0.000
B-01-04	Ref-2003	0.311	0.046	0.109	0.038
B-05-06	Aug_burn	0.090	0.295	-0.009	0.533
B-05-07	Aug_burn	0.046	0.380	0.033	0.253
B-05-08	Aug_burn	0.133	0.093	0.047	0.073
B-06-05	Aug_burn	-0.074	0.748	-0.033	0.813
B-06-07	Aug_burn	0.177	0.113	0.051	0.122
B-06-08	Aug_burn	0.251	0.023	0.065	0.064
B-10-03	Aug_burn	0.111	0.319	0.056	0.214
B-10-04	Aug_burn	0.063	0.319	0.027	0.258
B-10-05	Aug_burn	0.962	0.233	0.406	0.102
B-11-03	Aug_burn	-0.173	0.837	-0.034	0.738
B-11-04	Aug_burn	0.085	0.298	0.033	0.255
B-11-05	Aug_burn	0.060	0.378	0.028	0.299
B-13-10	Aug_burn	0.084	0.330	0.064	0.113
D-01-10	May_burn	-0.126	0.669	-0.039	0.670
TD-1900	May_burn	-0.201	0.723	-0.021	0.584
TD-2000	May_burn	-0.268	0.811	-0.033	0.627
TD-2100	May_burn	0.063	0.438	0.096	0.234
TD-2200	May_burn	-0.097	0.593	0.026	0.348
TD-2300	May_burn	0.034	0.474	0.025	0.420
TD-2400	May_burn	-0.080	0.583	0.009	0.498
TD-2500	May_burn	0.037	0.449	0.021	0.445

In both May_burn and Aug_burn groups, there was high within group variation (Coefficient of variance: $CV > 1.0$) in both degree (delta) and rate of vegetation change (slope) along the TSLF vector. The slope did not differ significantly (Mann-Whitney U-test; $p = 0.07$) between those two burn groups. Our expectation was that the mean rate of change, i.e. vegetation recovery, would be faster in May_Burn than in the Aug_Burn group. Visual analysis of trajectories revealed that the trajectory of several May_burn sites had shifted roughly in the opposite direction of the TSLF vector during the 4th year after fire (**Figure 21**). In the May_burn group, mean Bray-Curtis dissimilarity between post-fire Year 4 and pre-burn samples was higher than the dissimilarity between post-fire Year 3 and pre-burn samples (**Figure 22**), suggesting that the vegetation recovery process at several May_burn sites changed in direction between Years 3 and 4. Within the group, a visible shift of sites in ordination space toward increasing hydroperiod suggested that vegetation in post-fire Year 4 was indicative of wetter conditions than in previous years (**Figure 23**). However, an analysis of annual water level at those sites revealed that mean

manual water depth was significantly lower in 2007/2008 (May 1 to April 30) than in other years, but the mean water level in 2008/2009 did not differ from previous years (**Figure 24**).

The rate of post-fire vegetation change along the TSLF vector at individual sites flooded immediately after fire was influenced by post-fire hydrologic conditions. For the Aug_burn sites, we used Everglades Depth Estimation Network (EDEN) water depth data to quantify the post-fire hydrologic conditions. We calculated maximum water depth and mean water depth for the period in which sites remained flooded immediately after the fire, i.e. for the immediate post-fire period when the water was above the ground. Additionally, mean water depth for the post-fire Year 1 (WD_Yr1) was also calculated. The rate of vegetation change (slope) at the Aug_burn sites was negatively correlated with all three measures of post-fire hydrologic condition (**Figure 25**). While vegetation recovery towards pre-burn composition was slow, and vegetation composition even after four year of fire was significantly different from pre-burn samples at most of these sites, (**Table 2**), recovery process seemed to be especially impeded when post-fire water depth exceeded 30 cm (**Figure 25a**). At three sites where water depth was >30cm, the slope in trajectory analysis was negative suggesting that vegetation composition at those sites were currently on an opposite trajectory than normal, which may lead to a vegetation state different from that which predominated prior to burn. However, the results should be cautiously interpreted as the relationship is based on the EDEN water depth, which inherently incorporates a high degree of uncertainty, originating from the coarse spatial scale of the elevation data, i.e., surveyed by USGS along 400 x 400 m grid. A more robust approach could be to use the mean annual water depth, calculated from the elevation obtained from field measurements of water depth in conjunction with local stage derived from the EDEN water surface data; the EDEN stage, which is based on a robust network of stage recorders, independent of the USGS elevation data. However, that would require multiple measurements of water depth at individual sites during the wet season. For a subset of sites, at which water depth was measured during wet season in 2003 and 2005 by the periphyton (PI – Evelyn Gaiser) and vegetation study group, respectively, comparison between mean annual water depths obtained from EDEN water depth data and field measurements revealed a moderately strong relationship in the marl prairies ($n = 232$, $R^2 = 0.77$). EDEN-estimated water depths for prairie sites were lower than those estimated from field measurements of water depth (**Figure 26**).

In summary, fire, an integral part of marl prairie ecosystem, is likely to create vegetation mosaics within the landscape, particularly when its effects on vegetation structure and composition is mediated through other disturbances, such as changes in hydrologic regime. While the interval between fire and post-fire hydrologic events is important in shaping the response of vegetation to the synergetic effects of these two disturbances, it is the relative strength and duration of secondary disturbance, e.g., the depth of post-fire flooding in marl prairies, that determines the course of post-fire vegetation recovery trajectories, which in turn shapes the vegetation mosaic pattern. Our study of vegetation response to fire and hydrology also reveals that prairie vegetation recovering from a single disturbance, such as fire, is especially sensitive to annual variation in hydrologic regime. Differences of only a few cm in mean annual water depth could offset the recovery trajectories of vegetation that has not reached a stable state. Finally, it is recommended that fire's use as a management tool for restoration of marl prairie habitat, be coupled with management of the post-fire hydrologic conditions, in order to produce the desired results.

5. Vegetation, hydrology, and CSSS population

As in 2008, the annual CSSS population survey was conducted jointly by Everglades National Park personnel and Dr. Pimm's team in 2009. Sparrow sub-population B was not assessed in 2009, limiting the scope of our analysis of the relationship between CSSS distribution and vegetation change between 2005 and 2009 to the 5 sampled sub-populations (A and C-F). Sparrow populations were surveyed at 213 sites, of which 62 (30 unburned and 32 burned) were close to vegetation sites surveyed in 2009. Of these 62 sites, CSSS were observed in 2005 or 2009 only at 12 sites - six sites in sub-population E, and two sites in each of A, C and F. Four burned sites --- three burned in 2008 and one in 2007 ---supported sparrows in 2005 but not in 2009. In contrast, at four unburned sites, two in sub-population E, and one in both A and C, sparrows were absent in 2005, but one or two sparrows were present in 2009 (**Figure 27**). At the other four unburned sites, all in sub-population E, sparrows were either absent in 2009 or if present, density was lower in 2009 than in 2005. At these sites, change in bird number in relation to vegetation-inferred hydroperiod in 2009 could simply be a sign of stochastic variation, because the change in vegetation and vegetation-inferred hydroperiod were within an acceptable range observed when all sites were surveyed for the first time during 2003-2005 (Ross et al. 2006).

In general, the probability of CSSS occurrence decreases when hydroperiod increases beyond a threshold. In a healthy population, however, while sparrows are likely to remain concentrated in the most favorable part of their habitat, they may occasionally visit marginal sites. For instance, one relatively wet site (*Cladium* marsh) in sub-population E, the 2nd healthiest sub-population, was unoccupied in 2005, but two individuals were observed in 2009, even though the site showed an increase in vegetation inferred hydroperiod from 264 to 296 days flooding per year. In the same sub-population, birds were also sighted at two new census sites in 2009. At those sites, vegetation, as visually recorded by bird survey personnel, was dominated by sawgrass (*C. jamaicense*), spikerush (*Eleocharis* spp) and beakrush (*Rhynchospora* sp.), indicating that the sites were relatively wet. In sub-population E, several sites, particularly those near Shark Slough, have shown a change in vegetation indicative of increasing wetness in recent years (**Figure 4**; see also Sah et al. 2007, 2008 and 2009). While sparrows are occasionally sighted at these locations, it is likely that a continuation of the recent trend will adversely impact the local sparrow population.

In sub-population A, sparrows were sighted at six sites in 2009. There were five other sites at which birds were sighted in one or more of the last three years (2007-2009). Most of these occupied sites are located in areas that have experienced a change in vegetation to drier types, primarily caused by decrease in hydroperiod (**Figure 28**). A strategy to improve sparrow habitat using hydrology and fire as tools may help to restore a robust sparrow population in this part of area A.

In 2009, vegetation was sampled at 67 burned census sites. Only thirty two of these --- two burned in 2007, and 30 in 2008 --- were surveyed for sparrows in 2009. None of them supported CSSS one or two years after fire. Since sparrows were observed in 28% of them in at least one of the 3 years preceding the fire, it is most likely that the sparrows will return to those sites in next few years, particularly when vegetation recovery at the sites is rapid (**Figure 14**).

Other researchers have also shown that sparrows re-colonize the burned area in 3-5 years after fire (Pimm et al. 2002; LaPuma et al. 2007). Sites burned in 2005 and flooded within 7-15 days after fire, were not surveyed for birds in 2008 or 2009. Thus, it is not clear how the sparrow would respond to vegetation change mediated by the interaction of fire and hydrology at these sites. Since vegetation recovery at these sites is very slow, regular monitoring of the burned sites for sparrows during this recovery stage is desirable.

References

- Armentano, T. V., Sah, J. P., Ross, M. S., Jones, D. T., Cooley, H. C. and Smith, C. S. 2006. Rapid responses of vegetation to hydrological changes in Taylor Slough, Everglades National Park, Florida, USA. *Hydrobiologia* **569**: 293-309.
- Ball, J. P. 1990. Influence of subsequent flooding depth on cattail control by burning and mowing. *Journal of Aquatic Plant Management* **28**: 32-36.
- Busch, J., Mendelssohn, I. A., Lorenzen, B., Brix, H. and Miao, S. 2004. Growth responses of the Everglades wet prairie species *Eleocharis cellulosa* and *Rhynchospora tracyi* to water level and phosphate availability. *Aquatic Botany* **78** (1): 37-54.
- Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18**: 117-143.
- Collins, S. L. and Smith, M. D. 2006. Scale-dependent interaction of fire and grazing on community heterogeneity in tallgrass prairie. *Ecology* **87** (8):2058-2067.
- Forthman, C.A., 1973. The effects of prescribed burning on sawgrass, *Cladium jamaicense* Crantz, in south Florida. M.S. Thesis, University of Miami, FL, 83 pp.
- Foster, D. R. 1988. Disturbance history, community organization and vegetation dynamics of the old-growth Pisgah Forest, South-Western New Hampshire, USA. *Journal of Ecology* **76** (1): 105-134.
- Foster, D. R., Knight, D. H. and Franklin, J. F. 1998. Landscape patterns and legacies resulting from large, infrequent forest disturbances. *Ecosystems* **1**: 497-510
- Frelich, L.E. and P.B. Reich. 1998. Disturbance severity and threshold responses in the boreal forest. *Conservation Ecology* **2**(2): 7.
- Fukami, T. 2001. Sequence effects of disturbance on community structure. *Oikos* **92** (2): 215-224.
- Herndon, A., Gunderson, L. and Stenberg, J. 1991. Sawgrass (*Cladium jamaicense*) survival in a regime of fire and flooding. *Wetlands* **11**:17-27.
- Kirkman, L. K. and Sharitz, R. R. 1994. Vegetation disturbance and maintenance of diversity in intermittently flooded Carolina Bays in South Carolina. *Ecological Applications* **4** (1): 177-188.
- Kotun, K. Sonenshein, R., and DiFrenna, V. 2009. Analysis of flow across Tamiami Trail: An historical perspective. South Florida Natural Resources Center, Everglades National Park, Homestead, Florida. Technical Report (Draft).

- La Puma, D. A., Lockwood, J. L. and Davis, M. J. 2007. Endangered species management requires a new look at the benefit of fire. The Cape Sable seaside sparrow in the Everglades ecosystem. *Biological Conservation* **136**: 398-407.
- Li, J., Duggin, J. A., Loneragan, W. A. and Grant, C. D. 2007. Grassland responses to multiple disturbances on the New England Tablelands in NSW, Australia. *Plant Ecology* **193**: 39-57.
- Lockwood, J.L., Ross, M.S., Sah, J.P., 2003. Smoke on the water: the interplay of fire and water flow on Everglades restoration. *Frontiers in Ecology and the Environment* **1**, 462–468.
- McKee, K. L. and Baldwin, A. H. 1999. Disturbance regimes in North American wetlands, p. 331–363. *In* L. R. Walker (ed.), *Ecosystems of Disturbed Ground*. *Ecosystems of the World* 16. Elsevier, Amsterdam, The Netherlands.
- Minchin P. 1998. DECODA: Database for Ecological Community Data. Anutech Pty. Ltd., Canberra, Australia.
- Minchin, P.R., Folk, M. and Gordon, D. 2005. Trajectory Analysis: a New Tool for the Assessment of Success in Community Restoration. Meeting Abstract, Ecological Society of America 90th annual meeting, Montreal, Quebec, August 7-12, 2005.
- Pahl, J. W., Mendelsohn, I. A., Henry, C. B. and Hess, T. J. 2003. Recovery trajectories after in situ burning of an oiled wetland in coastal Louisiana, USA. *Environmental Management* **31** (2): 236-251.
- Paine, R. T., Tegner, M. J. and Johnson, E. A. 1998. Compounded perturbations yield ecological surprises. *Ecosystems* **1**: 535-545.
- Pathak, C. S. and Palermo, S. 2006. Rainfall-Based Management Plan for Water Conservation Area 3A in the Florida Everglades. American Society of Civil Engineers /Environmental and Water Resources Institute World Water & Environmental Congress 2006 May 21-25, 2006. Omaha, Nebraska, USA
- Peters, D. P. C., Pielke, R. A. Sr, Bestelmeyer, B. T., Allen, C. D., Munson-McGee, S. and Havstad, K. M. 2004. Cross scale interactions, nonlinearities, and forecasting catastrophic events. *Proceedings National Academy Sciences* **101**:15130-15135.
- Pimm, S. L., Lockwood, J. L., Jenkins, C. N., Curnutt, J. L., Nott, P., Powell, R. D. and Bass, O. L. Jr. 2002. Sparrow in the Grass: A report on the first ten years of research on the Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*). Report to Everglades National Park, Homestead, FL. Ponzio, K. J., Miller, S. J. and Lee, M. A. 2004. Long-term effects of prescribed fire on *Cladium jamaicense* crantz and *Typha domingensis* pers. densities. *Wetlands Ecology and Management* **12**: 123-133.

- Ross, K. A., Taylor, J. E., Fox, M. D. and Fox, B. J. 2004. Interaction of multiple disturbances: importance of disturbance interval in the effects of fire on rehabilitating mined areas. *Austral Ecology* **29**: 508-529.
- Ross, M. S., Sah, J. P., Snyder, J. R., Ruiz, P. L. Jones, D. T. Cooley, H. C., Travieso, R. and Hagayari, D. 2006. Effect of Hydrology Restoration on the Habitat of the Cape Sable Seaside Sparrow. Annual Report of 2004-2005. A report submitted to Everglades National Park, Homestead, FL.
- Sah, J. P., Ross, M. S. Snyder, J. R., Ruiz, P. L., Jones, D. T., Travieso, R., Stoffella, S., Timilsina, N., Cooley, H. C., and Barrios. B. 2007. Effect of hydrological restoration on the habitat of the Cape Sable seaside sparrow. Annual Report of 2005-2006. A report submitted to Everglades National Park, Homestead, FL.
- Sah, J. P., Ross, M. S., Snyder, J. R., Ruiz, P. L, Stoffella, S., Kline, M., Shamblin, B., Hanan, E., Ogurcak, D. and Barrios. B. 2008. Effect of hydrological restoration on the habitat of the Cape Sable seaside sparrow. Annual Report of 2006-2007. A Report submitted to Everglades National Park, Homestead, FL.
- Sah, J. P., Ross, M. S., Snyder, J. R., Ruiz, P. L, Stoffella, S., Kline, M., Shamblin, B., Hanan, E., Lopez, L. and Hilton, T.J. 2009. Effect of hydrological restoration on the habitat of the Cape Sable seaside sparrow. Annual Report - FY 2008. A report submitted to USACOE, Jacksonville, FL.
- Saha, S., and Bradley, K. 2007. Changes in plant communities from 2003 to 2007 in Taylor Slough of the Everglades National Park. A report submitted to Everglades National Park, Homestead, FL.
- Science Coordination Team (SCT), The role of flow in the everglades ridge and slough landscape, South Florida Ecosystem Restoration Working Group, 62 pp., 2003.
- Snyder, J. R. and Schaeffer, C. 2004. Seasonal fire effects on muhly grass (*Muhlenbergia capillaris* var. *filipes*). Final Report # IAA Number F5120010007 submitted to Big Cypress National Preserve, Ochopee 34141, FL.
- Stone R. 1998. Yellowstone rising again from ashes of devastating fires. *Science* **280**:1527-8.
- Turner, M.G., and Dale, V.H., 1998. Comparing large, infrequent disturbances: What have we learned? *Ecosystems* **1**, 493-496.
- Walker, L. R., and F. S. Chapin, III. 1987. Interactions among processes controlling successional change. *Oikos* **50**:131-135.
- Werner, H., 1975. The Biology of the Cape Sable seaside sparrow, In Report to US Fish and Wildlife Service. Everglades National Park, Homestead.

Wu, Y., Wang, N. and Rutchey, K. 2006. An analysis of spatial complexity of ridge and slough patterns in the Everglades ecosystem. *Ecological Complexity* **3** (3): 183-192.

Zedler, J. B., and Kercher, S. 2004. Causes and consequences of invasive plants in wetlands: opportunities, opportunists, outcomes. *Critical Reviews in Plant Sciences* **23**:431–452.

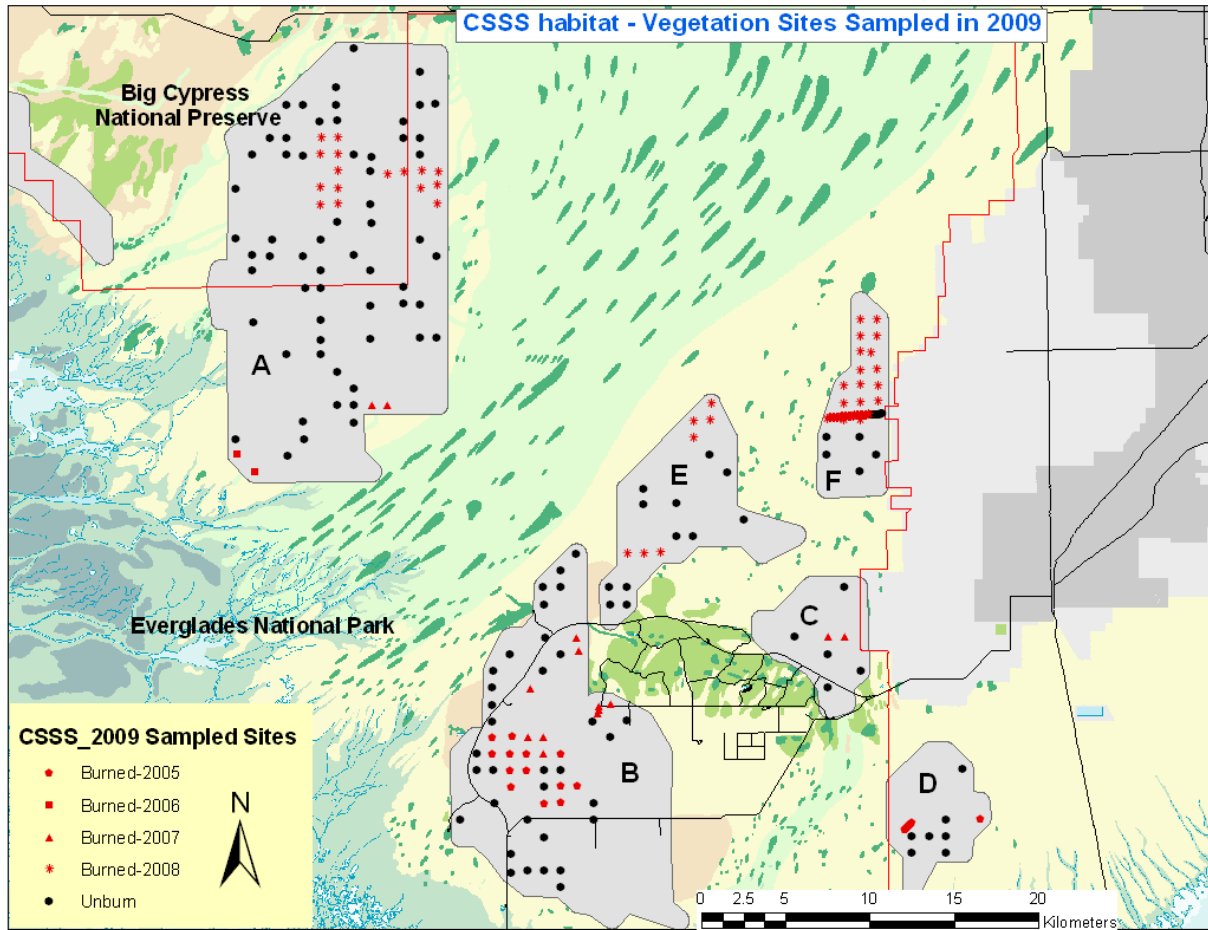


Figure 1: Location of sites within the Cape Sable seaside sparrow (CSSS) habitat sampled for vegetation in 2009.



Figure 2: CSSS vegetation monitoring site burned in 2008 and sampled in 2009

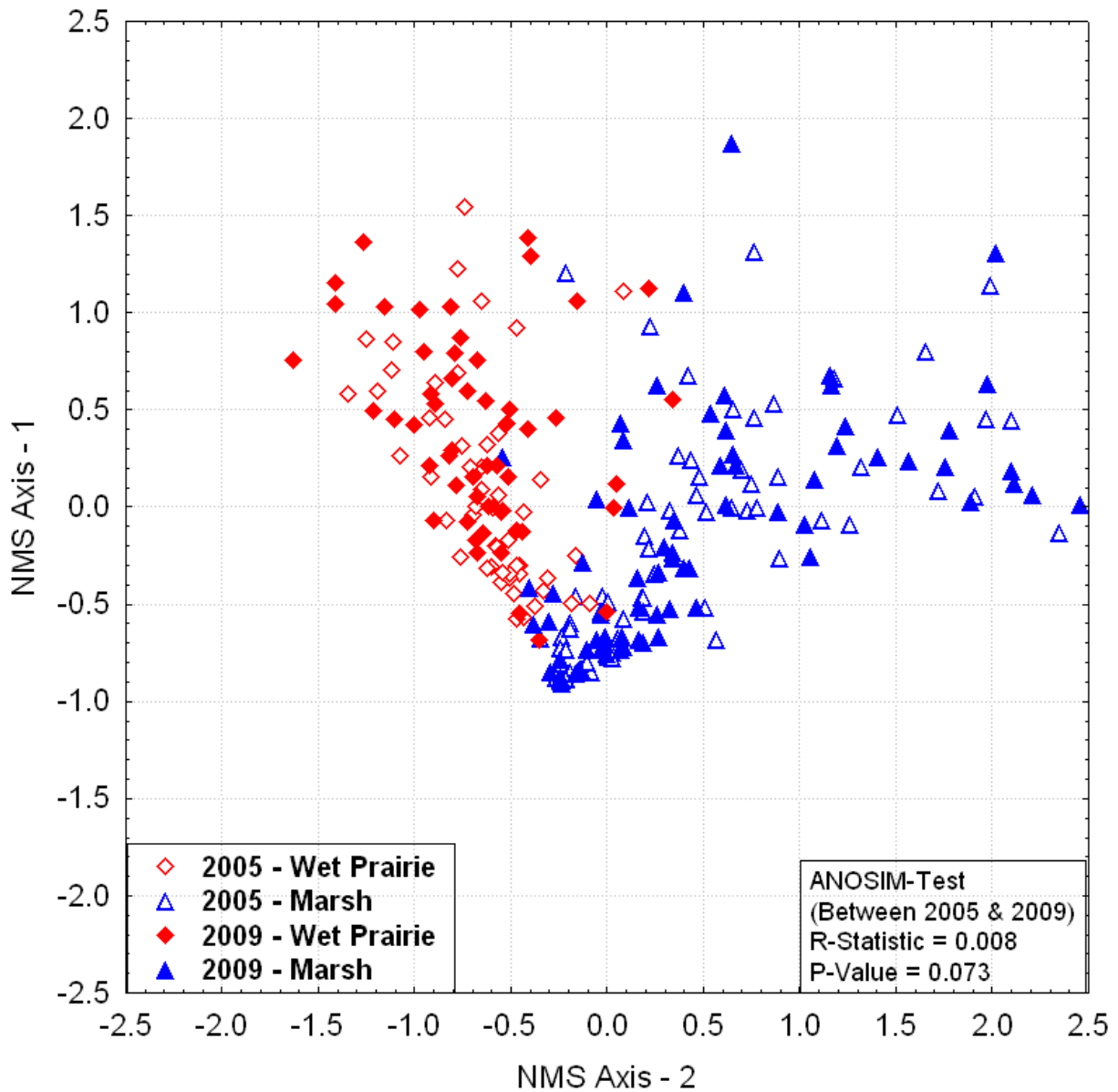


Figure 3: Site scores from 2-Axis non-metric multidimensional scaling (NMS) ordination based on relative cover of species at 124 unburned CSSS census sites sampled in both 2005 and 2009. The distinct grouping between marsh (blue) and wet prairie (red) are easily distinguishable regardless of years sampled, and samples from 2005 (open) and 2009 (closed) are mostly limited within the cloud of marsh and prairie points. Both wet prairie and marsh samples from 2009 (filled red and filled blue, respectively) present in different colored clouds show that the sites have changed in vegetation composition in four years.

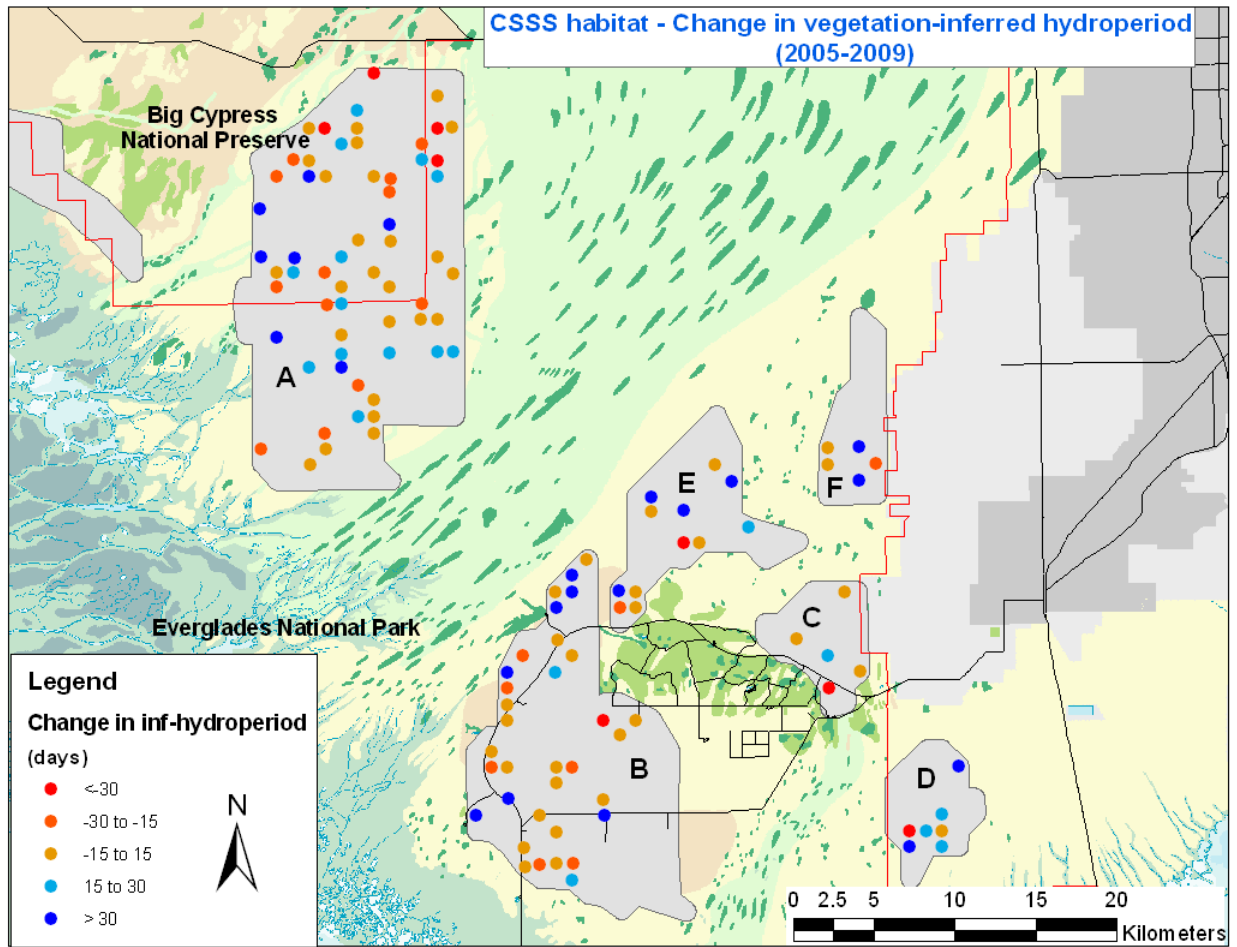


Figure 4: Change in vegetation inferred hydroperiod between 2005 and 2009 sampling at 124 unburned sites within CSSS habitat.

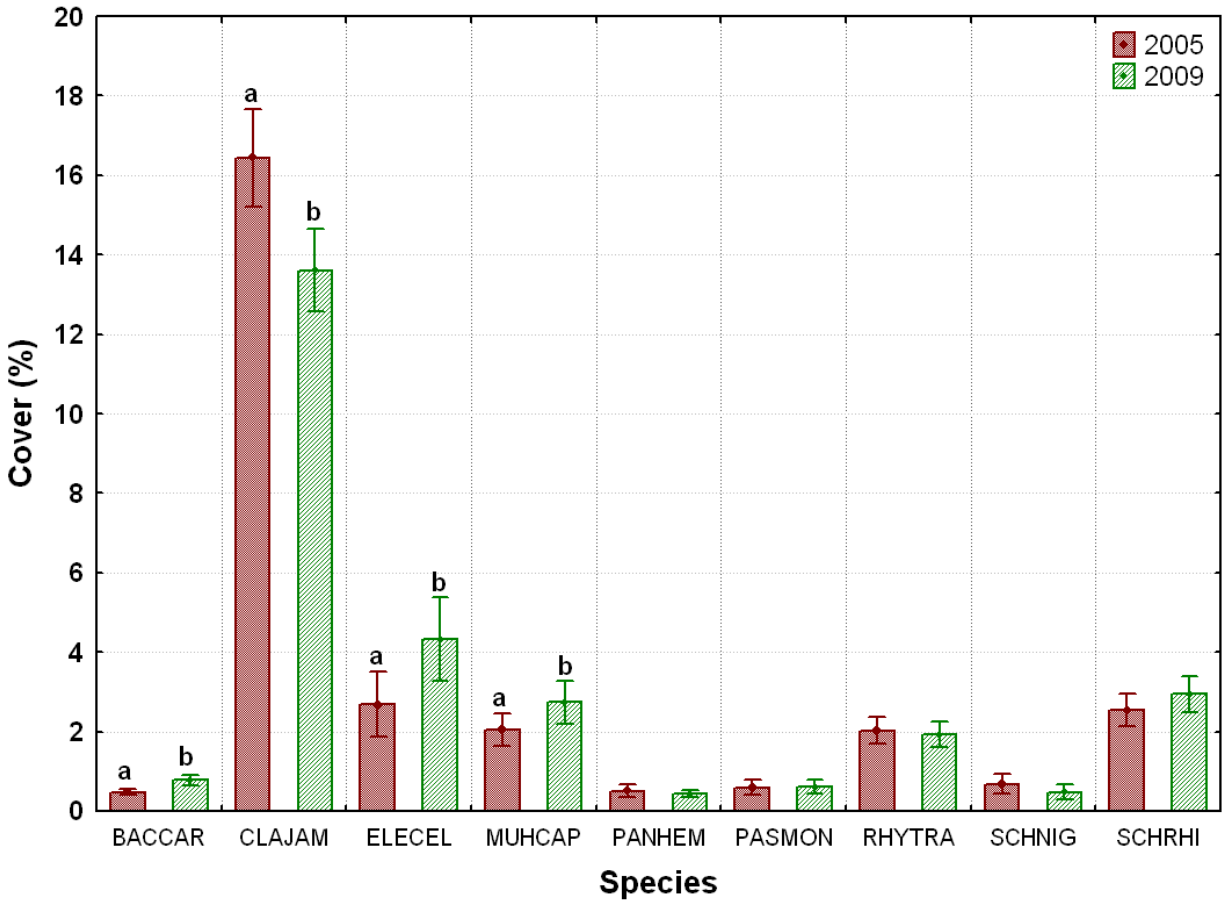


Figure 5: Mean (± 1 S.E.) cover of major species (mean cover $>0.5\%$) at the 124 unburned CSSS census sites sampled in 2005 and 2009. Different roman letters indicate significant difference (pair wise t-test; $p < 0.05$) in cover of the particular species between the two sampling events. BACCAR = *Bacopa caroliniana*, CLAJAM = *Cladium jamaicense*, ELECEL = *Eleocharis cellulosa*, MUHCAP = *Muhlenbergia capillaris* var. *filipes*, PANHEM = *Panicum hemitomon*, PASMON = *Paspalum monostachyum*, RHYTRA = *Rhynchospora trayci*, SCHNIG = *Schoenus nigricans*, and SCHRHI = *Schizachyrium rhizomatum*.

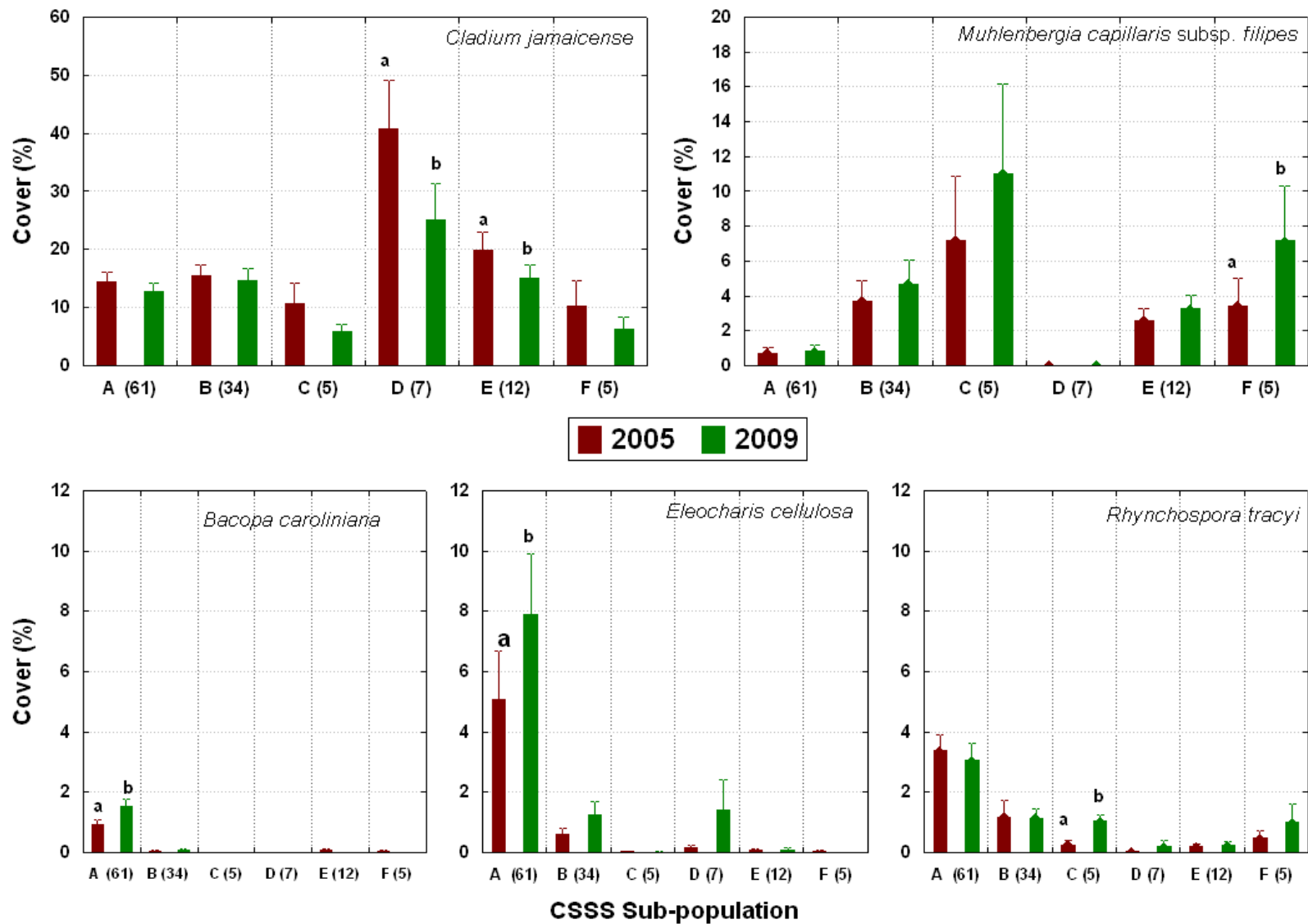


Figure 6: Mean (\pm 1 S.E.) cover of five major species that differed significantly in one or more populations at the unburned CSSS census sites sampled in both 2005 and 2009. The number of sites sampled in each sub-population is given in parenthesis.

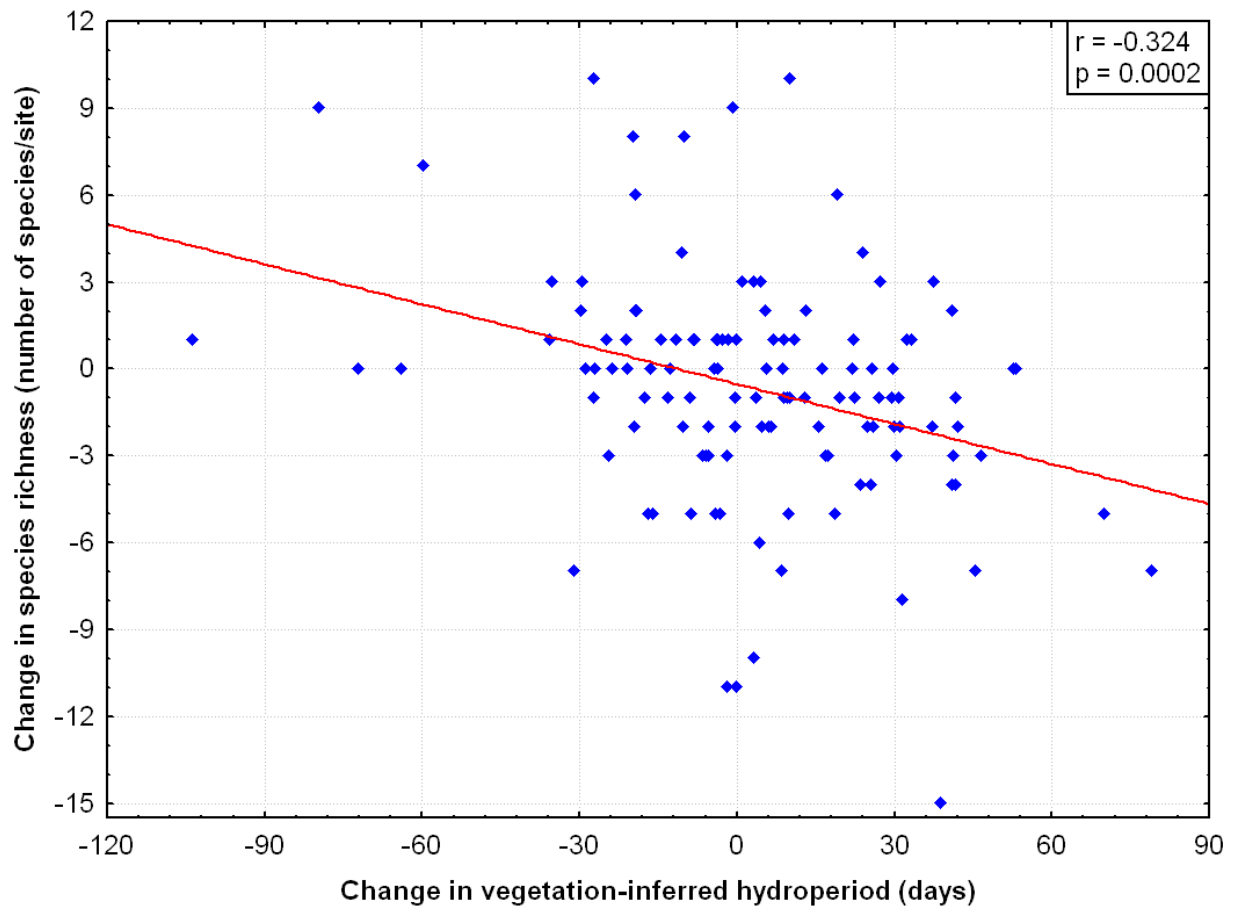


Figure 7: Relationship between change in vegetation-inferred hydroperiod and species richness at the 124 unburned CSSS census sites sampled in 2005 and 2009.

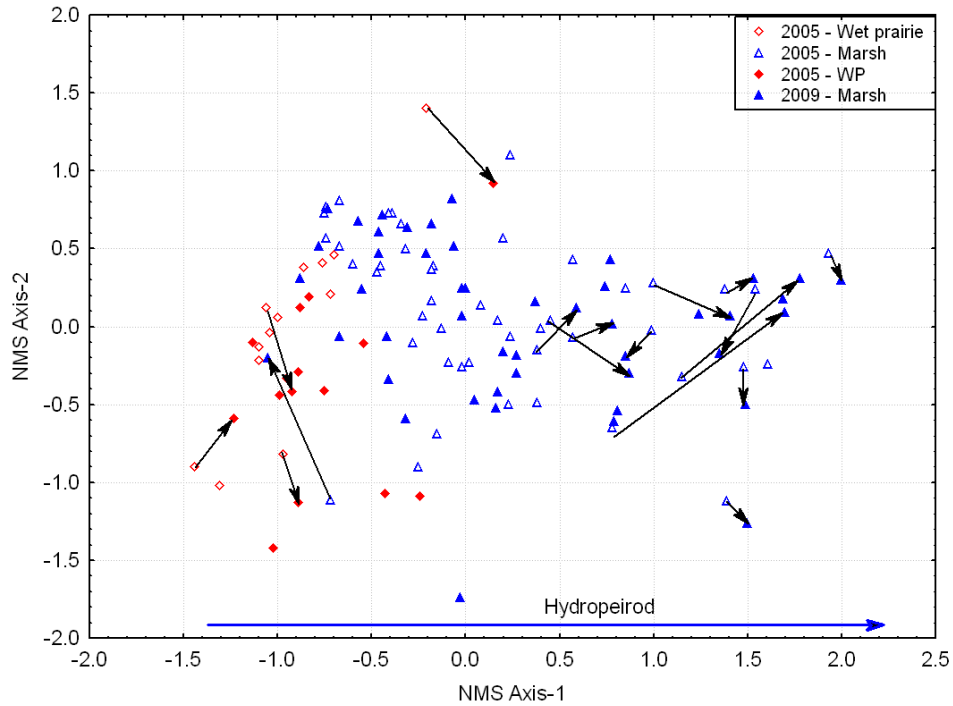


Figure 8: Non-metric multidimensional scaling (NMS) ordination based on relative cover at 72 plots on Sup-population A. Arrows show the shift in site position in ordination space due to dissimilarity in vegetation structure and composition between 2005 and 2009.

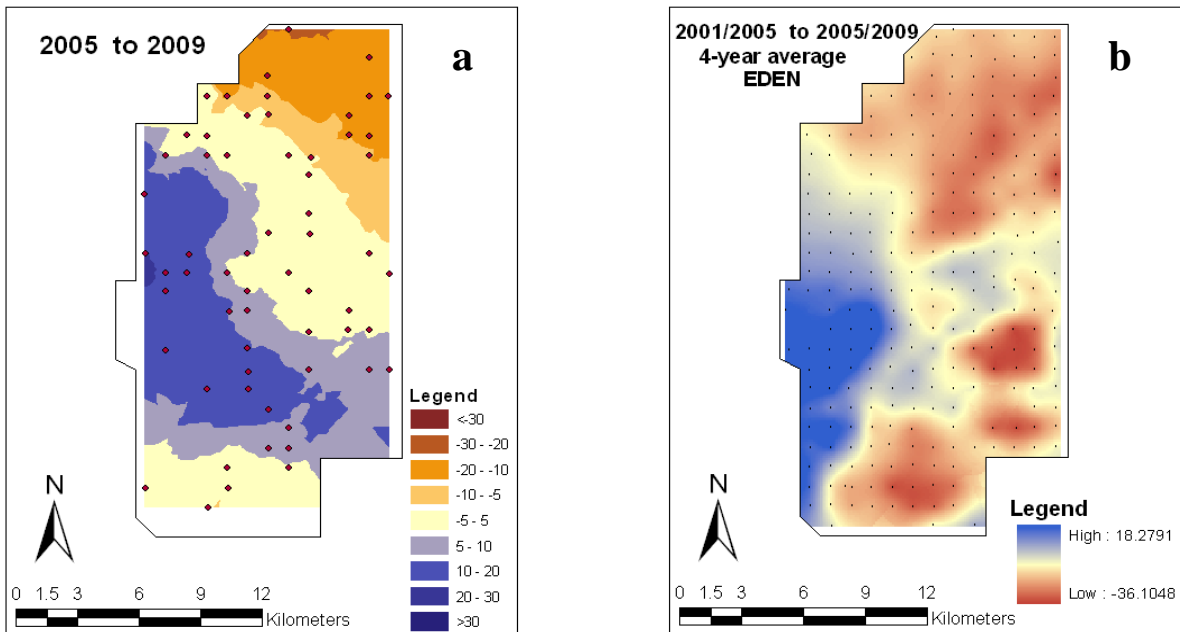


Figure 9: Change in vegetation-inferred (a) and EDEN-data based (b) hydroperiods (days) between 2005 and 2009 within the habitat of CSSS sub-population A.

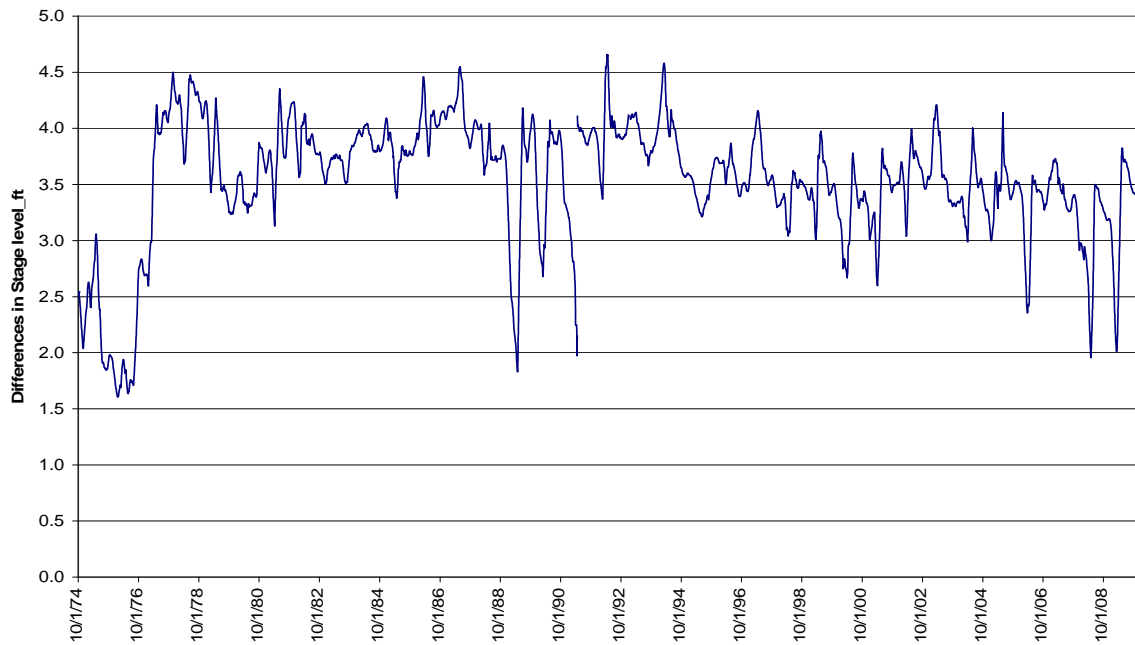
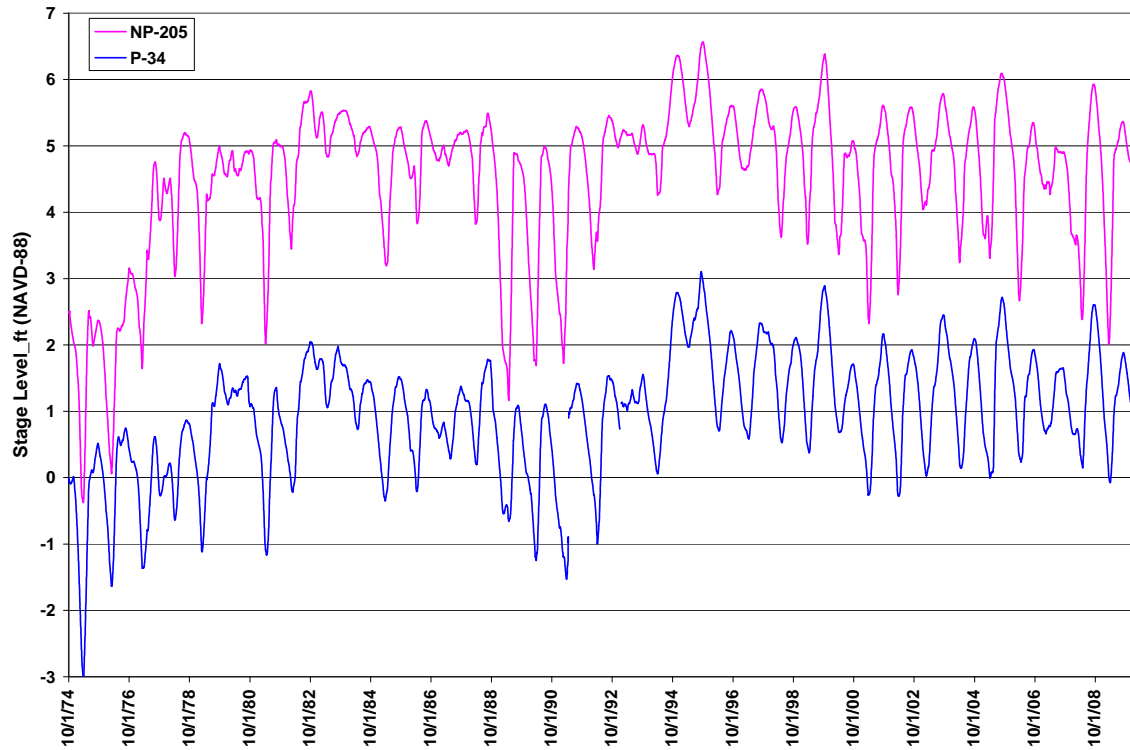


Figure 10: Water level (ft-NAVD 1988) at stage recorders at NP205 and P34. (A) 60-day moving average stage level (B) 60-day moving average stage differences between two stage recorders, N-P205 and P-34.

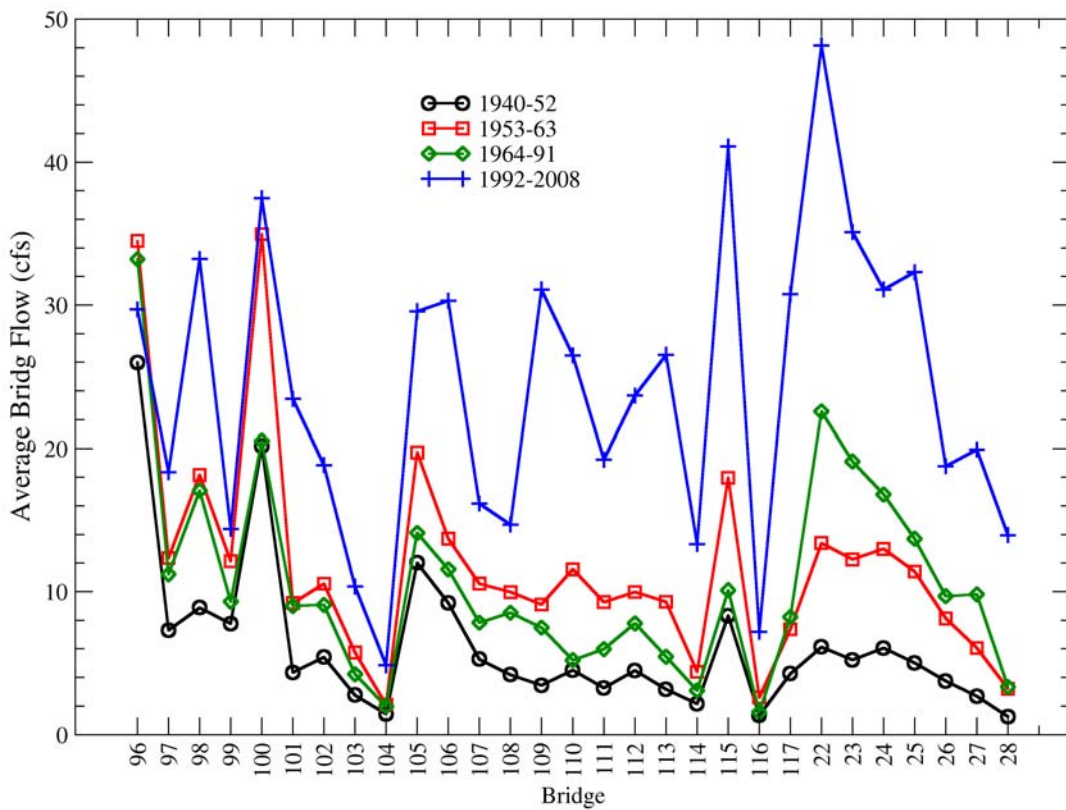


Figure 11: Location map of the culverts and bridges on the Forty Mile bend to Monroe Station section of Tamiami Trail (a) and mean water flow through them (b). The number of bridge starts from west, separately for the sections in Collier and Dade County. (Curtsey: **Kotun et al. 2009**)

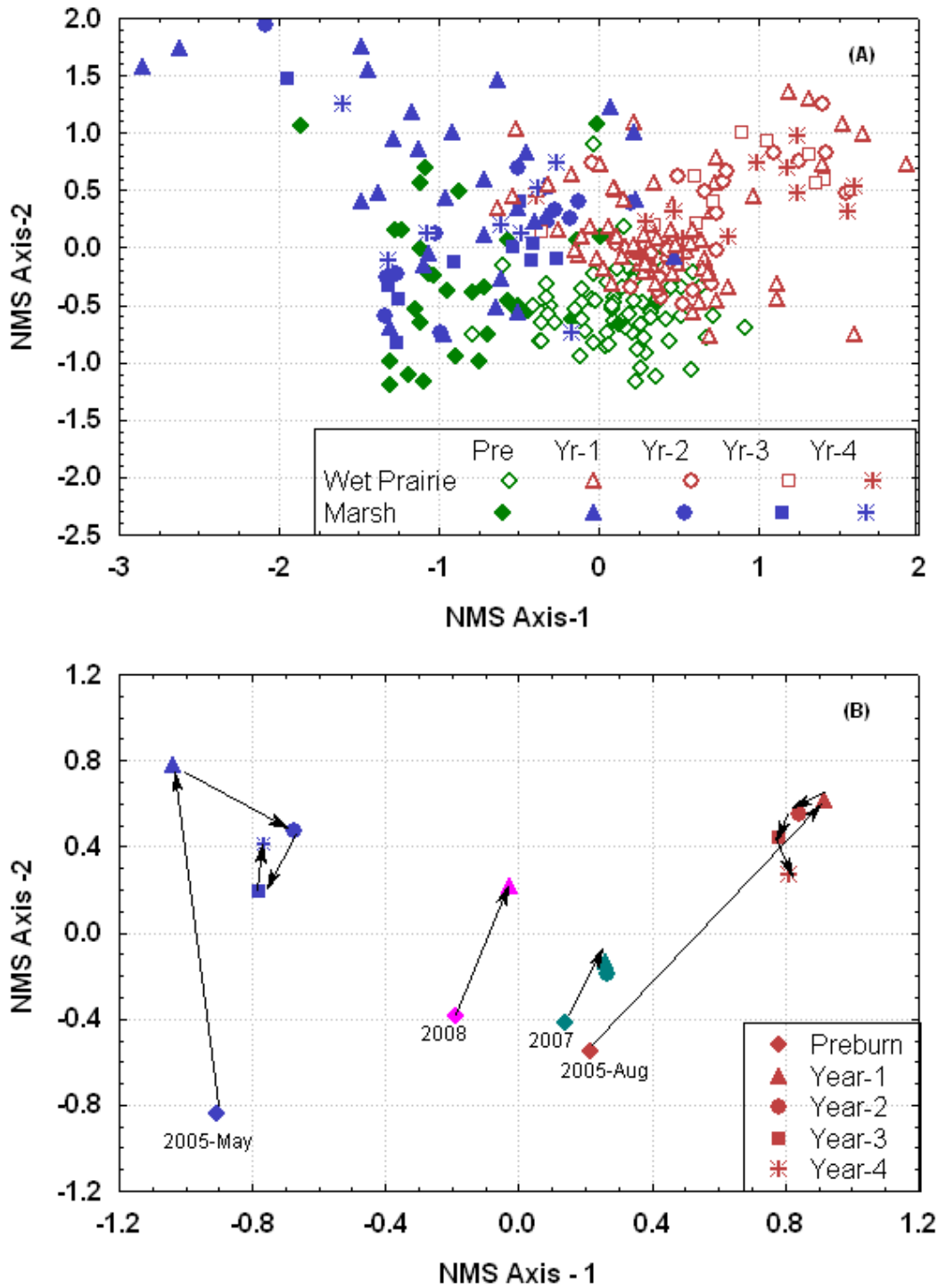


Figure 12: Two-Axis non-metric multidimensional scaling (NMS) ordination based on total cover at 101 sites burned during 2005-2008 and sampled prior to burn and 1-4 years after fire. (A) All sites with multiple samples (B) Centroids of sites grouped by burn year. Sites burned in 2005 are sub-grouped in May-burned and Aug-burned sites. Year (1-4) represents post-fire years.

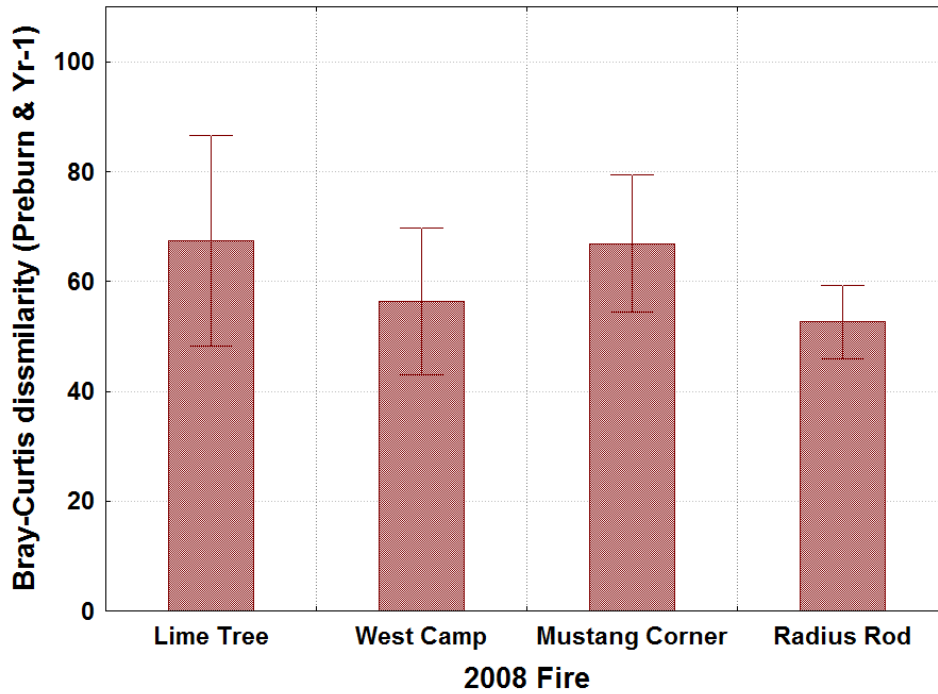


Figure 13: Mean Bray-Curtis dissimilarity (%) between pre-burn and one year after fire vegetation at sites burned in one of four wildfires in 2008.

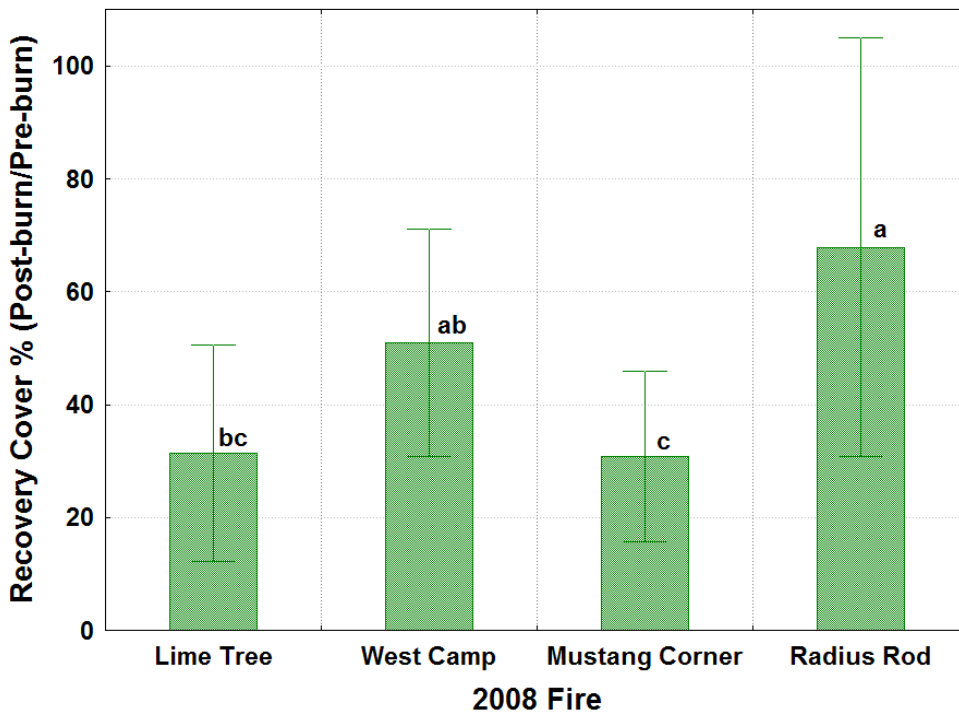


Figure 14: One-year post-fire mean vegetation cover expressed as a percent of pre-burn vegetation cover at sites burned in one of four wildfires in 2008.

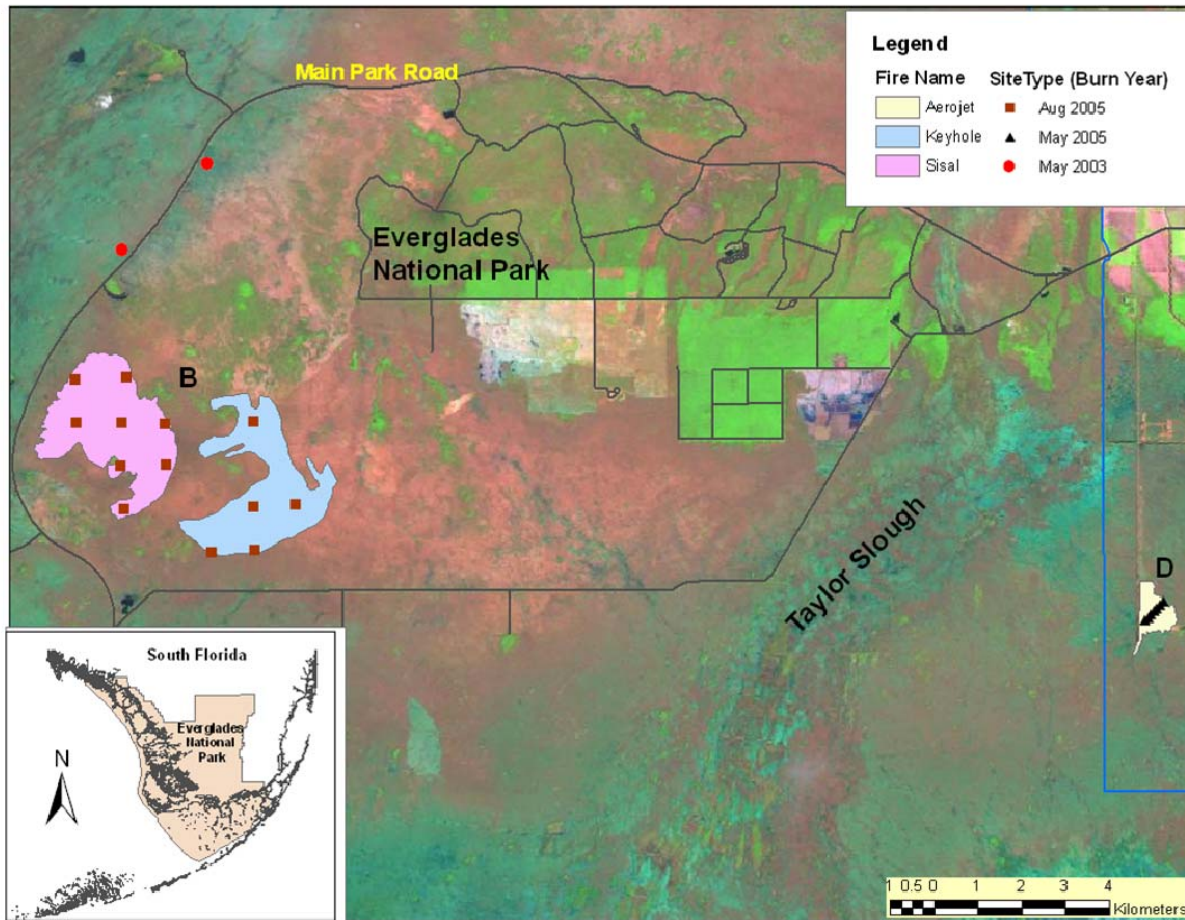


Figure 15: CSSS vegetation monitoring sites burned in 2005 fires. Three fires, two in sub-population B and one in sub-population D, burned 21 sites. Two sites burned in 2003 and monitored for 4 years after fire are shown as reference sites.

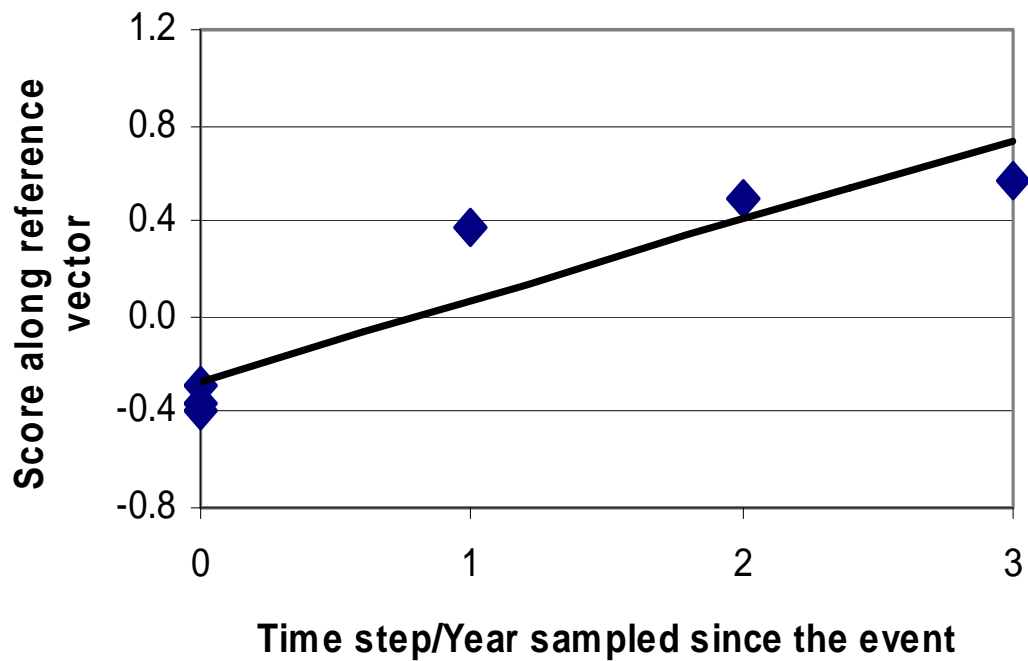
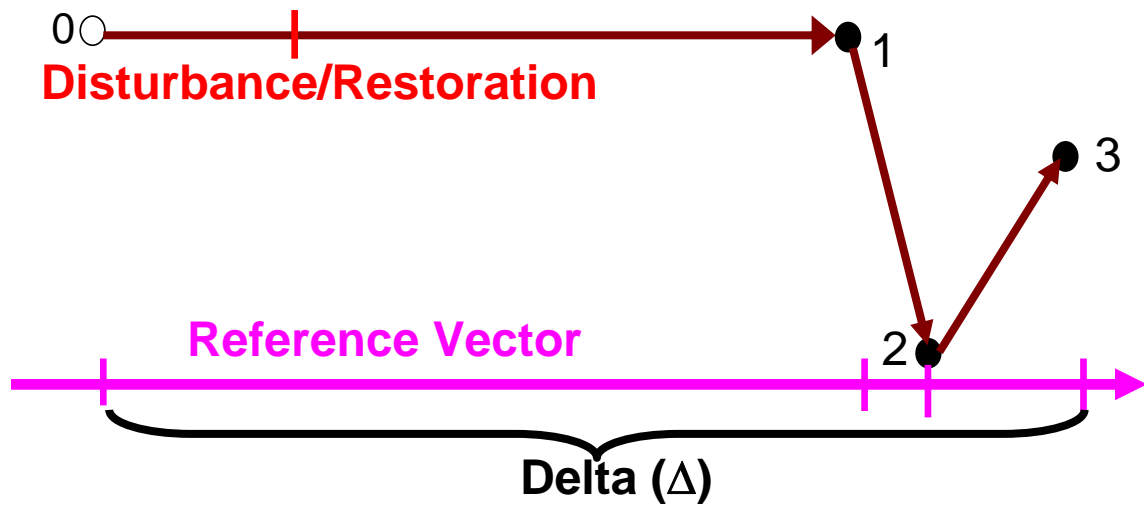


Figure 16: Schematic representation of two statistics calculated (A) to quantify the degree (Delta Δ), and (b) rate of change (Slope) in vegetation composition along a reference vector.

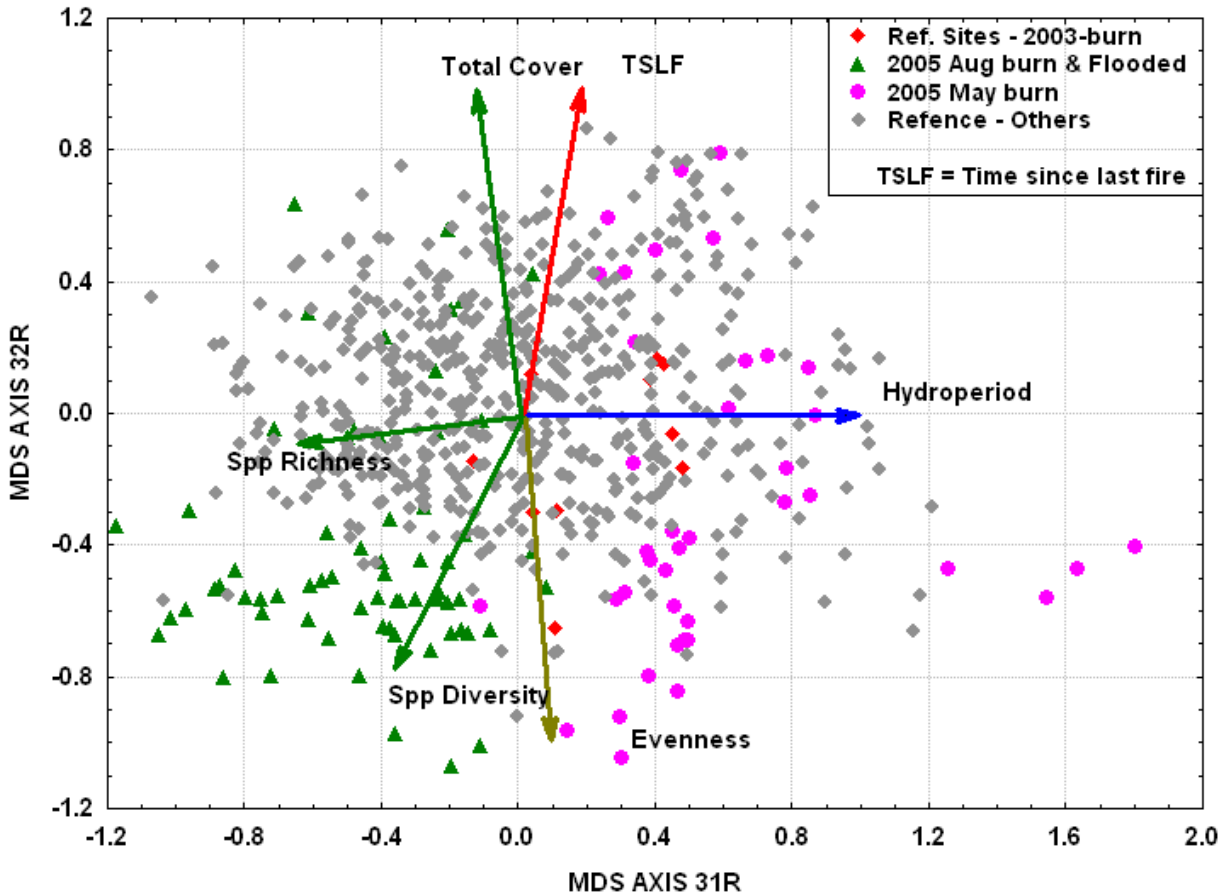


Figure 17: Site scores for Axis-1 and 2 from 3-Axis non-metric multidimensional scaling (NMDS) ordination based on species cover values at both burned and unburned sites. Burned sites are sites burned in 2003 and 2005, sampled before fire and annually for 4 post-fire years. Reference sites are the census and transect sites sampled during 2003 and 2005 in sub-populations B-F. Hydrology vector is based on hydroperiod values calculated for transect sites, and time since last fire (TSLF) vector is based on fire data (1981-2005) for both census and transect sites. Ordination axes were rotated to perfectly align the hydroperiod vector with the first axis.

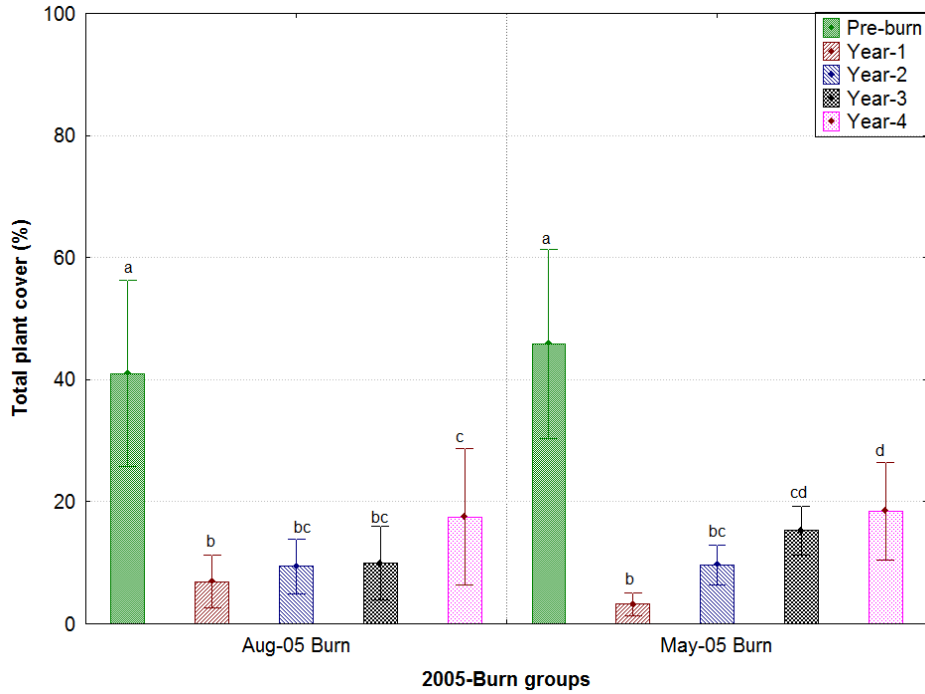


Figure 18: Mean total plant cover (%) in pre-burn and subsequent year samples after fire for two groups of sites, one burned in May 2005 and the other in August 2005. Different letters indicate significant differences (Tukey HSD-test; $p < 0.05$) in mean total cover between sampled years within each burn group.

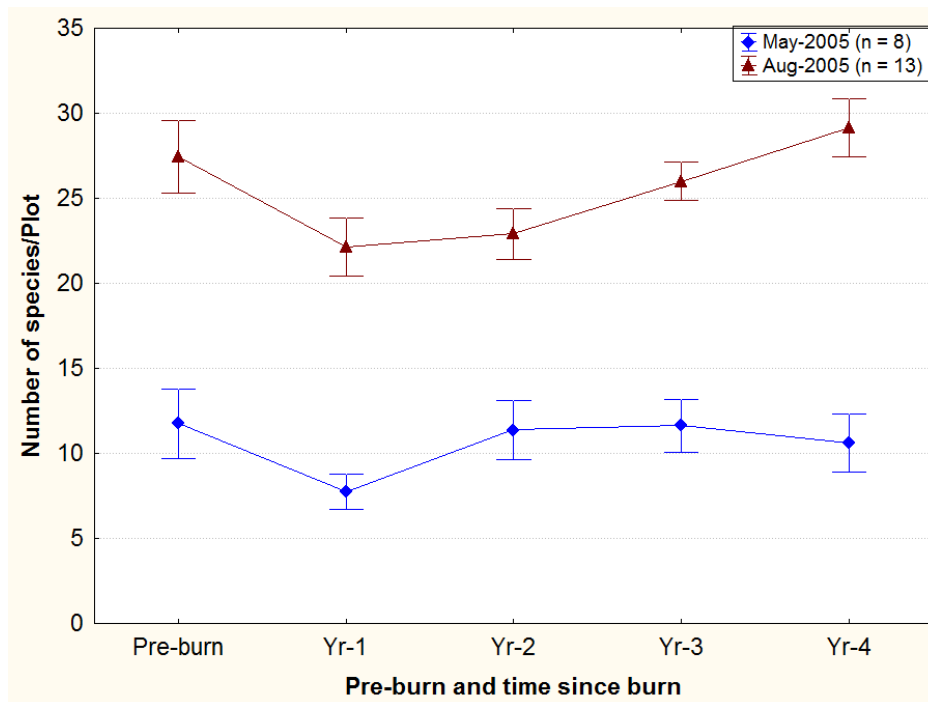


Figure 19: Change in number of species at the two sets of census sites, burned in May 2005 (May_burn) and August 2005 (Aug_burn), and sampled annually for four post-fire years.

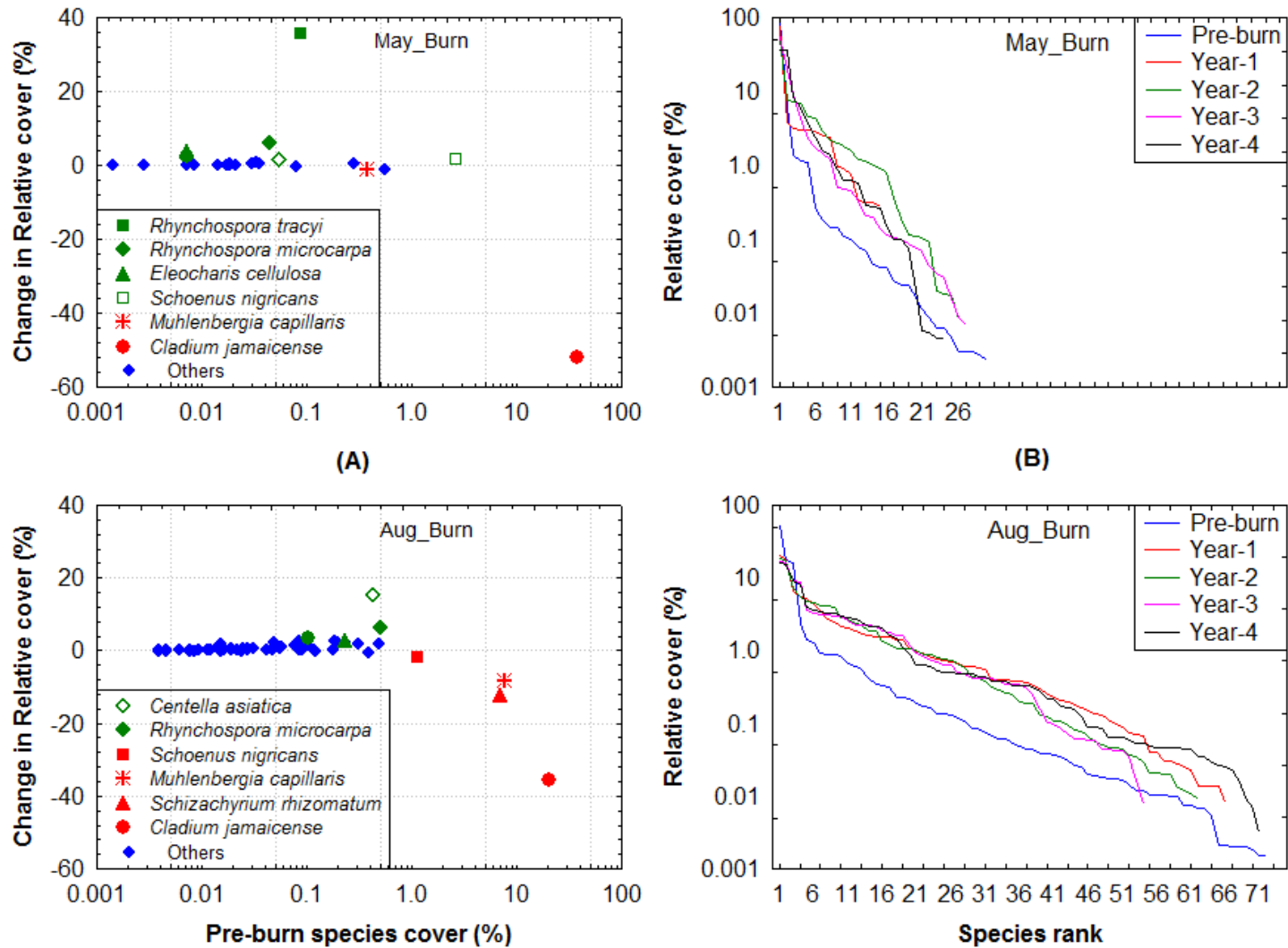


Figure 20: Change in the relative cover of species (A) in four years after fire, and species rank abundance (B) at the sites burned in May 2005 (May_burn) and August 2005 (Aug_burn), and re-sampled annually for four post-fire years.

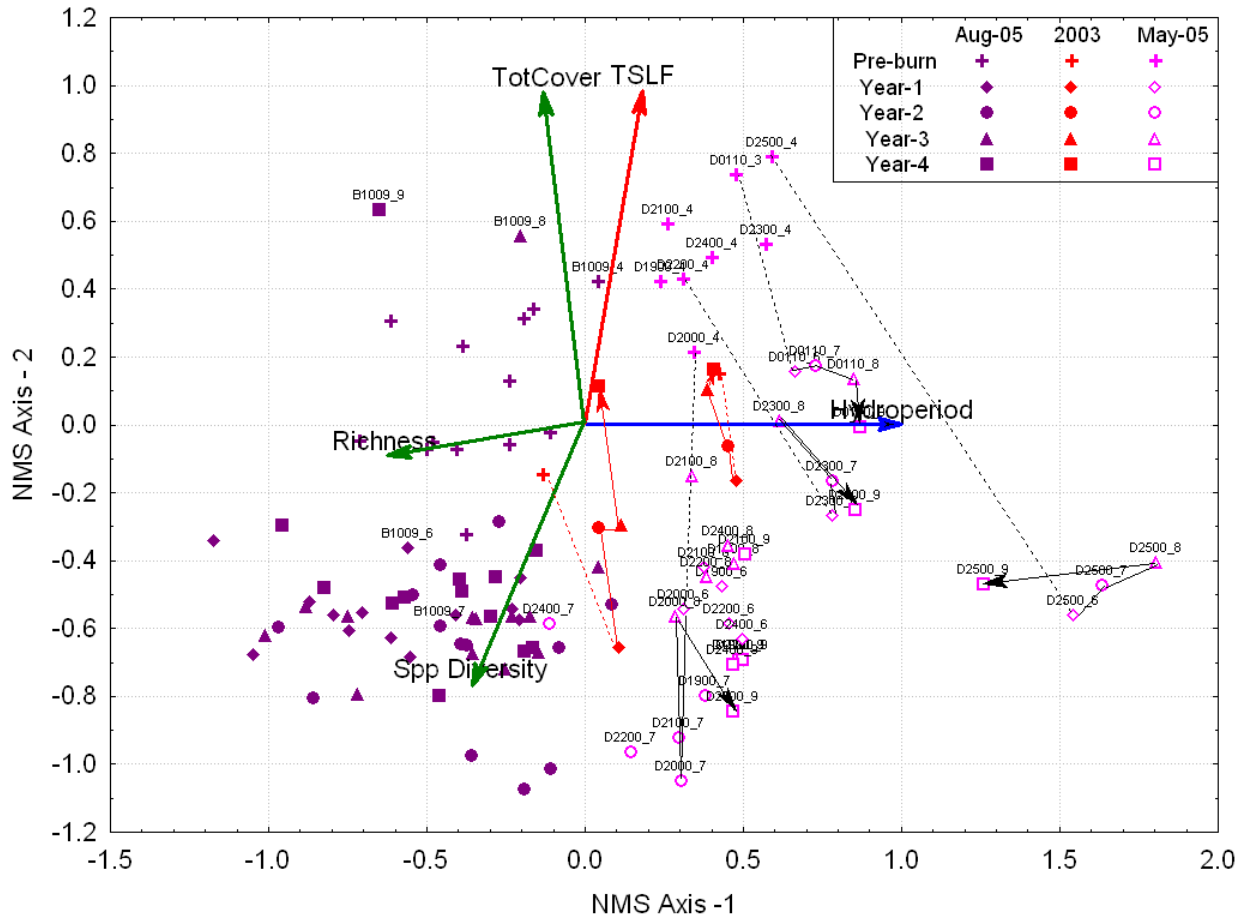


Figure 21: Site scores for Axis-1 and 2 from 3-Axis non-metric multidimensional scaling (NMS) ordination based on total cover at 2 sites burned in 2003 and 21 sites burned in 2005. Two sites burned in 2003 are used as reference sites. Sites joining the repeated samples of the same site show trajectory of the site.

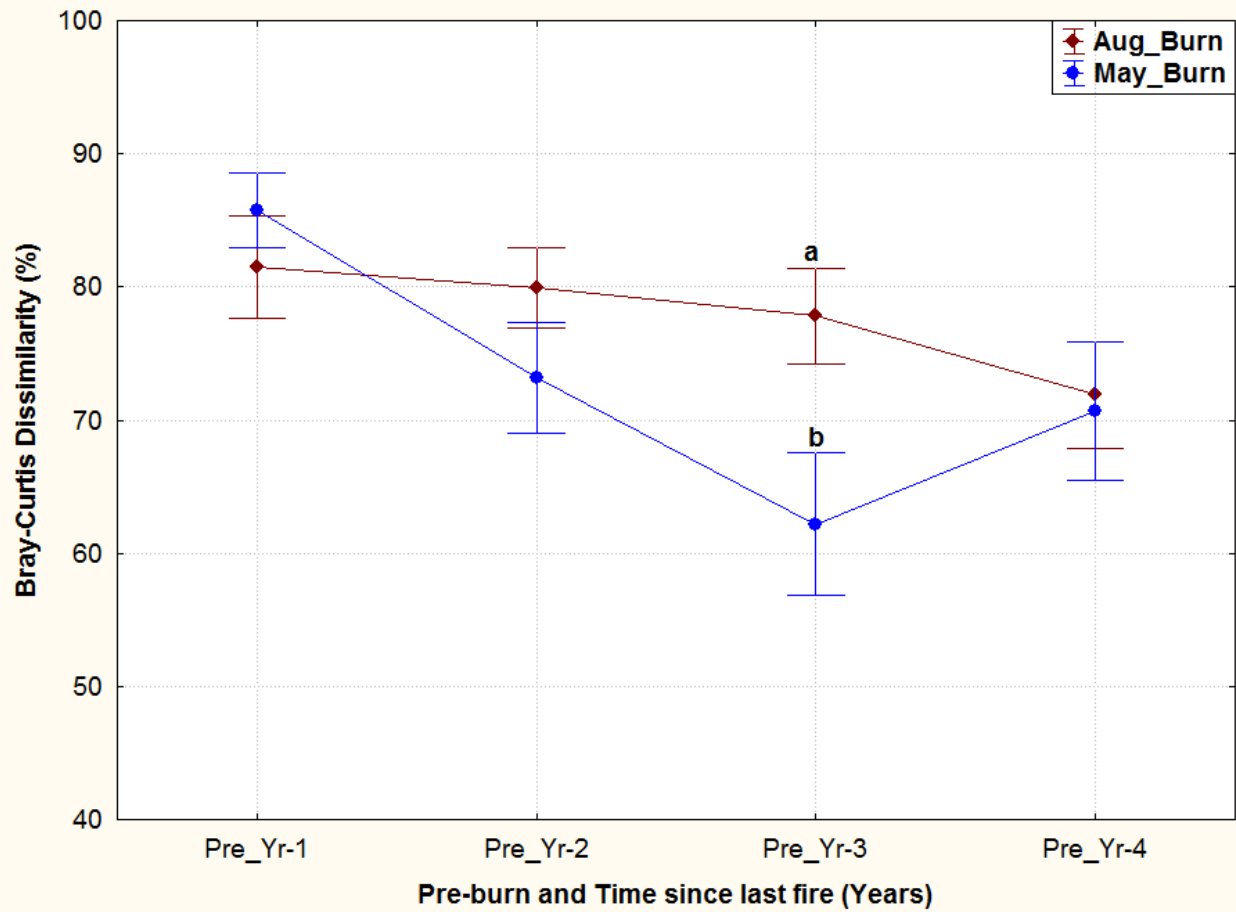


Figure 22: Mean Bray-Curtis dissimilarity (%) between pre-burn Post-fire year for two groups of sites, one burned in May 2005 (May_Burn) and the other in August 2005 (Aug_Burn).

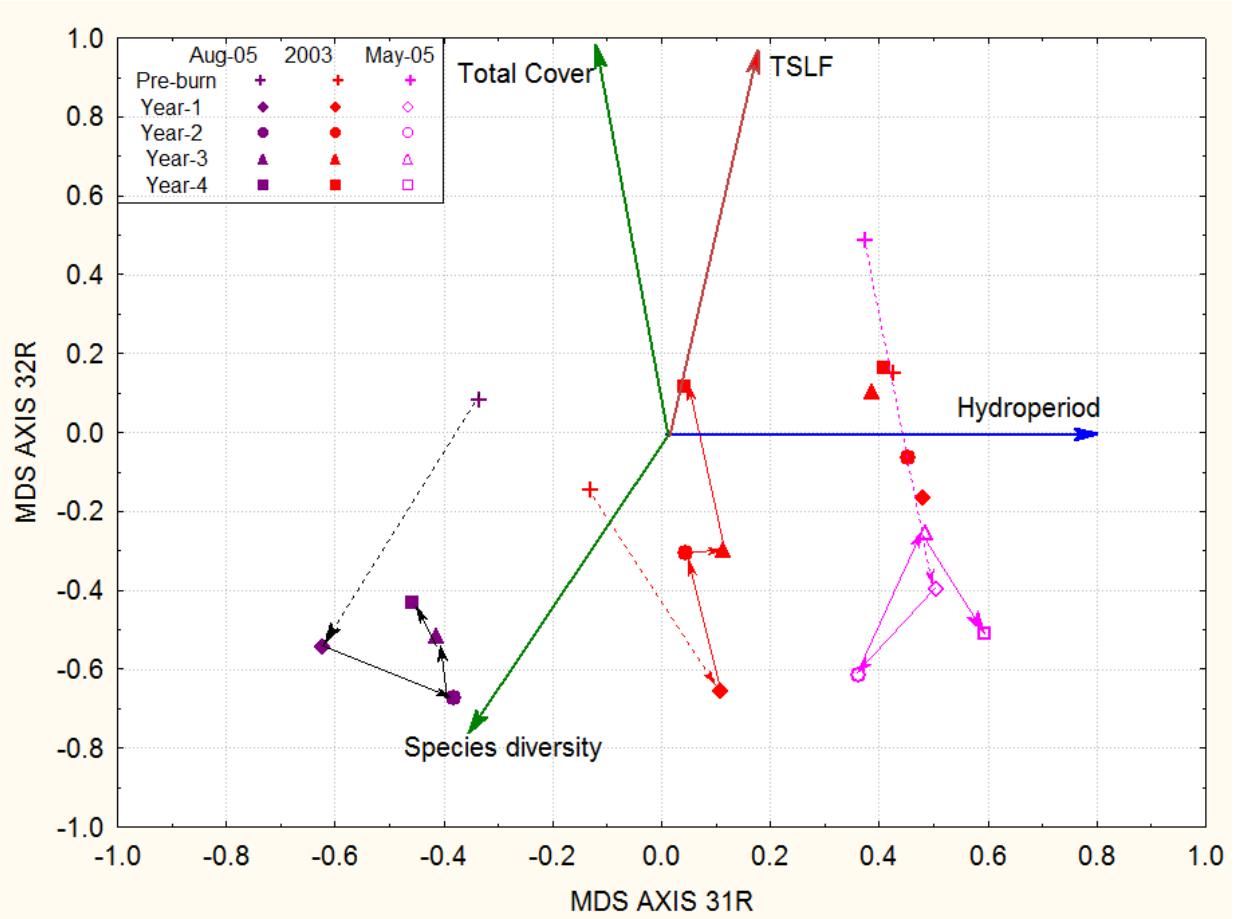


Figure 23: Site scores for Axis-1 and 2 from 3-Axis non-metric multidimensional scaling (NMS) ordination based on total cover at 2 sites burned in 2003 and 21 sites burned in 2005. Two sites burned in 2003 are used as reference sites. For the sites burned in 2005, points in ordination space represent centroids of sites grouped by month of burning and post-fire hydrology condition.

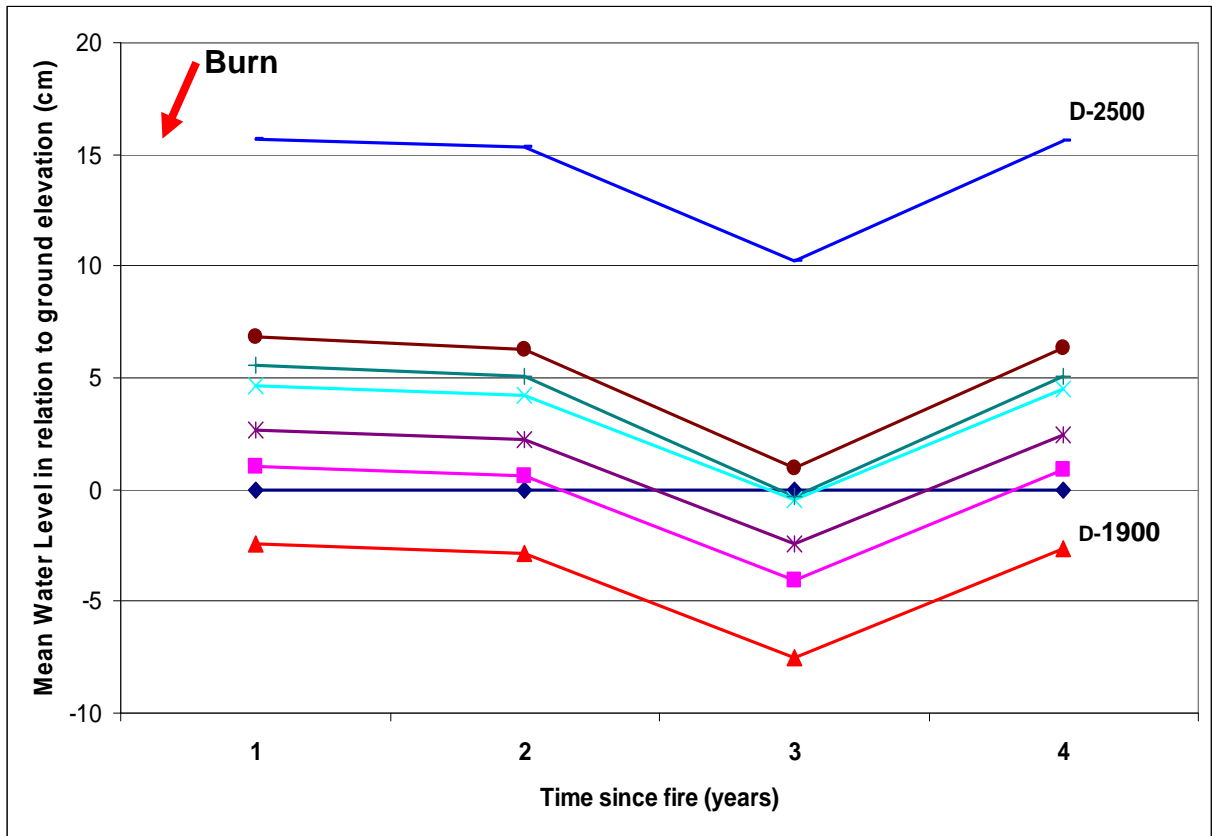


Figure 24: Mean annual water depth at the sites on Transect D burned in May 2005. Mean Water depth is based on the ground elevation and EDEN water stage data.

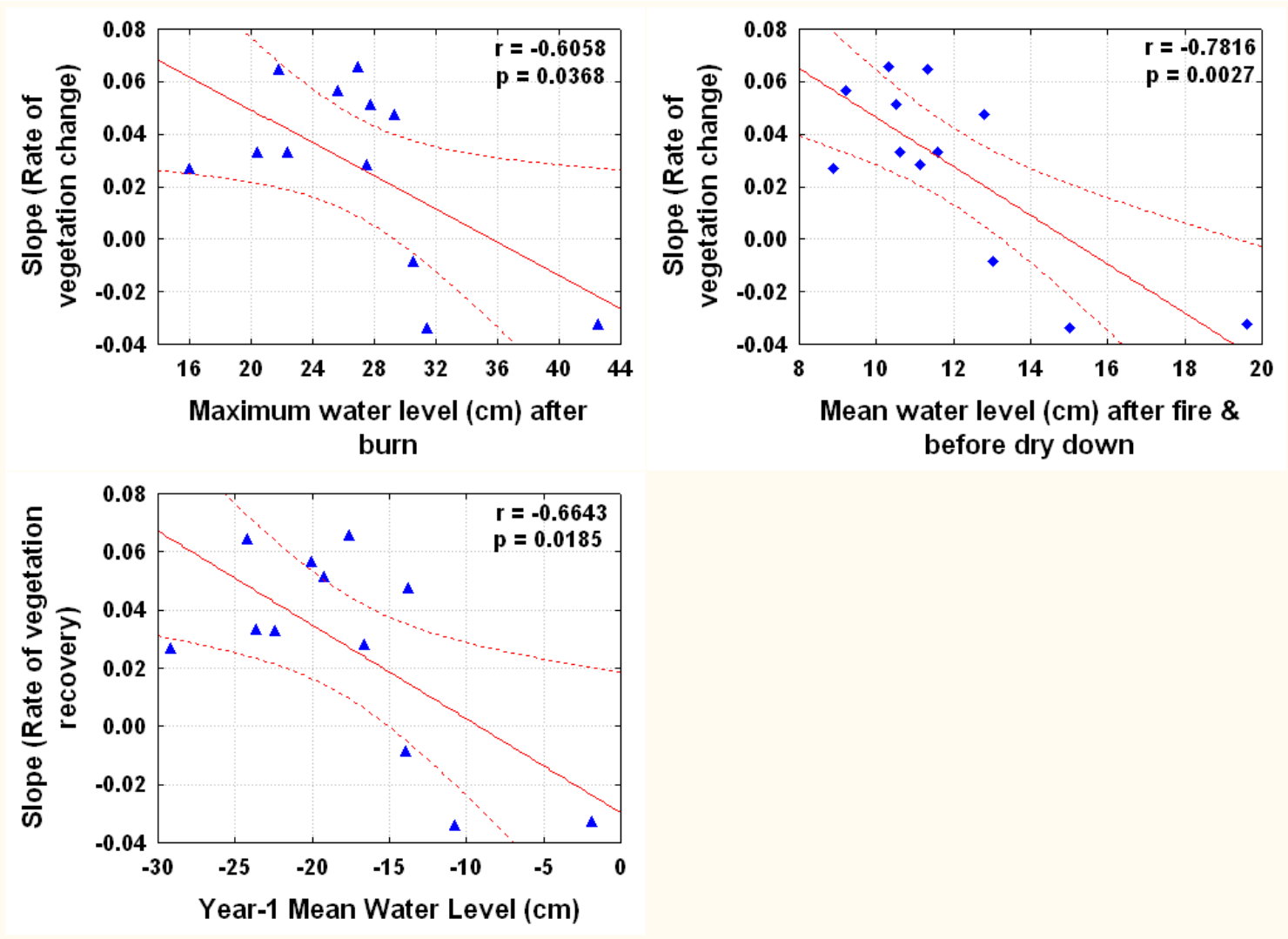


Figure 25: Relationship between post-fire hydrologic conditions at August burn sites and rate vegetation recovery (slope) along time since last fire vector in non-metric multidimensional spacing (NMS) ordination space. One site (B-10-09) lowest water depth with much higher slope value was considered as outlier, and excluded from analysis.

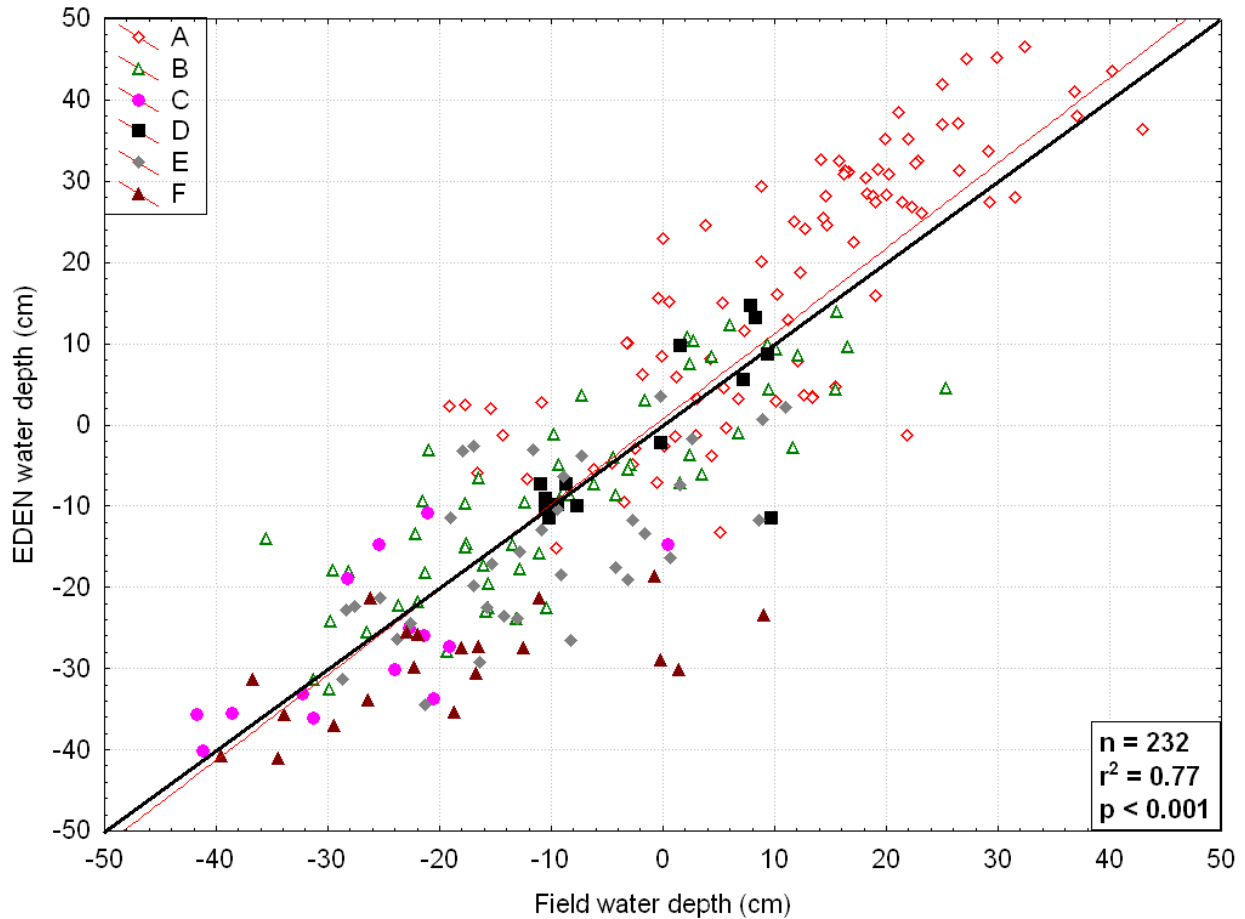


Figure 26: Relationship between mean annual water depths (averaged over 9 years, May-1, 2000 to April 30, 2009) obtained from EDEN water depth data and field measurements. EDEN water depth is based on ground elevation derived from USGS survey along 400 x 400 m grid and EDEN water surface elevation (stage). Field water depth is based on ground elevation obtained by subtracting the measured water depth from the EDEN stage value for the same day.

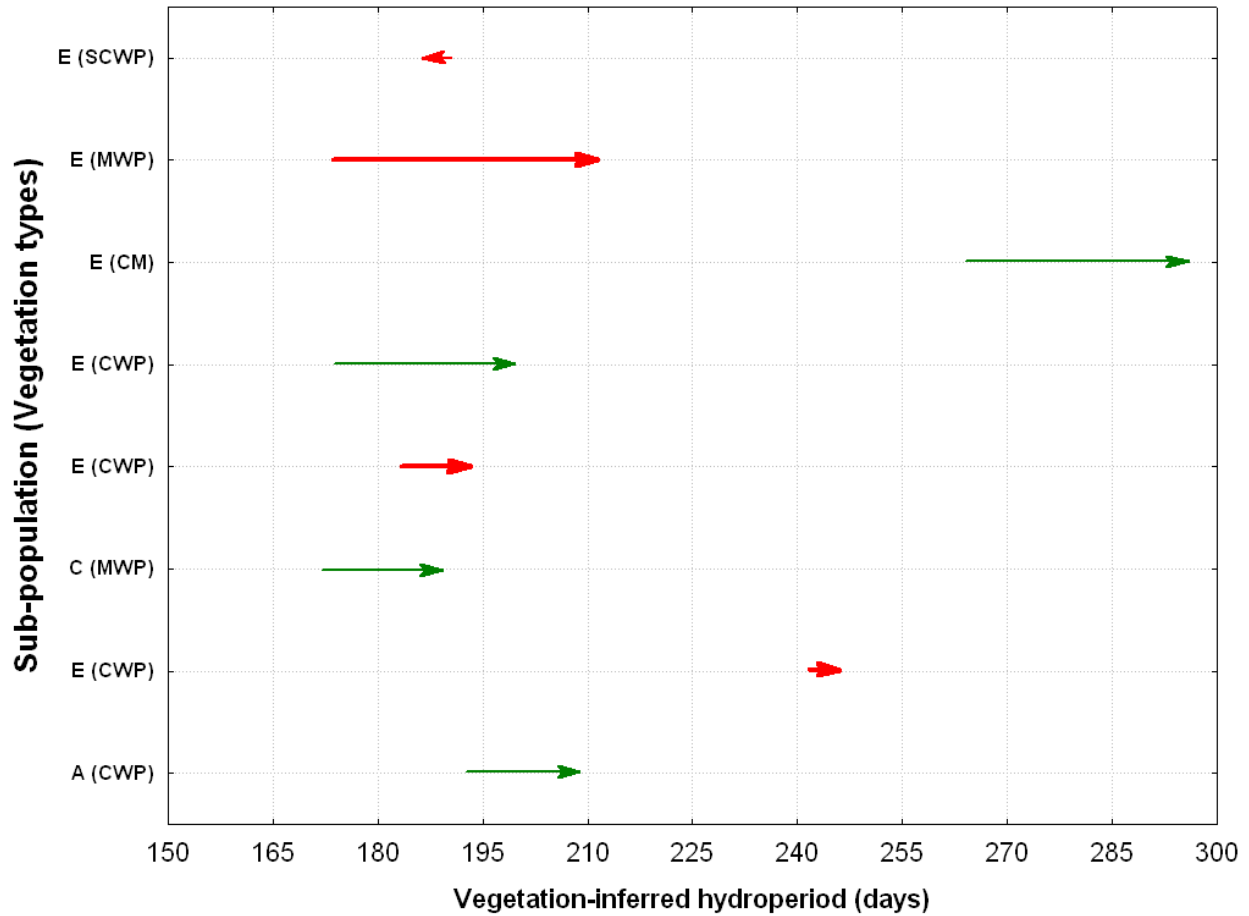


Figure 27: Change in CSSS counts with a change in vegetation inferred hydroperiod (days) at the sites which were sampled in both events, 2005 & 2009, and were not burned at least for 4 years prior to 2009 sampling. Only those sites, at which CSSS population was surveyed in both years, and the count was ≥ 1 in either 2005 or 2009 survey are included. Green and red lines show gain and loss in CSSS numbers, respectively. The thickness of line indicates the CSSS count as 1 or 2 that were gained or lost in increasing order.

Change in Hydroperiod (2005 to 2009) & CSSS Counts

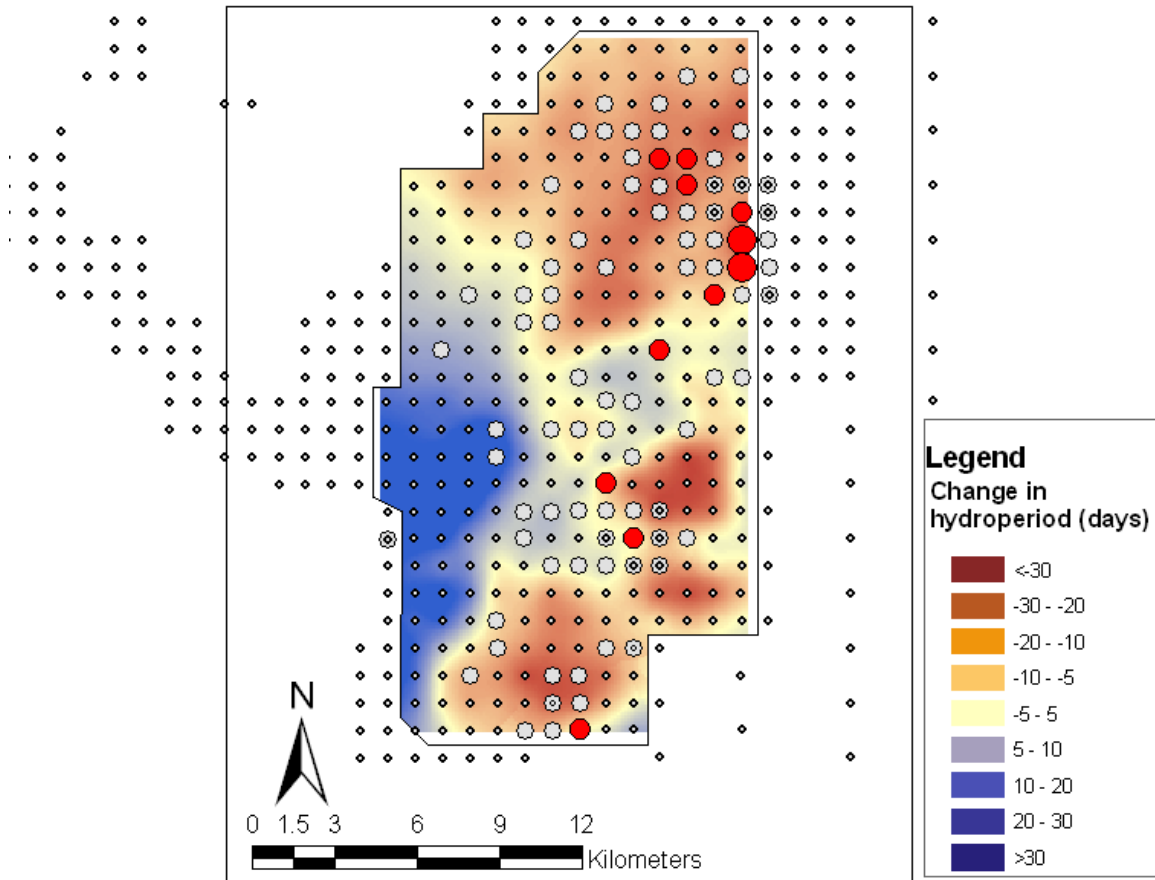


Figure 28: Change in 4-year average hydroperiod (days) between 2005 and 2009 and sparrow counts in 2007, 2008 and 2009. Gray circles represent the sites visited in three years, and red circles represent the number of birds (1 or 2) in one or more years. Hydropeiods were calculated using EDEN data and averaged over 4 water years (May 1 to April 30) before 2005 and 2009 sampling.