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# Characterizing Vegetative Communities Across the Salt Marsh to Upland Ecotone in Connecticut: Indications of Tidal Inundation Stress in the High Marsh

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THE UNIVERSITY OF NEW HAVEN

CHARACTERIZING VEGETATIVE COMMUNITIES ACROSS THE SALT MARSH TO UPLAND  
ECOTONE IN CONNECTICUT: INDICATIONS OF TIDAL INUNDATION STRESS IN THE HIGH  
MARSH

A THESIS

Submitted in partial fulfillment  
of the requirements for the degree of  
MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

BY

Matthew J. Ormrod

University of New Haven

West Haven, Connecticut

May 2019

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## ABSTRACT

The viability of Connecticut's future salt marshes remains uncertain as pressure from multiple anthropogenic stressors and accelerated relative sea level rise continue to undermine the dynamic ecogeomorphic mechanisms that allow these landscapes to persist in times of environmental change. Observed rates of relative sea level rise in the Long Island Sound estuary appear to be accelerating since recording began in the early 1930s. Furthermore, as much as 90% of the land parcels expected to undergo habitat change as marine ecosystems migrate landward are privately owned and managed. This finding suggests that, in addition to these intrinsic ecogeomorphic feedbacks that make salt marshes viable, sociopolitical variables will also play a key role in the sustainability of these ecosystems in the future.

This thesis characterized vegetative community structuring at the salt marsh to upland boundary at five different sites along the Connecticut Coast. Nearly 40% of the marshes sampled exhibited manifestations of tidal inundation stress including high relative percentages of the low marsh species *Spartina alterniflora* (stunted) and deposited tidal wrack mats in the high marsh zone. Common reed, bare areas, and turf lawns had the highest average percent cover type of all the cover types identified within the transition zone. Six of the fourteen transects were observed to have these features prevailing near the apparent salt marsh to upland edge. Despite these apparent disturbances, the transects sampled in this thesis were found to have high variability in plant community assemblages both within and between each study site location. Other than observing species richness to increase from west to east across the state, the presence of tidal restricting structures, adjacent upland cover type, and geographic variables were not found to be good predictors of the variation in vegetative assemblages in the marshes studied in this thesis. This finding suggests that local variations, such as topography, competition, and tidal regimes, are prevailing conditions controlling plant community assemblages across the high marsh to upland ecotone.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	iii
ABSTRACT.....	iv
TABLE OF CONTENTS.....	v
CHAPTER I:	
Introduction .....	1
Late Holocene sea level trends in the Long Island Sound estuary .....	2
Salt marsh adaptations and responses to sea level fluctuations.....	3
Salinity, inundation and plant community structure.....	6
Study objectives .....	7
CHAPTER II:	
Materials and Methods.....	9
Environmental settings of study marshes .....	10
Sherwood Island State Park, Westport, CT.....	10
Stony Creek and Pine Orchard Marshes, Branford, CT .....	11
Hammonasset Beach State Park, Madison, CT .....	12
Waterford Beach Park, Waterford, CT.....	13
Barn Island Wildlife Management Area, Stonington, CT .....	13
Data Analysis of Sample Photographs .....	14
CHAPTER III:	
Results .....	17
CPCe output .....	17
CHAPTER IV:	
Discussion .....	20
References.....	24
APPENDIX A .....	55

## LIST OF TABLES

Table 1.	Coordinates to Salt Marsh Sites .....	31
Table 2.	Species List and Information.....	32
Table 3.	Principal Components Analysis Scores.....	33
Table 4.	Results of Two-way Group Similarity Analysis (ANOSIM) .....	33

## LIST OF FIGURES

Figure 1.	50-Year Variation in Relative Sea Level Rise (NOAA), New London, CT .....	35
Figure 2.	Salt Marsh Plant Community Structure.....	35
Figure 3.	Conceptual Cross-section Model of Salt Marsh Plant Community Structure .....	36
Figure 4.	Sample of Field Notes and Supplemental Photographs .....	37
Figure 5.	Location Map of Study Salt Marshes .....	38
Figure 6.	Transect Locations at Sherwood Island State Park, Westport, CT.....	39
Figure 7.	Transect Locations at the Branford Marshes, Branford, CT .....	40
Figure 8.	Transect Locations at Hammonasset Beach State Park, Madison, CT.....	41
Figure 9.	Transect Locations at Waterford Beach Park, Waterford, CT .....	42
Figure 10.	Transect Locations at Barn Island Wildlife Management Area, Stonington, CT.....	43
Figure 11.	Species Richness by Site .....	44
Figure 12.	Average Percent Cover Type within the Lower High Marsh Zone.....	44
Figure 13.	Average Percent Cover Type within the Higher High Marsh Zone .....	45
Figure 14.	Average Percent Cover Type within Transition Zone.....	46
Figure 15.	Principal Components Analysis .....	47
Figure 16.	Non-metric Multidimensional Scaling Analysis by Transect.....	48
Figure 17.	Non-metric Multidimensional Scaling Analysis by Marsh Zone .....	49

Figure 18.	Cluster Analysis Dendrogram by Transect.....	50
Figure 19.	Principal Components Analysis Showing Grouped Transects .....	55

## **LIST OF PHOTOS**

Photo 1.	Transect BI2 Salt Marsh to Upland Transition .....	52
Photo 2.	Transect BI1 Salt Marsh to Upland Transition .....	52
Photo 3.	Transect HSP1 Salt Marsh to Upland Transition .....	53
Photo 4.	Transect HSP2 Salt Marsh to Upland Transition .....	53
Photo 5.	Transect BI2 Salt Marsh to Upland Transition .....	54
Photo 6.	Transect WBP1 Salt Marsh to Upland Transition.....	54

# **CHAPTER I**

## **Introduction**

Connecticut salt marshes continue to be an important area of research due to the uncertainty of their persistence under accelerated sea level rise (ASLR) and multiple anthropogenic stressors within the coastal zone. Modern infrastructure creates physical barriers that impede salt marsh tendencies to adjust their position within the tidal frame with changing sea levels. Seaward development within the coastal zone coupled with the transgression of the sea is referred to as coastal squeeze (Doody, 2004) and serves as the basis of the concern regarding the trend of net losses to Connecticut's tidal wetlands over the past century. It is estimated that Connecticut tidal wetlands have decreased 27% in total area since 1880 (Basso et al. 2015). In addition to these losses, Connecticut salt marshes are experiencing increases in areas of permanent open water at low tide on the marsh platform and a restructuring of plant communities consistent with increased tidal inundation (Tiner et al. 2006, Tiner et al. 2013). These trends suggest Connecticut's tidal wetlands are becoming increasingly salt-stressed over time at successively higher elevations within the marsh. Despite their apparent stability through time, it is unclear whether or not these ecosystems can keep pace with the observed rates of ASLR in addition to multiple anthropogenic stressors (i.e. nutrient pollution, coastal development, shore armoring, land management practices, etc.).

Salt marshes are characterized by high productivity and are known to provide a myriad of ecosystem services such as coastal flood protection, nutrient and toxicant uptake and transformation, maintenance of key fisheries, habitat for migratory and resident birds, carbon sequestration, as well as recreation, property and tourism value (Barbier et al, 2011, Mitsch and Gosselink, 2015). Human activities have both direct and indirect impacts on these ecosystems which can affect many of their self-sustaining mechanisms that allow them to persist during periods of environmental change. Historically, Connecticut salt marshes have been able to withstand sea level fluctuations since their appearance approximately 4,000-6,000 years before present (Redfield, 1965; Orson, Dreyer and Niering, 1998;



Kirwan and Megonigal, 2013). However, these earlier marsh systems formed and developed under different conditions (Redfield, 1965) and human impacts were likely negligible during those times.

### **Late Holocene sea level fluctuations in the Long Island Sound estuary**

Van de Plassche (1991) suggested several Late Holocene sea level fluctuations along the shore of the Connecticut coast at an average rate of  $0.8 \text{ mm year}^{-1}$  over the past approximately 2,000 years. Redfield (1965) estimated that the mean high water level has risen, relative to the land, at an average rate of about  $1.0 \text{ mm year}^{-1}$  during the last 2,100 years. Prior to that time, this same study found an average rate of rise of  $3.05 \text{ mm year}^{-1}$  extending back at least 3,700 years. Nydick et al. (1995) estimated a two-meter sea level rise in Connecticut over the last 1,500 years with an increase from 1.3- to  $1.8 \text{ mm year}^{-1}$  during the last 1,000 years and 2.9- to  $3.3 \text{ mm year}^{-1}$  over the last 300-400 years. These apparent accelerated rates within the last three to four centuries in New England agree with other studies (Kirwan and Megonigal, 2013).

The National Oceanic and Atmospheric Administration (NOAA) has been directly measuring changes in RSLR within LIS as part of the National Water Level Observation Network. The Bridgeport, CT station has measured an average rate of increase of  $2.93 \text{ mm year}^{-1}$  from 1964-2018. The New London station has measured an average rate of increase of  $2.65 \text{ mm year}^{-1}$  from 1938-2018. Stations in New York have also seen steady increases in sea level. For example, the Montauk station shows an average increase of  $3.32 \text{ mm year}^{-1}$  from 1947-2018. The Kings Point (1931-2018) and Port Jefferson (1957-1992) stations have seen average increases of 2.54- and  $2.44 \text{ mm year}^{-1}$ , respectively.

Furthermore, these rates appear to be accelerating overtime as the variation of the 50-year relative sea level trend at New London has increased from  $1.4 \text{ mm year}^{-1}$  between 1945-1995 to an average increase of  $3.28 \text{ mm year}^{-1}$  from 1965-2015 (Figure 1). Future sea level rise in Long Island Sound is estimated to be one half-meter greater than the national tidal datum average as published in the 2012 NOAA Technical Report OAR CPO-1 (O'Donnell, 2018). This is due in part from the geomorphology of

the LIS basin and the observed rate of subsidence of the Connecticut coast averaging  $-0.70 \text{ mm year}^{-1}$  since the early 1930s (Zervas et al., 2013). Given the variability in sea level within LIS, Connecticut salt marshes must be ephemeral systems and require both the vertical and horizontal space to migrate accordingly; in addition to other abiotic and biotic variables that make them viable.

### **Salt marsh adaptations in response to sea level fluctuations**

Halophytic gramminoids that dominate salt marshes are termed foundation species because of their ability to modify their physical environment which promotes the development and persistence of the greater salt marsh community (Bruno and Bertness, 2001; Gedan and Bertness, 2010). Accretion is the vertical and lateral movements through which salt marshes adapt to fluctuating sea levels by manipulating their elevation relative to tidal conditions. These adaptive processes are complex and operate through a variety of interconnected ecogeomorphic feedbacks. Above ground vegetative shoots decrease the velocity of water flowing between them which influences deposition of suspended sediment and organic matter (Clark and Patterson III, 1985; Mudd, Howell, and Morris, 2009). Regular tidal inundation is the primary force which carries allochthonous mineral sediments to the marsh platform (Charles and Dukes, 2009; Weston, 2014; Kearney and Turner, 2016). Therefore, those portions of the marsh that are inundated more frequently receive more inorganic sediments than those areas of the marsh being inundated less frequently.

Watershed-derived sediments, rather than marine-derived sediments, can be important sources of substrate materials for salt marshes in LIS because marine reworking of sediments is thought to be limited due to the estuary's protected geography. Furthermore, the LIS watershed covers six states with an approximate area of  $16,000 \text{ mi}^2$ . Major tidal rivers, such as the Connecticut and Thames, are thought to be the source of approximately 80% of all the freshwater inputs into LIS (Harrison and Bloom, 1977) and are likely major sources of substrate materials used by salt marshes. In addition to supplying freshwater and substrate materials, non-point source pollutants are also carried to LIS from these and other tidal rivers as the LIS watershed is densely populated with more than eight million people living within its boundaries

(MRB ten Brink et al, 2000). Engineered structures such as dams, groins, jetties, and seawalls as well as sediment and erosion control management techniques inhibit transport of these needed substrate materials (Weston, 2014; Huff and Feagin, 2018; Gedan et al., 2009; Bertness et al, 2001).

Accretion processes also occur beneath the salt marsh platform and can contribute substantially towards the maintenance of elevation in sediment-starved marshes of Southern New England (Bricker-Urso et al., 1989). Below ground biomass is accumulated through a balance of root growth and decay (Kirwan and Guntenspergen, 2012; Kirwan et al., 2012). Low marsh species were found to have lower stem, root and rhizome density compared to high marsh species in Connecticut (Warren and Niering, 1993). This finding suggests the importance of conserving those marshes with high marsh capital (i.e. those with a relatively high proportions of the marsh platform above mean high water). However, Carey *et al* (2015) found that organic matter accumulation has been declining in the past three decades within salt marshes around Narragansett Bay, Rhode Island, and found that water-retention in the highly-porous, organic rich peat layers to contribute more towards maintaining elevations relative to both organic matter accumulation and mineral deposition. Nuttle *et al.* (1990) described the mechanisms of water storage in New England salt marshes and noted the importance of marsh swelling and dilation and how they relate to elevation changes. These fluctuations, which are generally concomitant with diurnal tide cycles, depend heavily upon the composition of the marsh edaphic characteristics (e.g. dilation increases with increasing shrink-swell capacity of the marsh peat).

Morris et al. (2002) postulates the submergence-productivity loop (SPL) and serves as a good summation of the overall accretion processes. The SPL theory is a dynamic equilibrium taking place between sediment accretion, marsh elevation, primary productivity, and mean sea level. Over long timescales, the build-up of autochthonous organic material (i.e. *in situ* marsh peat) and allochthonous inorganic sediments (i.e. watershed- or marine-derived) allow salt marshes to manipulate their platform relative to the tidal regime. This dynamism assumes a stable and constant source of sediment or organic matter supply, and, a rate of sea level rise that does *not* exceed the maximum accretion rate of any given

salt marsh. Average accretion rates across several hundreds of marshes on the East Coast of the United States range between 0.1 and 0.6 cm year<sup>-1</sup> (Turner et al., 2000). Anisfeld *et al.* (1999) found similar accretion rates in both tidally-restricted and unrestricted marshes in Connecticut using various isotope proxies. Carey *et al.* (2017) also found similar accretion rates on both a front-marsh and brackish marsh on the Thames River in Waterford, Connecticut. Albeit, the two marshes in the latter study had a high degree of variation likely due to their proximity to the Thames River – a major source of substrate materials.

During times of accretion or subsidence, salt marshes need the necessary space to move both laterally and vertically across the landscape. Again, lateral movements into adjacent upland areas of Connecticut are limited due to the extent and intensity of development that has occurred over the past approximately two centuries. Some of the primary anthropogenic factors limiting salt marsh accretion include: impervious surfaces, transportation corridors, and land management practices (i.e. mowing, shoreline armoring). The latter is especially important for Connecticut, where approximately two-thirds of the landmass serving as suitable migration habitat for salt marshes is privately owned and managed (Welchel et al., 2015).

Other important components of New England salt marshes include tidal creeks, mosquito ditches, pools and salt pannes. These landscape features have been known to provide essential habitat for nekton, shellfish, crustaceans, waterfowl and wading birds (Boesch & Turner, 1984; Gedan et. al., 2011). Tidal creeks within salt marshes serve as a conduit for nutrient and sediment fluxes which affect plant productivity, vegetative zonation, and marsh elevation (Warren and Niering, 1993). Natural levees form along creek banks when flood waters deposit both organic and inorganic suspended materials. Coarser sediments are deposited nearest the levee and finer particles are deposited with increasing distance from the creek banks. Creek banks are stabilized by roots and rhizomes (predominantly *S. alterniflora* due to high soil salinities) which provide structural edaphic integrity by binding sediments and enhancing drainage via macropores (Deegan et. al., 2012). These features ultimately enrich the dynamism of any

given salt marsh unit and add to the complexity of the ecogeomorphic feedback loops which make these ecosystems viable.

As part of the New Deal during the economic depression in the 1930's, 90% of the Atlantic coastal marshes were grid-ditched in an effort to drain open water features where mosquitos were thought to be breeding (Bourn and Cottam, 1950). The effects of ditching are numerous and typically include: altered flow paths and hydrology, altered sedimentation processes, altered soil composition (organic matter decomposition), subsidence of high marsh interiors, altered vegetative patterns, and wildlife behaviors (for better or worse) associated with habitat change (Tiner, 2013).

### **Salinity, inundation and plant community structure**

Tidal inundation is a master variable controlling soil salinity and vegetative gradients in salt marshes (Miller and Egler, 1950; Lefor et al., 1987; Orson and Howes, 1992; Carey et al., 2015). Levine *et al.* (1998) described salt marshes of New England and how they exhibit a strong vegetative gradient. These gradients are thought to occur primarily due to the combination of competitive displacement and variation in physiological stress (i.e. anoxia and salinity, Figure 2). Species that are more tolerant of anoxic and hypersaline soils occupy the lowest elevations of the salt marsh landscape closest the seaward edge. Species that are better competitors for resources, such as soil nutrients and light, occupy higher elevations of the salt marsh. Wilson and Keddy (1986) and Grime (1979) found that no species can simultaneously be the best competitor and the most stress tolerant. These trade-offs have been shown to limit the expansion of low-elevation species into higher portions of the marsh (e.g. the terrestrial border) and vice-versa; species die when transplanted to elevations outside of their ideal range (Bertness, 1991a, Janousek and Mayo 2013). Nutrient enrichment studies have been shown to reverse the competitive displacement hierarchy and destabilize marsh edaphic conditions (Levine *et al.*, 1998; Fox *et al.*, 2012; Wong *et al.*, 2015; Turner, 2016). Again, LIS is the sink of a densely populated drainage basin and is commonly known to experience anoxia events in the warmer months.

For a typical New England salt marsh, *Spartina alterniflora* (short form and tall form) usually occupies the intertidal zone where complete submergence of the vegetation occurs on a regular basis. Areas that are inundated less frequently (i.e. higher elevations) typically have lower soil salinity concentrations and are occupied by the species: *Spartina patens*, *Distichlis spicata*, and *Iva frutescens*. The most elevated portions of the salt marsh (inundated less frequently during spring tides and storm events) are characterized by communities of *Panicum virgatum*, *Phragmites australis*, *Limonium carolinianum*, *Aster spp.*, and *Triglochin maritima* (Bertness, Ewanchuk, and Silliman, 2002; Mitsch and Gosselink, 2015). The zonation of these vegetative communities (Figure 3) varies from site to site but is strongly correlated with tidal inundation and its subsequent effects on soil edaphic conditions (Niering and Warren, 1993).

The margin of the low marsh zone is the seaward edge and the margin of the high marsh zone is the upland border. It is because salt marshes exist in this narrow range with sharp environmental gradients that make them ideal indicator ecosystems of environmental change (Risser, 1995); especially vegetative communities which can respond relatively quickly to those aforementioned environmental variables. For example, studies in a California salt marsh have shown that the marsh to upland ecotone, as defined by the vegetative community structure, can shift relatively quickly (up to a decade) when environmental variables force the system; in this case increased tidal inundation was suspected to cause up to a one meter shift of the boundary inland (Wasson *et al.*, 2013).

## **Study objectives**

Questions I addressed in this thesis are:

How do the ecological characteristics of the high marsh to upland transition zones vary across different Connecticut salt marshes, and, how do these compare to current models of salt marsh zonation?

Are variations in the high marsh to upland transition related to differing patterns of tidal inundation, geomorphological setting and/or surrounding land use among the marshes?

What insights do the results provide regarding potential future changes Connecticut salt marshes may undergo in the face of climate change related phenomena?

## CHAPTER 2

### Materials and Methods

To address these questions a total of 14 transects across five sites were chosen to collect percent vegetation cover data. A one square-meter polyvinyl chloride quadrat was used as the sampling frame for each study transect. A digital camera was used to photograph the sampling quadrat from a direct-overhead position. Hand written notes and other photographs supplemented the direct-overhead sample photos (Figure 4). Each transect was 30 meters in length, with 20 meters in the apparent high marsh zone and 10 meters in the high marsh to upland transition zone. A global positioning unit was used to collect coordinates for each end of every transect (Table 1). A total of three 30-meter transects were sampled at each site with exception of the Branford marshes, where only two transects were sampled.

Individual transect locations were randomly selected within each site but predominantly resided in areas that were amiable for future marsh migration to occur based on information in Ryan and Welchel (2015) and the Sea Level Affecting Marshes Model (SLAMM) by Warren Pinnacle Consulting Incorporated (2015). The term high marsh is used in a general sense here rather than its true definition which accounts for the marsh-platform elevation and position within the tidal frame relative to an established vertical datum. For the purposes of this study, the apparent edge was defined as that part of any given marsh in which a change in vegetation is observed from predominantly graminoid species to predominantly shrub-scrub species (Photos 1-6). Previous studies (Cui et al., 2011; Veldkornet et al., 2015) suggest that the location of the salt marsh-upland border ultimately depends on what parameter is being measured. This thesis specifically looked at plant communities and their change in structure from a point which was completely halophytic in nature, to a point which was completely terrigenous in nature ( i.e. inhabited by a community of plants not typically associated with salt marshes). For the latter, this typically included an abutting mixed deciduous forest and/or scrub-shrub community. Turf lawns were encountered in several of the study transects and were also considered as a member of the upland



community based upon the apparent rise in elevation with increasing landward-distance away from the salt marsh.

Individual transects were further categorized based upon whether or not they were tidally restricted and by the adjacent upland cover type. Requirements needed to meet the tidally restricted category were based upon the presence of engineered structures along the tidal creek(s) connecting each marsh unit to LIS. These structures included culverts (road overpasses), dikes, tide gates, and earthen berms or trails. The adjacent upland cover was divided into two categories: forested or suburban. To assess the upland cover type, a straight line was drawn in continuation of the azimuth direction of each transect. Suburban cover types included turf lawns and residential neighborhoods. These two categories sufficiently described the upland cover type of all transects sampled.

All five study sites were located on the northern coast of the Long Island Sound estuary in Connecticut and include (from west to east): Sherwood Island State Park, the Atilio J. Banca and Pine Orchard marsh complexes (Branford Marshes), Hammonasset Beach State Park, Waterford Beach Park, and Barn Island Wildlife Management Area (Figure 5). Tides in LIS are semidiurnal with average tidal ranges increasing from the eastern end of the basin to the western end of the basin. This observed phenomena was also considered when addressing the study objective questions described on the previous page.

### **Environmental Setting of Study Marshes**

#### *Sherwood Island State Park, Westport, Connecticut*

As the westernmost marsh complex studied, transects at Sherwood Island State Park lay behind an expansive sandy beach shoreline (Figure 6). Transect SI1 lies at the headland of a coastal forest adjacent Sherwood Millpond – a tidally restricted embayment. Transect SI2 is found southwest of SI1 in a protected pocket-like basin with forested upland to the west and turf grass to the south and east. A small tidal creek to the north, which has been altered by ditching, serves as the only exchange path of sea water

from marsh to LIS. Transect SI3 is found east of SI1 and SI2. This transect is almost hydrologically isolated from the other two transects and lies adjacent to a larger tidally-restricted creek. Transect SI3 grades gently into a grass turf upland.

Anisfeld et al (2017) used a “synthetic” high-tide data set (2006-2015) to define their marsh migration zones at this site which averaged between 1.31 m (the elevation of the marsh that is inundated 20% of the year) to 1.78 m (inundated 0.5% of the year) above mean sea level (MSL; NAVD88). This study found that MSL, mean high water (MHW) and the lower boundary of the migration zone (1.31 m NAVD88) rose at rates between 4.2- and 4.4 mm year<sup>-1</sup>. Furthermore, the elevation of the highest astronomical tides (HAT), occurring mostly in early spring, rose at 5.7mm year<sup>-1</sup>; highlighting the importance of storm events and interannual variability in tidal hydrology affecting plant community structure.

#### *Stony Creek and Pine Orchard Marsh Complexes, Branford, Connecticut*

Two transects were sampled in these Branford marshes. Both transects, BMSC1 and BMSC2, lie within tidally restricted back-bay environments (Figure 7). A walking path (former Shore Line Electric Railway) bisects these marsh complexes from east to west, approximately paralleling the shoreline. This path creates a physical barrier between these transects and the open waters of LIS at Stony Creek Harbor. Further inland of these transects, the Shoreline East Railway rises steeply from the level of the marsh platform and approximately parallels the walking path. Transect BMSC1 lies adjacent to a small, ditched tidal creek and has a sharply contrasting transition zone where a sheer granite-wall outcropping abuts the marsh proper. Exchanges of seawater between the salt marsh at this transect site and LIS occur via an approximately eight-foot concrete culvert. BMSC2 has a gently-sloping gradient whose upland consists of a turf grass baseball field – a former salt marsh that was filled. A small, possibly manmade, ancillary creek to the west serves as the closest conduit for seawater exchange. This smaller ancillary creek joins with a larger tidal creek to the southwest and connects with LIS under an approximately 40-foot wide Pratt through truss bridge (built in 1907). The presence of grid-ditches still remains at both transects sites

in Branford. Mean tidal ranges are approximately 1.9 meters here with average salinities between 19-28 psu (Luk and Zajac, 2013).

*Hammonasset Beach State Park, Madison, Connecticut*

All transects at this site are found behind an approximately three-mile long sandy beach to the south. The Hammonasset River, the main source of freshwater at this site, is found to the north which flows east into Clinton Harbor (Figure 8). Salt marshes at this site have been historically altered through filling with dredge sediments, tidal inhibition by construction of access roads, and mosquito ditching (CT DEEP, 2002). The westernmost transect, HSP1, is confined to a small basin surrounded by a sandy beach and dune environment to the south, and turf grass uplands to the north, east, and west. A small manmade creek northwest of the transect serves as the only exchange path with LIS. This engineered creek flows west through an approximately 20-foot culvert underneath an access road where it eventually connects to a larger creek. The central transect, HSP2, is found near the center of the park in between the main pavilion area and Meig's Point Nature Center. This transect grades gently into a grass turf upland. Further south, an access road is found adjacent to the leeward side of a fenced-off dune. The major source of freshwater at this transect is Dudley Creek – a tributary of the Hammonasset river that flows south then east towards the Nature Center. Restoration activities in the vicinity of HSP2 include the removal of a low-earthen dike and excavations intended to increase tidal flushing, which were completed in 1995. The easternmost transect, HSP3, appears to have little hydrologic alterations with exception of ditches perpendicular to the main tidal creek. This transect lies near the eastern terminus of the park and grades gently into a rocky shrub-scrub upland. Its main source of freshwater is via a tidal creek to the north which exchanges tidal flow with LIS near the mouth of the Hammonasset River as it flows into Clinton Harbor.

### *Waterford Beach Park, Waterford, Connecticut*

Waterford Beach Park transects are found on the western bank of the Thames River as it enters LIS (Figure 9). The main source of freshwater for these transects derive from Alewife Cove; a basin draining approximately 2,500 acres of mixed wooded and suburban-developed upland. The westernmost transect, WBP1, grades gently into a mixed back-dune and forested upland environment. Tidal exchanges with LIS appear to be limited by an approximately 10-foot culvert beneath a beach-access path. The central transect, WBP2, lies just north of the main tidal creek which connects Alewife Cove to LIS. WBP2 grades gently into a turf grass upland. The easternmost transect, WBP3, is found further upstream the main tidal creek connecting Alewife Cove to LIS. This transect is found approximately 600 feet west of this tidal creek within an ancillary pond. The WBP3 transect graded moderately into a grass turf upland.

Tidal ranges in other Waterford salt marshes average 0.73 m and were found to be keeping pace with RSLR averaging an increase in elevation of 4.2 mm year<sup>-1</sup> from 1994-2015; presumably due to sufficient sediment availability, lower salinity concentrations, and greater elevation capital (Carey *et al.*, 2017).

### *Barn Island Wildlife Management Area, Stonington, Connecticut*

The three transects at Barn Island are the easternmost transects in this study (Figure 10). These marshes formed within a drowned finger valley of the Easter Upland physiographic region of Connecticut (Bell, 1985) and are protected from LIS by Sandy Point and Napatree Point – which are ephemeral sand spits. Behind these narrow, sandy barriers are Little Narragansett Bay and Wequetequock Cove. Historically, these marshes were used for agricultural purposes in the eighteenth and nineteenth centuries and multiple dikes were installed between 1940 and 1968 which restricted tidal flow to approximately 130 acres of salt marsh. Salt marshes at this site are thought to be outpaced by RSLR with average marsh elevation increases of only 2.3 ( $\pm$  0.24) mm year<sup>-1</sup> from 2003-2013 (Carey *et al.*, 2017).

The westernmost transect, BI1, is found on the eastern bank of the Wequetequock River mouth, its primary source of freshwater. Here, the marsh grades gently into forested uplands to the west and is directly exposed to waters from LIS in Wequetequock Cove. The central transect, BI2, is found on the western margin of the headland opposite transect BI1. This marsh lies in a narrow pocket-like embayment where the marshes fringe forested upland borders to the north, east, and west. This transect grades moderately into forested upland to the east. A walking path and former engineered tidal gate (i.e. dike) is found approximately 400 feet to the southwest. Multiple improvements to the engineered tide gate have been made beginning in 1978 (Dreyer et al, 2015). At present, a seven-foot diameter culvert was constructed in 1982 with reported colonization of pool features by *S. alterniflora* post-installment (Dreyer et al, 2015). The easternmost transect, BI3, is found north of Parting Cove and northeast of Bloom's Point. The marsh in this transect has not been historically altered by engineered structures, however, it has been extensively ditched. The salt marsh grades gently onto an engineered stone and earthen berm currently used as a walking path.

### **Data Analysis of Sample Photographs**

The direct-overhead photographs were imported and processed into the Coral Point Count with Excel Extensions (CPCe) program (Kohler and Gill, 2006). Due to the inherent variability in photograph heights and angles, each quadrat was manually drawn in this program (guided by the photographed quadrat within the picture) with careful attention to maximize the sampling area. A random point generator overlaid 20 points onto each image. A code file was written for the program which included abbreviations for plant species identified in this thesis including the entities "bare ground" and "turf" (Table 2). After all photographs were coded, an Excel spreadsheet of percent cover for each quadrat was generated.

Subsequent descriptive and multivariate methods were carried out using NCSS statistical software (NCSS Statistical Software, version 2010; Kaysville, Utah, USA) and PAST 3 statistical

software (Hammer et al, 2001). Multivariate analyses included a principal component analysis (PCA), a hierarchical clustering analysis, a two-way analysis of similarity (ANOSIM) and a non-metric multidimensional scaling analysis (nMDS). The PCA was used in part to reduce the data set with the intent of identifying potential groupings of salt marsh transects with regards to the average percent cover type. This type of analysis can also elucidate both the number and extent to which different components (in this case the average percent cover type) are causing variation amongst the sample transects. A cluster analysis was also performed to aid in identifying potential similarities in the average percent cover type across all transects. To further test whether significant (i.e.  $p \leq 0.05$ ) differences existed amongst transects, and within transects but among different marsh zones, a two-way analysis of group similarities was performed. Lastly the ordination technique of non-metric multidimensional scaling was conducted to further aid in better understanding any potential patterns in plant community structure across all site and transects. By understanding these potential variations and similarities, inferences can be made regarding their observed plant community structure and how they potentially differ from the idealized zonation of a typical New England salt marsh (as described by Levine et al., 1998). Further examinations regarding the immediate upland cover type, geographic variations, and tidal restrictions will supplement the results of the non-parametric tests discussed above.

To further reduce the data set, each transect was divided into three zones: the lower high-marsh (LHM), higher high marsh (HHM), and transition (T). The initial 10 meters of the 30-meter transect was assigned as the LHM, the next 10 meters as the HHM, and the final 10 meters landward of the marsh as the T zones. Again, the purpose of this thesis was to characterize plant communities across an apparent edge which was defined by the observed transition of graminoids to woody, shrub-scrub plants. It should be noted that, in addition to the turf cover type, common reed was also considered as an edge species as it displays similar characteristics as those higher plants (i.e. shrub-scrub, woody) with regards to outcompeting salt marsh halophytes, and, is widely considered as an aggressive, human-induced alteration (Bertness et al, 2002). The 19 meters before this edge consisted of entirely halophytic

gramminoids and/or bare ground with the exception of occasional forbs, sedges, rushes, and outlying shrubs.

## CHAPTER 3

### Results

#### CPCe Output

A total of 420 individual photos and 8,400 randomized points were analyzed for this study. The most common species found across the study sites was stunted *S. alterniflora*, which accounted for approximately 33% of the average cover type across all zones. The second most abundant cover type was bare ground (17%), which included features such as salt pannes, pools, and deposited tidal wrack. *Distichlis spicata*, *Iva frutescens*, *Juncus gerardii*, *Phragmites australis*, *Salicornia europea*, and *Spartina patens* were the next most abundant species found across all sites making up between 3-11% of the average percent cover type across all zones. Species richness generally increased from west to east across the state (Figure 11).

The LHM (Figure 12) and HHM (Figure 13) were dominantly covered by stunted *S. alterniflora* accounting for 57% and 46% of the average percent cover type within those zones across all sites, respectively. The next highest average percent cover type for the LHM was *D. spicata*, bare ground, and *S. patens* accounting for 17%, 15%, and 9%, respectively. Behind stunted *S. alterniflora*, the next highest average percent cover for the HHM were *S. patens* (18%), *D. spicata* (15%), and bare ground (12%). The T zone (Figure 14) was dominated by two cover types: *P. australis* and bare ground comprising nearly 50% of the average cover types across all transects. The next highest average percent cover types across this zone were turf (13%) and *I. frutescens* (10%).

A principal components analysis (PCA) found that 47% of the variation of the average percent cover type is explained by component one and 90% of the variation can be described by four components (Table 3). A scatter graph of the PCA (Figure 15) found transects BI1, BI3, HSP2, HSP3, SI3, and WBP3 to be closely grouped in quadrant one with stunted *S. alterniflora* describing the variation of these transects from the others. Transects BMSC1, HSP1, and WBP2 also appear to vary from the other transects because of the average percent cover values of three cover types: bare ground, *D. spicata*, and *J. gerardii*. In the third quadrant, transects BMSC2 and SI1 appear to vary based upon the average percent



cover of *S. patens*. Lastly, transects SI2 and WBP1 are found in quadrant four with the cover type *P. australis* causing the variation from the other transects. Based upon average cover type by transect, much of the variation (90%) between transects across all sites was due to four species: stunted *S. alterniflora*, *D. spicata*, *S. patens*, and *P. australis*. However, variation among transects within each geographic location was found to have high variability as depicted by the relative large spread in distance between them (Figure 19, Appendix).

A non-metric multidimensional scaling analysis (nMDS, Figure 16), using the unweighted pair group method with arithmetic mean and Bray-Curtis similarity index, was computed for all transects by percent average cover and yielded similar results as the PCA above. Transects BI1, BI3, HSP2, HSP3, and SI3 are closely grouped suggesting high similarity amongst these transects. A second nMDS analysis included averages of percent cover type for the high marsh (including both the LHM and HHM) and the transition zone (Figure 17) for all transects. This analysis shows a clear separation has formed between the two categorical zones. Within the high marsh zone, two groups showed close similarity: (1) transects BI1, HSP3, WBP1, and WBP3; and (2) transects BI3, BMSC2, and HSP2 formed the other closely related group. The transition zone percent cover averages only had one closely related grouping consisting of the transects BI1, HSP1, HSP3, and SI1. Again, these grouping of transects from different site locations suggest high variability in the transition zone.

A cluster analysis for the transect averages was computed using the Bray-Curtis similarity index and unweighted pair group method with arithmetic mean. This dendrogram (Figure 18) shows transects BI1, BI3, HSP2, HSP3, and SI3 were at least approximately 68% similar with transects HSP3 and SI3 having the most similarity of all the transects – approximately 78%. Aside from these similar transects, no clear trend of geographic similarities was indicated by the dendrogram analysis. For example, transects WBP1 and WBP3 were found to have approximately 60% similarity, however, the central transect at these Waterford marshes, WBP2, was dissimilar (<30%) from the other two. This appears to be true for all of the sites, that is, transects within the same site location showed high variability amongst each other.

The analysis of group similarities (ANOSIM) was conducted using two factors: by site and by marsh zone (i.e. the LHM, HHM, and T; Figure 20). Through this analysis I concluded that the clustering of transects by site was not significantly different ( $p = 0.44$ ), however, the groups did differ significantly ( $p = 0.01$ ) with regards to the average percent cover type across marsh zones.

The majority (71%) of study transects were tidally restricted to some degree. These include: BI2, BI3, BMSC1, BMSC2, HSP1, HSP2, SI1, SI2, SI3, and WBP1. Six of the fourteen transects had forested uplands while the other half had some combination of turf or suburban-residential upland cover. Transects BI1, BMSC2, HSP1, HSP2, SI2, SI3, WBP2, and WBP3 all had mixed suburban and turf cover types immediately upland the salt marsh.

## Chapter 4

### Discussion

The ecological characteristics across the high marsh to upland transition zones in this thesis could be almost completely (90%) characterized by the variation in the average percent cover of four species: stunted *S. alterniflora*, *D. spicata*, *S. patens*, and *P. australis*. The three multivariate methods conducted (PCA, nMDS, and cluster analysis) yielded a consistent grouping of six transects but also suggested high variability between transects both within and across site locations. Transects BI1, BI3, HSP2, HSP3, SI3, and WBP3 were found to have relatively high similarities (between 68- and 78%) with regards to their average percent cover type. These transects were found to be inconsistent with the typical models of plant community structure within New England salt marshes. Rather, they were dominated by stunted *S. alterniflora* in the high marsh and had relatively high average percent cover types of: bare ground, *P. australis*, and turf; predominantly within the transition zone. Of these six disrupted transects, three were tidally restricted to some extent (BI3, HSP2, and SI3) and four of the six had turf uplands (BI1, HSP2, SI3, and WBP3). Transects BI1 and HSP3, which also exhibited the disrupted plant community structure, had no tidal restriction and no development within the immediate upland.

Interestingly, despite having such high similarities, the average percent cover type within the transition zones of transects BI1 and HSP3 were quite different. Transect BI1 had relatively higher species richness while transect HSP3 was mostly bare ground. Despite these differences, the high marsh zones (i.e. the LHM and HHM) for these transects were, on average, 84% and 94% stunted *S. alterniflora*, respectively. The cluster analysis showed these transects to be more similar (i.e. less variation) to transects with predominantly *P. australis*, bare ground, and turf in the transition zones which included transects BI3, HSP2, SI3, and WBP3. These patterns indicate that variation within the transition zone, or across the high marsh to upland ecotone, is high – even within the same site locations.

Transects SI1, SI2, SI3, HSP2, WBP3, and BI2 were found to have tall *S. alterniflora* at the edge (albeit in low percentages) - usually found in or near the bare patches preceding the scrub-shrub community. Typical salt marsh models would suggest that these edge zones are hypersaline as this variant of smooth cordgrass is most salt tolerant. However, Hartman (1988) found that recolonization of bare patches in New England salt marshes was primarily controlled by the proximity of *S. alterniflora* to these bare patches and less so by soil edaphic conditions such as salinity and sulfide concentrations. All of these transects, with exception to SI1, had stunted smooth cordgrass in the preceding quadrats which fit the model put forth by Hartmann (1988).

Transects BI2, SI1, WBP1, and WBP2 had the highest variation in average percent cover type amongst all transects (i.e. they were less similar to any of the transects). Transect BI2 showed a high degree of variation amongst transect sites due to its ecologically-rich upland which included *Clethra alnifolia*, *Osmunda cinnamomea*, and a canopy of *Carya spp.* The SI1 transect appears to show more variation between other transects based upon the abundance of *S. patens*. However, it was less similar to other transects with abundant *S. patens* cover in the high marsh zones (such as BMSC2) likely due to the upland cover type of white oak, which was unique to this transect. The westernmost transect in Waterford, WBP1, had some similarity to other transects with regards to a near monoculture of *S. alterniflora* in the LHM and HHM, however, this transect graded into a back-dune environment with a mixed community of *Baccharis halimifolia*, *Solidago sempivirens*, and *Myrica pensylvanica*. The central Waterford transect, WBP2, had a high degree of variation from other transects because a dense, narrow stand (3-4 m in width) of *Ammophila breviligulata* was identified – this being unique to this site. This transect showed a moderate degree of similarity to HSP1 due to the high percent cover type of *Distichlis spicata* and *Spartina patens* in the high marsh.

A two-way analysis of group similarities found that the transects were not significantly different with regards to each of their average percent cover type. However, a significant difference did exist between the community assemblages across the different marsh zones. The latter result was consistent

with an nMDS analysis of transects grouped by marsh zone (Figure 17). This figure shows a clear separation between the high marsh community assemblages and the transition assemblages. Again, I believe this results speaks to the high amount of variation found across sites. Although a grouping of six transects were consistently found in the other multivariate methods, the ANOSIM analysis found no significant difference between these “disturbed” transects and the remaining eight.

These eight other transects generally agreed with the plant community structure models as presented by Niering and Warren (1980), however, the remaining six other transects were consistent with changes reported by Deegan *et al* (2012), Bertness *et al* (2002), and Warren and Niering (1993). That is, a restructuring of the plant community consistent with increased inundation. These altered marsh transects suggest that the migration of the salt marsh plant community inland will occur in pulses. For example, *S. alterniflora* will continue to expand at the expense of the high marsh community, however, episodic periods of vegetative die-offs and subsequent creation of bare patches will precede colonization by the low marsh halophytes (i.e. stunted and tall form of *S. alterniflora*).

Qualitatively, transects that had bare areas within the high marsh were soft when stepped upon suggesting destabilization of edaphic conditions. The presence of wrack lines was also observed at many of the apparent edge boundaries with predominantly bare ground cover. Specifically, transects SI1, SI2, SI3, BMSC2, HSP2, HSP3, BI2 and BI3 were all observed to have wrack lines at the edge of the marsh proper and adjacent transition. Transect HSP2 was observed to have wrack lines on both the marsh- and upland border-side of the shrub-scrub zone; and even beyond the end of the sampling transect near the access road. The latter observation possibly indicates that this transect is low in elevation relative to mean sea level. Wrack mats are known to cause disturbance patches in salt marsh plant communities by smothering the existing vegetation. (Valiela and Rietsma, 1995; Tolley and Christian, 1999). Invasion by common reed at the transition suggests that brackish conditions are prevailing, or were historically significant, or a combination of freshwater inputs and nutrient pollution are facilitating invasion and colonization.

The data presented in this thesis suggest that some of the salt marsh transects sampled show signs of tidal inundation related stress. Relatively high average percent cover of the low marsh species *S. alterniflora* (stunted) was found directly bordering the scrub-shrub boundary between the marsh proper and the adjacent shrub-scrub edge. The idealized model shows a mixed community of *D. spicata*, *S. patens*, *J. gerardii*, and *I. frutescens*. There was little evidence to suggest that the presence of engineered structures (i.e. tidal restrictive-structures) and upland cover type had any impact on the variation in plant communities across all transects. Rather, the transects within each site location often displayed high variation amongst each other and, in some cases, were more similar to transects at other sites. Although the variation in tidal range across LIS was thought to influence salt marsh plant community structure, it appears that local variations in the tidal inundation regime are prevailing. Marsh capital, sediment availability, and socioeconomic decisions are likely the most important factors governing salt marsh sustainability in the future. In other words, those marshes that have the physical space to accrete, and are allowed to do so, combined with a steady and sufficient sediment supply, are most likely to persist under the observed accelerated rates of RSLR. Therefore, conservation efforts should focus on protecting salt marshes abutting a low-sloping upland which is managed by a person or entity open to passive land management techniques.

Site specific elevation and tidal range data would likely be a better predictor in the variation of plant community structure. Additionally, obtaining longitudinal data would likely elucidate structural changes in vegetative communities of these salt marshes. The six “disrupted” transects discussed in this study likely represent those marsh units most vulnerable to coastal squeeze based upon the observed cover types sampled in this thesis. On the other hand, the remaining eight transects appear to generally fit the theoretical models and displayed relatively high diversity.

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## Tables

**Table 1.** Coordinates to study transects in this thesis. BI = Barn Island Wildlife Management Area, BMSC = Banca Marsh Stony Creek (Branford marshes), HSP = Hammonasset Beach State Park, SI = Sherwood Island State Park, WBP = Waterford Beach Park. The numbering following the site acronym corresponds to the location of the transect within each site from west to east. The westernmost transects in each site begins with the number one (1).

Transect ID	Marsh Coordinate	Upland Coordinate
SI1	41.116323; -73.325779	41.116122; -73.325902
SI2	41.113404; -73.337289	41.113150; -73.337106
SI3	41.115245; -73.338877	41.114971; -73.338945
BI1	41.339047; -71.879285	41.339004; -71.878960
BI2	41.341037; -71.875283	41.341011; -71.875673
BI3	41.339408; -71.865571	41.339611; -71.865835
WBP1	41.304059; -72.108127	41.303805; -72.108304
WBP2	41.306143; -72.103755	41.306600; -72.104016
WBP3	41.308875; -72.104369	41.308763; -72.104491
HSP1	41.266336; -72.564741	41.265970; -72.564334
HSP2	41.254234; -72.549327	41.254001; -72.549549
HSP3	41.250839; -72.540847	41.250535; -72.540819
BMSC1	41.269928; -72.755355	41.269698; -72.755000
BMSC2	41.270280; -72.761496	41.270590; -72.761257

**Table 2.** Species list identified in this thesis with common names, code identifiers, and average percent coverage across all transects in this thesis.

Species name	Common name	Code	AVG % Cover
<i>Quercus alba</i>	White Oak	QA	0.20
<i>Quercus ilicifolia</i>	Bear oak	QI	1.07
<i>Quercus velutina</i>	Black oak	QV	0.17
<i>Pinus rigida</i>	Pitch pine	PR	1.07
<i>Juniperus virginiana</i>	Eastern red cedar	JV	0.20
<i>Carya spp.</i>	Hickory	CS	0.27
<i>Alnus ssp.</i>	Alder	AR	0.04
<i>Myrica pensylvanica</i>	Northern bayberry	MP	1.39
<i>Rosa virginiana</i>	Virginia Rose	RV	0.29
<i>Baccharis halimifolia</i>	Groundsel bush	BH	0.63
<i>Iva frutescens</i>	High-tide bush	IF	3.94
<i>Clethra alnifolia</i>	Sweet pepperbush	CA	0.13
<i>Atriplex patula</i>	Marsh orach	AP	0.20
<i>Osmunda cinnamomea</i>	Cinnamon fern	OC	0.13
<i>Solidago sempervirens</i>	Seaside goldenrod	SS	0.52
<i>Spergularia marina</i>	Salt sandspurry	SM	0.04
<i>Scirpus robustus</i>	Saltmarsh bulrush	SR	0.15
<i>Ammophila breviligulata</i>	American beach grass	AB	0.79
<i>Limonium carolinanum</i>	Sea lavender	LC	0.01
<i>Distichlis spicata (DS)</i>	Spike grass	DS	10.77
<i>Juncus gerardii</i>	Black grass	JG	3.15
<i>Phragmites australis</i>	Common reed	PA	9.22
<i>Salicornia europaea</i>	Glasswort	SE	0.98
<i>Spartina alterniflora short</i>	Smooth cord grass (stunted)	SAS	32.98
<i>Spartina alterniflora tall</i>	Smooth cord grass (tall)	SAT	0.82
<i>Spartina patens</i>	Salt hay	SP	8.96
<i>Triglochin maritima</i>	Arrow grass	TM	0.25
Bare ground	NA	BG	16.94
Turf	NA	T	4.71

**Table 3.** Scores of the PCA show that 90% of the variation in the average percent cover type by transect can be described by the first four components.

Principal Components Analysis		
PC	Eigenvalue	% variance
1	760.533	47.317
2	368.779	22.944
3	179.016	11.138
4	144.107	8.9658
5	62.7264	3.9026
6	39.7657	2.4741
7	25.9765	1.6161
8	12.6565	0.78743
9	9.4193	0.58603
10	1.66632	0.10367
11	1.09732	0.06827
12	1.02636	0.063856
13	0.539541	0.033568

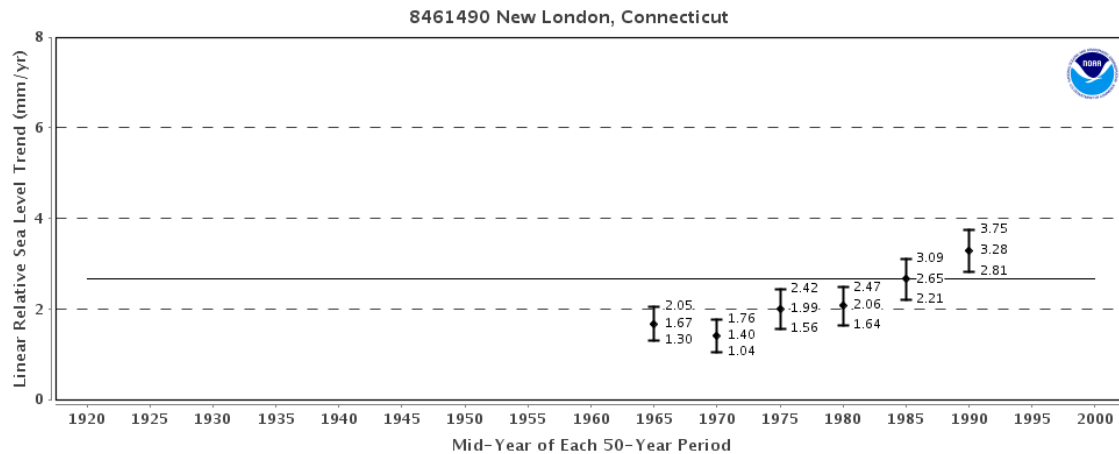
**Table 4.** Results from the group similarity analysis (ANOSIM) indicate no significant differences between groups by site location, however, there are significant differences between the groups based upon the average percent vegetation cover factor across all transects.

Analysis of Group Similarities (ANOSIM)	
Factor	<i>p-value</i>
Site	0.4443
Marsh Zone	0.0115

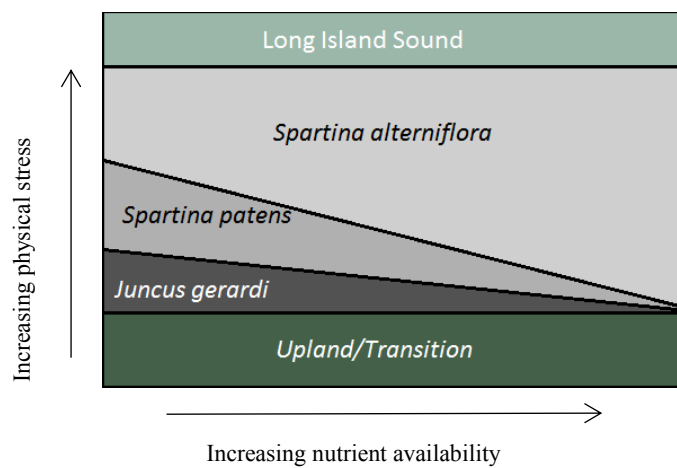


## FIGURES

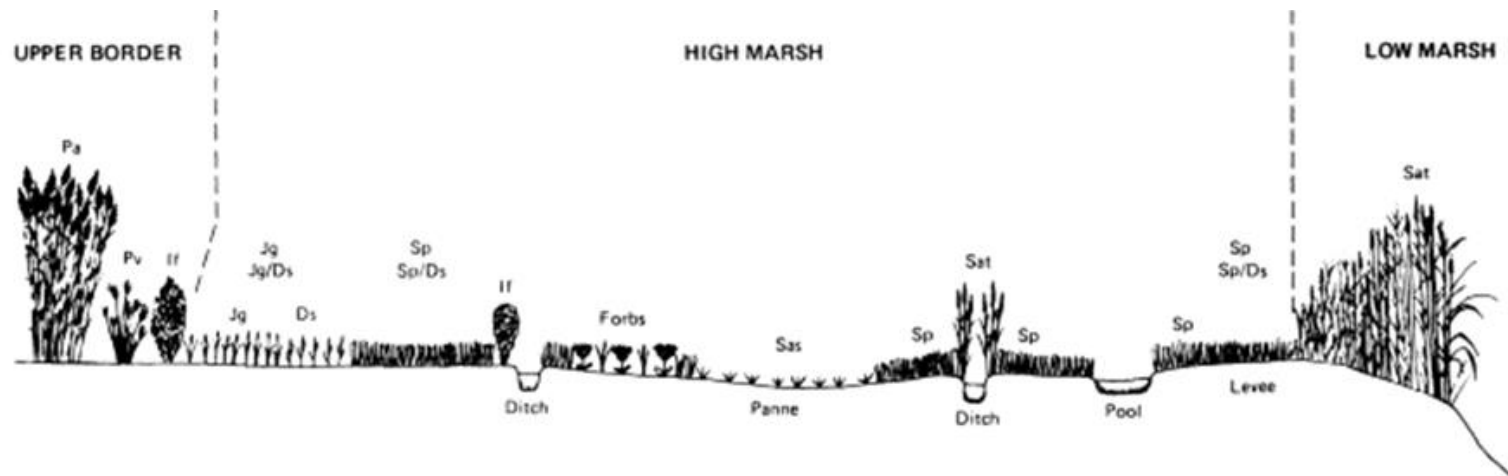
**Figure 1.** The National Oceanic and Atmospheric Administration’s New London, CT station portrays the variation of the 50-year relative sea level (RSL) trend. An apparent acceleration of RSL is observed since the buoy began recordings in 1938. From 1945 to 1995 the average rate of RSL was  $1.40 \text{ mm year}^{-1}$  ( $\pm 0.36 \text{ mm year}^{-1}$ ). This rate increased to average of  $3.28 \text{ mm year}^{-1}$  ( $\pm 0.47 \text{ mm year}^{-1}$ ) from 1965 to 2015.



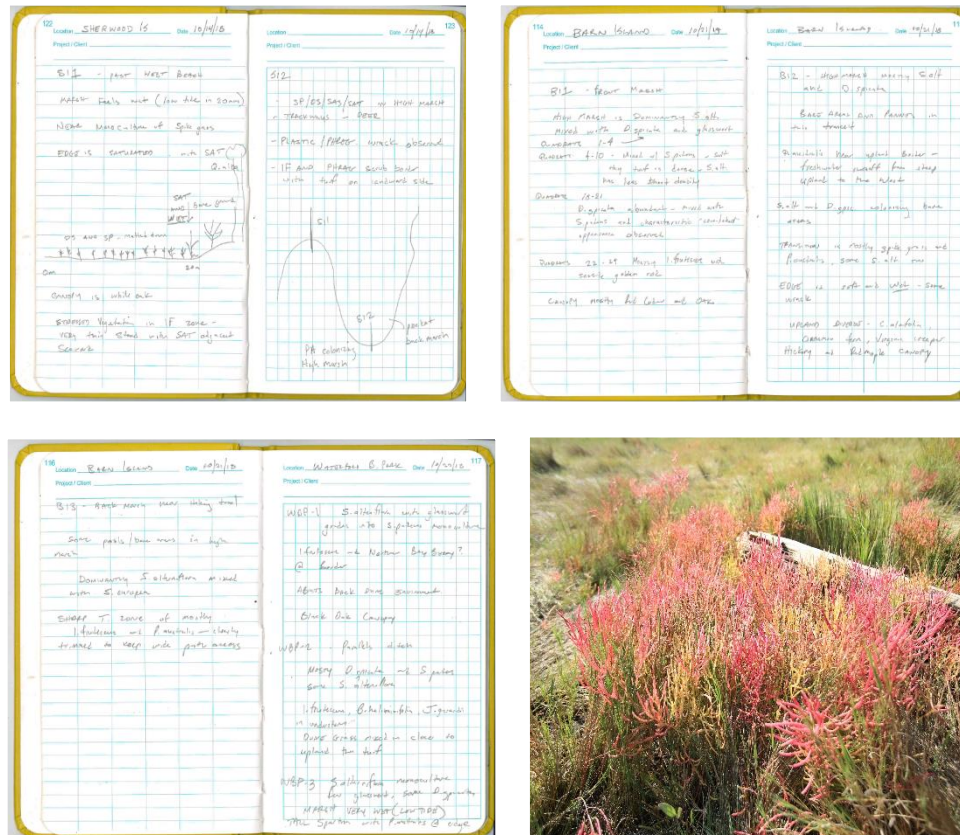
**Figure 2.** A conceptual diagram showing plant community structure as a function of increasing physical stress and competitive displacement (from Levine *et al.*, 1998). Other nutrient enrichment studies have shown this hierarchy can be reversed when nitrogen levels are increased (Fox *et al.*, 2012; Turner, 2016.)



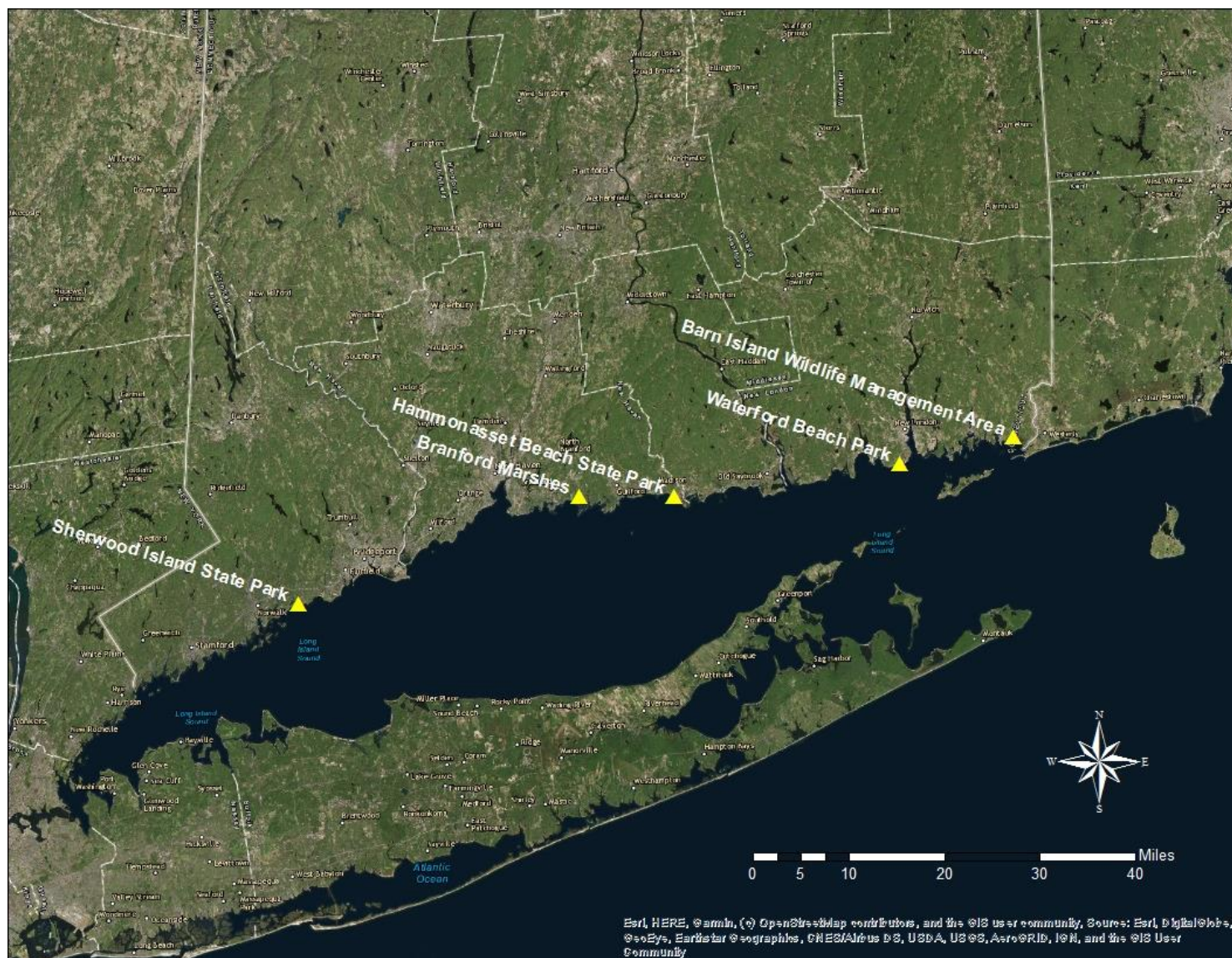
**Figure 3.** A conceptual model of the typical plant community structure of a southern New England salt marsh from Niering and Warren (1980).  
 Sas = *S. alterniflora* tall; Sat = *S. alterniflora* tall; Sp= *S. patens*; Ds= *D. spicata*; Jg = *J. gerardii*; If= *I. frutescens*; Pv = *P. virgatum*; and Pa= *P. australis*.



**Figure 4.** Samples of field notes and other photographs used to aid in plant identification.



**Figure 5.** Locations of study salt marshes across the northern shore of the Long Island Sound estuary





**Figure 6.** Locations of transects at Sherwood Island State Park.





**Figure 7.** Transect locations within the Branford marshes.



**Figure 8.** Transect locations within Hammonasset Beach State Park in Madison, CT





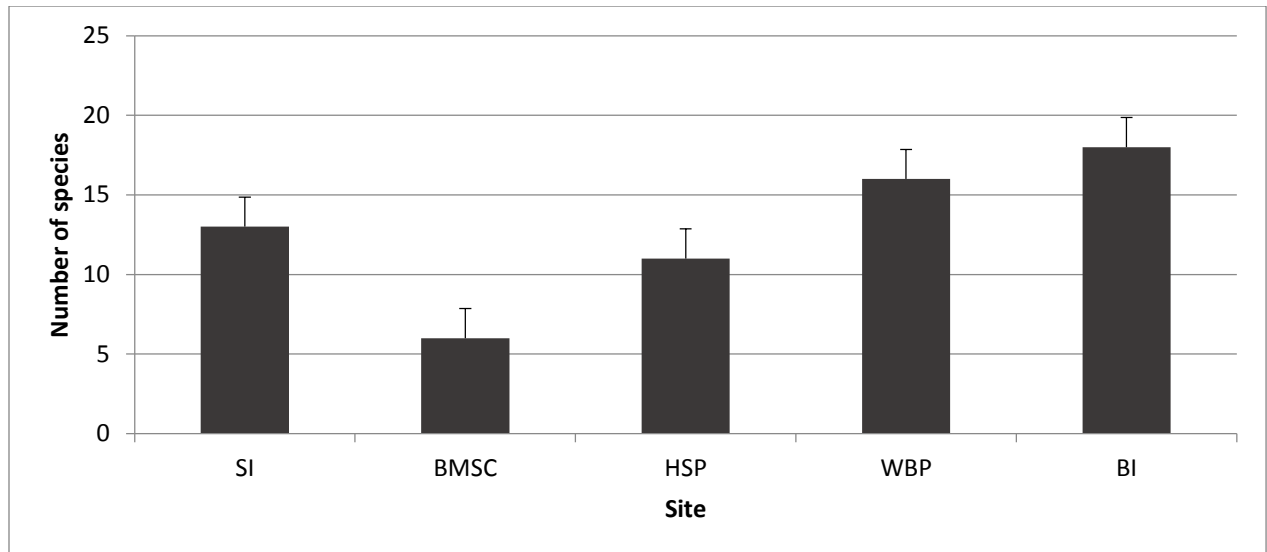
**Figure 9.** Transect locations at the salt marshes in Waterford, Connecticut.



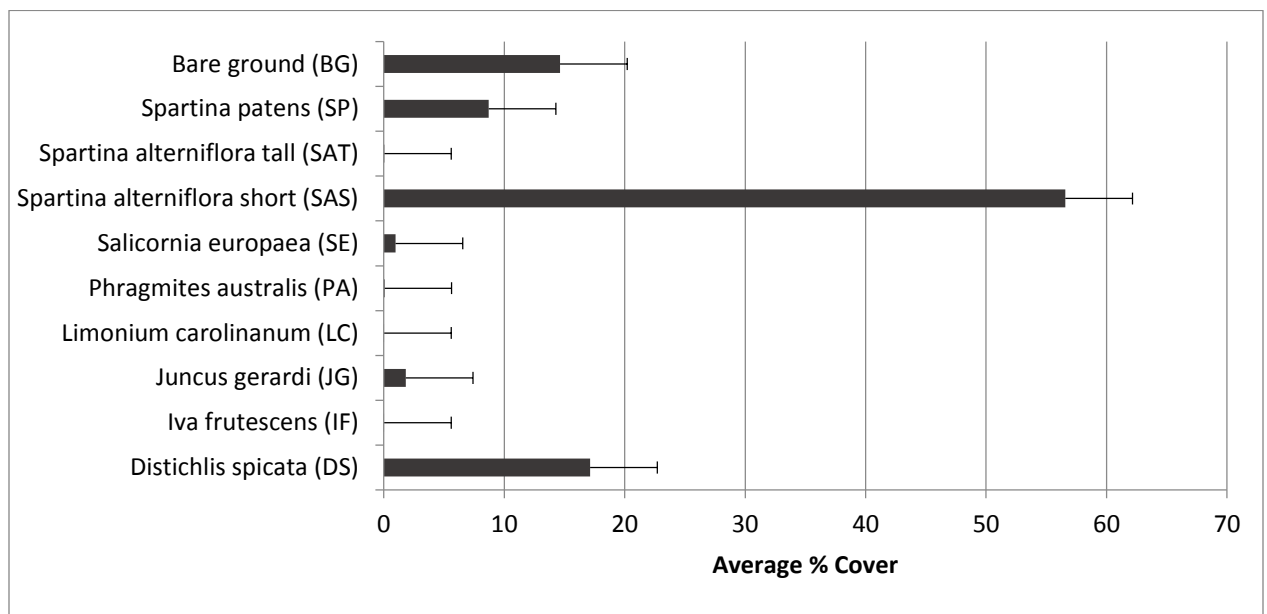
**Figure 10.** Transect locations at Barn Island Wildlife Management Area in Stonington, CT.



**Figure 11.** Number of species identified by site (+ 1 S.E.). BI = Barn Island Wildlife Management Area, WBP = Waterford Beach Park, HSP = Hammonasset Beach State Park, BMSC = Banca Marsh Stony Creek (Branford marshes), SI - Sherwood Island State Park

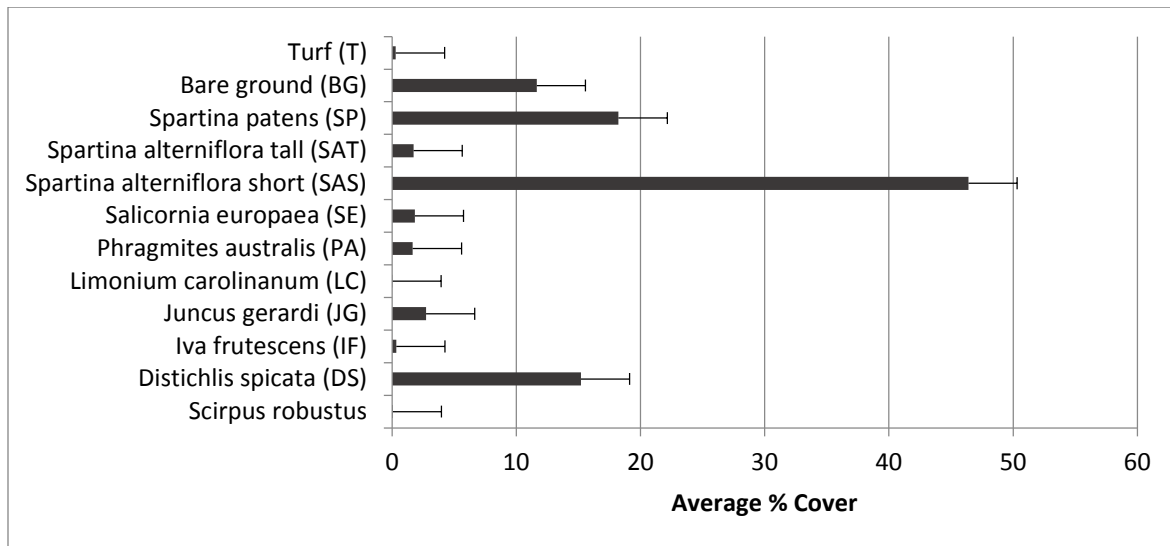


**Figure 12.** Average percent cover by species within the lower high marsh zone (LHM) across all sites ( $\pm$  1 S.E.).

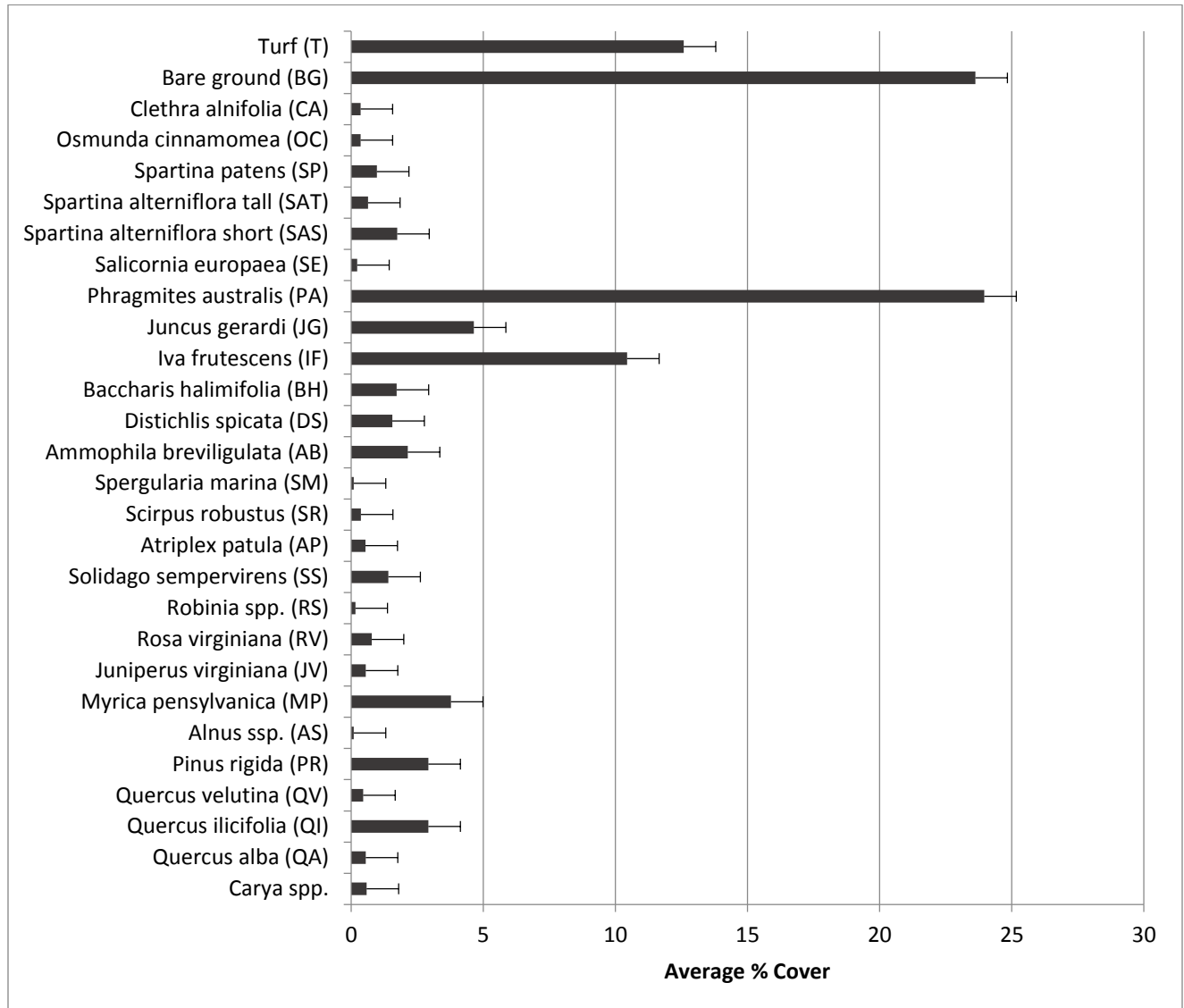




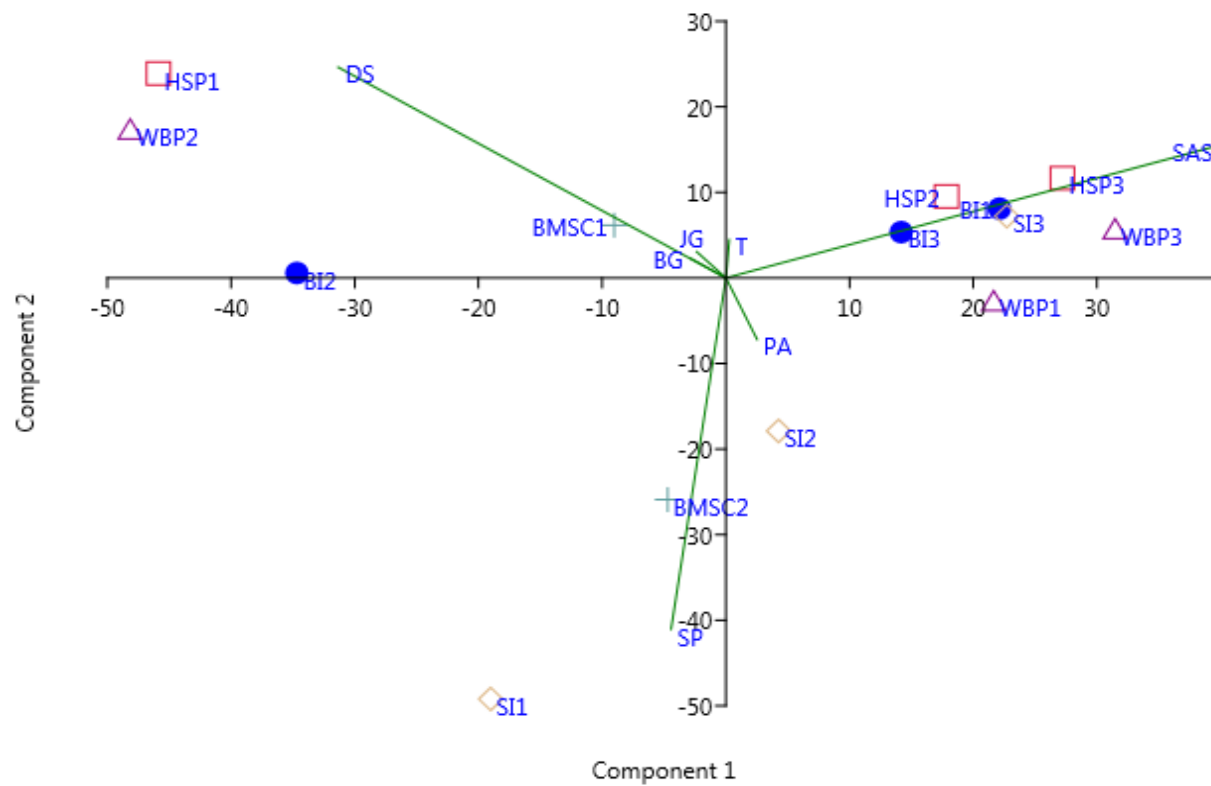
**Figure 13.** Average percent cover by species within the higher high marsh zone (HHM) across all sites ( $\pm$  1 S.E.).



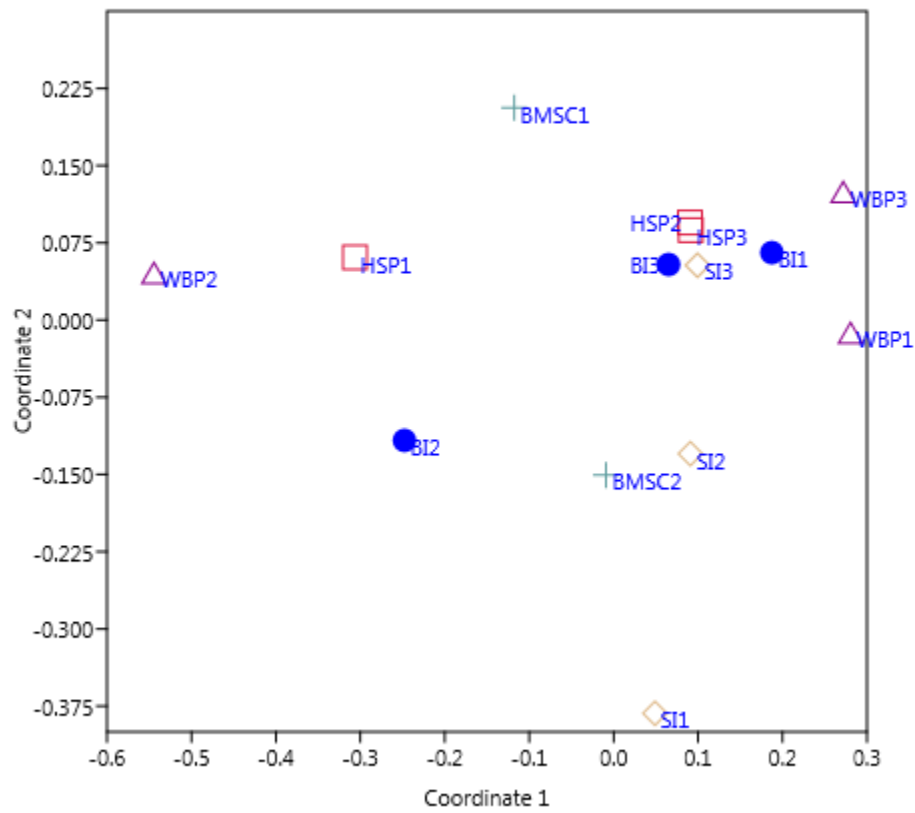
**Figure 14.** Average percent cover by species within the transition zone (T) across all site (+ 1 S.E.)



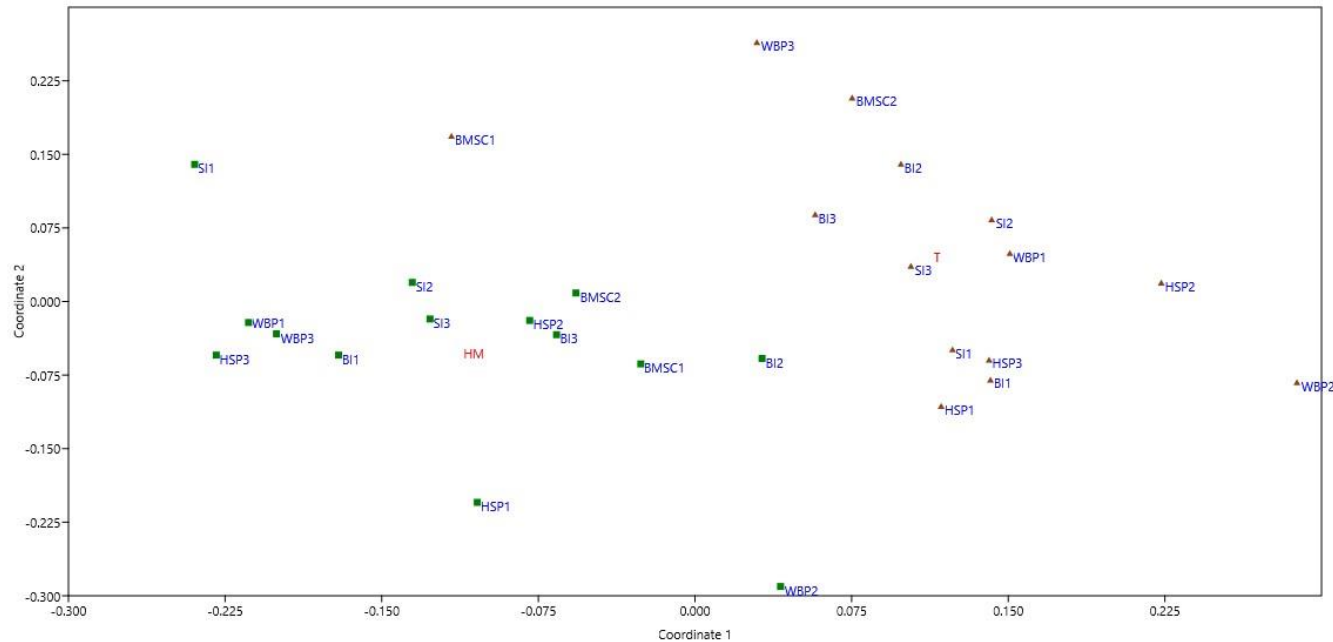
**Figure 15.** A principal components analysis depicting average percent cover type for each transect sampled in this thesis. Ninety percent of the variation between the transects (by average percent cover) can be described by four components. Transects BI1, BI3, HSP2, HSP3, SI3, and WBP3 show little variation. (Note, only seven of the 13 components shown here. See Table 3 for complete list of component variances).



**Figure 16.** A non-metric multidimensional scale analysis, using the Bray-Curtis similarity index, depicting the average percent cover type by each transect. Transects BI1, BI3, HSP2, HSP3, and SI3 show a close grouping suggesting little variation amongst these specific transects.

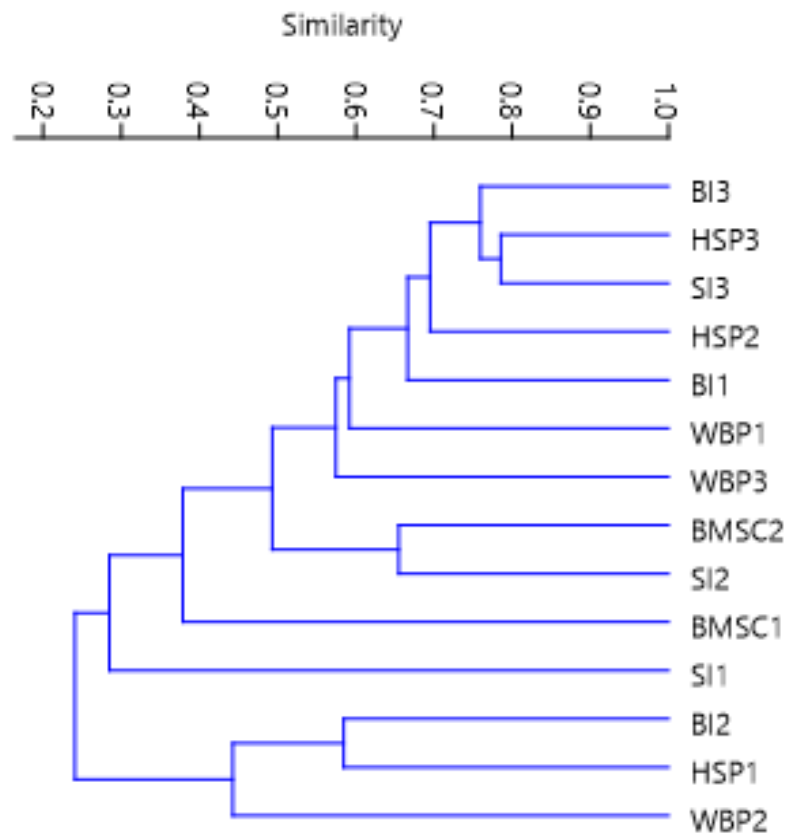


**Figure 17.** A non-metric multidimensional analysis of the average percent cover type of each transect grouped by the zones: high marsh (green squares, both the LHM and HHM are included in this zone) and transition (brown triangles). A clear separation between the two zones agrees with plant community structure models where diversity generally increases from the salt marsh to upland communities.





**Figure 18.** A dendrogram analysis of the average percent cover type for each transect (Bray-Curtis similarity index and unweighted pair group method with arithmetic mean).



## **PHOTOGRAPHS**

**Photo 1.** Transect BI2 at Barn Island Wildlife Management Area. Common reed (right) is seen here with a mixed stunted cordgrass, salt hay, and spike grass community.



**Photo 2.** Transition zone at Barn Island. This transect had the highest diversity in the study. Smooth cordgrass and glasswort (top right) is seen transitioning to a community of salt grass, black grass, and marsh elder (center).



**Photo 3.** A transition zone at Hammonasset State Park shows a narrow band of common reed at the saltmarsh edge. The smooth cordgrass, common reed, and turf cover pattern (from high marsh to upland) was commonly observed in this study



**Photo 4.** This transition zone at Hammonasset State Park shows spike grass colonizing a disturbed area at the edge. Turf grass (left) cover may facilitate marsh migration as inundation increases at successively higher elevations on the saltmarsh.





**Photo 5.** Bare areas at the saltmarsh transition zone were a common feature in this study. Smooth cordgrass (tall form) was observed inhabiting this bare area near the edge before giving way to common reed and high tide bush (right) and turf(not shown).



**Photo 6.** Transect WBP1. In between smooth cord grass (left) and high tide bush (right), salt hay (middle) is presumably being squeezed out due to increased inundation in the high marsh.



## APPENDIX

**Figure 19.** A principle component analysis depicting the variation between transects based upon their average percent cover type. Transects were grouped with ovals to highlight the high variability in cover type within each geographic location.

