CONTINUED MONITORING OF THE BUCKTOWN CREATED MARSH:

2006 - 2010 VEGETATIVE AND EDAPHIC CHARACTERIZATION
AND
NUTRIENT STATUS OF SEDIMENT AND PLANT TISSUE

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INTRODUCTION

The creation and restoration of coastal wetlands is a key component of the management of coastal habitats, as through these activities critical ecological functions can be maintained or restored (Craft et al. 2002). An impediment to our understanding of the efficacy of creation and restoration efforts is the paucity of long-term datasets that enable the description and evaluation of how ecological functions change over time as restoration sites mature. Without such investigations, determinations of how trajectories of ecological functions vary through time lack sufficient resolution to be beneficial to coastal managers. This is important because investigations into ecological function in restored salt marshes have found that there is often a lag between the construction of wetland habitats and the provision of equivalent ecosystem services (Craft et al. 2002). Historically, many long-term studies of the ecological functions associated with created and restored coastal habitats have focused on salt marshes, resulting in less available information on oligohaline and brackish marshes (Sacco et al. 1994; Zedler 2000; Craft et al. 2002). Therefore, a substantial need exists for long-term monitoring of restored oligohaline and brackish marshes to fill knowledge gaps for coastal mangers and provide a greater understanding of likely trajectories of ecological functions in these restored systems.

Beyond understanding the ecological trajectories of restored oligohaline marshes, there is additionally a need to provide an understanding of these trajectories in the context of stressors common to these habitats. Such research is critical as stressors may act to substantially alter the trajectories of restored marshes such that they do not achieve the anticipated level of ecosystem function and associated ecosystem service provision. Two such stressors in southern coastal Louisiana are herbivory and elevated nutrient loadings (Slocum and Mendelssohn 2008). As described below, both of these factors can have substantial effects on vegetative species composition and biomass production (Slocum and Mendelssohn 2008; McFalls et al. 2010), which can enhance or degrade ecosystem function and service provision.

Herbivory has been shown to be a factor important in altering both vegetative species composition and biomass production in coastal oligohaline marshes in Louisiana (Geho et al. 2007; McFalls et al. 2010). A major component of herbivory impacts in coastal Louisiana oligohaline wetlands is the introduced vertebrate herbivore *Myocastor coypus* (Molina), commonly referred to as the nutria (Baker, Mouton, and Linscombe 2005). Nutria-attributed herbivory is often implicated as a major stressor to both forested and herbaceous wetlands in the Lake Pontchartrain Basin (Keddy et al. 2007). For example, Slocum and Mendelssohn (2008), in a study conducted in the Tchefuncte River area on the north shore of Lake Pontchartrain, found that herbivory by nutria tended to reduce plant biomass and increase the time required for plots to recover from lethal disturbance. Similarly, McFalls et al. (2010) found that plots where vertebrate herbivores were excluded had 1.4 times greater biomass than plots where vertebrate herbivores were not excluded.

Although the complete, long-term impacts of nutrient introduction on fresh water and oligohaline coastal marshes in Louisiana is not currently fully understood (Swarzenski et al. 2008; Hester and Fisher, in review), there is general agreement that, within certain ranges, nutrient addition tends to result in enhanced aboveground production by many plant species (Slocum and Mendelssohn 2008; McFalls et al. 2010). For instance, Slocum and Mendelssohn (2008) reported that nutrient addition somewhat reduced species diversity, but increased biomass by approximately 50%. Interestingly, McFalls et al. (2010) in a study conducted in the Pass Manchac area of Lake Pontchartrain found that nutrient introduction significantly increased plant biomass in plots where herbivores were excluded, but did not significantly increase biomass in unexclosed plots. However, it should be noted that these studies were conducted in natural oligohaline marshes; our understanding of how nutrient introduction may impact restored coastal marshes, particularly over longer periods of time, is quite limited.

The Bucktown marsh is a created oligohaline marsh in southeastern Louisiana. The research effort presented herein was initiated to address two primary questions regarding the Bucktown created marsh, which can be viewed as a model system for created oligohaline marshes in this region. Firstly, do the vegetative coverage and species composition, as well as key soil characteristics, exhibited by the Bucktown marsh indicate that this marsh is on a trajectory to become similar to natural oligohaline marshes in the region? Secondly, what is the effect of stressors, such as herbivory and eutrophication, on the sustainability and ecological function of this oligohaline wetland? Long-term monitoring of this created marsh is enabling the evaluation of the trajectory of this restoration project and is also providing insights into factors that may alter this trajectory, such as nutrient enrichment and herbivore grazing intensity.

METHODS

Study Site

The Bucktown marsh is a mitigation marsh (1.42 hectares in area) that was constructed outside the Lake Pontchartrain levee immediately adjacent to the “Bucktown” neighborhood of greater New Orleans. Marsh substrate was obtained through hydraulic dredging of the nearby Bucktown Harbor in the summer of 2000 with a target elevation of 1.5 to 2.0 NGVD (Burke and Kleinpeter 2001). The planting of 1,030 trade gallons and 8,000 vegetative plugs of salt-hardened *Spartina alterniflora* (Vermillion accession) was completed by August 2, 2003, with the anticipation that other wetland vegetation would also rapidly colonize the marsh (Burke and Kleinpeter 2001). More general information and documentation on the Bucktown Created Marsh can be found at SaveOurLake.org (see the coastal program webpage).

Study Implementation

Twenty, 1.0-m^2 permanent plots were established on June 30, 2006 throughout the Bucktown created marsh site, with 5 replicate plots being established in each of four primary habitat types that were described in a previous assessment completed prior to Hurricane Katrina (Hester et al. 2005). The primary habitats delineated at this time included the following: a lower elevation *Spartina alterniflora* dominated marsh on the western portion of the created marsh (hereafter referred to as the Western Low Marsh zone), a higher elevation marsh dominated by *S. alterniflora* with *Schoenoplectus americanus* occurring as a sub dominant (hereafter referred to as the High Marsh zone), a higher elevation *Iva frutescens* dominated zone (hereafter referred to as Scrub Shrub), and a lower elevation *Spartina alterniflora* dominated marsh on the eastern portion of the created marsh (hereafter referred to Eastern Low Marsh zone). A continuous-recording water-level gauge was installed in the eastern portion of the low marsh habitat at the inception of the study. The elevation of the gauge and all plots were surveyed so that frequency, depth, and duration of flooding could be determined at each plot. All plots were characterized in regard to vegetation and soil in the summer and fall of 2006, 2007, 2008, 2009, 2010, and summer of 2011 as further described below.

Vegetation and Soil Characterization

Plant community composition was determined by visual estimation in the summer and fall of each year since the inception of the monitoring project in 2006. Soil cores were collected to a depth of 15 cm using a 5-cm diameter thin-wall aluminum corer each summer during the project period for the determination of soil bulk density and organic matter content. Soil samples were dried at 65º C until a constant weight was achieved. Thereafter, soil samples were homogenized using a mortar and pestle and a subsample was combusted at 500 ºC for 5 hours to determine organic matter content through the loss-on-ignition method. Additionally, changes in marsh surface elevation were determined using sediment elevation tables (SET) and feldspar markers that were installed in the Western Low Marsh and Scrub Shrub habitats in 2006 (see Cahoon et al. 2002 for details on SET installation and protocols).

Nutrient Impacts

Soils and *Spartina alterniflora* leaf tissue were collected from each plot in the summer of 2008, 2009, and 2010 to assess general trends in soil and leaf tissue nutrient concentrations, as well as to identify specific alterations to nutrient status that may have resulted from openings of the Bonnet Carre spillway. Archived soils that were collected from the Bucktown site in summer 2006 were characterized for nutrient content to provide background data that preceded any opening of the Bonne Carre. Soils were dried to a constant weight at 65º C and then subjected to a 1:2 (w:v) extraction with deionized water following the methods of Soil and Plant Analysis (1999). Water extracts were sent to the Microbiology Testing Laboratory at Southeastern Louisiana University for determination of ammonium. Aboveground plant tissue was dried, homogenized using a Wiley Mill, and then sent to the Soil Testing and Plant Analysis Lab at Louisiana State University for determination of total nitrogen and carbon content.

Herbivory Impacts

Because of visual evidence of apparent herbivory impacts in early 2009, three herbivore exclosure devices (PVC frames with coated wire panels) were paired with existing unexclosed plots to yield three pairs of exclosed/unexclosed plots (one pair in the High Marsh zone, two pairs in the Eastern Low Marsh zone). These first three exclosures were installed on March 30, 2009. To provide greater insight and statistical rigor, an additional three herbivore exclosure devices were constructed, paired with existing unexclosed plots, with two exclosed/unexclosed plots installed in the Scrub Shrub zone and an additional exclosed/unexclosed plot installed in the High Marsh zone on July 13, 2010. Thus, there are currently two replicates in each of the following habitat zones: a) Eastern Low Marsh, b) High Marsh, and c) Scrub Shrub (i.e., 6 exclosures total).

Statistical Analyses

Total vegetative cover was analyzed in a repeated measures one-way ANOVA RBD (Analysis of Variance Randomized Block Design) framework using the GLM model procedures of JMP 9.0. Any data collected at only one point in time were subjected to univariate one-way ANOVA analysis using the GLM procedures of JMP 9.0. Vegetative communities of permanent plots in summer of all years were evaluated for differences through the Multiple Response Permutation Procedures of PC-ORD 5.1. Also, summer community composition was assessed for the presence of environmental gradients using nonmetric multidimensional scaling analysis (nMDS), performed using PC-ORD 5.1. For this analysis the Sorensen distance matrix wax employed, with initial dimensionality of 6 axes and stepwise reduction of a single dimension until optimal stress reduction was achieved. Stability criterion was set to 0.00010 and the number of model runs was 40 for real data and 50 for randomized data. See Clarke (1993) for discussion of Multiple Response Permutation Procedure and nonmetric multidimensional scaling.

RESULTS

Long-Term Monitoring

Total vegetative cover

A significant effect of both time and the interaction of time with vegetative zone was detected in total vegetative cover (Figure 1; H-F= 10.147, p<0.001, and H-F= 5.550, p< 0.001, respectively). Within Summer 2006, all zones displayed substantial cover, but the Eastern Low Marsh had significantly greater total cover than all other zones (Contrast F=29.3315, P < 0.0001). Interestingly, no significant effect of zone was detected for Fall 2006. A significant effect of zone on total cover was detected for Summer 2007 (Figure 1 Top Panel; F= 4.7852, P = 0.0145), but in this instance was largely a result of the High Marsh Zone having lower total cover than the other zones (Figure 1; Contrast F = 12.836, P = 0.0025). However, by Fall 2007, the High Marsh and Scrub Shrub zones had significantly greater total cover than the Eastern Low Marsh and Western Low Marsh zones (Figure 1 Top Panel; Contrast F= 15.4346, P = 0.0012). Interestingly, no significant difference between zones in total vegetative cover was detectable for Summer 2008, Fall 2008, Summer 2009, and Fall 2009. A significant effect of zone on total vegetative cover was detected for Summer 2010 in which the High Marsh zone demonstrated greater total vegetative cover than other zones (Figure 1 Top Panel; Contrast F= 7.0773, P = 0.0171). Interestingly, no significant effect of zone on total vegetative cover was detectable for Fall 2010 and Summer 2011. However, a trend towards lower total vegetative cover in the Eastern and Western Low Marsh zones than the High Marsh and Scrub Shrub zones in Summer 2011 (Figure 1).

Live Spartina alterniflora cover

A significant effect of zone was found for live *S. alterniflora* cover in Summer 2006 (Figure 1 Bottom Panel; F= 22.7650, P< 0.0001). This likely results from the higher live *S. alterniflora* cover in the Eastern Low Marsh and Western Low Marsh than High Marsh and Scrub Shrub zones (Figure 1 Bottom Panel; Contrast F=19.8925, P= 0.0002). A significant effect of zone was found for live *S. alterniflora* cover in Fall 2006 (Figure 1 Bottom Panel; F= 16.446, P< 0.0001), with higher live *S. alterniflora* cover in the Eastern Low Marsh and Western Low Marsh zones than the Scrub Shrub and High Marsh zones. A significant effect of zone was found for live *S. alterniflora* cover in Summer 2007 (Figure 1 Bottom Panel; F= 8.227, P= 0.0015). Similarly, this difference appears to stem from the lower live *S. alterniflora* cover in the Scrub Shrub zone than the Eastern Low Marsh and Western Low Marsh zones (Figure 1 Bottom Panel; Contrast F= 8.628, P= 0.0097). A significant effect of zone was found for live *S. alterniflora* cover in Fall 2007 (Figure 1 Bottom Panel; F= 4.523, P= 0.0018), with the Scrub Scrub zone having less live *S. alterniflora* cover than other zones. In a similar fashion, in Summer 2008, the Scrub Shrub zone demonstrated significantly lower live *S. alterniflora* cover than the Eastern Low Marsh, High Marsh, and Western Low Marsh zones (Figure 1 Bottom Panel; Contrast F= 5.648, P= 0.0303). A significant effect of zone was found for live *S. alterniflora* cover in Fall 2008 (Figure 1 Bottom Panel; F= 8.227, P= 0.0015), with the Eastern Low Marsh zone having greater live *S. alterniflora* cover than other zones. However, in Summer

2009, the High Marsh zone had significantly greater live *S. alterniflora* cover than the Eastern Low Marsh, Scrub Shrub, and Western Low Marsh zones (Figure 1 Bottom Panel; Contrast F= 5.998, P= 0.0262). In Fall 2009 live *S. alterniflora* cover was significantly lower in the Scrub Shrub zone than other zones (Figure 1 Bottom Panel; F= 7.727, P= 0.0014). A significant effect of zone was found for live *S. alterniflora* cover in Summer 2010 (Figure 1 Bottom Panel; F= 6.8170, P= 0.0011). This difference likely stems from the lower live *S. alterniflora* cover in the Scrub Shrub zone than the Eastern Low Marsh, High Marsh, and Western Low Marsh zones (Contrast F=19.8925, P= 0.0002). Live *S. alterniflora* cover was significantly greater in the High Marsh and Western Low Marsh zones than other zones in Fall 2010 (Figure 1 Bottom Panel; Contrast F= 8.672, P= 0.0012). Of great interest is that *Spartina alterniflora* live cover was greatly diminished in all zones in Summer 2011, although no significant effect was detected between zones (Figure 1 Bottom Panel).

Vegetative composition

Average vegetative cover by species for each vegetative zone is presented in Figure 2 (Western Low Marsh), Figure 3 (High Marsh), Figure 4 (Scrub Shrub), and Figure 5 (Eastern Low Marsh) for the qualitative evaluation of trends in species composition by zone. As expected, MRPP revealed significant differences among habitat types within the Summer 2006, Summer 2007, Summer 2008, Summer 2009, Summer 2010, and Summer 2011 sampling periods (Figure 6; T= 4.90, P< 0.001; Figure 7; T= -7.03, P< 0.001; Figure 8; T= -4.39, P=0.001; Figure 9; T= -5.521, P< 0.001, Figure 10; T= -4.775, P< 0.001, respectively), suggesting that these habitats are maintaining distinct species assemblages. In the case of the both the Eastern and Western Low Marsh zones, which have been dominated by *Spartina alterniflora*, this is driven by the increasing occurrence of other species within the Western Low Marsh beginning in Summer 2008, whereas the Eastern Low Marsh has experienced only a slight increase in the occurrence of other species in the last few years. The High Marsh zone, as expected, continues to have lower coverage of *S. alterniflora*, but relatively high cover of other species typical of high marsh habitats in Louisiana, and is thus differentiated from the other marsh zones. The Scrub Shrub zone remains dominated by *Iva frutescens* and, importantly, the extent of coverage by this species has been relatively constant or increasing over time.

Interestingly, a primary gradient positively correlated with *Iva frutescens* (r = 0.815) and inversely correlated with *Spartina alterniflora* (r = -0.930) was detected for Summer 2006 (Figure 6). The existence of two gradients based on nMDS of vegetative community composition in the Summer 2007 sampling period (Figure 7) was corroborated by detection of these gradients again in Summer 2008 (Figure 8; p=0.0196). These gradients can be interpreted with axis 1 being inversely correlated with *Iva frutescens* (r = -0.930) and axis 2 being positively correlated with *Spartina alterniflora* cover (r = 0.779) and inversely correlated with *Schoenoplectus americanus* (r = -0.718). As with previous analyses, *Spartina alterniflora* and *Iva frutescens* are the primary species representing these gradients. *Spartina alterniflora* is inversely correlated with axis 2 (r = -0.815) whereas *Iva frutescens* is positively correlated with axis 1 (r = -0.843). Although the strength of these correlations is weaker in Summer 2009 (Figure 9), *Spartina alterniflora* was positively correlated with axis 1 (r = 0.665), whereas *Iva frutescens* was inversely correlated with axis 2 (r = -0.576). However, in Summer 2010 (Figure 10), *Spartina alterniflora* was again strongly, but inversely correlated with axis 1 (r = -0.757), whereas *Iva frutescens* was strongly, inversely correlated with axis 2 (r = -0.968). Interestingly, in Summer 2011 (Figure 11), although *Spartina alterniflora* was again strongly, but inversely, correlated with axis 1 (r = -0.822), *Iva frutescens* was strongly correlated with axis 2 (r = 0.644).

Edaphic variables and elevation

A significant effect of time was detected for both soil organic matter and soil bulk density (Figure 12; F= 6.43, p= 0.0162, F= 5.23 p= 0.0174, respectively). Interestingly, this seems to be driven by higher soil organic matter in years 2009 and 2010, with concomitant reductions in soil bulk density. These results suggest that local vegetation is being incorporated into soils as they mature, thereby increasing soil organic matter and reducing soil bulk density. Overall, elevation changes as measured by sediment elevation table in the Western Low Marsh was minimal (< 1cm) from 2006 up to 2009, however, an increase of approximately 3 cm was noted from Summer 2009 to Summer 2010; Figure 13 Top Panel). Interestingly, inspection of feldspar markers revealed a large apparent influx of sediment with a corresponding increase in surface elevation for the 2006 to 2007 (4 cm) and 2007 to 2008 (10 cm) periods. Water level data indicates that flooding duration has tended to be greater in the Western Low Marsh than other vegetative zones assessed in this study (Figures 14 and 15; Top Panel).

Soil nutrient status

Surficial soils (upper 15 cm) collected in the Summer 2008 (after an Bonnet Carre opening) had significantly greater ammonium content than surficial soils collected in Summer 2006, Summer 2009, and Summer 2010 (Figure 15; Bottom Panel; F= 7.45, p= 0.0149). It is important to note that no significant effects of zone were detected within individual seasons indicating that the increase in surficial ammonium in 2008, and subsequent decrease thereafter, was a relatively consistent effect regardless of marsh zone.

Leaf tissue nutrient status

Leaf tissue nitrogen was significantly higher for *S. alterniflora* leaf samples collected in 2009 than 2008 and 2010 (Figure 18 top panel; F= 37.915, p= 0.0257). Interestingly, no significant differences among plant zones in regard to *S. alterniflora* leaf tissue nitrogen were detected. However, leaf tissue carbon is significantly higher for *S. alterniflora* leaf samples collected in 2010 than 2008 and 2009 (Figure 18 bottom panel; F= 24.465, p= 0.0131). Also, *S. alterniflora* leaf tissue collected in the Scrub Shrub zone had significantly lower carbon than the other zones (Figure 18 bottom panel; F= 16.179, p= 0.0061). No significant effect of time or zone was detected for *S. alterniflora* leaf tissue phosphorus (Figure 19).

Evaluation of herbivory

No effect of exclosure was detected on total cover or live *S. alterniflora* in Summer 2010 or Fall 2009, after the installation of the initial three exclosures. Similarly, no effect of exclosure was detected on total cover or live *S. alterniflora* in Fall 2010 or Summer 2011, after the installation of the full complement of exclosures (Figure 20).

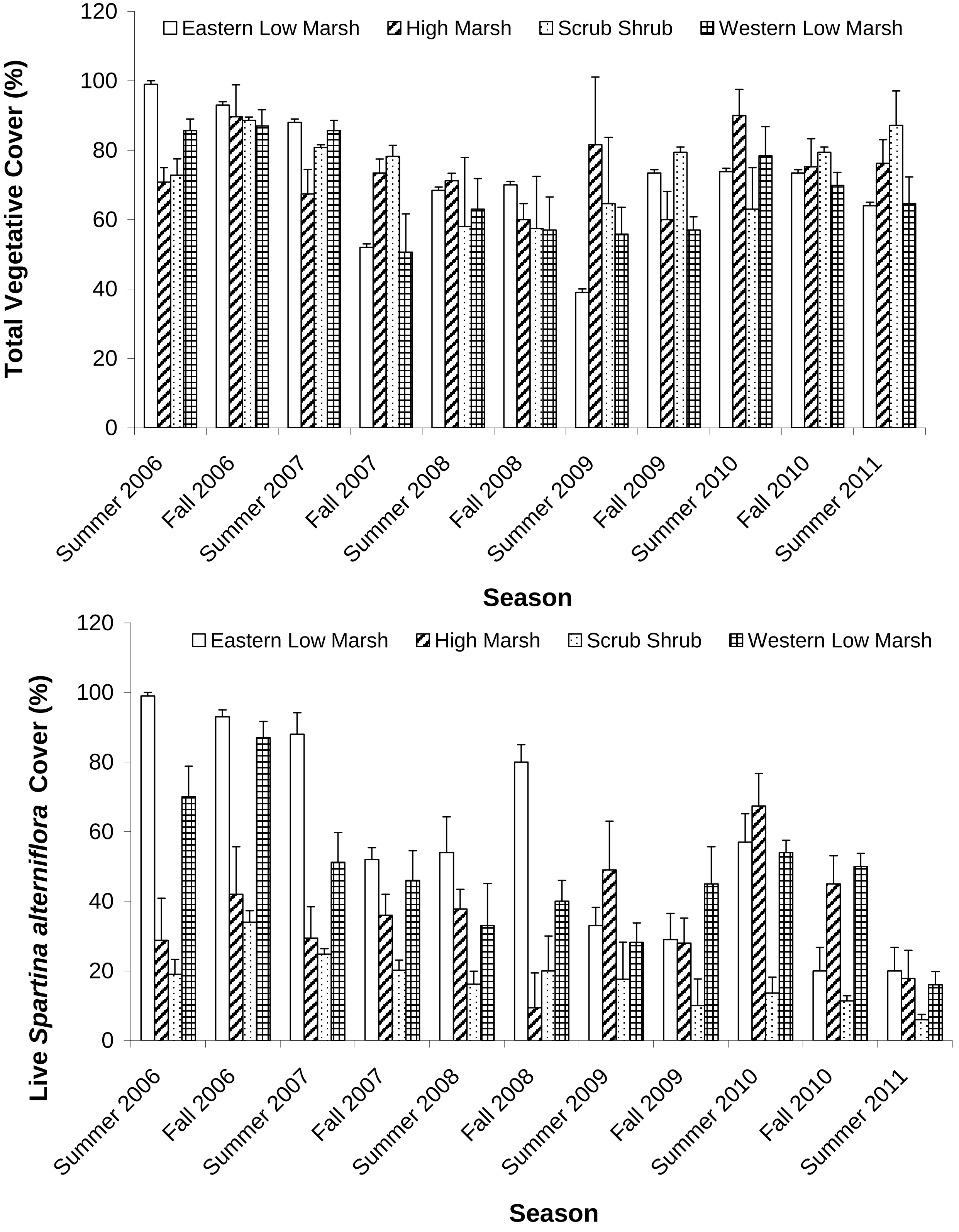

Figure 1. Top Panel; Effect of time on total species cover in the four Bucktown marsh habitat zones. Bottom Panel; Effect of time on Live *S. alterniflora* cover in the four Bucktown marsh habitat zones.

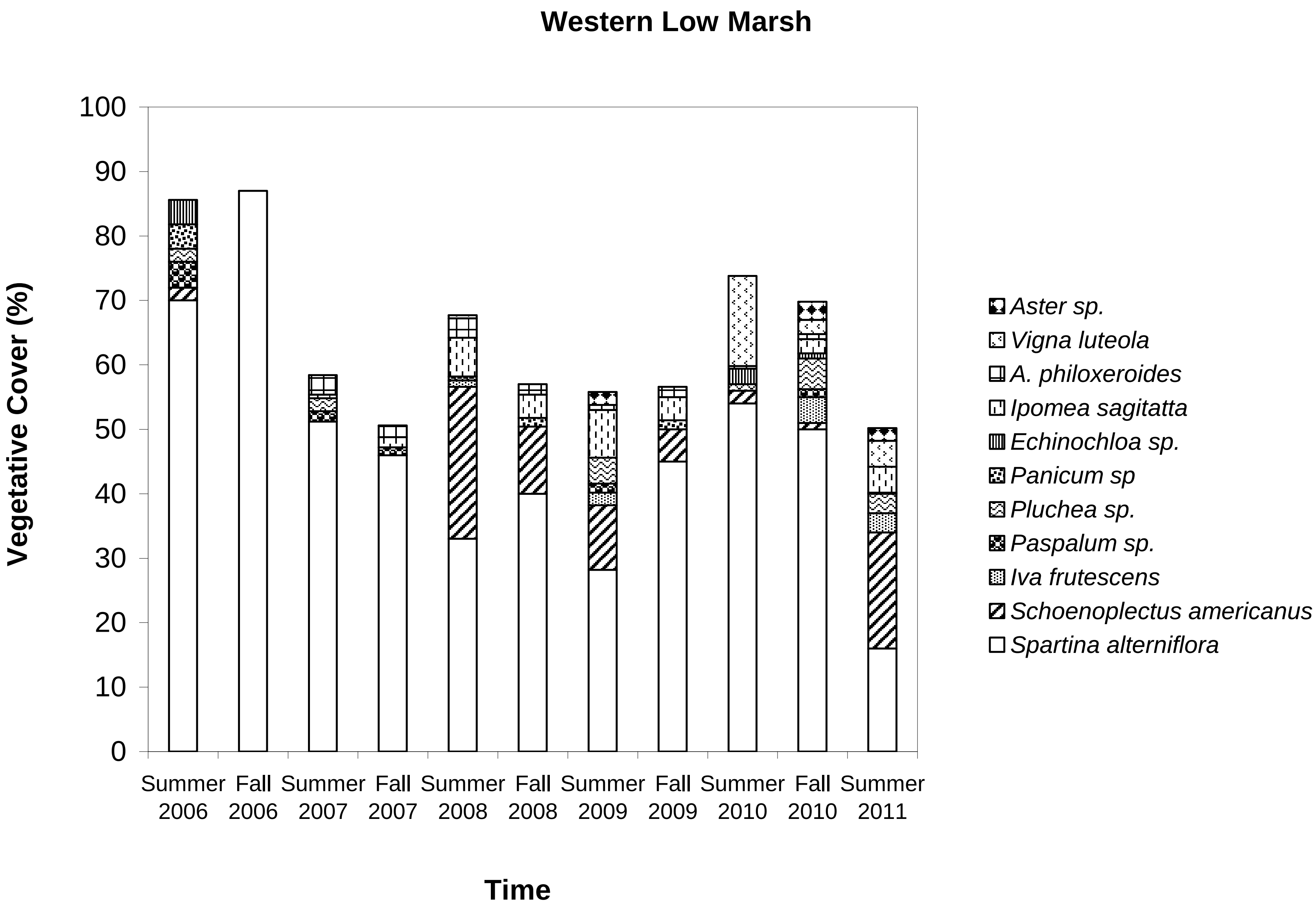

Figure 2. Effect of time on vegetative species composition and abundance in the Western Low Marsh zone.

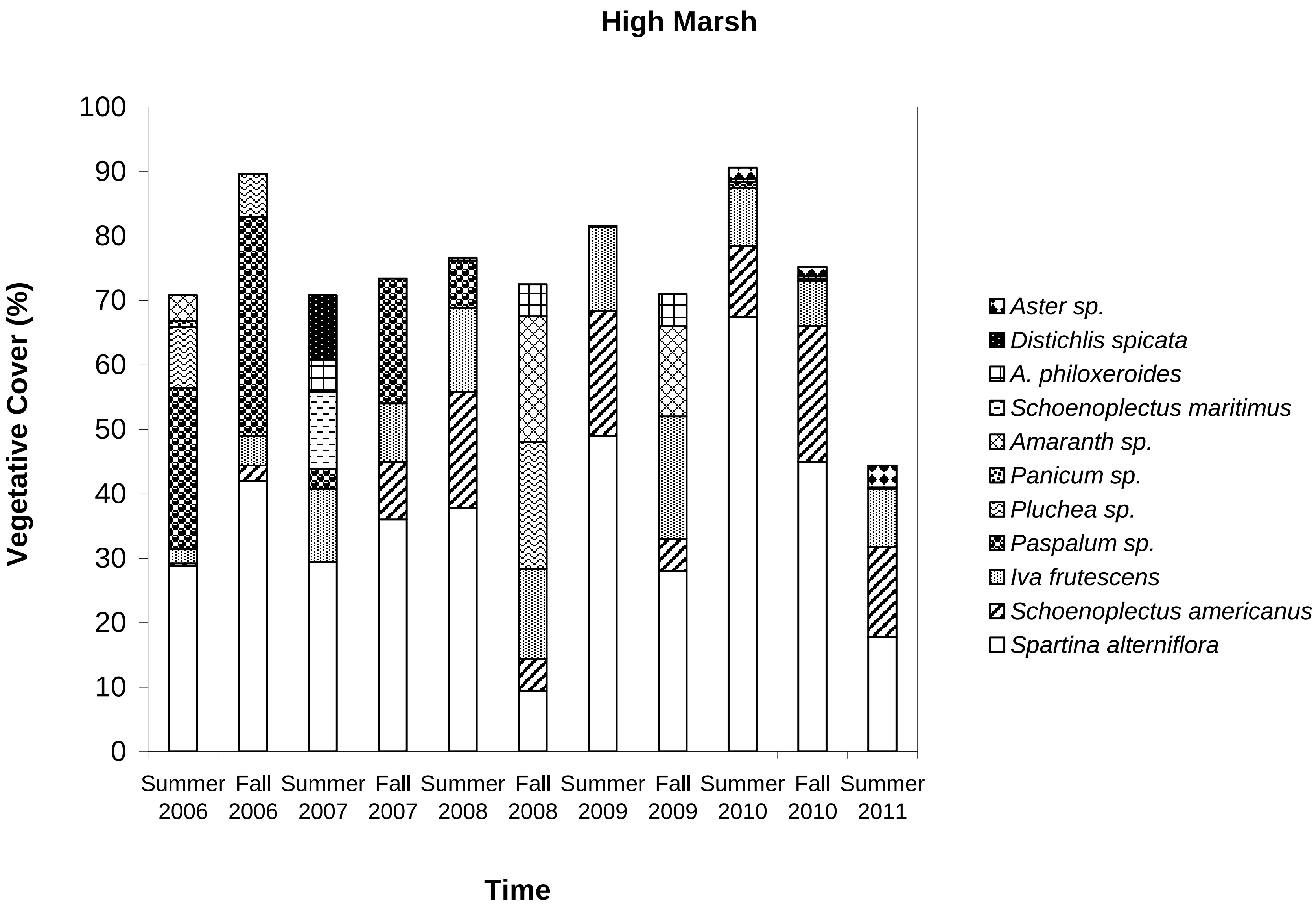

Figure 3. Effect of time on vegetative species composition and abundance in the High Marsh zone.

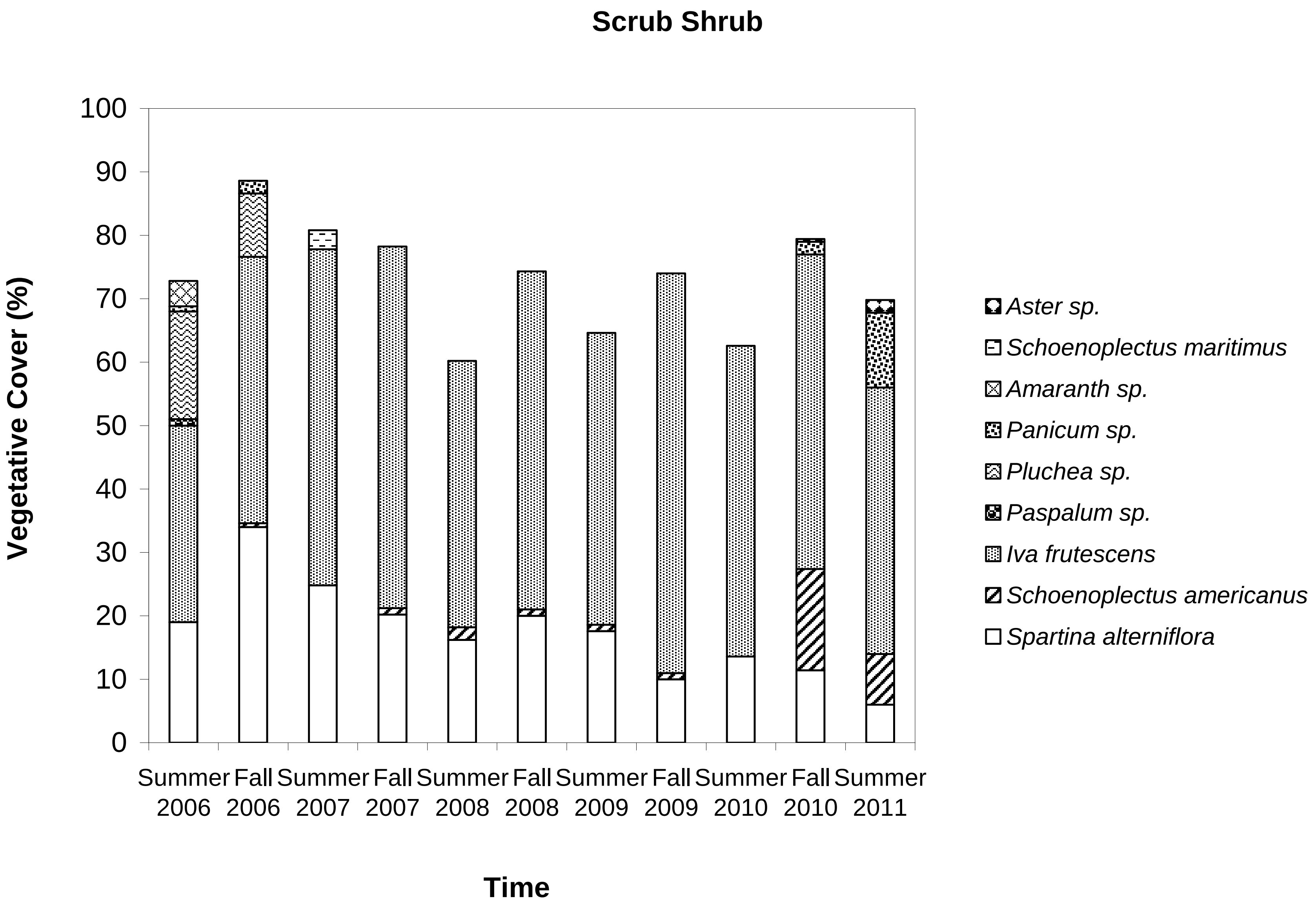

Figure 4. Effect of time on vegetative species composition and abundance in the Scrub Shrub zone.

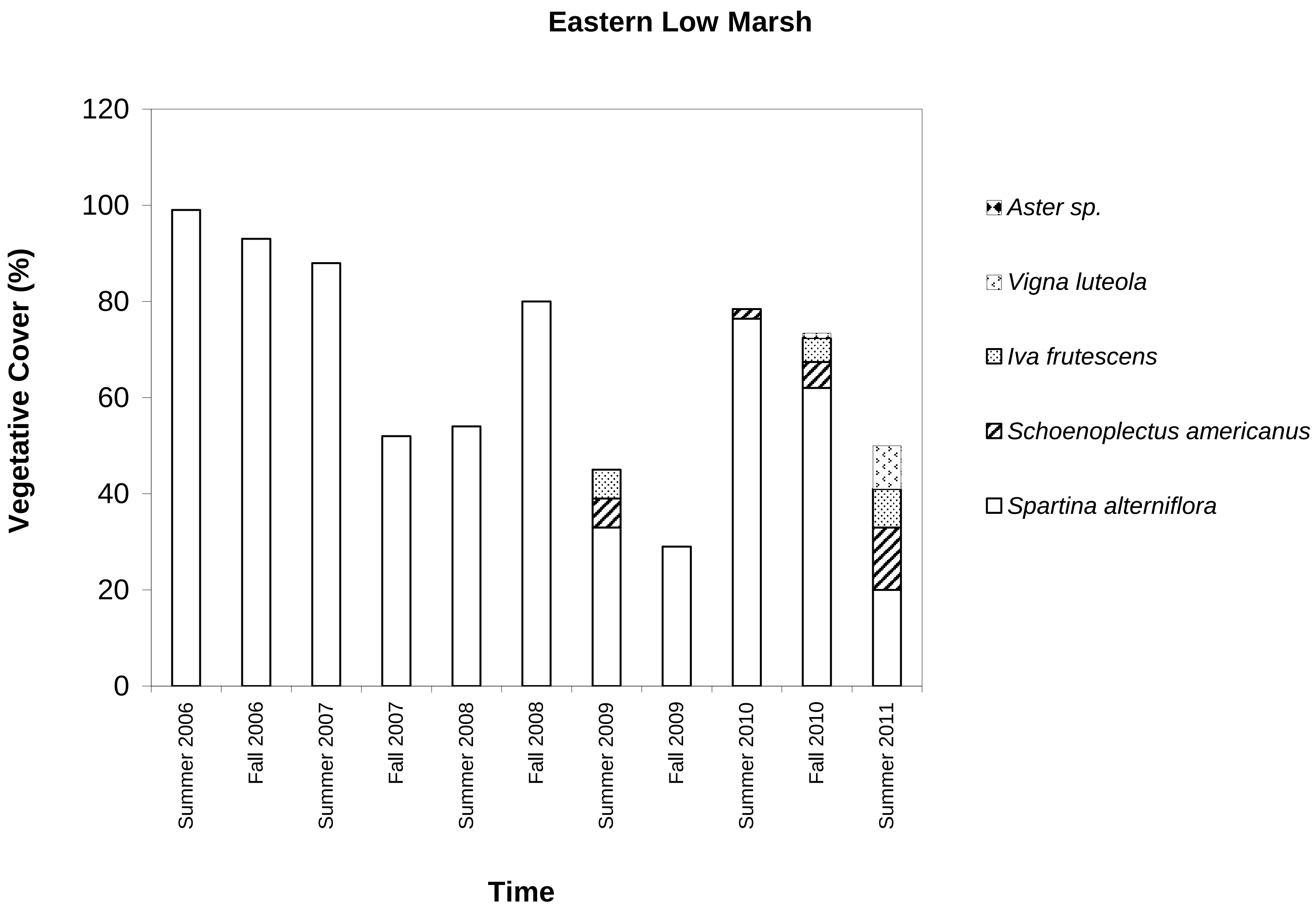

Figure 5. Effect of time on vegetative species composition and abundance in the Eastern Low Marsh zone.

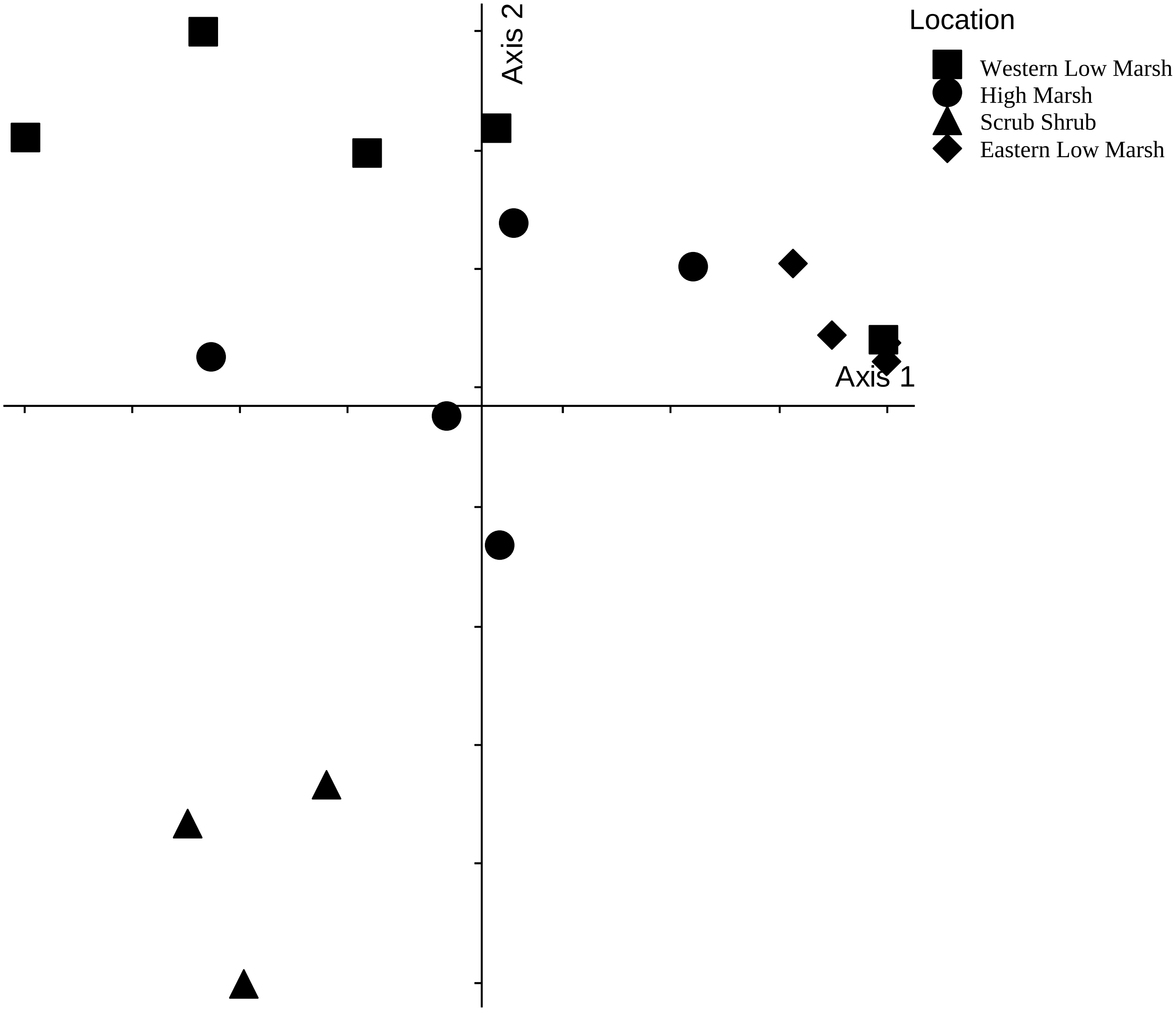

Figure 6. Similarity of permanent plots and vegetative zones for Summer 2006 as determined by nonmetric multidimensional scaling. The X axis correlates with *Iva frutescens* cover; the Y axis inversely correlates with *Spartina alterniflora* cover.

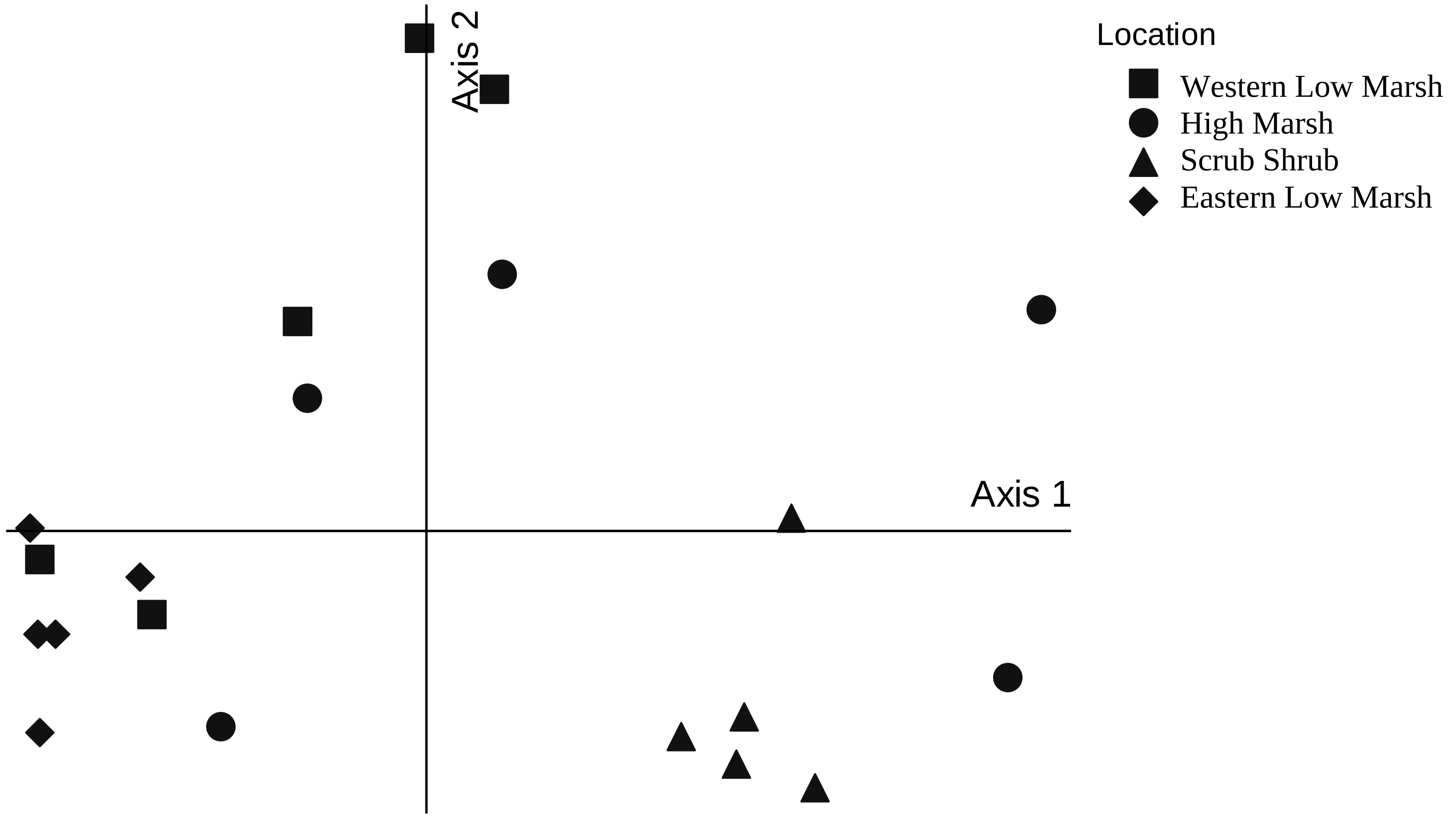

Figure 7. Similarity of permanent plots and vegetative zones for Summer 2007 as determined by nonmetric multidimensional scaling. The X axis correlates with *Iva frutescens* cover; the Y axis inversely correlates with *Spartina alterniflora* cover.

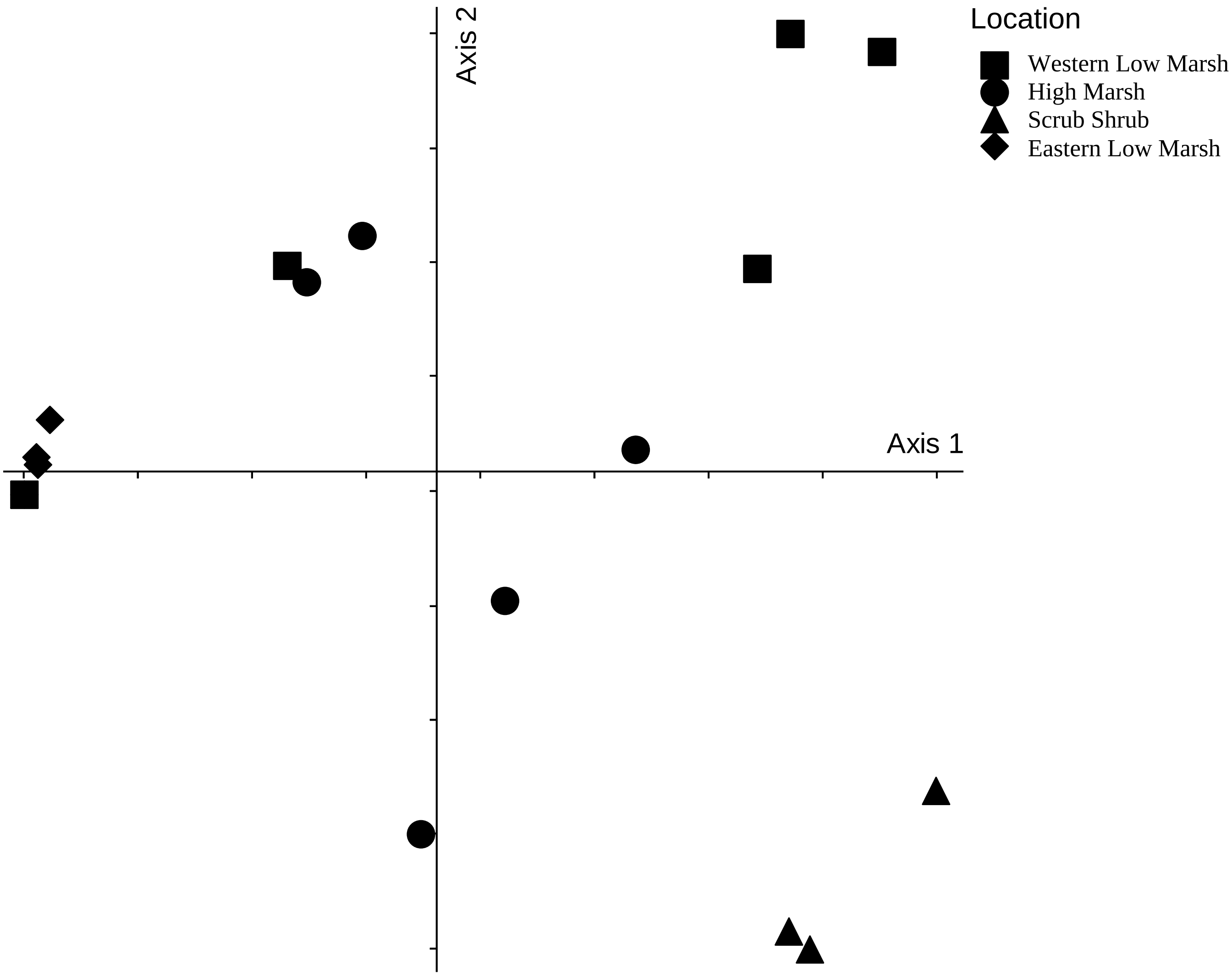

Figure 8. Similarity of permanent plots and vegetative zones for Summer 2008 as determined by nonmetric multidimensional scaling. The X axis inversely correlates with *Iva frutescens* cover; the Y axis correlates with *Spartina alterniflora* cover.

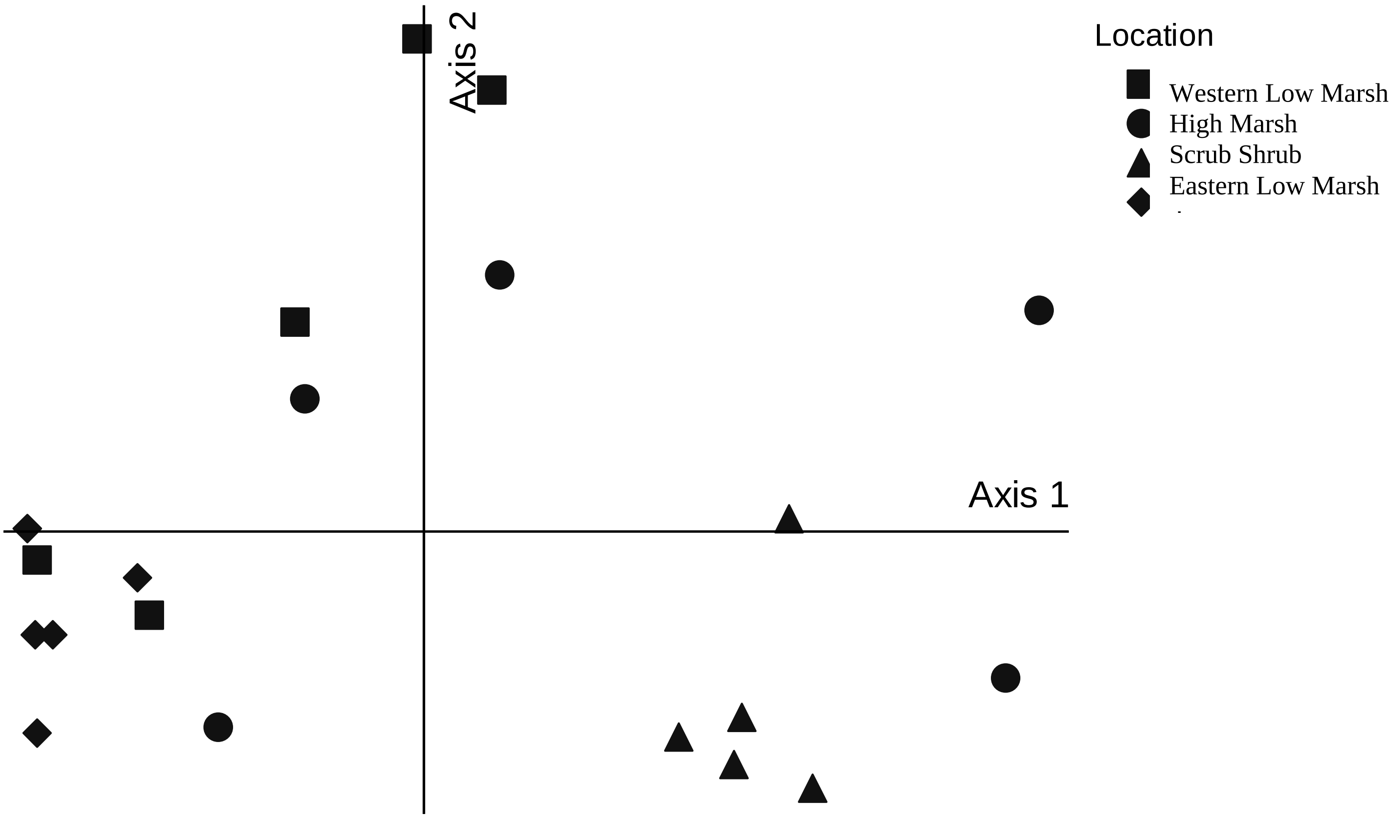

Figure 9. Similarity of permanent plots and vegetative zones for Summer 2009 as determined by nonmetric multidimensional scaling. The X axis inversely correlates with *Iva frutescens* cover; the Y axis correlates with *Spartina alterniflora* cover.

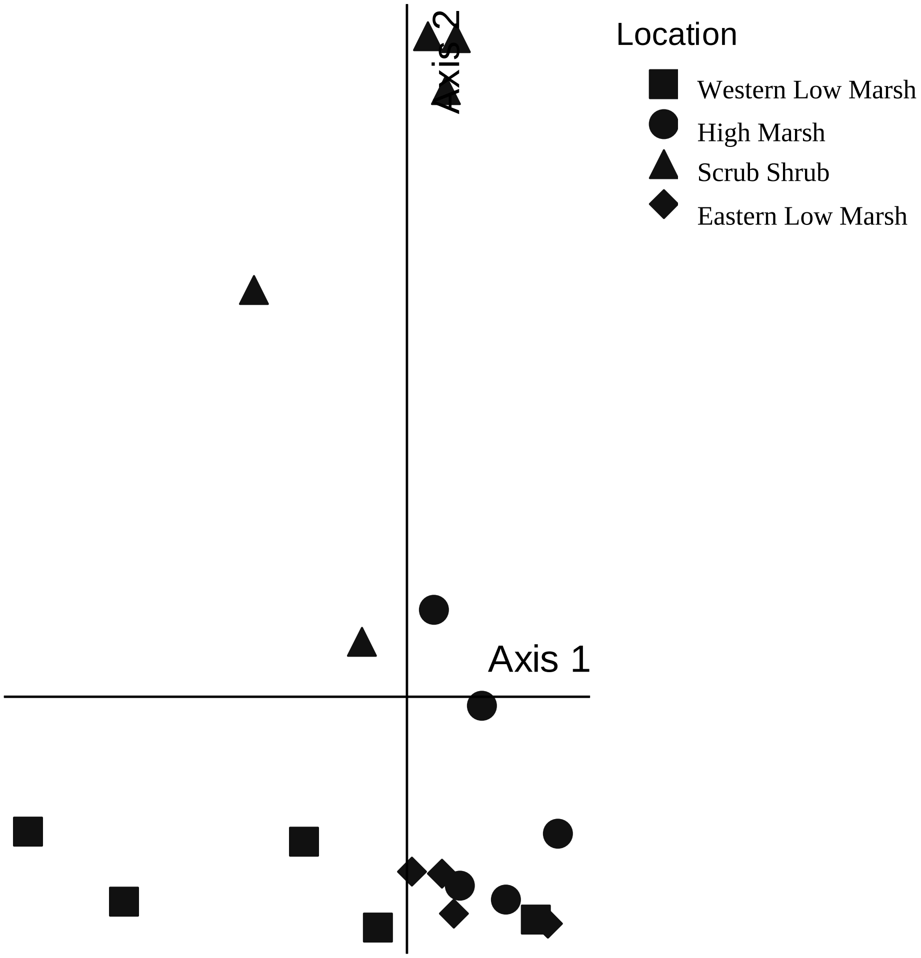

Figure 10. Similarity of permanent plots and vegetative zones for Summer 2010 as determined by nonmetric multidimensional scaling. The X axis inversely correlates with *Iva frutescens* cover; the Y axis correlates with *Spartina alterniflora* cover.

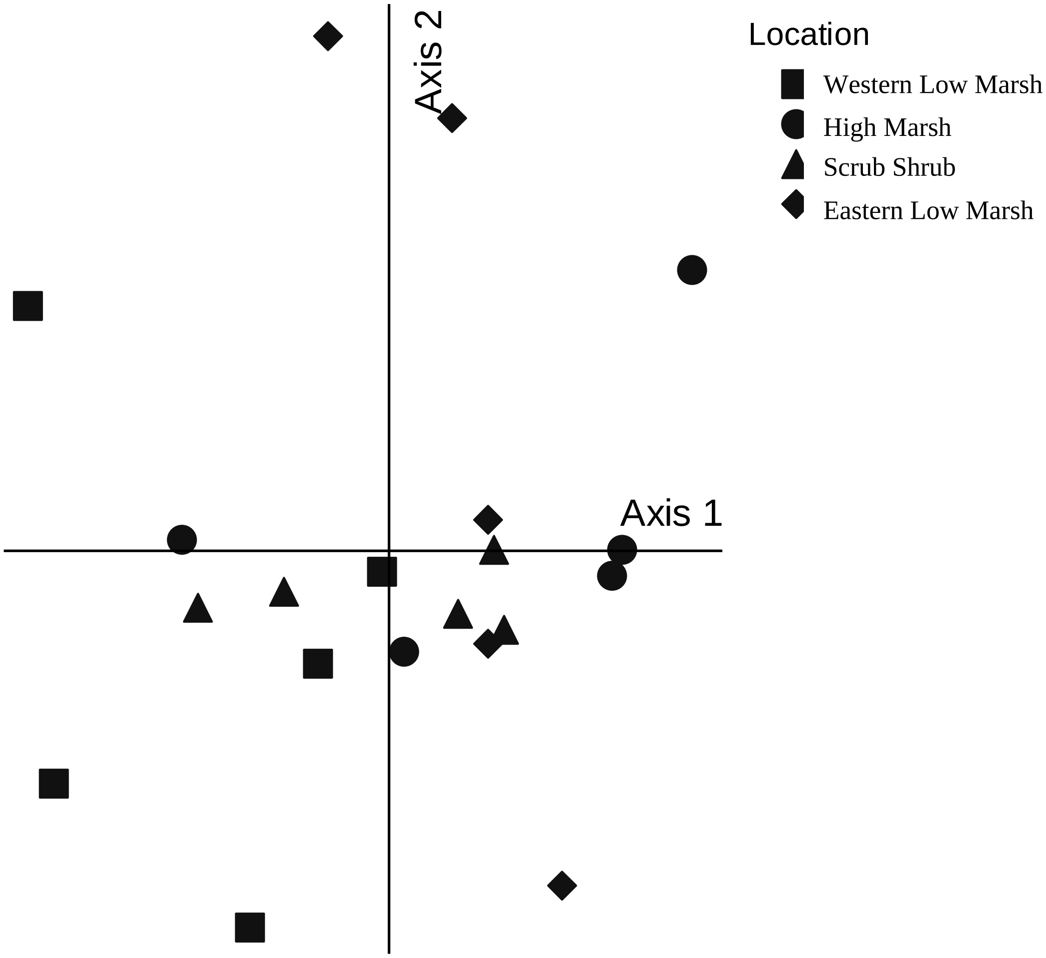

Figure 11. Similarity of permanent plots and vegetative zones for Summer 2011 as determined by nonmetric multidimensional scaling. The X axis inversely correlates with *Iva frutescens* cover; the Y axis correlates with *Spartina alterniflora* cover.

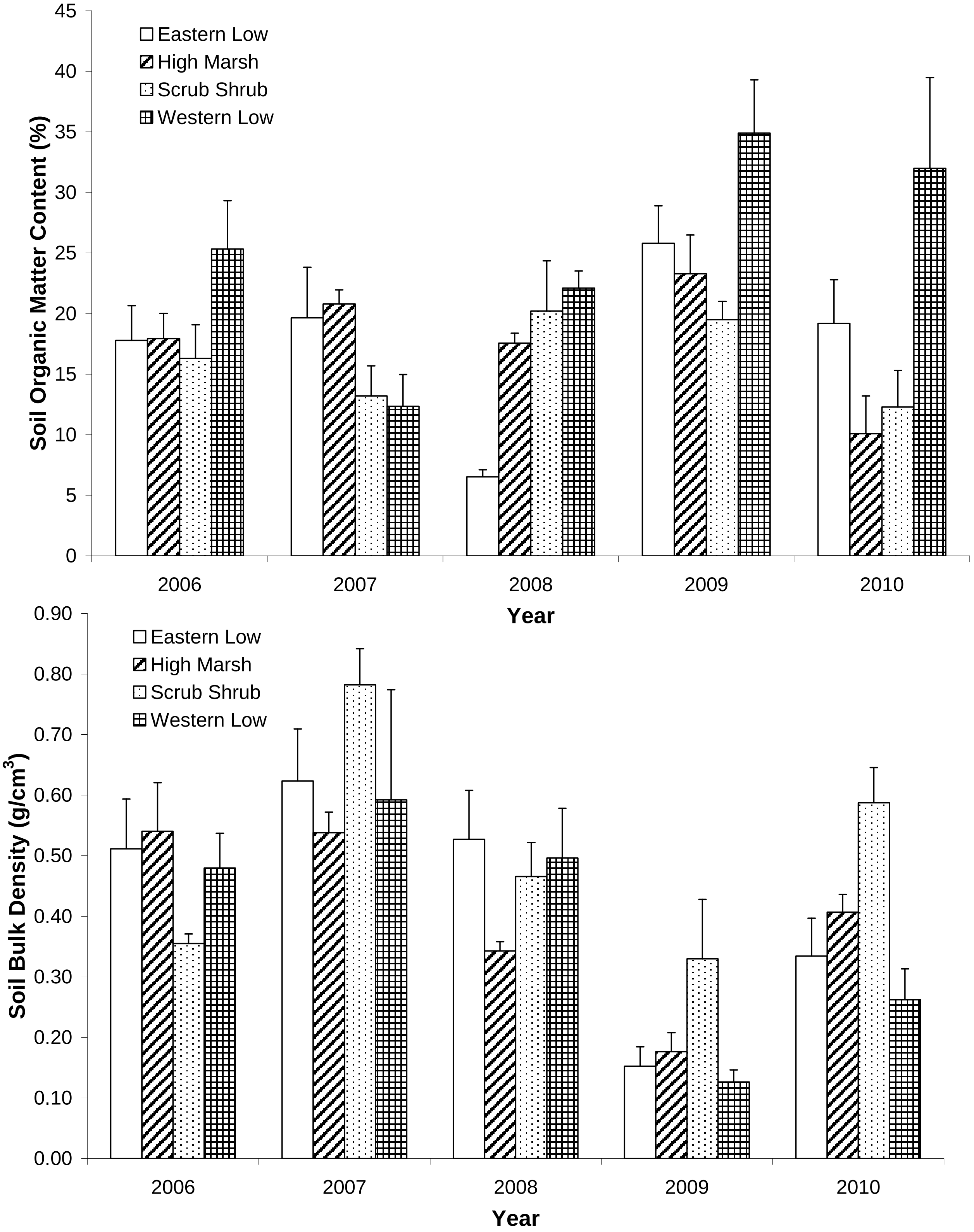

Figure 12. Top Panel: Effect of vegetative zone on soil organic matter in Summer 2008 (%; mean +/- se). Bottom Panel: Effect of vegetative zone on soil moisture content (dry weight basis) in Summer 2008 (%; mean +/- se).

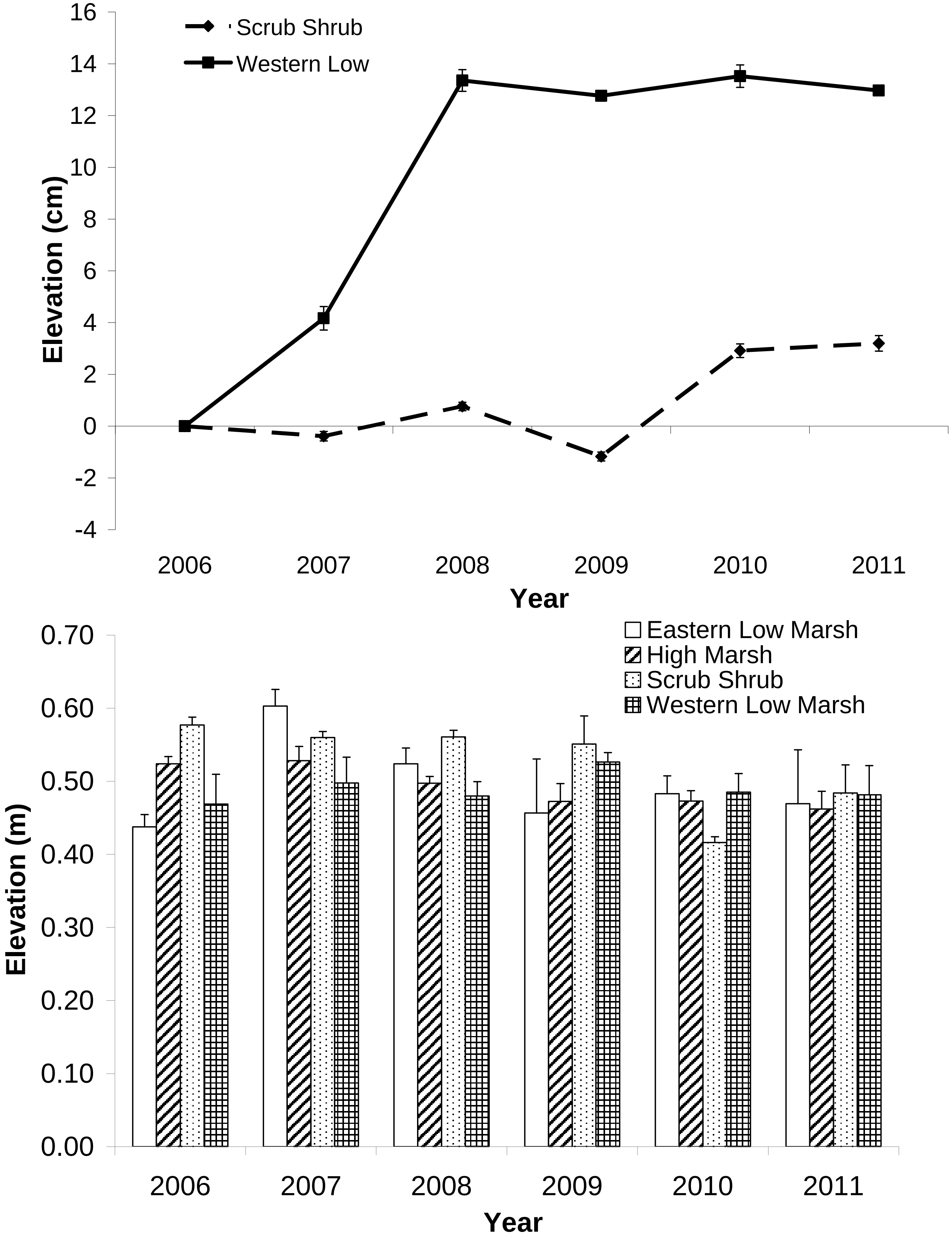

Figure 13. Top panel: Surface elevation change as determined from SETs in the Scrub Shrub and Western Marsh Zone over time (mean +/- se). Bottom panel: Plot relative survey elevations through time corrected to the lowest plot elevation (mean +/- se).

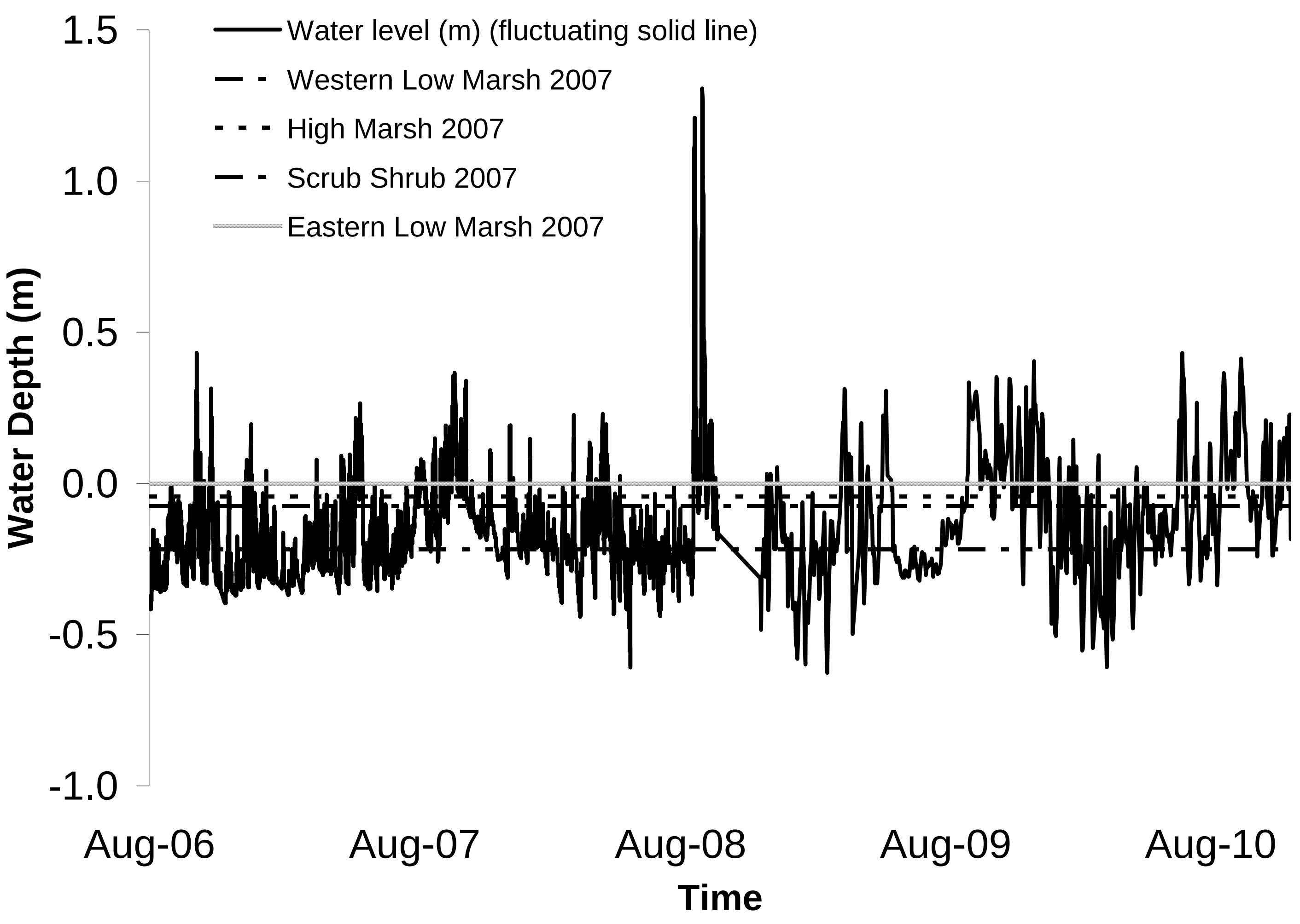

Figure 14. Flooding depth to the soil surface in 2 hour increments for each zone of the Bucktown marsh over time (8/13/2006 to 8/13/2010). The Eastern Low Marsh zones received an input of sediment in 2007 that is believed to be due to nearby anthropogenic dredge and fill operations

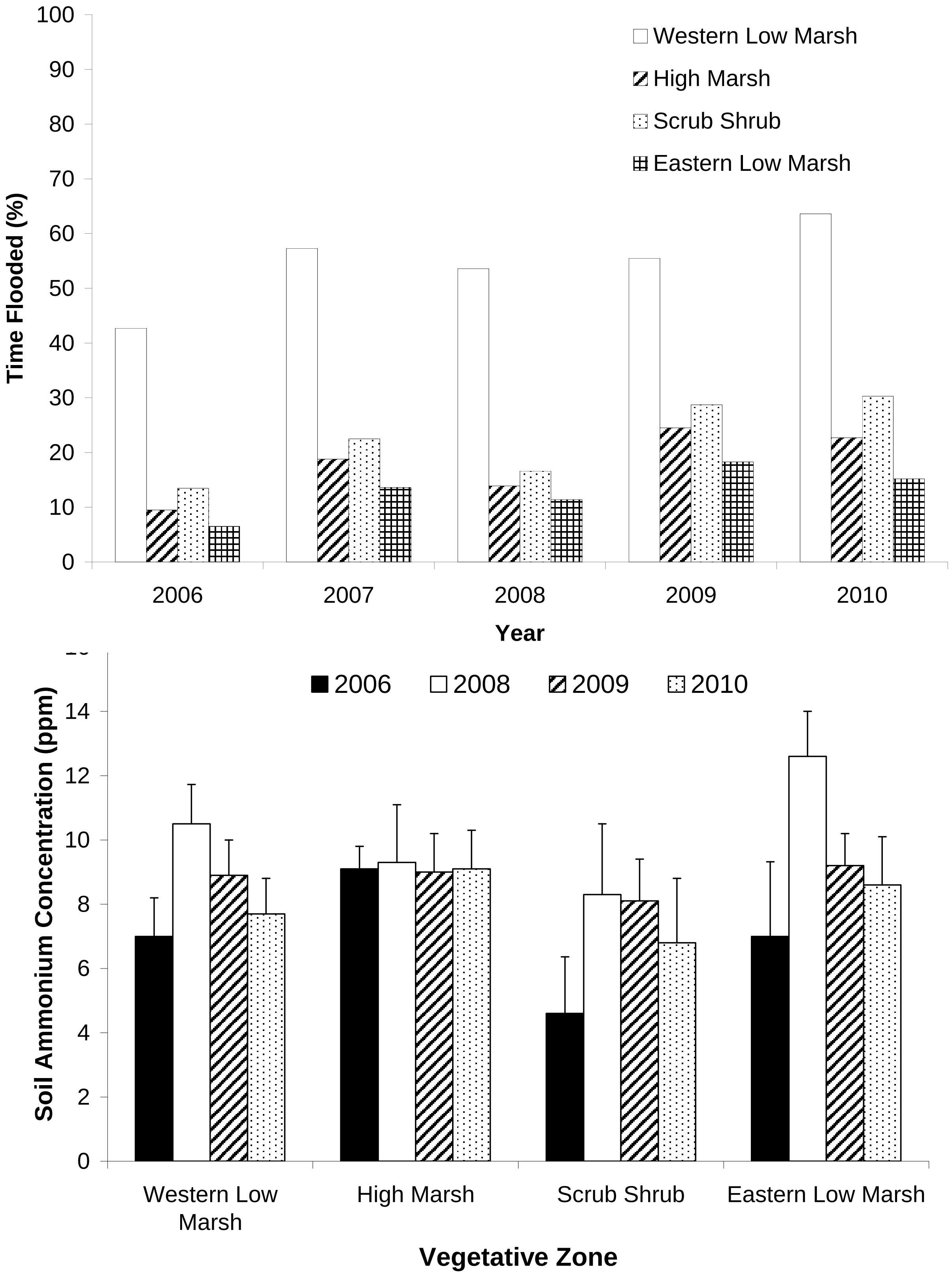

Figure 15. Top Panel: Effect of vegetative zone on percentage of time flooded for plots. Bottom Panel: Effect of year and vegetative zone on soil ammonium concentration (ppm, mean+/- se).

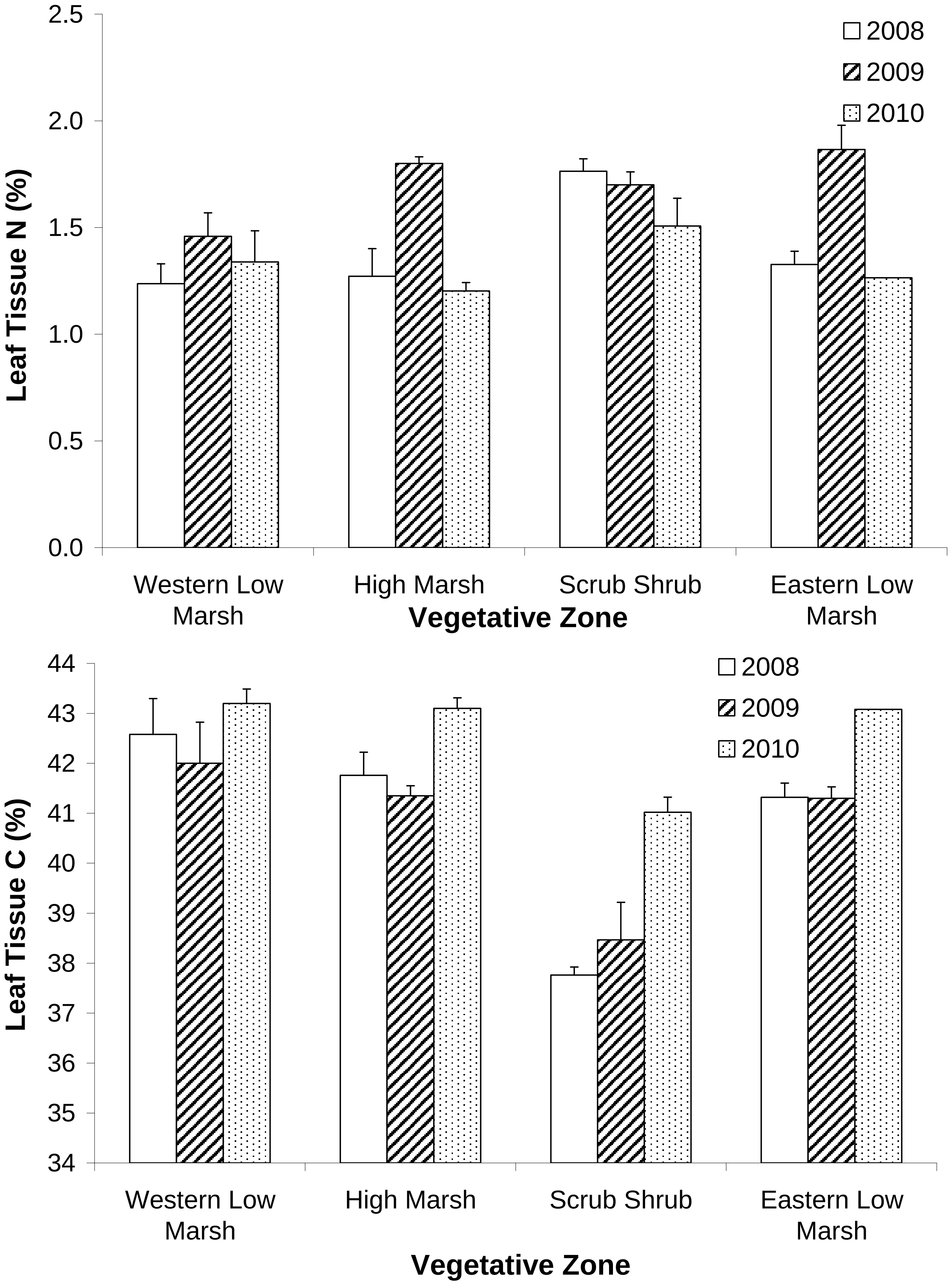

Figure 18. Top Panel: Effect of year and vegetative zone on leaf tissue nitrogen (%, mean+/- se). Bottom Panel: Effect of vegetative zone on leaf tissue carbon (%, mean+/- se).

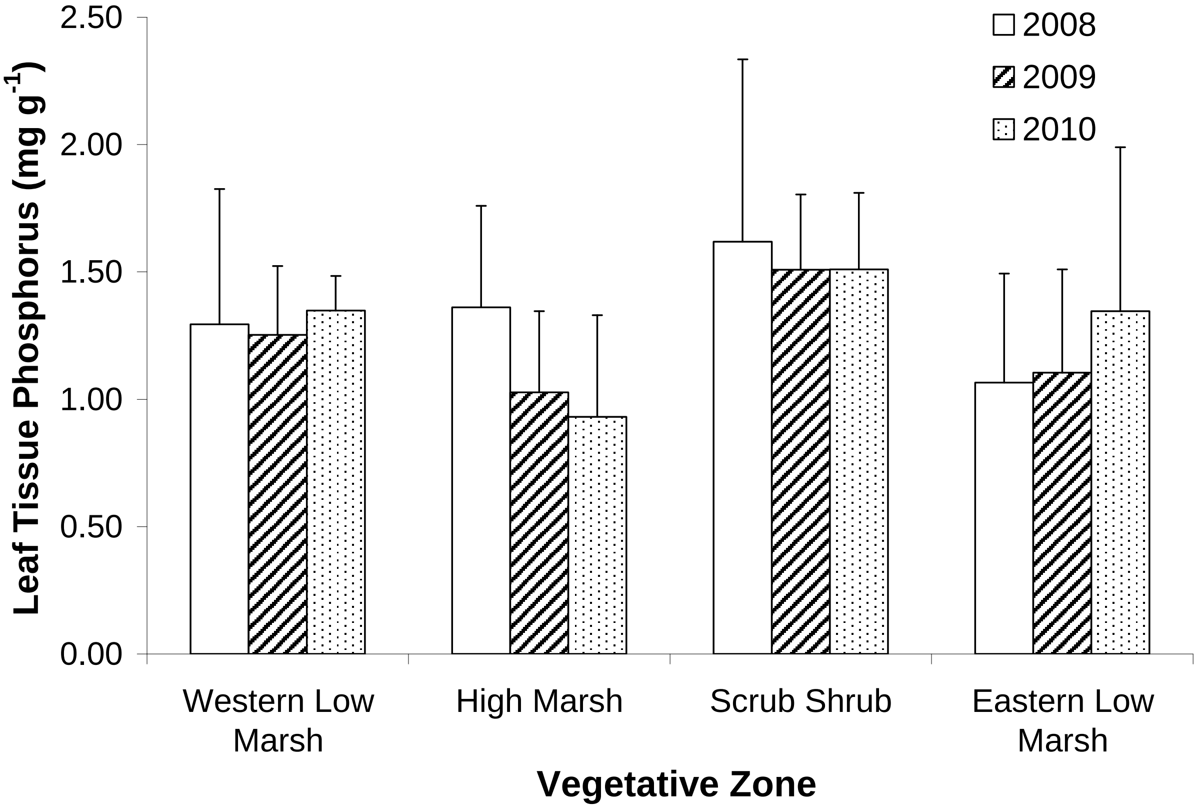

Figure 19. Effect of year and vegetative zone on leaf tissue phosphorus (mg g^{-1}, mean+/- se).

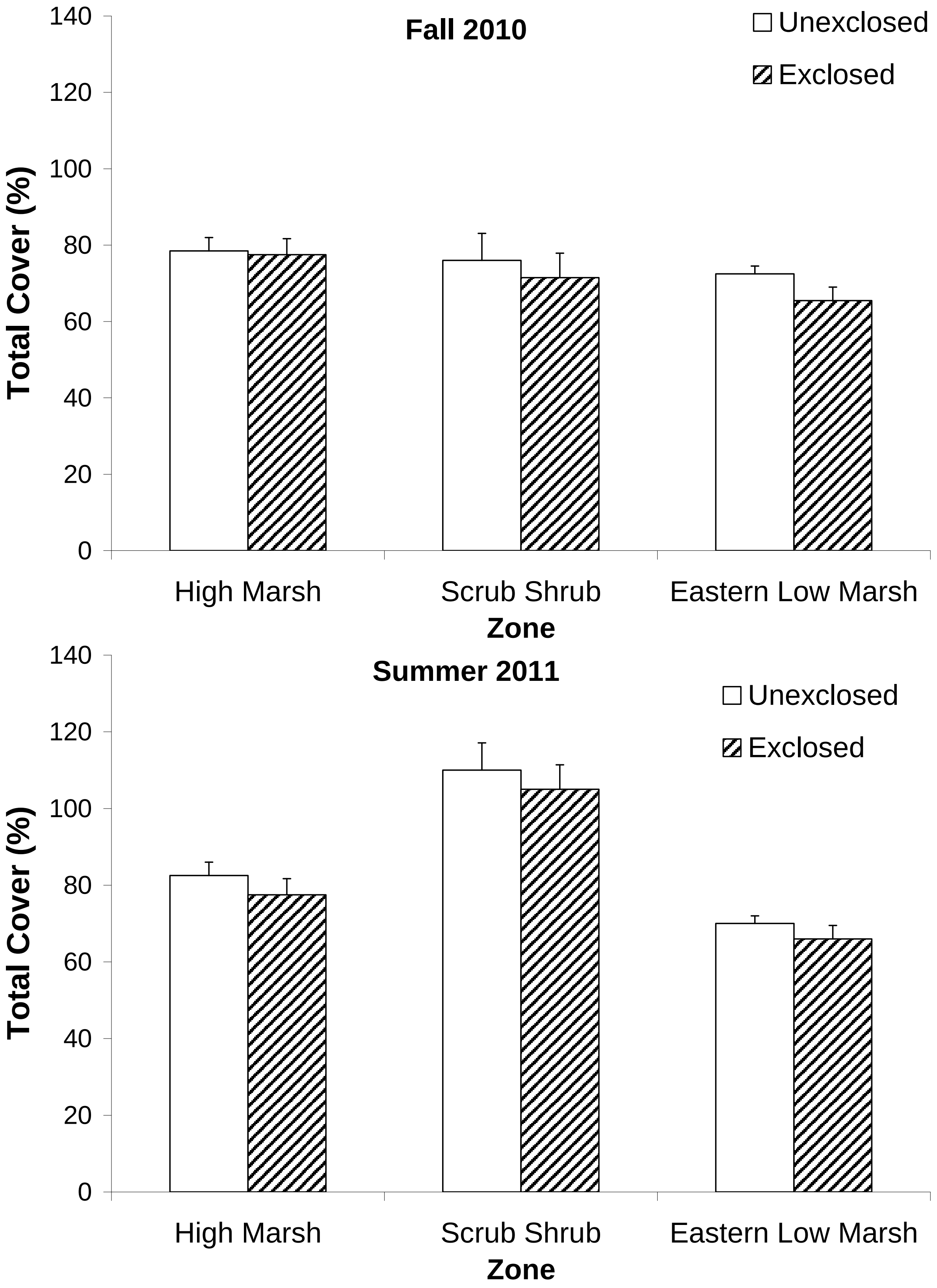

Figure 20. Top Panel: Effect of vegetative zone and exclosure on total species cover in Fall 2010 (%; mean+/- se). Bottom Panel: Effect of vegetative zone and exclosure on total species cover in Summer 2011 (%; mean+/- se).

Discussion and Conclusions

Long-Term Monitoring

As with previous investigations of the Bucktown marsh, examination of data sets collected in 2009, 2010, and Summer 2011 indicate that the Bucktown created marsh area continues to progress towards a vegetative composition characteristic of a healthy brackish marsh in coastal Louisiana. Importantly, although there has been some interannual variation in total vegetative cover and the cover of key, desired vegetative species, overall, it appears that high vegetative cover and the presence of desirable species have generally been maintained, as discussed below. Similarly, the soils of the created marsh area appear to be developing as would be anticipated for a young, herbaceous wetland in coastal Louisiana in terms of soil bulk density and organic matter. Soil elevation, as evaluated by sediment elevation tables and laser level surveys of individual plots, appears to be relatively stable other than a sediment influx event between 2007 and 2008. Interestingly, minimal impacts of the stressor of herbivory, as discerned through the use of nutria exclosure devices were detected. However, nutrient influx, as ascertained through comparisons of pre- and post-Bonne Carre opening data sets, appears to be altering both soil and vegetation nutrient status in the Bucktown marsh site.

As previously reported, a high level of vegetative cover by desirable, native Louisiana wetland plant species was discerned for all marsh zones in Summer 2006, soon after the inception of the project. Considerable annual and seasonal variation in both total vegetative cover and species composition was noted. However, it appears that all zones are maintaining total vegetative coverage and species composition that are comparable to natural oligohaline marshes in Southeastern Louisiana. Interestingly, live cover of *S. alterniflora*, which was the only species planted during the marsh creation and initially a major component of the Western and Eastern Low Marshes, appears to have decreased from relatively high levels in 2006 to more moderate levels in 2007. Although substantial annual and seasonal variation was noted for *S. alterniflora* live cover in the Western and Eastern Low Marshes during the 2007 to 2010 time period, *S. alterniflora* live cover appears to have generally achieved a moderate level in these zones. Importantly, this reduction in live *S. alterniflora* cover in the Western and Eastern Low Marsh zones is largely offset by increases in other desirable wetland plant species, such as *Schoenoplectus americanus*.

A substantial introduction of sediment was noted to have occurred in the Eastern and, to a somewhat lesser extent, Western Marsh zones in Fall of 2007. The Eastern Low Marsh surface was found to have a net increase in elevation subsequent to this event (Hester et al. 2007). However, the coverage and composition of plant communities in the Eastern, and particularly in the Western, Low Marsh zones appear to have exhibited some degree of recovery in Summer 2008. The maintenance of similar vegetative coverage and composition in the years beyond 2008 indicates that this represents recovery rather than seasonal effects or interannual variation. These two findings considered together suggest that the Eastern and Western Marsh zones quickly developed some degree of resilience that enabled their partial recovery from environmental perturbations within a single year.

The High Marsh zone has demonstrated relatively consistent total vegetative cover over the span of this study, with particularly high total vegetative cover notable in Fall 2006 and Summer

2010. The High Marsh zone demonstrated a substantial reduction in live *Spartina alterniflora* cover in fall of 2008, but no decrease in overall cover. However, by Summer 2010 the greatest average value for live *Spartina alterniflora* cover in the high marsh zone was observed. The High Marsh Zone has demonstrated a high degree of species richness in comparison to other zones, likely resulting from more hospitable conditions (e.g., little shading, lower soil water-logging intensity). This is important as it is the expansion of these native wetland plant species that has maintained a high degree of vegetative cover in the High Marsh zone during periods of reduced *S. alterniflora* cover.

The Scrub Shrub zone has been demarcated since the inception of the study by the presence of *Iva frutescens* thickets. The extent of this habitat has been generally noted to have increased over the course of this study, likely due to the hydrology of the area being favorable for the expansion of *I. frutescens*. Woody species, such as *I. frutescens*, provide unique and critical habitat (Havens et al. 2002) and therefore this increase in *I. frutescens* can be regarded as beneficial as it results in increased habitat quality. As was found with the High Marsh zone, plots within the Scrub Shrub zone have maintained a relatively constant extent of total cover. However, although the extent of *Iva frutescens* cover was generally similar throughout the study period in the Scrub Shrub zone, *S. alterniflora* cover appears to be decreasing over time, likely implicating the role of hydrology in structuring species composition. Currently, the proportion of time flooded for the not only the Scrub Shrub zone, but also the High Marsh and Eastern Low Marsh zones has been at or less than 30% for the duration of the study, which, as discussed, falls within the range where *I. frutescens* can successfully grow. This coincides with the general observation that the extent of *I. frutescens* has increased in these areas of the Bucktown marsh. With time, it will be interesting to note if subsidence of the created marsh surface may lead to a hydrologic regimes that eventually becomes less favorable for vigorous growth and expansion of *I. frutescens*. Thursby and Abdelrhman (2004) reported that *I. frutescens* in marshes along the Rhode Island coast became stunted as the hydrologic regime resulted in flooding of the marsh surface for 20% of the time. When flooded more than 30% of the time, *I. frutescens* has been reported to experience a substantial decline in growth and may be replaced by herbaceous species characteristic of that marsh type (Thursby and Abdelrhman 2004).

Over the course of the study two exotic species were noted, *Echinochloa crus-galli* and *Alternanthera philoxeroides*, which are not classified as noxious weeds in the state of Louisiana (USDA). These species are generally considered typical species for Louisiana marshes and in the case of *Echinochloa crus-galli* are thought to act as a food source for native avifauna. Both soil bulk density and organic matter have fallen within the greater ranges that would be expected for a healthy Louisiana oligohaline marsh throughout the duration of the study (Edwards and Proffitt 2006; Baustian and Turner 2006). Importantly, soil bulk density appears to be decreasing over time while soil organic matter appears to be increasing. This suggests that the soils of the Bucktown marsh have continued to improve along a trajectory towards natural oligohaline marsh, likely through the action of local vegetation. The proportion of time flooded for the various marsh zones has been relatively consistent on an annual basis, although some increase in the duration of flooding was noted in 2009 and 2010 for the High Marsh, Scrub Shrub, and Eastern Low Marsh zones. Also of great interest will be examining the effect of the lengthy opening of the Bonnet Carre Spillway opening from May 9, 2011 through June 20, 2011 (43 days) on the hydrologic regime of the marsh zones in the Bucktown marsh.

Herbivory impacts

Of great interest is that no effect of herbivore exclosure was detected during the sampling efforts conducted over the last year, even though strong visual evidence of herbivore activity and impact had been noted at the site in the previous year (e.g., nutria scat, remaining stems with apparent vertebrate herbivore-specific damage). However, herbivore activity is recognized to vary substantially from year to year due to a variety of factors (Slocum and Mendelssohn 2008). Also, the full complement of herbivore exclosures was fully deployed in Summer 2010, limiting our effective assessment to Fall 2010 and Summer 2011. Given these circumstances, and the interannual variation in vegetative composition found at the Bucktown marsh site, it is likely that additional sampling efforts will be required to adequately assess the role of herbivores in structuring the ecological trajectory of the site.

Soil nutrient status

Soil ammonium levels were higher in 2008 soil samples than archived (2006) soil samples in all zones except for the High Marsh zone. This suggests that the opening of the Bonnet Carre spillway between 2007 and 2008 did, in fact, result in increased soil ammonium concentrations at the Bucktown marsh. Soil ammonium concentrations continued to be elevated in 2009 and 2010, except in the Eastern Low Marsh zone. Although these findings are by definition correlative in nature, we are aware of no other potential sources for additional inputs of nitrogen to this site during the 2007 to 2008 time period other than the opening of Bonnet Carre Spillway. An additional and substantial opening of the Bonne Carre Spillway occurred in early Summer 2011 and soil samples have been collected and analyses are currently underway to evaluate alterations to soil nutrient status from this event.

Leaf tissue nutrient status

An increase in *Spartina alterniflora* leaf tissue nitrogen content was detected in 2009. Interestingly, the leaf tissue nitrogen concentrations for Summer 2009 for the High Marsh and Scrub Shrub zones are approaching levels reported by Morris (1982) as representing *S. alterniflora* grown in unlimited nitrogen supply during summer months (i.e., >2%). However, by 2010 *Spartina alterniflora* leaf tissue nitrogen content content was statistically indistinguishable from 2008 samples. It should be noted that the overall range of *Spartina alterniflora* leaf tissue nitrogen content values reported for this study fall within the range reported for *S. alterniflora* growing in other, naural coastal wetlands. For example, Pennings et al. (1998) found that the average leaf tissue nitrogen content of *Spartina alterniflora* was 1.83 % on Sapelo Island, Georgia. Similarly, Hester et al. (2008) investigated nutrient dynamics on Sapelo Island, Georgia, and Fourchon, Louisiana, and reported leaf tissue nitrogen concentrations of 1.66 %) for Sapelo Island and 1.32 % for Fourchon. Therefore, leaf tissue nitrogen concentration for *Spartina alterniflora* in the Bucktown created marsh appear to be generally within the expected range, other than in Summer 2009 where they appear to have been mildly elevated. Interestingly, the average *Spartina alterniflora* leaf tissue phosphorus concentrations were not found to vary by year or by vegetative zone, and were quite close to the value previously reported by Turner (1.3 mg g^{-1}; Turner 1993).

In conclusion, the ongoing monitoring of the Bucktown marsh area suggests that this created marsh largely exhibits ecological characteristics consistent with an oligohaline marsh in coastal Louisiana. The extensive nature of this monitoring data set has enabled both the quantification of seasonal and interannual variation as well as the elucidation of long-term trends in vegetative species cover and composition. Importantly, the indicators of edaphic status, soil bulk density and organic matter content, suggest that the soils of the Bucktown marsh are continuing to mature. Hydrology, as would be anticipated, continues to play a major role in structuring marsh vegetation, as indicated by actual measurements of marsh water level as well as by the flooding tolerances of key indicator vegetative species. Continued monitoring of the Bucktown marsh will allow for further insights into vegetation dynamics on multiple time scales as well as inform our understanding of trajectories of soil development and the provision of ecosystem services in a restored oligohaline marsh.

Literature Cited

Baker J., E. Mouton, and G. Linscombe. (2005) Nutria Harvest Distribution 2004-2005, and a Survey of Nutria Herbivory Damage in Coastal Louisiana in 2005. CWPPRA Project (LA-03b). Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA.

Baustian , J.J. and R. E. Turner. 2006. Restoration Success of Backfilling Canals in Coastal Louisiana Marshes. Restoration Ecology. 14:636-644.

Burke and Kleinpeter, Inc. 2006. Bucktown Harbor – Marsh Planting Project Annual Report. 2 pp.

Cahoon, D. R., J. C. Lynch, B. C. Perez, B. Segura, R. Holland, C. Stelly, G. Stephenson, and P. Hensel. 2002. A device for high precision measurement of wetland sediment elevation: II. The rod surface elevation table. Journal of Sedimentary Research. 72:734-739.

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18:117-143.

Craft, C. B., S.W. Broome, and C. L. Campbell. 2002. Fifteen years of vegetation and soil development following brackish- water marsh creation. Restoration Ecology 10:248–258.

Edwards, K. R., and E. C. Proffitt. 2003. Comparison of wetland structural characteristics between created and natural salt marshes in southwest Louisiana, USA. Wetlands. 23:344-356.

Geho, E. M., D. C. Campbell, and P. A. Keddy. 2007. Quantifying ecological filters: the relative impact of herbivory, neighbours, and sediment on an oligohaline marsh. Oikos. 116:1006 – 1016.

Havens, K. J., L. M.Varnell, and B. D. Watts. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecological Engineering. 18:305-316.

Hester, M. W. J. M. Willis, and C. E. Mayence. 2005. Plant Community Composition of the Bucktown Created Marsh: A Preliminary Assessment. Final Report, Lake Pontchartrain Basin Foundation.

Hester, M. W. J. M. Willis. 2007. Assessment of vegetative and edaphic characteristics of the Bucktown created marsh: year one. Final Report, Lake Pontchartrain Basin Foundation.

Hester, M. W. and K. Fisher. In Review. Response of freshwater floating marsh to altered nutrient loading and salinity regimes. Estuaries and Coasts.`

Keddy, P. A., D. Campbell, T. McFalls, G. P. Shaffer, R. Moreau, C. Dranguet, and R. Heleniak. 2007. The wetlands of Lakes Pontchartrain and Maurepas: past, present and future. Environmental Review. 15: 43 – 77.

LPBF Lake Pontchartrain Basin Foundation website: http://www.saveourlake.org/

McFalls, T. B., P. A. Keddy, D. Campbell, G. P. Shaffer. 2010. Hurricanes, floods, levees, and nutria: vegetation responses to interacting disturbance and fertility regimes with implications for coastal wetland restoration. Journal of Coastal Research. 26:901 – 911.

Morris, J.T. 1982. A model of growth responses by *Spartina alterniflora* to nitrogen limitation. Journal of Ecology. 70:25-42.

Ornes, W.H. and D.I. Kaplan. 1989. Macronutrient status of tall and short forms of *Spartina alterniflora* in a South Carolina salt marsh. Marine Ecology Progress Series. 55:63-72.

Pennings, S.C., T.H. Carefoot, E.L. Siska, M.E. Chase, T.A. Page. 1998. Feeding preferences of a generalist salt-marsh crab: relative importance of multiple plant traits. Ecology. 79:1968-1979.

Sacco, J. N., E. D. Seneca, and T. Wentworth. 1994. Infaunal community development of artificially established salt marshes in North Carolina. Estuaries 17:489–500.

Slocum, M. G. and I. A. Mendelssohn. 2008. Effects of three stressors on vegetation in an oligohaline marsh. Freshwater Biology. 53:1783 – 1796.

Swarzenski, C. M., T. W. Doyle, B. Fry and T. G. Hargis. 2008. Biogeochemical response of organic-rich freshwater marshes in the Louisiana delta plain to chronic river water influx. Biogeochemistry. 90: 49-63,

Thursby GB, and M.A. Abdelrhman. 2004. Growth of the Marsh Elder *Iva frutescens* in relation to duration of Tidal flooding. Estuaries. 27:217–224.

Turner, R.E., 1993. Carbon, nitrogen, and phosphorus leaching rates from *Spartina alterniflora* salt marshes. Marine Ecology Progress Series. 92: 135-140.

USDA PLANTS database: *Echinochloa crus-galli*: http://plants.usda.gov/java/profile?symbol=ECCR

USDA PLANTS database: *Alternanthera philoxeroides*: http://plants.usda.gov/java/profile?symbol=ALPH

Zedler, J. B. 2000. Progress in wetland restoration ecology. Trends in Ecology and Evolution 15:402–407